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INTERNATIONAL SYMPOSIUM ON
ARID ZONE RESEARCH AND DEVELOPMENT
CENTRAL ARID ZONE RESEARCH INSTITUTE, JODHPUR
February 14-18, 1978

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INTERNATIONAL SYMPOSIUM ON ARID ZONE RESEARCH AND DEVELOPMENT

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INTERNATIONAL AGENCIES

1. Food & Agriculture Organization
2. International Crops Research Institute for Semi-Arid Tropics
3. International Livestock Centre for Africa
4. United Nations Environment Programme
5. U.N.E.S.C.O.
6. World Bank
7. Ford Foundation

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1. Arab Centre for the Studies on Arid Zone
2. American Association for the Advancement of Sciences
3. United States Information Service

FOREIGN COUNTRIES

1. Afghanistan
2. Australia
3. Bangla Desh
4. Egypt
5. Ethiopia
6. Iran
7. Iraq
8. Israel
9. Japan
10. Kenya
11. Pakistan
12. Syria (SAR)
13. U.K.
14. U.S.A.
15. U.S.S.R.
16. West Germany

INDIA

1. Indian National Science Academy
2. ICAR Institutes
3. Agricultural Universities
4. Other Universities and Colleges
5. Planning Commission
6. Department of Science & Technology, Govt. of India
7. Rajasthan State Departments
8. Indian Institute of Public Administration

PREFACE

Organized efforts in the field of Arid Zone Research in India made its humble beginning in the year 1952 with the establishment of a Desert Afforestation Research Station at Jodhpur. Since then arid zone research has passed through several phases of expansion and strengthening. In 1957 the scope of activities of the Desert Afforestation Research Station was enlarged by the inclusion of soil conservation programmes and it was renamed as the Desert Afforestation and Soil Conservation Station, on the recommendations of Dr. A. Y. Goor, F. A. O. expert. In 1958, a scheme of pasture development was initiated for the improvement and management of grasslands. Later, in October 1959, on the recommendations of Mr. C. S. Christian, deputed by the UNESCO, this station was further re-organized and was redesignated as the Central Arid Zone Research Institute (CAZRI), with the object of undertaking inter-disciplinary integrated research on land resources and ecology of natural environments, including socio-economic studies for the arid and semi-arid regions of India for their reclamation, improvement and maintenance of productivity at optimum levels.

Besides CAZRI, a number of other ICAR institutes, several Universities and the Defence Science Organization, and various specialised agencies of the State government have contributed significantly to arid zone research and development technology. It is also noteworthy that several organizations of national importance have been maintaining offices and laboratories in this region, specifically for obtaining information on the arid eco-system.

In 1962 the Arid Zone Research Association of India was formed with the prime objective of serving as an international forum for research and development workers concerned with arid zone problems. This Association was conceived as a specialized interdisciplinary body of scientific workers striving towards a common goal, viz. the understanding and amelioration of desertic conditions. Another activity of this Association is the publication of an interdisciplinary quarterly journal — 'Annals of Arid Zone.'

On the completion of 25 years of organised arid zone research in India in 1977, the Association considered it appropriate to commemmorate the Silver Jubilee through a number of activities. An International Symposium on "Arid Zone Research & Development" was organised at Jodhpur during 14-18 February 1978, in collaboration with the UNESCO, the Indian Council of Agricultural Research, the Department of Science & Technology, Government of India, the Ford Foundation and the Central Arid Zone Research Institute. For this purpose a national Organizing Committee was formed with Dr. M. S. Swaminathan, F. R. S., formerly Secretary, Department of Agricultural Research and Education, Government of India and Director General, Indian Council of Agricultural Research (ICAR) as Chairman and the Director, CAZRI, Jodhpur as Convener. The inaugural session of this Symposium was held in the morning of February 14, 1978, under the Chairmanship of Dr. M. S. Swaminathan. Dr. A. Ramachandran, Secretary, Department of Science and Technology, Government of India, delivered the inaugural address. The welcome address was presented by Dr. D. R. Bhumbla, Chairman of the Association and formely Deputy Director General, ICAR. Prof. M. Kassas, addressed the inaugural session as the personal representative of Dr. M. K. Tolba, Executive Director of UNEP. Dr. M. Vannucci of the UNESCO South Asia Office, New Delhi, addressed on behalf of the Director General of the UNESCO. Prof. J. A. Mabbutt addressed on behalf of the United Nations University and the International Geographical Union.

In all, 389 delegates participated in the symposium presenting 181 scientific papers, out of the 253 contributed, in the following 6 technical sessions of the symposium:

(I) Environmental Analysis; (II) Resource Utilization; (III) Wildlife Conservation, Desert Zoology and Plant Protection; (IV) Human Resources and Socio-Economic Constraints; (V) Desert Management Technology and its Adoption; and (VI) Desertification — A Panel Discussion. The Plenary Session, chaired by Prof. J. A. Mabbutt, with Dr. A. Warren acting as the Rapporteur, summed up the deliberations of the symposium in the form of recommendations as guidelines for follow up action.

Besides the International Symposium the other activities organized on this occasion were:

1. A 3 week International Training Course on *"Integrated Natural Resources Survey,"* organized by the CAZRI, with the support of UNESCO.
2. A scientific exhibition of models, charts, specimens and publications, depicting the advancement in knowledge, and the available technology for development of arid and semiarid zones.
3. A 2 day field trip for the delegates.

Popular lectures were delivered by the following scientists on topics shown against each:

1. Dr. P. R. Pisharoty - Eye in the Sky
2. Prof. M. Kassas - Desertification - the global menace
3. Prof. Randall Baker - The Administrative Trap
4. Dr. K. S. Sankhla - The Colourful desert

The Indian National Science Academy had arranged a Group Discussion on the Rajasthan Desert, with Dr. S. P. Raychaudhuri as the Convener.

The Symposium happily coincided with the United Nations year of Desertification and was timely in the sense that it was held only a few months after the United Nations Conference on Desertification held in August-September 1977 at Nairobi, Kenya. Therefore, the Symposium served an additional purpose as a follow up of the Plan of Action to combat desertification adopted by the U. N. Conference.

This volume is based on the proceedings of and the scientific papers presented at the symposium. The Association is grateful to the scientists for their contribution and their participation. A few of the papers contributed to the symposium are being published separately in the September and December 1980 issues of Annals of Arid Zone.

We must record here the continued support of UNESCO to CAZRI and to arid zone research in India in general. It was particularly gratifying that Dr. C. S. Christian, on the basis of whose report CAZRI was organised and established in 1959, actively participated in the symposium.

We hope that this volume, which is a record of dedicated efforts and commitments, will be of interest to various agencies and individuals concerned with arid zone problems.

The Symposium owes much of its success to the guidance and support provided by Dr. M. S. Swaminathan, F. R. S., Chairman of the Organizing Committee. The Association will ever remain grateful to him. A number of organizations and individuals deserve our special appreciation for their support. The entire staff of CAZRI, and a large number of members of the Arid Zone Research Association of India made commendable efforts to make the symposium a land mark. I must single out the contribution made by Dr. Ishwar Prakash, Secretary of the Organizing Committee, for the success of this programme.

My colleagues in the Editorial Committee have given their best to the task entrusted to them. I thank all of them. I would particularly like to thank Dr. P. K. Ghosh, Mr. R. K. Abichandani and Dr. S. Kathju for their hard work in seeing the manuscript through the press, and Mr. Tufail Khan for able office assistance. The proprietors of the Harvard Press, Jodhpur, have earned our appreciation and we thank them for their efficiency and cooperation in printing this volume.

H. S. MANN

Jodhpur
September 1980

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INAUGURAL SESSION

WELCOME ADDRESS

D. R. Bhumbla
Chairman, Arid Zone Research Association of India and
Deputy Director-General, Indian Council of Agricultural Research, New Delhi

It gives me great pleasure to extend a warm and hearty welcome on behalf of the Government of India, Indian Council of Agricultural Research and the Arid Zone Research Association of India and on my own behalf to all the distinguished guests, delegates and participants of this International Symposium on 'Arid Zone Research and Development'. I consider it my privilege to be associated with this symposium organized by the Arid Zone Research Association of India with the support of the UNESCO, Department of Science and Technology and the Indian Council of Agricultural Research.

I must compliment the Association for its initiative and efforts to organize this symposium on this occasion coinciding with the 25 years of Arid Zone Research in India and the United Nations Year of Desertification. It is indeed encouraging that a number of International Agencies have actively participated in this symposium. They are: United Nations Environment Programme (UNEP), United Nations Educational, Scientific and Cultural Organization (UNESCO), Food and Agriculture Organization (FAO), United Nations Research Institute for Social Development (UNRISD), ESCAPE, Ford Foundation, East African Agricultural and Forestry Research Organization, Arab Centre for Studies of Arid Zone, American Association for the Advancement of Science, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Academy of Science of USSR and International Livestock

Centre for Africa (ILCA). A large number of research institutions and universities from India and foreign countries are represented.

It is indeed gratifying that the UNESCO has been kind in choosing India and particularly CAZRI as the venue of an International Training Course on 'Integrated Resources Survey' (4 weeks) which coincides with the Silver Jubilee celebrations. We take due pride that the UNESCO has provided this opportunity to CAZRI for conducting this course for the second time in the last 8 years. The co-sponsorship and support of the Department of Science and Technology (Govt. of India) is most encouraging.

This symposium is timely in the sense that it is being held only a few months after the United Nations Conference on Desertification held at Nairobi. Besides taking a stock of 25 years of achievements of Arid Zone Research in India, this symposium is in a good position to reflect and formulate a meaningful Plan of Action to combat desertification. Perhaps no other place could be a better venue than the CAZRI, Jodhpur, for convening this International Symposium. This Association has organized a number of scientific activities including its publication, "Annals of Arid Zone" which has published over 460 scientific papers in the last 16 years of its existence, but this is the first occasion that an International Symposium is being organized, and I am happy about the response that we have received from the national and international agencies. I understand that more than 250 papers have been contributed from within the country and from 35 agencies abroad.

You may perhaps be aware that the Government of India in pursuance of the recommendations of the UNESCO Advisory Committee for Arid Zone Research established a Desert Afforestation Centre at Jodhpur in 1952 with a view to standardising the techniques for reclaiming the desert areas. It was about the same time that the Indian National Science Academy (then known as National Institute of Sciences of India) held a symposium on Rajasthan Desert. This symposium recommended the setting up of a Rajasthan Development Corporation for the development of this area in all its ecological and related aspects. Later the Government of India decided to expand and intensify the research programme of the Desert Afforestation and Soil Conservation Station and established CAZRI in 1959.

The CAZRI has now 7 Divisions and there are 105 scientists working in the Institute. I am sure in the next few days of your stay at Jodhpur you will be able to visit and meet the scientists at the Institute. In addition to the facilities at Jodhpur, the CAZRI has a number of Regional Stations and Range Management Areas in Western Rajasthan. The CAZRI has collaborated with International Agencies. At present the following three projects could be specifically mentioned:

(a) UNESCO's "Man and the Biosphere" Project No. 3: "Productivity of Grazing land Ecosystem".

(b) 'Monitoring Desertification Processes and Related Natural Resources in Arid and Semi-Arid Areas of South-West Asia'.

(c) 'Social Aspects of Desertification Processes'.

The value and relevance of the research carried out at this Institute is well reflected in the formulation of development plans in the States like Rajasthan, Haryana and Gujarat. The Institute has made its due contribution to the United Nations Conference on Desertification. I am sure most of you must have seen the publication "Desertification and its Control" which was brought out on that occasion.

It is my privilege to be associated with the Association as its Chairman for many years now. I participated in the symposium on 'Problems of the Indian Arid Zone' held at Jodhpur in December 1964. As Deputy Director-General Incharge of this Institute at the Indian Council of Agricultural Research Headquarters for the last over 4 years now I am particularly happy to welcome you all at this occasion.

The CAZRI has been fortunate to have distinguished scientists as its Directors, Shri G. S. Lamba, Dr. P. C. Raheja, Shri C. P. Bhimaya and now Dr. H. S. Mann. The effective leadership provided by these persons helped the Institute in doing an excellent job and now it is recognised not only in this country but internationally as a premier Institute in Desert Research. Valuable data and technology on reclamation, improvement and amelioration of desertic conditions have been evolved. This symposium would provide a useful forum to discuss all this and other related matters. Besides the contribution of this Institute a number of other agencies have contributed and the contributions made by these agencies are also available to this symposium.

The symposium will provide an opportunity to our scientists to interact with the distinguished participants and thus would improve the quality of research work. It is hoped that meaningful and fruitful recommendations will emerge for planning research for the next several years. I also hope that the symposium will give thought to the National Plan to combat desertification as a follow-up action of the United Nations Desertification Conference.

To my friends from foreign countries. I have a special word. You are in Jodhpur at a nice time of the year. The Director, Dr. Mann and the scientists of this Institute have made all possible efforts to make your visit comfortable and fruitful.

I once again welcome all of you to the symposium and I wish you a very happy and fruitful stay here. Jodhpur is a historic city and I hope you will be able to find time to visit the places of tourist interest. With these words I thank you all.

ARID ZONE RESEARCH IN INDIA - 25 YEARS

H. S. Mann
Vice-Chairman, Arid Zone Research Association of India and
Director, Central Arid Zone Research Institute, Jodhpur

In welcoming you all to the Central Arid Zone Research Institute (CAZRI) on this special occasion of the 25th anniversary of Arid Zone Research in India, I may recollect some of the more important events that have led to this memorable day.

In 1951, the Government of India's First Five Year Plan Planning Commission, stated, *inter alia,* that:

> "The Great Indian Desert of Rajasthan has been spreading outwards in a great convex arc .... at the rate of half a mile per year...."

Taking note of the alarm, and in recognition of the vital role that this arid region must necessarily play in the national economy, the Indian National Science Academy (INSA) (then known as the National Institute of Sciences of India) held a Symposium on the Rajputana Desert in 1952. Emphasising the inadequacy of scientific information and data available at the time, and the need for research about this desert, Dr. Hora, the then President of INSA had mentioned:

> "Rajasthan desert requires not only a great deal of *knowledge* and *thought* but a *careful planning* and suitable action .... I wonder if any one knows precisely what Rajasthan desert is, how it came into existence, what is its present behaviour and why it is spreading, if it is spreading

at all. I have failed to get an appropriate answer either from geographers, or geologists or even from biologists and archaeologists. Everyone has replied that very little is known about this desert and what little we know cannot form the basis for planning for the immobilisation of the desert. A great deal of *research and investigation,* is therefore needed."

The key words in this quotation are research and investigation, thought knowledge, careful planning and suitable action.

This was stated in 1952. Today, when we meet 25 years after to commemorate the Silver Jubilee of Arid Zone Research in India, what could be the answers to these questions and our response. Perhaps, specific and meaningful answers can be compiled only after the deliberations of this Symposium. Nevertheless, I might make a few observations:

(a) *Research and investigations*

Establishment of the Desert Afforestation Research Station at Jodhpur in 1952, its expansion as the Desert Afforestation and Soil Conservation Station in 1957, and its further reorganization, expansion and redesignation as the Central Arid Zone Research Institute in 1959 are adequate indications of the Government's response to the call for initiating, expanding and intensifying research and investigations on arid zone problems.

Initially started with four scientific Divisions in 1959, the CAZRI has now seven Divisions, besides having the main centres of three All India Coordinated Projects, namely:

(a) Dryland Agriculture;
(b) Millet Improvement; and
(c) Cropping Pattern and Use of Saline Water in Agriculture.

An All India Coordinated Research Project on Rodent Control is in operation at this Institute under the ICAR's Coordinating and Monitoring Centre for Rodent Research and Training. This Project has emerged out of the basic and applied research in this discipline at CAZRI.

During the last 25 years a number of specialised agencies, other than the CAZRI, have been established and have significantly contributed to arid zone research and development technology. These are:

(a) Central Sheep and Wool Research Institute, Avikanagar, Rajasthan
(b) Indian Grassland and Fodder Research Institute, Jhansi, U. P.
(c) Central Soil Salinity Research Institute, karnal, Haryana
(d) National Bureau of Soil Survey and Land Use Planning
(e) Central Soil and Water Conservation Research and Training Institute, Dehra Dun, U. P.
(f) Defence Laboratory, Jodhpur
(g) Universities in Haryana, Gujarat, Udaipur, Jaipur and Jodhpur
(h) Desert Development Commission
(i) Rajasthan Canal Project
(j) Drought Prone Area Programme (DPAP).

Additionally, the laboratories and offices of a number of Central and State agencies are located in the region. To name a few:

Indian Space Research Organization
Physical Research Laboratory
Geological, Botanical, and Zoological Surveys of India
Ground Water Board

are operating in the region. We are indeed happy that several Vice-Chancellors, the Directors and scientists of these institutes are participating in this Symposium.

(b) *Thought*

Scientists at the Research Institutions and Development Departments have given due thought to the identification and conceptualization of the arid zone problems for planning investigations for their solutions. The CAZRI alone has published over 1320 scientific and technical papers since its establishment. Conceivably, a good deal of serious scientific thought is preceded the preparation of these papers. Besides the scientific efforts of the institutions within the region, a good deal of mature thought has been devoted to the desert problems by senior scientists and administrators at the national and state level, and the international scientific community in a number of ways. Presence amongst us today of the two eminent scientists of India—Dr. M. S. Swaminathan, the Chairman and Dr. A. Ramachandran, the Chief-Guest of this session, and over forty eminent scientists from abroad is a witness to this support.

(c) *Knowledge (and technology)*

At the CAZRI, research and investigations are being conducted by a team of over 100 scientists, with the collaboration of over 150 technical staff on inter-disciplinary projects:

Agricultural Economics, Agronomy, Agrostology, Animal Physiology and Nutrition, Animal Production, Cartography, Climatology, Genetics, Geology, Geomorphology, Hydrology, Microbiology, Organic Chemistry, Pedology and Soil Chemistry, Physics (Wind and Solar Energy), Plant Ecology, Plant Physiology, Production Economics, Range Management, Silviculture, Sociology, Soil Conservation & Agricultural Engineering, Soil Physics, and Toxicology and Plant Protection.

Participation and coordinated involvement of biological, physical and social scientists in problem-oriented research is a unique feature of the functioning of the CAZRI—which was envisaged and emphasised by Mr. C. S. Christian in his report for the establishment of this Institute.

It hardly needs to be mentioned that for improving productivity and developing self-reliant villages, technology by itself is inadequate. The development processes involve interaction between at least four broad categories: population, resources, technology and social institutions. Science provides essential facts for enlightened decisions and planning. Sociologists with their skill to understand the every day realities of life are contributing to this over-all objective.

On the basis of the available research, I am in a position to say that sufficient knowledge and technology is now available for the reclamation, improvement and maintenance of productivity of arid lands at a sufficiently higher level. It is not easy at an occasion like this to review all the achievements nor practical to place relative value on each of them. I might mention a few of the inter-disciplinary contributions:

(a) the arid and semi-arid regions of India have been precisely delineated.
(b) an inventory of the natural resources of about one-third of the arid region is now available.
(c) appropriate technology has been evolved for:
  (i) desert afforestation
  (ii) sand dune stabilization
  (iii) improving and stabilizing crop production
  (iv) water harvesting, conservation and utilization
  (v) saline water use
  (vi) management of pasture rangelands and natural vegetation in various desert ecosystem and their utilization
  (vii) livestock management
  (viii) arid horticulture.

Contributions in individual disciplines have been made in diverse fields. Mention may be made of:

(a) the biological heterogeneity in relation to production traits in farm animals
(b) water use economy in desert sheep and goats
(c) solar energy utilization for agricultural and domestic use (water heater, oven and dryer)
(d) identification of the existence of prior river systems (now buried) and their influence on hydrology, origin and distribution of salinity and salt deposits.

Economic analysis of the recommended technology has indicated favourable cost-benefit ratios, net pay back period, internal rates of return, and employment potential. For example, in 16 years period an hectare of unstabilised sand dune in Bikaner district has yielded 82 quintals of timber and 7 quintals of grass, at an annual average cost of rupees one thousand and a gross income of rupees two thousand employing nine sixty eight man days. These estimates extrapolated to about 24,000 ha of unstabilized sand dunes in Bikaner district, as assessed by our Integrated Surveys, would generate an annual return of rupees forty eight million at an average annual cost of rupees twenty four million and generating an employment of over 23 million man-days.

I invite you to the exhibition that has been organised at this occasion with the cooperation of sister organizations and the industry. The exhibition includes models, charts, diagrams and publications depicting the present state of knowledge and the technology available for desert development. While perusing the material of your own interest, I would like you to scan through the publications on display, such as the Agricultural Atlas of Rajasthan and the maps and material prepared for the publication of atlases on ground water, agro-demography and sheep ecology. A wealth of knowledge has been summarized in these documents.

The Rajasthan desert may be the dustiest and the most thickly populated desert of the world. May I add another distinction: the arid zone of India is, perhaps, the most intensively scientifically studied arid region of the world. We now feel quite confident that a multi-pronged strategy can be launched to dissolve the vicious circle of low productivity, low income, unemployment, deforestation, overgrazing and desertification.

As you all know, the United Nations Conference on Desertification was held in Nairobi in August-September 1977. An atmosphere of confidence providing the conference was generated by the knowledge that sufficient technology is now available to initiate national, regional and international development projects to combat desertification, which is well reflected in the Plan of Action adopted by the conference. The CAZRI and its sister organizations in India have made their due share of contributions to this hope, optimism and confidence on the prospects of arid lands development. Scientists from all over the world visits us. A large number of training courses and projects—national and international—has been organized like the one sponsored by the UNESCO to coincide with this Symposium. We take pride in being told that the CAZRI is recognized as leader in the field of arid lands research and that India has adequate research facilities and infrastructure.

I am, nevertheless, quite conscious of the still-lingering gaps in certain disciplines and inadequacies in our understanding and in the development technology. The 25th anniversary of research effort is an occasion to pause, take stock and plan for the future. Much has been accomplished and much more lies ahead. This Symposium, therefore, is an excellent forum in this particular context.

(d) *Planning for development*

India launched its First Five Year Plan in 1951. It is a coincidence that the 25th anniversary of arid zone research in India takes place in the last year of India's Fifth Five Year Plan. Commenting on the results of the development plans and programmes in the desert areas, the Honourable Minister. for Agriculture & Irrigation, Shri Surjit Singh Barnala has recently stated:

> ". . . . despite useful contribution and efforts by research organizations, we have not been able to achieve a significant breakthrough on the development front. A major reason for this is the lack of an integrated approach. The available scientific information on the rational use of eco-system resources are yet to be converted into action programmes. The development of the desert area, thus, is a major task which covers programmes under many disciplines and consequently several departments."

Emphasizing the need for quick application of Science to the national problem, Dr. Ramanna, President of the INSA, has recently stated:

> "A delay in its (Science) application may lead to wrong conclusions as to the value of Science to society itself and detract from the use of the methods of Science to future development.

In recognition of such considerations and to learn more about the problem at the grass-roots level and to gain insight into the process of the transfer of technology from the research institutions to the rural areas, Operational Research Projects have been initiated by the Indian Council of Agricultural Research. The CAZRI is implementing one such project entitled, "Arid Land Management". The implementation of this project has provided an opportunity for the scientists, the development agencies and the farmers to work together. It is a valuable experience for initiating larger pilot projects.

With the availability of global wisdom and experience reflected in the Plan of Action adopted by the U.N. Conference on Desertification, galaxy of talent present here and the contribution to this Symposium, I feel confident of the fruitful deliberations of this Symposium and working out a meaningful and pragmatic programme for development and research for the arid region. The timing of this Symposium could not have been more appropriate. The presence with us today of Prof. Kassas as the personal representative of Dr. Tolba, the Executive Director of the UNEP and Dr. Rozânov, from the same organization, is most fortunate. Presence amongst us of Mr. Christian, who has been associated with this Institute since its inception is inspiring and encouraging.

Let me end with a prayer from the Rig Veda—"Let noble thoughts come to us from every side" for, thought is the seed of action—and action is what is needed now to make the Biblical prophecy come true —"The desert shall rejoice, and blossom as the rose".

REMARKS ON BEHALF OF UNESCO

M. Vannucci
Programme Specialist in Basic Sciences, UNESCO, New Delhi

Mr. President,
Distinguished Delegates,
Ladies and Gentlemen,

It is both an honour and a pleasure for me to be present here among the distinguished gathering to welcome on behalf of UNESCO the delegates at the inauguration of the 'International Symposium on Arid Zone Research and Development' which has been organised by the Arid Zone Research Association of India from 14-18 February 1978 with the assistance of the Indian Council of Agricultural Research and UNESCO.

I am glad to note that participants from Afghanistan, Australia, Bangladesh, Egypt, India, Iran, Pakistan and the United Kingdom are attending this Symposium which is of great significance since it will cover such topics as 'Reviewing and making an inventory of the technology available for development of the arid lands', 'Evaluating areas of research where the developed technology can be immediately transferred to the field for the benefit of the rural population', 'To pinpoint the gaps in the existing scientific knowledge on desert reclamation technology for the purpose of adequately strengthening the weaker areas of research' and to evolve a realistic research programme for the development and management of arid lands and drought prone areas.

I am thankful to Dr. H. S. Mann, Director, Central Arid Zone Research Institute, Jodhpur, and Convener of the Symposium for so kindly inviting me on this inaugural ceremony — an occasion which coincides with the Silver Jubilee celebration of the arid zone research in India since the Desert Afforestation Research Station at Jodhpur was established in 1952. Later in 1959 this Research Station became the foundation of the CAZRI which was established with the assistance of UNESCO with the object of undertaking inter-disciplinary study of the land resources and ecology of natural environments, along with socio-economic activities of the arid and semi-arid regions in coordinated manners to achieve purposeful and useful results.

The impetus provided by UNESCO has made this Institute today as one of the internationally acknowledged centres of desert research, where studies are undertaken in diverse fields of science. Among other major objects for the setting up of this Institute, were to undertake studies on land, soil, water and vegetation (pasture and tree) resources of arid and semi-arid regions with a view to conserve these resources and suggest ways and means for their efficient utilization to increase production and improve the living conditions of human populations. This Institute has already done very useful work, some of which include: increasing production in a drought year; control of white grubs; the understanding of desertification processes and energy flow in arid and semi-arid areas, climatic changes and solar energy utilization. In 1952 with the collaboration of UNESCO a symposium on the Rajasthan desert was organized by the National Institute of Sciences of India (now Indian National Science Academy) at Delhi. This was followed by several international symposia many of which were supported by UNESCO. In 1964, a 'Symposium on Problems of Indian Arid Zone', jointly organised by then ministry of Education, Government of India, and UNESCO was held at Jodhpur to discuss problems relating to then Indian arid zones.

The progress of mankind implies a continuous increase in water consumption and water is the crucial problem of arid and semi-arid regions. The intensification of water resources exploitation entails their progressive exhaustion and degradation thus hindering economic and social development. The water problem is therefore not merely a question of developing sources of water, but also one of regulating man's impact on water resources. The improvement of knowledge of the hydrological cycle and of the methods of evaluation of water resources, as well as a better assessment of these resources at the national, regional, continental and global levels, and of their fluctuations in space and time, are essential for the proper utilization and management of water resources for the benefit of mankind.

The problem of the arid zone is so great and so far-reaching in its implications that it is not possible for any country directly affected, or indeed, for the rest of the world, to ignore the plight of these desert and semi-desert lands. The development of the desert area is a major task necessitating the concerted efforts of several disciplines and in consequence concerns a number of sciences and technologies. The most urgent step is to check the expansion of desert areas. Much of it stems from the appropriate development of water resources.

UNESCO is so much concerned with this problem that it launched as early as in 1948 an international programme of research into the world's arid areas, which cover a third of its land surface. Thousands of scientists from some 40 countries collaborated in studies ranging from underground water research, climatology, solar and wind energy to plant, human and social ecology. This programme was renewed in 1957 with its conversion into a major project known as 'Major Project on Scientific Research on Arid Lands'. The International Hydrological Decade launched by UNESCO in 1965 was an extension to this programme. It was man's first concerted attempt to take stock of his diminishing available resources of fresh water and to coordinate world-wide research and ways of making better use of them.

UNESCO has always encouraged research in the arid and semi-arid areas by the promotion of modern methods and dissemination of scientific results, ideas and publications. For this purpose, studies are conducted on such subjects as groundwater, hydrology and soil moisture problems, environmental problems, the physics of water, ecology and control of excessive of water weeds, water quality, saline water and hydrological mapping. As part of UNESCO's contribution to the achievement of the IHD, it has collected, exchanged and disseminated information concerning research in hydrology and has thus facilitated contacts between workers in this field. To this end, UNESCO has already published under the series 'Arid Zone Research' 30 publications; in addition special mention may be made of the Book entitled 'A History of Land Use in Arid Regions'.

UNESCO has published under the series 'Earth Sciences' 15 publications and under the series 'Ecology and Conservation' 6 publications which can also prove useful for research work in this field. UNESCO's quarterly bulletin entitled 'Nature and Resources' also published articles relating to research on deserts in various parts of the world.

UNESCO assists Member States in the training of specialists in geology, geochemistry, geophysics, geomorphology and geothermics. Particular emphasis is placed on the training of specialized manpower for the developing countries in the applied sector of these sciences, through the organization of long-term postgraduate courses on the one hand, and of short-term refresher courses for technicians and graduates on the other. The 'Regional Training Course on Integrated Natural Resources Survey in the Arid Zones' which has been organized by the Central Arid Zone Research Institute from 21 January to 13 February 1978 has been assisted by UNESCO. The purpose of this course is to help in planning area development programmes based on integrated surveys and resource inventories. The course which is meant for planners, ecologists, foresters, soil conservationists, town planners and university lecturers has included in the programme such subjects as agrometeorological parameters; geomorphology in relation to integrated survey; geology in relation to geomorphological and soil classification; land-use and land capability; vegetation and range inventories.

The study of the problems of arid zones involves a special methodology and techniques. During the past some years much expertise in this field has been developed for the study of arid and semi-arid ecosystems. However, much work will have to be done in the field of research and even more in the field of training and development of manpower. The U.N. Conference on Desertification held at Nairobi from August 29 to September 9, last year, also placed much emphasis on this subject.

Under its Man and the Biosphere Programme, UNESCO has already published 41 reports. You may be interested to know that Report No. 29 relates to "Expert panel on Project 4: Impact of human activities on the dynamics of arid and semi-arid zones' ecosystems, with particular attention to the effects of irrigation."

Also under its MAB programme, UNESCO financially supported the International Geographical Union Working Group which was established at the Montreal International Geographical Congress in 1972, in organizing a 'Conference on Desertification in and around Arid Lands' at Alice Springs, Australia, from 24 November to 2 December 1974. The mandate given to the IGU Working Group was to 'collect evidence on the nature and causes of environmental changes constituting an extension of deserts into marginal areas or an intensification of desert conditions in arid regions'. An important step towards fulfilling that mandate was taken in November 1974 when some thirty experts in arid-zone research met in Central Australia for a five-day field tour of desert lands around Alice Springs followed by a two-day seminar devoted to studies of environmental changes in Australian and other desert areas.

You are surely aware that years of disastrous drought in the Sahel, the vast semi-arid region bordering the Southern Sahara, from Mauritania to the Sudan, have left destitute most of its nomad peoples. The Special Issue of UNESCO Courier (April 1975) examines the tragic plight and uncertain future of the peoples of the Sahel in the aftermath of drought and famine. UNESCO through its aid projects has helped seven Sahel countries which include Chad, Gambia, Mali, Mauritania, Niger, Senegal and Upper Volta.

The present symposium may thus be regarded partly as one more contribution of UNESCO towards tackling one of the major problems that mankind is facing today: that of desertification and increasing aridity of vast areas of the world at a time when more land would have to be put under cultivation for the growing number of the world population.

I have every hope that the participants will be benefited much through mutual discussions and exchange of ideas, and will have an enjoyable stay in this historical city of Jodhpur, that has coped always with the semi-arid conditions of its environment.

Before concluding, I must express our gratitude to the Government of India, for the generosity to act as host of this Symposium and also to Dr. M. S. Swaminathan, Chairman, Organizing Committee; Dr. H. S. Mann, Convener, and their staff for making excellent arrangements for this Symposium.

With these words I wish the Symposium every success.

Thank you.

REMARKS ON BEHALF OF CSIRO

C. S. Christian
Member, Governing Council (Retd.), CSIRO, Canberra, A.C.T.

Dr. Swaminathan,
Ladies and Gentlemen,

Thank you for this opportunity to offer my greetings and good wishes to the Central Arid Zone Research Institute and to the Symposium on Arid Zone Research and Development.

I was very anxious to come to this 25th anniversary of the Institute. I am happy to be here. One reason is that it may be a little more difficult to come to the 50th anniversary. However I will not promise not to come. Several speakers have very kindly referred to my part in the early days of this Institute. In a small way, I feel part of it. That is another reason why I wished to come.

I really did not come here to talk but, rather, to listen and to admire. The 250 papers to be presented to the symposium will give us ample opportunity to listen. The Institute, and the great variety of work being done here, will give us plenty to admire.

My part was to produce an original plan. Any one can do that. To take a plan, implement it, develop it, and modify it to suit circumstances, requires the efforts of many others. This is what the successive Directors of the Institute, their staff, and the many agencies which have helped them, have done.

The present world status of the Institute, the results it has achieved, and the work in progress, are the products of their efforts. There is a great deal to admire, as you will see as you move around the Institute in the next few days.

Dr. Mann referred to the sociological and economic studies in the Institute—the activities of the original Division of Human Factors. These studies concern people. The ultimate objective of research and development of arid zones must be the improvement of the lives of the people living in them, not just the advancement of scientific research or the researcher. I hope that during the symposium you will continually hear this objective in mind, the objective of benefiting people.

I congratulate the Institute on its achievements over the last 25 years. I hope it will be equally successful in the next 25 years and I give it my very good wishes.

REMARKS ON BEHALF OF UNEP AND UNCOD

M. Kassas
Personal Representative of Executive Director, UNEP, Nairobi

1. Dr. M. K. Tolba, Executive Director of the United Nations Environment Programme, asked me to convey to you his greetings and to express his appreciation of this important symposium. It was to his deep regret that he was not able to be here in person and to enjoy the pleasure and the privilege of sharing with you the deliberations of your scientific meetings. He also wanted me to express his appreciation of the initiative taken by the Arid Zone Research Association of India in holding this international symposium in this great centre of scientific research: the topic is important and the place is most appropriate.

2. The establishment of the Central Arid Zone Research Institute in Jodhpur some 25 years ago was a far-sighted action by the Government of India and was one of early national contributions to the international scientific movement: arid zone research, initiated and guided by UNESCO. This institute did not only contribute to our basic knowledge of desert ecology and arid zone processes but had also managed to carry out successfully applied research that helped to solve several problems of rational land-use in arid lands and development of resources of the Indian desert and drylands. The work of this Institute on development of: crop breeds suitable for dryland farming especially small grains and legumes,

fodder plants, appropriate methodologies of irrigation and farming practices, technologies of biogass production and solar energy utilization, etc. is well known all over the world.

3. In the preparation for the United Nations Conference on Desertification, Dr. M. K. Tolba acting as Secretary General of the Conference enjoyed the full support of this Institute and he wanted me to underline a few examples of this support and valuable contribution to this international enterprise. This Institute undertook the preparation of one of the principal case studies: Luni Development Block, Rajasthan, India, presented to the Conference. The high standard of this study was very much appreciated and was an added credit to this Institute and to it notable director: Dr. H. S. Mann. This Institute and the Arid Zone Research Association of India provided support and valuable assistance to the Conference regional preparatory meeting for Asia and Oceania held in Delhi in April 1977. The notable success of that meeting was due to the enthusiastic support of the Indian institutions and to the leadership of Dr. M. S. Swaminathan who chaired the meeting. These two men had their important roles in the Conference. Dr. H. S. Mann was one of the leaders of the Nairobi Seminar on Desertification that was organized by the world scientific community (associations for the advancement of science in USA, Latin America, Britain, France, East Africa and India) and held (21-25 August 1977) immediately before the Conference. Dr. M. S. Swaminathan was elected by the Conference to chair the Committee of the whole which was a principal organ of the Conference. His chairmanship was combination of leadership and grace and the Conference was indeed most fortunate to have him in this post.

4. Dr. M. K. Tolba wanted me to acknowledge on his behalf the moral, political, technical and financial support that India provides to the United Nations Environmental Programme. This indicates clearly that the Government and political leadership of India are fully committed to the objectives of improving the quality of life, development without destruction of the environment and its life-supporting systems, and international cooperation in management of our only one earth. Development plans of India were among the first in the world to incorporate environmental issues; recent statements of H.E. The Prime Minister show his deep concern with environmetal issues. These important political statements are sources of encouragement to the United Nations Environment Programme.

5. Dr. M. K. Tolba remembers with special respect and affection his recent visit to India and the constructive discussions with H. E. The Prime Minister. He wanted me to express his gratitude for the kindness and sympathy with which he was received in India.

6. Allow me—Mr. Chairman—to end with a personal note, to express my happiness to be here today in this great centre of scientific research and development, and my gratitude for being invited to share with my many friends and colleagues the experiences and discussions of this international symposium.

INAUGURAL ADDRESS

A. Ramachandran
Secretary to the Government of India,
Department of Science and Technology, New Delhi

I am pleased to be here this morning to be amongst a gathering of distinguished scientists drawn from different lands who are making earnest efforts to fight one of the most serious challenges facing 1/6th of the human population. Arid lands and deserts are not new to man but have been its constant companions. In fact, as we learn from history, deserts have been the cradles of great civilizations and religions. Unfortunately over the span of several centuries the situation has changed dismally, both on account of nature's vagaries as well as man's inadvertancy towards his surroundings and environments. It is no wonder that more than 1/3rd of the terrestrial land area today is arid and much of it has become a desert. Probably you are all aware that the rate of loss of land or productivity through desertification has grown to the order of 50,000 sq. kms. per year and 30 million sq. kms. are vulnerable to desertification. This is indeed a frightening picture especially for the world teeming with population, recurrent food shortages and environment hazards. The future of more than 1/6th of the world population living in the arid lands is threatened by the spread of desert conditions. These figures bring home the urgency of concerted efforts to be undertaken at national, regional as well as international levels in order to stop or to halt the advance or spread of deserts, as also better utilisation of arid areas for the benefit of mankind without disturbing the delicate eco-system.

As is evident from the nature of this problem, any meaningful strategy has to be of an integrated character involving sociological, economic, scientific and technical thrusts. It is self-evident that all arid zone problems may not be susceptible to quick solutions. We would have, therefore, to plan short-term and long-term measures with the provision for continuous assessment as well as planning and management at every stage. Unfortunately some of the ideal solutions would be difficult from the point of view of implementation mainly because of scarce resources especially in the developing countries. Such countries would have to make hard choices in the allocation of their scarce resources in order to yield maximum results. Depending on the level of national awareness and the availability of trained manpower and scientific base, each country will naturally follow a certain sequence in its efforts to solve these problems.

Fortunately through the deliberations of the World Conference on Desertification, we have now with us adequate information regarding specific problems encountered by the developing countries as well as the factors preventing the application of available technology. Keeping in view the fact that the U.N. Conference on Science & Technology for Development is to be held next year at Vienna, as a part of its preparatory work for the Conference, it would become an important part of their exercise for the countries faced with the problems of desertification, to take inventory of current research and development programmes (with emphasis on development). This would enable the Conference to develop a programme of action, especially the application of science and technology to solve the special problems of arid areas. During my brief address, I shall be focussing attention mostly on the application aspect of science and technology to the problems relating to arid zones.

During the past quarter century it is encouraging to note that the quantum of research work as well as specialised research institutes dealing with arid zone problems have increased significantly. Rapid technological changes are also quite discernible particularly in the arid as well as in the semi-arid areas. In many countries, necessary sound research base has been created resulting in a valuable flow of scientific and technical advances such as new forms of irrigation, development of genetic strain resulting in drought resistant crops with shorter life cycles and not sensitive to photo periodism, energy collection and conversion devices, desalination and brackish water treatment, etc. Perhaps one of the most significant advance relates to the weather monitoring systems using satelite technology, thus enabling us to have a unparalleled opportunity for rapid collection and dissemination of the weather data on a global scale. While it is necessary to strengthen the research activities in various aspects of desertification, it is also necessary to consolidate what is considered to be essential, so that existing and future technology efforts become more appropriate and applicable for local conditions.

The following factors will have to be taken into account while seeking technological solutions to the problems of the desert areas.

Human resources in the arid areas have to be treated as the most valuable resource since these people are a repository of considerable environmental knowledge evolved over centuries of human existence. For these very reasons, these people have survived so long despite hostile environment, since they had acquired profound understanding of the environment in which they lived. It seems to me as imperative, that attention be paid to the understanding of scientific problems of their land use methods and survival strategies. Highest priority will have to be given for the adaptation or development of such technologies which will impose less thermal stress on the human populations in the arid areas. This is within the realm of achievement of the existing known science and technologies. When such facilities are provided, arid zones could become attractive for human settlements as can be seen from the many experiencing advanced countries.

In evolving scientific and technological strategies, highest attention will have to be paid to the various aspects of energy utilization. It is well known that energy inflow from the Sun into the deserts is on an average 275 watts per sqm. This may seem surprising as the angle of incidence of the solar rays in most of the deserts is not as high as at points nearer the Equator. More energy, however, reaches the ground surface in the arid areas mainly as a result of clear sky and the anti-cyclonic weather conditions prevailing throughout the year. It is through efficient trapping of this energy through the cultivation of selected plants, that we could significantly add to the animal and human food production. This approach would mean large scale cultivation aimed at bio-mass production. The limiting factor for large scale application of this solution would, however, be the availability of water. Outstanding results can be obtained where water is judiciously used in the arid zones for the trapping of this energy through plant production. The other effective use of high solar energy incidence would be through cultivation of crops specially adapted through genetic improvement for desert conditions. The climatic features of the desert, namely the high intensity day time solar radiation and the nightly long wave outgoing radiation could be taken into account while designing buildings and in the choice of materials for such purposes. In addition it should be possible to promote the development of low cost simple technology systems for utilising solar energy for winter heating and hot water supply and night radiation for summer cooling. Technologies are being developed, some of which are in a fairly advanced stage, for desalination of saline or brackish water found in the ground water supplies in most deserts. Where the supplies of brackish ground water are substantial, it should be possible for the agricultural scientists to develop salt tolerant crop plants, vegetables as well as livestock. In some cases saline water could directly be used for irrigation purposes. It now seems certain that brackish water could be utilized for protein cultivation in the form of algae.

As stated earlier, water availability is the single most crucial factor for the development of desert regions. Considerable work would have to be done using the deep drilling technologies for the accurate assessment of the ground water reservoirs in the desert areas as also the extent of the recharge of these reservoirs. This work has to be intensified since the ground water reservoirs in arid zones, represents the accumulated water supplies collected through centuries. Aquifer management and the technologies associated with it have to be given the importance they deserve. After the accurate assessment of the ground water supplies has been made, then only strategies have to be developed for the efficient use of the water taking into account the factors such as evaporation, seepage control, etc. Artificial materials such as plastics could be used for maximising effective use of water by delivery systems, the reducing losses into the area and through the soil. Where the water has to be stored in open reservoirs, evaporation losses could be reduced by the use of a plastic foam like film which is porous enough to permit the exchange of gases but impervious to the water vapour. Large scale experiments are being supported in some of the states in this country especially in big reservoirs in trying out the use of this technique.

While evolving strategies for the application of science and technologies towards solving the problems of desert areas, it would be prudent to identify the research gaps so that concerted efforts could be made on a national, regional or international basis to fill these gaps.

Notwithstanding the fact that many advances have been made in tackling arid zone problems a great deal remains to be done. Let me briefly go over a few of the areas which need to be attended to for a viable solution of many of the problems that we face today.

Relationship between climate and desertification processes is a phenomenon yet far from detailed understanding. It will perhaps require combined effort, the areas which need to be attended to needed to be undertaken round the world in many countries, over a prolonged period of time before we arrive at a stage of knowledge when climatic variations over arid zones in general and deserts in particular can become predictable sufficiently in advance to prepare the local inhabitants of any kind of hazards that such changes may entail. Notwithstanding the long-term duration of such studies, I hardly need emphasise the urgency ot undertaking such studies.

Propagation of woody vegetation and forestry is another very important area. The multiple functions are organic material in any eco-system, and the rapid rate at which such supplies are being depleted, it becomes imperative that attention should be given to include such resources into new and modified land use framework.

Attention must be focussed on surveying and evaluation of the extent of physical and organic resources, which are dispersed in different arid zones. This is important on account of such resources being a functional base for any future development plans that we may wish to undertake. Much remains to be done, for instance in the fields of assessment of genetic material and the economic potential of many flora and fauna. Surprisingly, little has been done on the cross zone identification and selection of plants and animals. All this requires intensive study of propagation and selection.

At the base of the ecological problem is the disproportionate relationship between human population and the existing resources and technology. It would be impossible to assess the critical population density in any area if we have no reliable data on human or stock populations. Similarly without any measure of growth we have no idea of the severity of the problems that may arise in the future. The general problem involving the parameters of size, dynamics, distribution, rates and reasons for migration, etc., are still vague and undefined. This is not the question of data collection but obtaining an understanding through such information about the nature of the dynamics, which ought to govern the growth of the eco-system.

The use of alternative or unconventional energy sources in drylands, usually favoured with sunlight and wind, should be vigorously investigated as a means of preserving organic material, of reducing the tedious human labour so often involved with fuel collection, and of providing the people of the dryland with simple, inexpensive and convenient devices to serve their daily lives.

Distinguished scientists, I have great pleasure in inaugurating this International Symposium. May I also wish the CAZRI many decades of useful service and that by the time it celebrates the Golden Jubilee, its record of work would have significantly improved the quality of life of people living in arid areas.

CHAIRMAN'S REMARKS

M. S. Swaminathan
Director General, ICAR, and Secretary to the Govt. of India, New Delhi

It is the main duty of the Chairman to control time during a meeting. I find, however, that the time has already run short and, therefore, I shall say only a few words: First of all, I would like to commend the initiative and preparations made by the CAZRI staff for organising the Symposium. Sister institutions and universities have also lent their valuable support. We are also happy to have with us today a number of scientists from foreign countries. I hope that during the forthcoming few days during the scientific discussions, feasible strategies to combat desertification will be formulated and attempts will be made for identifying the gaps in our knowledge for the management of deserts. We are fortunate that this symposium is being held at a time when the Planning Commission is finalising the strategy for growth during the next five years. The Government of India has already announced that in the next Plan agriculture and rural development will receive overriding priority. Dr. Kang, Chief of Agriculture, is with us and I am sure we will be benefited by his presence.

Dr. Mann has stated how in 1952 when the nucleus of the present Institute was started not much knowledge about the Indian desert was available but as a result of 25 years of research, we have now much more information available as is evidenced by the books, monographs, research bulletins and research publications by the scientists of CAZRI and other organisations. We have also some knowledge about the arid and semi-arid regions in Karnataka, Andhra Pradesh and there is a move to strengthen research in these desert pockets by organising regional stations in these States. Also, after the UN Conference on Desertification, we have adequate knowledge on a relevant plan of action which could be utilized immediately for the benefit of the people living in these areas. The available data have also shown the existence of considerable untapped production reservoir, even at current levels of technology. While there are a large number of liabilities, there are fortunately also several assets upon which we can capitalise. The question, therefore, is how to proceed further. For speedy progress, there has to be community action, involving also rural women and children. For example, in the desert the rainfall is erratic and during a good rainfall period, such as last year, we should embark upon a massive tree planting programme. For taking advantage of good seasons, we should have a "Good Weather Code" which can help to build the ecological infrastructure essential for agricultural advance. Similarly, to minimise the impact of adverse weather, we should have a "Drought Code" which provides guidelines for introducing crop life-saving techniques and contingency plans to suit different weather models.

It is essential in the deserts to plan the water budget scientifically, particularly when the major source is from rains. Canal and ground water irrigation should be economical and based on high production management system with low water consumption. We would like to see the initiation of operational research projects on water use with reference to the Rajasthan Canal area and also in ground water irrigation systems.

In order to ensure stable income for desert people, special attention should be given to post-harvest technology. An agro-industrial complex based on desert flora and fauna should be organised in each district.

The Nairobi Desertification Conference rightly called for a halt to all man-made processes which cause either the destruction or dimunition of the biological potential of land. It further concluded that given a right blend of political will and professional skill, it should be possible to achieve this goal before the end of this century. If we can mobilise the entire community and take preparatory action for implementing a "Good Weather Code" in desert areas, we can achieve the desired end even earlier. This will call for a massive extension effort involving the mass media. A desert development symphony has to be created involving the release of synergetic interactions among all the agencies working on the control of desertification.

I am confident that this jubilee symposium will be able to take stock of what we have done so far, identify lacunae in our knowledge and suggest strategies for desert management.

VOTE OF THANKS

Ishwar Prakash
Secretary, Arid Zone Research Association of India,
Central Arid Zone Research Institute, Jodhpur

Dr. Ramachandran, Dr. Swaminathan, Dr. Bhumbla, distinguished delegates,

It is my proud privilege to express our gratitude to this distinguished gathering for encouraging us by their presence here today. We are grateful to Dr. Ramachandran for kindly sparing time for giving us a thoughtful inaugural address. Dr. Swaminathan, our Director General, has been kind enough, not only to specially come here for chairing the inaugural session, but he has also been advising us as the Chairman of the Organizing Committee on various aspects of planning of this Symposium right from the start. We also express our gratitude to our Chairman, Dr. Bhumbla, for the welcome address and for guiding us in organizing the Symposium.

It has been possible for a number of foreign delegates to participate in this symposium through the good offices and financial support of the UNESCO. We are especially obliged to Dr. M. Vannucci and to Dr. V. G. Podoinitsin for taking personal interest in the matter. Our thanks are also due to the UNESCO for providing financial assistance to this institute in its arid land major programme in the past. Dr. J. A. Mabbutt has been with us here on behalf of the United Nations University and it was our privilege to discuss many matters regarding the symposium with him. We are also grateful to Dr. M. Kassas and Dr. Rozanov for representing UNEP and UNCOD at the Symposium.

The Indian Council of Agricultural Research has supported us with generous financial assistance for arranging the symposium. We thank the ICAR for this most needed help. We are grateful to Indian National Commission for UNESCO and to Shri S. P. Tuli, Under Secretary DARE for their help. We also acknowledge with thanks the financial support given to us by the Department of Science and Technology, Government of India.

We thank all the delegates for having so readily responded to our invitation and for sparing time from their busy schedules to participate in the symposium.

We believe that this gathering of experts from various parts of the world is going to generate even greater interest than has been hitherto shown in the sciences of desert management and accelerate developmental activities.

We are indeed fortunate to have amongst us a very special delegate in the person of Mr. C. S. Christian of the CSIRO, Australia, whom we regard as the father of the CAZRI as he was instrumental in planning the structure and scope of activities of this Institute.

On this occasion we would like to respectfully remember and express our deep gratitude to our pioneers in arid zone research in this country, who are no more, viz., (1) Dr. P. C. Raheja, who was the first Director of the Institute and who opened new vistas of research on desert management; (2) Shri Mahendra Prakash, the jubilant forester, who initiated the work of range management, roadside plantation and sand dune fixation; (3) Shri A. K. Chakravarty, who had been here as Agrostologist and Head of Division of Plant Studies, and (4) late P. M. Dabadghao who was the pioneer agrostologist in the country. We also remember those dedicated members of the supporting staff who are no more with us.

We are grateful to Shri C. P. Bhimaya and Dr. Mukhtar Singh, our retired Directors for graciously accepting our invitation to participate in the Silver Jubilee celebrations of arid zone research in India and in the deliberations of the symposium.

We are thankful to various agencies of the Rajasthan State Government and of the Government of India for assisting us in organizing the symposium and to our colleagues both from within the institute and from outside, and for their unstinted cooperation in organizing the Symposium. The Members of the Executive Committee of the Association have been providing guidance for various arrangements and we express our gratitude to them.

We are thankful to the individuals, organizations and commercial firms who have come forward to arrange tea, lunch and dinner for the delegates and the advertisers who have supported us in our publishing endeavour. Thanks are also due to Shri Narendra Sisodia, Collector, Jodhpur, and other colleagues of the State Government for help at all the stages.

I will be failing in my duties if I do not mention here that the original idea of holding this symposium and the guidance for executing it have come from our Director, Dr. H. S. Mann, who is also the Vice-Chairman of our Association. Without his invaluable support it would not have been possible for us to gather here today in this fashion. His enthusiasm has always been infectious and one could not but be moved by it. On behalf of my colleagues and on my own behalf, I express our deep gratitude to Dr. Mann.

Thank you once again.

SCIENTIFIC SESSIONS

I. 1.1

MULTIPLE EVIDENCE FOR CLIMATIC CHANGE IN RAJASTHAN

D. P. Agrawal[1], R. P. Dhir[2], R. V. Krishnamurthy[1],
V. N. Misra[3], S. C. Nanda[3] and S. N. Rajaguru[3]
[1]*Physical Research Laboratory, Ahmedabad,*
[2]*Central Arid Zone Research Institute, Jodhpur,*
[3]*Deccan College, Poona*

INTRODUCTION

We discuss below some of our results that have a bearing on climatic change in Rajasthan. Geomorphologic and palynologic studies, related to palaeoclimatic changes, have been carried out by various other workers (Bryson and Baerris, 1967; Ghose *et al.,* 1966; Singh *et al.,* 1974; Verstappan, 1970). We have, in addition, used radiometric, stable-isotopic, SEM (scanning electron microscopy), and sedimentologic techniques (Agrawal and Pande, 1977). As some of our results have been discussed earlier (Agrawal *et al.,* 1976), here we confine ourselves to a discussion of the evidence from Bap Boulders area, Malhar Rann, and Gudlai well section—all located northwest of Jodhpur.

Sem data

SEM techniques to determine the ancient environments have now been established (Krinsley and Doornkamp, 1973) and have also been used in India (Agrawal and Roy, 1977; Pant *et al.*, 1977).

We studied, under SEM, quartz grains from *kankar*-bearing and *kankar*-free deposits for environmental clues. The main sites studied were Chirai, Chamu and Gudlai (all north-west of Jodhpur). At all the sites we discovered an alternation between *kankar*-bearing relatively compacted deposits and loose sandy layers. The quartz grains from the *kankar*-bearing deposits showed V-shaped indentations (Fig. 1, 2 & 3) probably indicative of subaqueous transport. The intervening loose sand grains showed upturned plates, solution/precipitation (Fig. 4)-suggesting aeolian activity.

The SEM studies indicate that there have been wet and dry phases alternating with each other. We will also discuss here if we can date these events. Let us first examine the evidence of glaciation in Rajasthan.

Bap boulders

During our survey we also examined the Bap Boulders, near Bap, north-west of Jodhpur. From the truncated boulders, striations and moraines one can infer that they probably represent an ancient glaciation. There has been a general consensus that these glacial remains are several hundred million years old (probably Permo-carboniferous), but recently a suggestion has been made that they belong to the Quaternary period.

One should, however, note that nowhere did the Pleistocene glaciation come down lower than 40° N Lat, except in mountaneous regions. In India, barring the Himalayan ranges and their foot hills, the lowest recorded moraines are near Dharmashala, about 32° N Lat, at the foothills. But Bap boulders are only about 27° N Lat and on the Thar desert at about 300 m altitude. Nowhere in the world Pleistocene glaciations have been reported at this latitude and altitude.

It has been estimated that in the last 150,000 years the maximum temperature variation between the coldest and the warmest periods is only 10°C (JOC, 1975). Whereas to bring the Ice Age glaciers down to tropical and sub-tropical latitudes one will have to bring down the temperatures by 18°C (Schneider and Dickinson, 1974), which is improbable for the Quaternary periods at least. This will bring down the snowline by *c.* 4000 m. And finally, there are no traces of moraines in the intervening areas between the Himalayas and Bap. All these considerations make the ascription of these glacial remains to Quaternary period improbable-rather absurd.

We can therefore rule out glaciations in Rajasthan during the Quaternary period. More than temperature variations, this area witnessed precipitation fluctuations. Singh *et al.'s* (1974) palynological work in the area has shown marked variations in rainfall during the Holocene period.

Other sites

We examined several profiles near Chirai, Chamu and Gudlai villages northwets of Jodhpur.

Starting immediately north of Jodhpur town the plain is dominantly made of light textured alluvial soil, often covered with dune sands. In the sections exposed by digging of tanks (*nadis*) and pits for road metal we found thick deposits of calcium-carbonate over a distance of more than fifty km to the north and west of Jodhpur. One

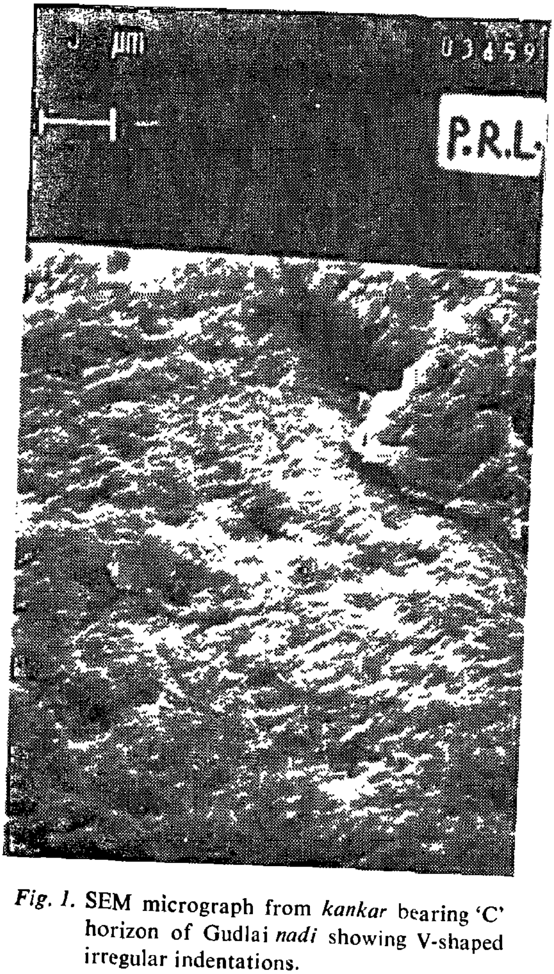

Fig. 1. SEM micrograph from *kankar* bearing 'C' horizon of Gudlai *nadi* showing V-shaped irregular indentations.

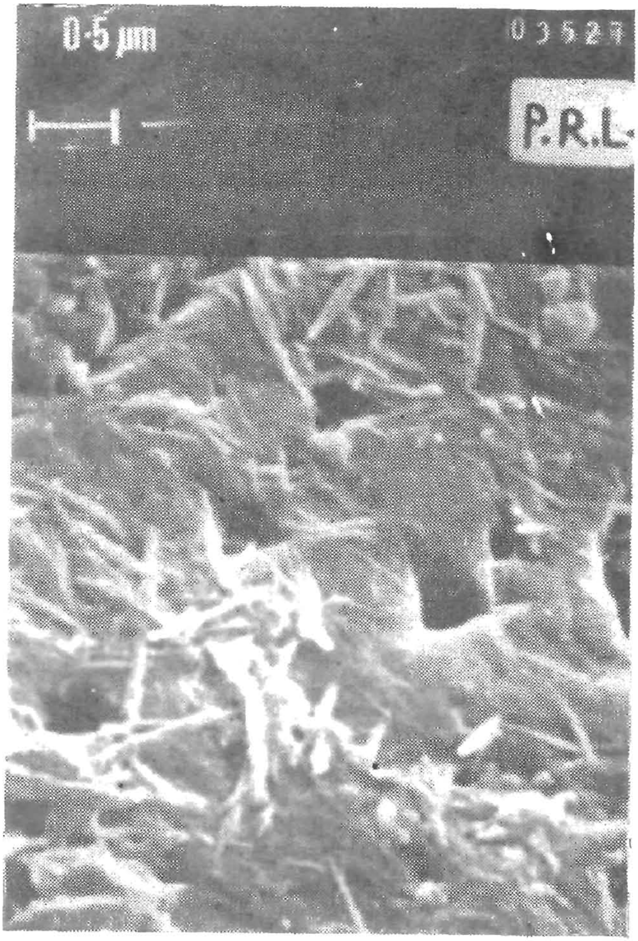

Fig. 2. SEM micrograph from the *kankar* bearing horizon of Chirai section showing V-shaped indentations.

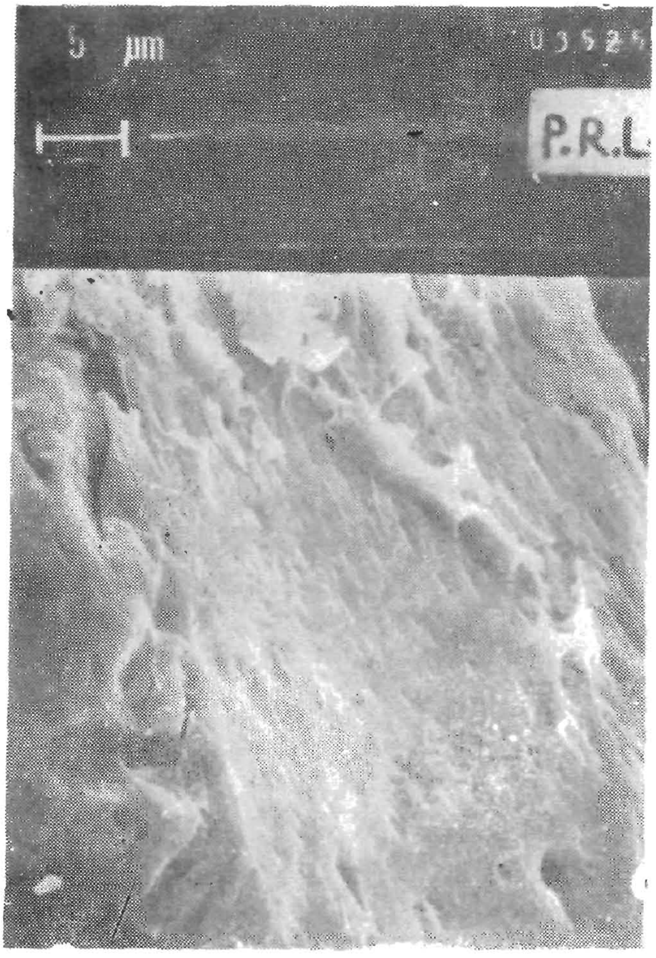

Fig. 3. SEM micrograph from *kankar* bearing horizon of Chirai showing V-shaped indentations directed randomly.

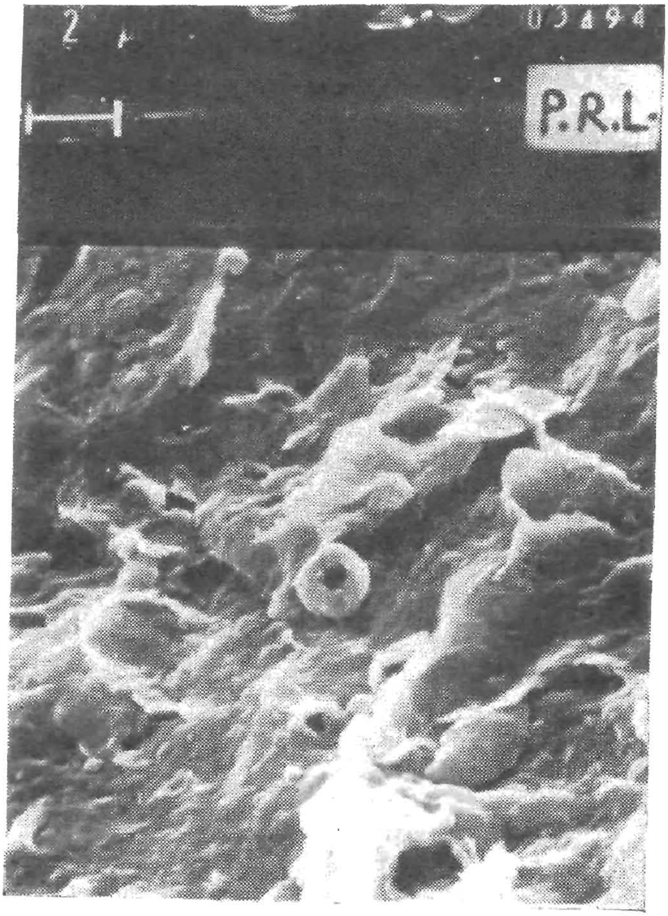

Fig. 4. SEM micrograph from Gudlai-D horizon (*kankar* free, loose sand/silt) showing solution/precipitation and upturned plates.

of the deepest sections (5.70 m) exposed was in a well near the village of Gudlai, 5 km north of Chamu. In this section we noted three layers of *kankar* separated by two layers of silty and sandy deposits, as shown below.

Section in the well at Gudlai village

Depth BS (cm)	Horizon	Thickness (cm)	Nature of sediments
50	E	50	*Kankar*
100	D	50	Silt
140	C	40	*Kankar*
320	B	180	Silt
570	A	250	*Kankar*, bigger nodules than in E & C

As discussed above the SEM studies show that the *kankar* bearing sediments were probably deposited when there was adequate water to transport these sediments. The intervening layers, however, showed evidence of aeolian transport. We therefore infer the former as representing wetter conditions.

It is known that *kankar* does not occur in humid climate (annual rainfall > 1000 mm) as it is leached away. In very dry conditions, sand dunes are active and no *kankar* forms to stabilize them. It appears that only the intermediate conditions (mildly humid) permit *kankar* formation.

To place these events in a chronological sequence, we have dated these caliche samples. But before we discuss the dates, let us examine the evidence from Malhar Rann.

Sedimentological analyses

Malhar Rann is a vast, shallow depression north of the town of Phalodi. The surface water in the depression as also the underground water is at present being used for commercial exploitation of edible salt. To draw underground water, mining companies dig wells and long narrow canal-like channels, thus exposing both basal solid rock and overlying softer sediments. The site was first visited by G. Singh when he collected soil samples from one of the wells. Subsequently in February, 1977 four of us (D.P.A., R.P.D., V.N.M. and S.C.N.) visited the site, studied the stratigraphy of several well sections and collected more samples for sedimentological and palynological analyses. The depth of the softer sediments in the wells on the fringes of the lake varies from 2.50 to 3.50 m but in the wells towards the central part of the lake it exceeds 5 m. The sediments show very fine laminations of deep red clayey beds altering with yellowish sandy layers. Two representative sections are reproduced below.

Section facing E in the canal-like cutting (on the property of Mr. Subhash Chandra)

Depth BS (cm)	Layer	Thickness (cm)	Description of the layer
39	1	39	Dominantly silty clay (reddish aggregated with occasional bands of very fine light yellowish brown sand
73	2	34	Thick bands of light greyish sand alternating with thin bands of reddish clayey silt
162	3	89	Dominantly reddish clayey silt in bands alternating with occasional bands of yellowish brown fine sand
202	4	40	Dominantly yellowish brown fine sand with lenses throughout of fine sands with slight admixture of clay, silt and organic matter
208	5	6	Dominantly reddish silt with occasional bands of yellowish brown fine sand
216	6	8	Dominantly yellowish brown fine sand with occasional bands of reddish silt
225	7	9	1 cm thick reddish silt alternating with 1-2 cm thick bands of yellowish brown fine sand
231	8	6	Gravelly loamy sand with 60-70 % gravel, very rounded, yellowish brown
238	9	7	Light fine sandy loam-yellowish brown with some pockets of greyish brown
245	10	7	Fine sand-greyish brown-with slight admixture of silt
260	11	15	Yellowish sand with occasional gravelly particles
—	12	—	Red sandstone

Section in the well on Mr. Ram Lal Mundhra's property

Depth BS (cm)	Layer	Thickness of layer (cm)	Description
83	1	83	Aggregated silty clay loam
150	2	67	Reddish clayey silt with thin bands of sand
240	3	90	Fine sand with lenses of silt-enriched sand
370	4	130	Clayey silt with thin bands of brown sand
510	5	140	Fine sand with alternating bands of silty clay
—	6	—	Sandstone

The lake sediments were analyzed to determine the nature of deposition, antiquity of the Rann, and palaeoclimatic fluctuations. Though sediments have yielded pollen, so far adequate material for ^{14}C dating has not been obtained. Mostly the samples are bereft of datable organic debris. Preliminary sedimentological analyses are given below and in Table 1.

Silty and clayey samples are found to be poorly sorted while sandy samples, excepting 7 and 9 (Table 1) are found to be moderately sorted and negatively skewed. Samples 7 and 9 are poorly sorted. Sand samples are essentially Leptokurtic.

Negative skewness and moderate sorting of sand samples show that they are certainly *not dune sands* as the latter are generally positively skewed and well sorted. These sands, therefore, may represent high energy shoreline environment and clayey samples low energy deep water environment. Gravelly sands appear to have been deposited in fluvio-lacustrine environment by feeder streams. Medium to fine sand fractions of all the samples were cleaned chemically and examined under binocular and petrological microscopes for determining morphoscopic characters and mineral composition respectively. These studies show that these sands are sub-rounded to subangular and do not show frosting and pitting over the surface. There are a few well rounded grains present in each sample.

Fine sand fractions are rich in quartz, weathered sodic felspar, muscovite, altered biotite, chlorite and epidote. Minerals present in minor amounts are zircon, tourmaline, garnet and dark coloured opaque minerals. On the whole the source of sand is from metamorphic rocks.

Significantly, the top samples (1 & 2, Table 1) contain relatively a smaller proportion of chlorite.

Table 1. Description* of Malhar lake samples from Rajasthan

Depth below surface (cm)	Description of the sample
0-39	Pinkish grey (7.5 YR 6/2). Silty clay
39-73	Pale brown (10 YR 6/3). Silty sand
73-152	Light brown (7.5 YR 6/4). Clayey silt
162-202	Light yellowish brown (10 YR 6/4). Fine sand
202-216	Light brown (7.5 YR 6/4). Sandy silty clay
216-225	Light yellowish brown (10 YR 6/4). Sand
225-231	Brown (7.5 YR 5/4). Gravelly sand
231-245	Brown (7.5 YR 5/4). Sand
245-260	Light yellowish brown (10 YR 6/4). Gravelly.

*The description of samples is based on textural studies by dry sieving and pipette analyses and colour by Munsell soil colour chart.

Chemical studies such as pH, organic matter and carbonate contents of finer (< 0.06 mm) fraction show that these sediments are alkaline (pH varying from 7.9 to 8.5), with organic matter varying from 0.15 to 0.55%, $CaCO_3$ from 8 to 40%. Clayey samples show relatively higher proportion of organic matter than sandy samples.

Clayey samples (Nos. 1, 3, 5 & 7, Table 1) have yielded pollen and their detailed study is in progress.

On the whole the sediments under study seem to have been deposited under fluctuating hydrological conditions on the shore of the Malhar Rann. High lake level is indicated by clays and low lake level is suggested by sands. Correct interpretation of sedimentary environment will be possible only after a study of sedimentary structures in the field, and of the nature of surrounding geology and morphology.

^{14}C & $\delta^{13}C$ *measurements*

Caliche *(kankar)* may be forming from the bicarbonates contributed by the percolating water containing atmospheric or biogenic CO_2 and the dead limestone of the soil (parent rocks). The following over all reaction has been suggested (Salomons, 1973).

$$2HCO_3^- + Ca^{++} \rightleftharpoons CaCO_3 + CO_2 + H_2O$$

From this it may be inferred that one half of the carbon atoms come from atmospheric/biogenic CO_2 and the other from the 'dead' limestone.

Generally the δ^{13}C values for the atmospheric CO_2, biogenic CO_2 from semi-arid regions and soil carbonates are −7% O, −12% O and +1 to 2% O respectively. The positive δ^{13}C values of caliche studied by us (Table 2) indicate that dead limestone formed part of the ^{14}C dated samples.

$T = \overset{\tau}{\tfrac{1}{2}} + \mathrm{Log}\,(1/(1 - 10^{-2}D)$ Where is the half-life of radiocarbon

It can be seen that the maximum aggravation of true age can only be by one half life of ^{14}C (5730 yrs). Therefore, by substracting this value from the observed values we can obtain the corrected dates. Table 3 gives both the corrected and uncorrected dates. Although this is an over-simplification, the finiteness of ages and stratigraphy do permit this interpretation.

Table 2. Stable isotope measurements of caliche samples

Site	Sample No. – Fraction No.	PRL No.	^{13}C (% O) PDB
Naliasar Lake	1-1	358 (C-1)	+ 2.33
,, ,,	1-2	,,	+ 2.65
,, ,,	2-1	359 (C-2)	+ 2.54
,, ,,	2-2	,,	+ 2.96
,, ,,	2-3	,,	+ 3.30
Gudlai *nadi*	3-1	373 (C-20)	+ 0.91
,, ,,	4-1	374 (C-19)	+ 3.91
,, ,,	4-2	,,	+ 2.73
,, ,,	4-3	,,	+ 1.71
,, ,,	5-1	375 (C-18)	+ 0.75
,, ,,	6-1	376 (C-17)	+ 0.79
Chirai	7-1	372 (C-22)	+ 1.31
,,	8-1	378 (C-23)	+ 0 61
,,	9-1	379 (C-24)	− 1.22
Chamu	11-1	— (C-26)	− 1.20
,,	12-1	— (C-27)	+ 2.39

Following the reactions given above for caliche formation and assuming that any error in the ^{14}C age is purely a 'dead carbon' effect, we can correct the ^{14}C dates for "dead" cabon and try to arrive at "true" ages.

The differences between true and apparent ^{14}C age, T, for a sample containing D% dead carbon is given by the following equation (Kusumgar, 1973).

We thus get wet phases at 7000 ± 500 (Horizon A), 15000 ± 2000 (C) and > 40,000 B.P. (D). These could of course be apparently younger because of the redissolution and recycling of *kankar* from

Table 3. ^{14}C Dates of caliche samples from Rajasthan

PRL No.	Site	Depth from surface (cm)	Fraction detail	Age B. P. $\tau_{\frac{1}{2}}=5730$ yrs		Age B. P. corrected for max. dead carbonate effec
358	Naliasar Lake	5	1st fraction (surface) 10 mts acid treatment	13120	+290 −280	7390
358	Naliasar Lake	5	2nd fraction (inner portion)	16030	+380 −370	10300
359	Naliasar Lake	10	1st fraction	16010	+610 −570	10280
359	Naliasar Lake	10	2nd fraction	20580	+940 −850	14850
359	Naliasar Lake	10	3rd fraction	22980	+720 −660	17250
373	Gudlai *nadi*	50	Total	12070	+460 −440	6340
374	Gudlai *nadi*	140	1st fraction	15400	+230 −220	9670
374	Gudlai *nadi*	140	2nd fraction	23570	+1090 −960	17840
374	Gudlai *nadi*	140	3rd fraction	18840	+600 −560	13110
375	Gudlai *nadi*	180	Total	27220	+3280 −2340	21490
376	Gudlai *nadi*	320	Total	> 40000		
379	Chirai	115	Total	23000	+710 −650	17270
378	Chirai	130	Total	22180	+600 −610	16450
377	Chirai	165	Total	28630	+2760 −2070	22900

the upper levels. But since *kankar*-bearing and *kankar*-free sand layers alternate, such admixture seems to have been confined to the limits of a given stratum.

It is interesting to note that at *c.* 7000 B.P. there is a wet phase in the northern salt lakes of Rajasthan (Singh *et al.*, 1974) which coincides with the wet phase at Gudlai. At *c.* 15000 B.P. deglaciation in Kashmir starts at *c.* 4000 m at Toshmaidan (Singh and Agrawal, 1976) which has been correlated with weathering of loess overlying the Upper Karewas in the main Kashmir valley (Pant *et al.*, 1977). At this time, Gudlai sequence also shows a wet phase. The third wett phase is probably contemporary with Middle Stone Age (Goudie *et al.*, 1973) and also with a perennial phase of R. Luni (Singh and Ghose, 1977).

CONCLUSIONS

Our preliminary studies show that there is no possibility of glaciations extending into Rajasthan during Quaternary period. Sedimentological, mineralogic and chemical analyses of Malhar Rann sediments indicate significant fluctuations in the lake levels, in the past, reflecting climatic changes. SEM studies of the Gudlai, Chamu and Chirai sediment-profiles indicate an alternation of wet and dry phases which can be dated to 7000 ± 500, 15000 ± 2000 and > 40,000 B.P. A climatic sequence which tallies with north Rajasthan and Kashmir.

These are of course preliminarv results; further detailed work is in progress.

ACKNOWLEDGEMENTS

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I. 1.2

PERIGLACIAL AND FLUVIO-GLACIAL LANDSCAPE IN JAISALMER DISTRICT

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INTRODUCTION

During early 1976 while working on Desert Evaluation Project in Jaisalmer and Barmer districts, Biswas located several occurrences of boulder beds, boulder conglomerates, heaps of Pre-Cambrian erratics in the valleys and hill tops of Jurassic rocks around Jaisalmer (26°55':70°55'). Several occurrences of similar nature were also observed in Barmer district. Ghosh joined him in May, 1976 and they together took traverses from east of Pokaran (26° 55':71° 55') to Kahla (26° 57': 70°47'), a distance of about 120 kms. As a result of these field studies it was possible to follow the erratics of Jalore-Siwana granite, Malani rhyolite and Delhi quartzite from Pokaran to the west of Jaisalmer. From lithological similarities and geomorphological considerations these boulder beds are correlatable with the Bap Boulders of type area and their continuity now can be traced from Deh (27°54':72°54'30") on the northeast to west of Kahla in the southwest. Further geomorphological and sedimentological studies by Biswas led to construct a sequential history of the present landscape of Jaisalmer area. Munshi (1977) has recently described a few more occurrences of boulder beds in Barmer district, but the present authors did not attempt any correlation with that area for lack of more details at present.

Mode of occurrence of boulder beds and spreads

Several modes of occurrences have been noted for these deposits. Around Pokaran large boulders of grainte lie over sandstone and shales. At places these boulders lie embedded within recent *kankar* layers. From Pokaran to Hamira (27°0':71°0') thick mat of pebbles and cobbles, occurs at several places, such as near Basanpir (26°55':71°5') and Bhojka (26°58': 71°13'). The individual occurrences are spread over several kilometres. Systematic search for bedded deposits in this part might reveal new occurrences. Near Hamira and Thaiyat (26°56':71°0') several deposits of drumlin like heaps have been located. Bedded deposits of tillitic nature are abundant around Jaisalmer town. Mention of a few localities such as Hanumanjika Mandir, Ratan Sar, Manhata sar, Kahla and Bhagat Mandir will illustrate such abundance. Angular boulders in association with cobbles, pebbles and gravels can be seen to be spread at several places, specially to the south-west of Jaisalmer town.

Lithology and associated structures

The most conspicuous lithologic element in these deposits is an assemblage of cobbles, pebbles and gravels of orthoquartzite not available in the surrounding country rock. These are abundant in all the occurrences. The boulders of granite around Pokaran have already been mentioned. Pebbles of granite have been observed to occur in all the deposits including the farthest one near Kahla. Pebbles of rhyolite have also been recorded from all the deposits and also from Masurdi river bed near the junction with Kakni river. Besides these, boulders, cobbles, pebbles and finer particles of local limestone form the major part of some layers of the most of the deposits. Pieces of fossil wood derived from the underlying Lathi formation of Jurassic age also occur in these deposits. The cementing material in these bedded occurrences is a mixture of fine grained to pasty calcareous and arenaceous matter. The deposit of Bhagat Mandir (26°59':70°51') is, however, free of igneous or metamorphic rock particles and is composed of boulders of local limestone and fine arenaceous particles. These are cemented by a fine pasty calcareous cement.

These deposits are ill sorted. Excepting the Bhagat Mandir deposit, all the bedded occurrences are glaring examples of extremely poor sorting. Large boulders are jumbled up in a mixture of cobbly to clayey matrix. The boulders vary in sizes from less than a metre to even 3 metres. These may be found lined up along with the rock material of smaller and uneven sizes. The boulders are mostly angular. Some are subrounded to rounded. The cobbles, pebbles and gravels are mostly subrounded to rounded. Some boulders and pebbles are fractured.

The boulder beds so far located are 2 to 5 metres in thickness. Although, poor sorting is the rule in individual layers, a graded bedding in the reverse order has been found. Above the Mesozoic basement occurs a layer of pebbles and gravels over which is found the most poorly sorted complex of tillitic nature. The combination may be repeated but the lower horizon is always formed of pebbles and material of lower particle sizes.

Striations and grooves have been observed over the surface of Jaisalmer limestone of Jurassic age. These are minor scratches to deep grooves upto 5 cms deep and 15 cms wide. The directions of the grooves is around N 30°E - S 30°W. Faceted and striated pebbles of quartzite have also been collected from these deposits.

Mode of transport of the deposits

The boulder beds in Jaisalmer district occur within a sand-stone-limestone country of considerable thickness, but abound in cobbles and pebbles of orthoquartzite, granite and rhyolite. These metamorphic and igneous rocks are similar to those occurring in Bap Boulders and can be traced almost continuously from southwest of Bikaner to the west of Jaisalmer, stretching over a distance of more than 250 kilometres over hills and valleys. Even if the Permocarboniferous age of Bap Boulders is accepted for the type locality, the present investigation undoubtedly shows that these boulders were carried to the localities of these bedded deposits at least during post-Jurrassic time. From their mode of occurrence, lithologic assemblage and structural features described above, the deposits are considered by the present authors to be of glacial origin. The only alternative to a glacial movement is fluvial transport. There are, however, several unsurmountable hurdles in the way to conceive that the latter process was operative. Firstly, these deposits do not occur along any definite valley. Secondly, these deposits occupy great width, sometimes upto six or seven kilometres. It is difficult to imagine such a wide river carrying huge boulders and spreading them in bedded form, that too with *reverse order of graded bedding*. Thirdly, from the gradual decrease in the sizes of the erratic elements of orthoquartzite, granite and rhyolite, a general westward movement is apparent. But, the deposits do not occur along a graded profile in this direction as is expected in case of river deposition. Fourthly, the erratic blocks gradually diminish in size with increasing distance from the source and even if a probable path of fluvial transport is inferred on this basis, the overall nature of the deposits indicate that the transporting agency did not lose its energy throughout its course which is not possible for a river. Fifthly, no base level of erosion is reached. The base of deposit shows an irregular profile when followed from east to west. For example, the deposits on the east of Jaisalmer are found to occur at a height of 242 m and the heights become 213 m and again 228 m towards west, not to speak of altitude barriers between two consecutive deposits. Such a sequence of heights cannot be explained in case of a fluvial transporting agency. Sixthly, the movement of the rocks occurred broadly from east to west, whereas all the major streams run in a broad north-south direction. Considering these points, the possibility of a fluvial origin for these deposits is ruled out.

GEOMORPHOLOGICAL HISTORY OF JAISALMER AREA

The major geomorphological configuration of the Jaisalmer area must have been well established before the deposition of the boulder beds took place. An analysis of the topographical features associated with these beds shows that they always occur below 850 ft (about 260 m) contour. The highest deposits occur at a height slightly above 800 ft (about 245 m) near Hanumanjika Mandir and the lowest at slightly above 650 ft (above 200 m) near Kahla. Considering their locations within the surrounding topographic expressions it is seen that the barrier of at least 850 ft (260 m) contour had to be crossed before any deposition could take place on the west of Jaisalmer. This means that ice movement occurred at least over this height. From the highest and lowest occurrences of the existing deposits, the minimum thickness of the ice can be computed to be 200 ft (about 60 m). From these considerations, it may be concluded, that, the Jaisalmer fort area (maximum height about 293 m) occupied a topographically higher position from the surrounding areas when these boulders were on the move within the ice. This becomes more obvious from the fact that when the areas of known occurrences of boulder beds in Jaisalmer district are joined together, the configuration takes a southerly turn around Jaisalmer town. The hilly tracts to the south of Jaisalmer may be conceived to be the southern boundary of the ice movement. The Barmer deposits do not seem to be associated with these occurrences. There are present almost continuous bedded deposits on the south and southwest of Jaisalmer. Then, the deposits are loose pebbles and boulders until the Kahla deposit about 14 km to the west of Jaisalmer town is reached. Thus a crescent shape of the deposits can be inferred in between the Jaisalmer town and the hills to the south of it. On the south of Jaisalmer town, boulder-free limestones contain grooves which indicate that movement of ice actually occurred around this centre. On the north of Jaisalmer also, grooves on basement indicate a movement parallel to the northeast-south west arm of the crescent. The restricted occurrence of boulder beds below 850 ft (about 260 m) contour, and presence of high altitude areas on south and north show that the ice was of the nature of a valley glacier, which also modified its valley during movement, as the grooves and torn off angular boulders testify. However, the deposition around Kahla would be possible only when ice movement occurred over 850 ft (260 m) contour on the west and north-west of Jaisalmer. This is a broad picture on the basis of data so far available. As has been described above, it seems that the 850 ft (260 m) contour level was not an appropriate receptacle for boulder deposits. Thus, all rock material within the moving ice was transported toward Kahla and beyond in a south-southwesterly direction from Jaisalmer side. But when melting of ice had begun, water would follow the natural slope of land which was northerly. In such a situation, erratic material, which had already been transported towards southwest would not be available to the melting ice on the north of Jaisalmer. But, the moving ice had already torn off a sizeable load of country rock. The melted water and perhaps melting ice also would carry this load and deposit on the north. This explains the occurrences of Bhagat Mandir boulder bed and the absence of any erratic material in it, excepting some finer quartz grains derived from moving orthoquartzite pebbles. The melted water carried the finer particles further, beyond the boulder bed zone. This finer material forms a flat terrain on the north of boulder bed and the reported depth of a well in this deposit is 40 ft (12 m), without reaching the hard rock basement. While water was flowing over the 850 ft (260 m) barrier, the accumulated water on the south of Jaisalmer was exerting pressure on its walls and finally broke through the altitude barrier at places. Here, the mass of water was enormous. The morainic material already deposited was disturbed and by a sluicing effect, the released water dissected the boulder bed further downstream.

With the disappearance of the ice, the channels had no load to carry. So, successive supply of water through these channels only deepened them and cut through the earlier deposits and carried further away some pebbles and smaller particles. On the north of Jaisalmer, ice spread was more and removal of this ice spread initiated some uplift and led to the formation of fingertip channels. With the deepening of the channels of northerly flowing streams, headward erosion had started. In this process, Kakni river reached Masurdi river and beheaded it near Kuldhar (26°52': 70°47'). All these indicate that climatic conditions were changing from cold to warm. Through several fluctuations, the warmer climate was reaching the semi arid to arid state. Processes operative in the desert environments had broken the larger blocks into smaller sizes and cementing material has been separated from the boulders and pebbles. Ultimately finer material has been blown away from the source. Much has been washed away down the streams. A part of the sand in the area is derived from this source. The pebbles of orthoquartzite mostly and rarely other erratics which survived this onslaught of these climatic fluctuations have given rise to widespread desert pavements above the limestone basement of Jaisalmer district.

DISCUSSION

By now it is obvious that the authors have laid stress upon two major points. One, there are occurrences of bedded boulders, cobbles, pebbles and fines over Jurassic formations around Jaisalmer. Two, these deposits contain erratic elements of orthoquartzite, granite and rhyolite which are faceted and striated and are far removed from their source. *These are observed facts.* The distance of transport for these erratic elements is more than 200 km. Fluvial transport was not considered feasible for these elements due to topographic configuration along the route and other sedimentological and structural factors. Glacial transport has been suggested for these deposits. However, there are two problems to such an explanation, namely, the latitude and topographic heights of the deposits. The most of the deposits described in this paper occur on the south of latitude 27°N and the maximum height of the deposits is slightly above 800 ft (245 m). A much higher altitude is necessary for snow formation at such a latitude. But reports of similar deposits and evidences of post-Mesozoic glaciation around areas of lower latitudes are on the increase from different parts of the Indian subcontinent. These two questions have been discussed in detail by Mukhopadhyay and Ghosh (1976) and from floral evidences cited by Darwin, they have inferred that climatic conditions were favourable during Pleistocene time for snow formation at heights to which the present day hills of Delhi and Aravalli rocks rise. In fact, during Pleistocene glaciation climatic zones were pushed equaterward so much so that the tropical deserts were lying between latitudes of 10° to 15° (Strahler and Strahler, 1973). Thus the presence of Pleistocene glacial activity around the latitudes 27° to 28° N is not surprising. The snow forming in hilly terrains around these latitudes gave rise to glaciers which moved downhill and later glaciofluvial movement had spread the rock material over lower altitudes.

A non-glacial phenomenon associated with the Pleistocene glaciation goes in favour of presence of glaciation associated with the hills of Aravalli and Delhi rocks. The intermontane pluvial lakes are such a phenomenon. The present day salt lakes on the other side of the Aravalli hills have a deficit water balance. But during the glacial period due to lower air temperature regime there was a surplus water balance and these lakes lay at a level much higher than at today and overflowed the present day lake periphery. This fact is well established from study of sediments of lake terraces at Didwana and Sambhar Salt lakes and discovery of fresh water fossils from the latter.

Such terraces may be an example of the periglacial landscape in Jaisalmer area. The salt lake of Kanod near Jaisalmer is a probable case worth investigating. True solifluction structure is difficult to recognise. Due to severe aeolian activity in arid climate soil cover has been highly disturbed. But some evidence is still left within the valley adjacent to the Jaisalmer fort. Polygonal fracturing of rock body and its downward flow over the underlying marly limestone is beautifully preserved along the sides of Rupsi butte structure. The scarp tops to the west of Kahla also present large blocks derived by frost action. Another example of solifluction structure can be seen along the road cutting to the north of Barabag (26°58':70°53').

It is generally agreed that glacial activity was over between 10,000 to 12,000 years from the present. This is supported from the disappearance of the pluvial lake condition in other parts of Rajasthan (Singh *et al.,* 1974). But agreement of opinion is absent so far the beginning of glacial epoch is concerned and the work in this part of the country has only started. However, taking the indirect evidence in consideration and comparing the world-wide phenomenon it can be said that glacial condition was prevalent in this area during the Quaternary Era. Further detailed and regional work is essential before the glacial period is subdivided into different subdivisions and if sufficient record of rocks is found to exist, the deposits can be fixed into a precise time stratigraphic scale.

Economic significances

When the glacial landscape is recognised in an area significant improvement will be possible in the preparation of a land use map. Where the glaciofluvial streams can be located fine sediments with groundwater potential will be easily discovered beyond the boulder bed zone and this will be of immense agricultural importance in the otherwise barren or sandy tract of the desert. The flat tract to the north of Bhagat Mandir is such an example.

The erratic pebbles and gravels of orthoquartzite from the bedded deposits and ground spreads can be and are being extensively used as road material and pavement and wall decoration. But the authors are afraid that many good depositional structures may be lost for ever by such constructional activities.

CONCLUSION

The authors have shown that a glacial condition existed upto later part of Quaternary Era in the Indian Subcontinent between latitude 26°N to 28°N and tried to arrange the events in a sequential pattern so that a clear picture emerges of what led to the formation of the post glacial landscape of the Jaisalmer area. The subject of glaciation is likely to be debated strongly. But no other logical explanation can be offered for the origin of these widely spread and illsorted bedded deposits having very distinctive structures and surrounding associations over hill tops and valleys of Jurassic age and containing erratic Pre-Cambrian rocks brought from distances of hundreds of kilometres.

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I. 1.4

PALAEOCLIMATIC ASPECTS IN THE EVOLUTION OF THE SAMBHAR SALT LAKE - A GEOMORPHOLOGICAL REVIEW

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INTRODUCTION

Sambhar lake trending almost E-W and having a semi-circular shape covers an area of about 240 sq km and is probably an erosional basin within the pre-cambrians, as indicated by the delineation of the Archean hills and basement. It is situated at an elevation of about 360 m above mean sea level and flanked almost on all sides by both Aravalli and Delhi rocks. Mostly, these are blanketed by dune sands or sand sheets excepting a few out cropping as sporadically scattered inselburgs.

The important drainage system in the area viz. Rupnagar in SW, Khandel and Mendha in NE along with their tributaries feed the lake seasonally. The drainage is strictly centripetal, a characteristic feature of most of the inland lakes of desert forming "Blosons". The rim of Sambhar lake is at about 364 m elevation.

The source of salinity had been a matter of controversy since long and many theories have been propounded for its origin. However, a salt impregnated silt-clay horizon seems to be the source of production of salt accumulating in the lake through surface and underground drainage into the lake from its arid and salinity infested catchment (Biswas *et al.,* 1975; Sinha, 1977).

Geological features

From drill/field studies and data from augerholes and well sections, pits, numerous river and *nala* cuttings, the following general geological sequence can be established in the area around Sambhar Salt lake.

Age	*Lithology*
Quaternary	Aeolian sands (Reactivated and mobile sands).
	Aeolian sands (Stable).
	Silty clays with fresh water fossils.
	Aeolian sands (Oxidised).
	Silty clay with rock fragments and calcareous concretions.
	Calc conglomerate.
Pre-Cambrian	Weathered mica-schist.
	Micaschist; Felspathic quartzites; pegmatites.

The structural hill ranges are formed of felspathic quartzites, with intrusive pegmatites, generally dipping 30° toward N70°W, they strike in a N20°E–S20°W direction, well jointed with 2 main sets. There are also quartzite inselbergs, scattered over the tract. Micaschists, with a considerable weathered zone, forming the basement formation in the area are found even within 14.0 m depth from ground level, overlain by lacustrine and aeolian sediments.

The micaschists are unconformably overlain by very hard and compact conglomerate which are calc-cemented. The conglomerates consists of sub-rounded pebbles of quartzite, quartz and micaschists having a maximum thickness of 1.0 m or so. The conglomerate horizon is overlain by a thick deposit of silty-clay associated with calcareous concretions, the thickness of which varies from 8.0 to 15.0 m. The silty clays are greyish white, occasionally associated with rock fragments and accessories such as micas to a limited extent. However, in the eastern and south-eastern periphery, they directly lie over weathered micaschists. More oxidised medium to fine grained sands of aeolian origin lie over the silty clay horizon with a maximum thickness of 1.0 m. These sands are typically aeolian, evidenced from their fineness, good sorting and total absence of any mica fragments or any matured heavy mineral constituent.

This oxidised aeolian deposit is overlain inturn by a silty-clay horizon consisting of a fossil assemblage large fresh water molluscs and ostracods (Roy, 1977). This horizon, having a maximum thickness of 2.0 m, is traceable over an area of 20 sq km along the south eastern periphery of the lake between Sambhar and Naliasar. The fossils include gastropods (*Viviporus* sp.), pelecypods (*Unio* sp.), and ostrapods (*Cyprides* sp. and *Limnocythera* sp.) of distinct fresh water habitat.

These silty clays are overlain by deposits of recent aeolian sands, which are generally stable except a few very recent mobile deposits. They are composed mostly of yellowish to brownish, medium to fine, well sorted sands. These are semi-consolidated, well vegetated, slightly dissected and generally cultivated. These are overlain by recent whitish aeolian deposits, well sorted, completely unconsolidated, constituted mostly of quartz sands, devoid of any mica or feromagnesion minerals.

Geomorphological features

The different geomorphic units and their specific landform features—both aggradational and erosional—can be envisaged from the geomorphological mapping around the area, and are summarised as follows:

Dunes/Interdunal flats and depressions
Playas/Bolsons etc.
Pediments/Burried pediments
Structural hills
Inselbergs.

Inselbergs, constituted of quartzite hill masses, are scattered sporadically in the area and their intervening areas are either blanketed by aeolian cover forming burried pediments, or they form pediplane surfaces.

The structural hill ranges consists mainly of felspathic quartzites underlain by micaschists, trendes N 20°E - S 20°W.

Pediments can be very well demarcated as one of the main geomorphic units in the area, though these are mostly covered by aprons of aeolian sands forming burried pediments. These are pronounced near the hill ranges, where from the break in slope starts.

As regards the flood plain of the present river valleys, mention can be made of the valley fill areas of the Khandel river catchment in the eastern part of Sambhar salt lake. The flood plain is extensively impregnated with calc-concretions associated with the silty horizon, as observed in the bluff sections of the river valleys. The flood plains are well cultivated as these are largely associated with silty deposits. These zones generally show good ground water potential.

Sambhar salt lake can be designated as a "Bolson" which has a centripetal drainage almost entirely surrounded by hills on all sides.

Most of the area around Sambhar is covered with sand dunes and sand sheets. They give rise to a sandy undulating topography of which the (i) recent and (ii) reactivated dunes are mostly seen in the northern part of the lake area near Kajipura. The recent dunes are mostly obstacle dunes, formed around a nucleus viz. a high hill, a village on the top of a stable dune, tall tree or even where the moisture divide line is formed on a local basis viz. the Sambhar lake proper in this case.

EVOLUTIONARY HISTORY OF THE LAKE AREA

The fresh water fossil assemblage in the lake area, described above, is indicative of the possibility, that, the Sambhar lake was of a fresh water regime at an earlier phase. The present salinity in the lake, in that case, might have been enriched due to the gradual onset of aridity, causing greater inputs of salts through feeders of the lake from the catchment of the Sambhar lake, due to much greater evaporation compared to precipitation. The lithological correlation, as revealed by the above succession, supports the idea that the first phase of humid climate with the deposition of conglomerates and silty clays with concretionary horizon, has been succeeded by an arid environment where we get oxidised reddish sands. These sands in turn are followed by fossiliferous lacustrine clays and silts, indicative of a humid phase. The onset of the present phase of aridity started just after this, causing the deposition of aeolian sands in the form of dunes and sand sheets. Of these dunes–some are comparatively stable with vegetal growth and cultivation, while some are very recent, comprising active and mobile sands resembling barchans and transverse dunes. Evidences of reactivation of stable dunes, presumably due to biotic interference, is extensive. Summarising the facts above, it can be concluded that there are two phases of humid environment, alternating with two phases of arid climates in this tract.

CONCLUSION

From the above discussion it is evident that the source of salinity in Sambhar lake is due to its geo-graphic disposition, lithology of catchment area, centripetal drainage-pattern and above all climatic factors. Accumulation of transported mineralised water in a closed basin through ages and their subsequent concentration through evaporation transformed Sambhar, originally a fresh water lake into a saline lake.

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I. 1.6

GEOMORPHOLOGICAL REVIEW OF A PART OF MENDHA RIVER CATCHMENT WITH SPECIAL EMPHASIS ON DESERTIFICATION PROBLEMS

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The river Mendha–one of the main feeders of the Sambhar Salt Lake–brings forth interesting quaternary evidences of both fluvial and arid cycles in ascertaining the geomorphological history of the area. This south-westernly flowing river arising out of the Aravalli hill ranges near Ajitgarh (45 M/SE) and mingling with the Sambhar lake near Nawa–Kuchaman Road (45 M/SW)–carries huge quantities of salt and adds these to the Sambhar lake water every year to a quantative degree of about 0.15 million tonnes of salt. An examination of the sediments clearly establishes a relationship between deposits brought under different fluvial and arid cycles reigned over the area in different climatic periods.

Geology and geomorphology

From the bluff section of the river Mendha and its tributaries, from the numerous *nalah* cuttings, from the sections established after auger drilling in different parts of the area, particularly on the river bed, as well as from the study of well sections—the following lithological correlation can be summarised and established as below:

Active and mobile dune sands.
Stable dune sands.
Dark brown hard silty clays.
Silt with little *kankars.*
Silt with more concentration of *kankars.*
Boulder zone—consisting of sandstones and siltstones with clay matrix.
Hard brown clay pellets with yellowish silts and little *kankars.*
Very fine yellowish brown sands (Aquifer zone)

Now, the bottom most unit indicates the sands derived from aeolian activity, as is evidenced from their good sorting, fineness, sphericity, contents of heavy minerals etc.—and thus it resembles deposition in an earlier arid epoch.

The boulder zone next indicates the beginning of a fluvial cycle with humid temperate climate with gradual deposition of sands, silts and clays. The alternating layers of deposition from coarser to finer sediments resemble deposition in different flood regimes with distinct time gaps.

All along the river and *nalah* beds—salt incrustations either in the form of milky white, powdery and spongy bicarbonate salts of sodium and calcium or in the form of calcareous or ferruginous concretions as nodules—are found scattered or impregnated particularly in those portions of the river bed where there is concentration of silts or silty clays on the river bed for their formation—invariably a semi-arid to arid environment is essential.

The silts and silty clay horizon are clear evidences of deposition under fluvial processes—as such an extensive, continuous and more or less uniformly thick deposition is rarely available in any other climate.

The youngest of all the units is the active and stable dunes. The active dunes and mobile dune sands are mostly concentrated adjacent to the river flood plains whereas the stable sand dunes are scattered with interdunal depressions in between. The distinguishing characters demarcating a stable dune from an active dune can be summarised in the points of the presence of vegetation, degree of compactness, degree of the effect of oxidation, presence of concretions—which are comparatively more in the earlier ones. In the area—most mobile dunes are either barchans or transverse, which of course might have been developed from the barchans only.

Considering all the lithological units—geomorphologically the area can be divided into the following units:

(vii) Sand dunes/Interdunal flats
(vi) Flood plains of recent river valleys
(v) Fluvial/Depositional terraces
(iv) Piedmonts/Bazadas
(iii) Pediplanes/Pediments
(ii) Structural Hills
(i) Inselburgs

Uniformly thick and long stretched deposits of silty clays mentioned above are indicative of a wide and large flood plain of the river. This flood plain is now blanketed by dune sands or sand sheets—and as such a clear demarcation of the natural levees or back swamps etc. of the flood plain is not possible now.

Paired fluvial terraces were observed along the river and altogether two number of terraces were noted indicating deposition and later vertical incision.

The piedmonts or the alluvial fan regions have been observed at the flank of the hill ranges near Ajitgarh and at Rajawas and Barjan near Nawa. The pediments, on the other hand, constitute those portions of the hill ranges actually wherefrom the break in slope starts.

North-east of Ajitgarh–we came across structural hill ranges–forming occasionally hogback structures–and rarely questas. Three adjacent hill ranges standing out near Ajitgarh area can be assumed to be the detached portions of the Shahpura range–while the intermediate parts constitute the burried pediments, covered by aeolian sediments at present.

A few isolated hillocks–around Mundro, Mau, Bharni and Aspura constitute the major inselburgs in the area–in which the denudational features and processes are quite well pronounced.

Geomorphic evolution

The area under survey has been affected by alternate humid and arid environments which are evidenced by the nature and type of their deposition, and their overall position in succession.

The newly constructed well section near Aspura represents an ideal section where at the bottom we are getting aquifer zone consisting of aeolian sands, which might have deposited under the earlier arid environment. The next overlying section constitutes an ideal fluvial section made up mostly of sands, silts and clays, deposited in humid environment and represent at least two flood epochs, as evidenced by the graded deposits in at least two columns. The above mentioned fluvial deposits have been found to be overlain by the present day aeolian deposits, consisting of stable dune sands and mobile dune sands which are borne in the arid to semi-arid environment and can be considered as the second phase of arid cycle in the area. Sometimes the present drainage system is found to cut the stable dunes indicating that in between the stable and active dune phases–there was another humid phase of short duration. But, the author assumes that the present climatic phase is the transitional phase zone in between the last phase of the past fluvial cycle and beginning of the present arid cycle. The flood plains of the present river channels are being blanketed gradually by aeolian sands; even near Aspura the river bed has almost been chocked up by the aeolian sands.

Considering all the above features–the following geomorphic succession can be established in the area:

III Arid environment–very fine, yellowish brown to greyish white sands.

II Humid environment–sands, silts & clays of fluvial characters.

.... peneplanation ....

I Arid environment–very fine, brownish to reddish brown sands.

Desertification processes in the area: That the area is facing a gradual desertification condition–can be well pronounced from the following observations:

i) *Advancement of sand movement* All along the north-south trending Aravalli hill ranges near Shahpura-Ajitgarh area-aeolian sands are getting accumulated both on the western and eastern flanks. The accumulation has more or less an oval shape on the western flank, while on the eastern flank–these have fan-shaped deposits. The direction of the wind, hill slope and wind gap might be responsible for all these deposits.

ii) *Choking up of the river bed*
The Mendha river bed is gradually being choked up from Nangal upstream. The width of the river has become very narrow and the river bed is more or less completely blanketed by recent aeolian deposits. In some places –on the river bed itself–we come across small barchans occasionally.

iii) *Calcareous or ferruginous concretions*
The river bed is very much impregnated with calcareous concretions–the formation of which can be suggested in the following process: salt bearing solutions get trapped in the silts and silty clay deposits; these get concentrated with the gradual approach of summer, oxidised and left on the river bed surface as white, spongy and greasy salt efflorescence. The molecules of these salt incrustations coalesce, become hard and ultimately takes the shape of nodules. In the present terrain–these nodules are being formed in the present semi-arid climatic environment, when the rate of evaporation is definitely more than the rate of precipitation.

iv) *Flattening of the river bed*
As the river sections are mostly constituting of fine sands–there are least vertical incision of the rivers. On the other hand, lateral accretion of the river is imminent–which flattens the river bed and widens gradually.

v) *Cultivation in the stable dunes*
This indirectly helps in increasing the desertic conditions in the area. The stable dunes are getting loosened by ploughing while cultivation, and later got deflated by wind action–and thus assisting the advancement of sand movement.

vi) *Unsystematic mining activities*
These assist desertification sometimes to a great extent which are very much prolific in the area–as the loose fine grains are easily deflated by wind action, and as they fall on the cultivated lands, these gradually destroy the fertility of the soil.

CONCLUSIONS

Thus the area suffered changes in climatic environment–and there reigned a remarkable humid environment in between two arid cycles. That the area is under desertic condition is evidenced from the advancement of sand movement from west to east, choking up of the river bed, widening and flattening of the river bed and overall decrease in water level of the open wells in the area. More study in the adjacent areas will show a clear picture of the regional geomorphic setup of the area.

I. 1.11

ENVIRONMENTAL ANALYSIS OF THE HOLOCENE POLLEN FROM SHALLOW SALINE AND FRESH WATER DEPRESSIONS IN THE RAJASTHAN DESERT

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Pollen evidence dating from 10,000 years is known from Lunkaransar, Didwana and Sambhar in the north of the desert (Singh *et al.*, 1974); from recent investigations at Kanod in district Jaisalmer in south-western region (Vishnu-Mittre and Saxena, MSS) and from about 3000 years from Pushkar and Budha Pushkar in eastern parts of the desert (Singh *et al., op. cit;* Vishnu-Mittre and Saxena, *op. cit.*).

The pollen grains are largely identified to the generic level rarely to specific level as in *Mimosa* species (Singh *et al.*, 1974), which on detailed and exhaustive studies are found to be indistinguishable specifically (Saxena and Vishnu-Mittre, 1977).

Usually pollen from local anemophilous plants within an area of 8-10 km from the site is the best represented in pollen sequences than that from distant and different vegetational and climatic regimes, which is of stray occurrence. Pollen from the local insect-pollinated plants is very often rare or scantily preserved. The anemophilous herbs produce pollen at the ground level which is usually not carried to much longer distances by wind unlike the anemophilous tree pollen.

In the light of the above the Holocene pollen grains from Rajasthan pollen diagrams are segregated into local and extralocal ones. The latter being either from Himalayas or from other climatic regimes are not considered for the environmental analysis. The reconstruction of plant communities from the local pollen assemblages is attempted by utilising the recent comprehensive autoecological and synecological data for the Rajasthan desert floristics (Gaussen *et al.*, 1972; Meher-Homji, 1977; Saxena, 1977). This is not an easy task. Quite a few species are common to plant communities in diverse habitats; the percentage frequency of taxa in each community, howsoever crudely known, has not been equated with that of their pollen in modern pollen spectra; and further their proportional pollen production vis a vis their frequency in modern communities remains to be worked out. The reconstruction of former plant communities in the absence of this precise information is attempted from their most characteristic taxa and from the relative frequencies of their pollen for their former abundance or rarity.

The past vegetation of northern Rajasthan desert as known from pollen analyses had a good proportion of *Artemisia* spp. not mentioned in the available aut-and synecological data. *Artemisia scoparia* and *A. nilagirica,* occur rarely here even today.

Syzygium pollen is derived and hence not considered here. *Oldenlandia* and *Mimosa* pollen grains being indistinguishable specifically are considered here as members of desert vegetation.

RECONSTRUCTION AND HISTORY OF DESERT PLANT COMMUNITIES

1. *The halophytic scrub desert*

This is represented by chenopod pollen. *Fagonia* was perhaps distributed here and *Euphorbia* too. As the chenopod and grass pollen remain indistinguishable specifically the chenopods most likely comprised *Chenopodium, Atriplex, Haloxylon, Suaeda fruticosa* together with several halophytic grasses such as *Aleuropus logopoides,* species of *Sporobolus, Eleusine,* etc. and sedges as *Cyperus rotundus.*

The halophytic scrub desert in saline areas and along the shores of saline lakes had a moderate beginning about 10,000 years ago, increased until about 6000 years ago thereafter with a sharp decline increased again during 5500-4000 years ago. The tremendous increase observed in the recent past is indeed indicative of the shrinkage of the lakes and spread of saline areas. The halophytic scrub too gradually expanded in the vicinity of Pushkar lake.

2. *The aquatic and marsh plants*

Typha in all the diagrams exhibits declining trend at 7500 years B.P. from the poor low values; and early and sporadic pollen of *Potamogeton* and *Nymphaea* observed only at Sambhar. In the recent past increase of *Lemna* and its subsequent decline and increase of *Typha* with sporadic pollen of *Nymphaea, Nelumbo* are observed in Pushkar lake pollen diagram. *Potamogeton* shows gradual rise between about 1000-400 years ago at Pushkar lake.

Blepharis, Lepidagathus, some composites, quite a few grasses (*Paspalum punctatum,* etc) including *Coix lacryma jobi* represented by pollen above 75 μ and sedges (*Scirpus articulatus, Eleocharis geniculata,* and species of *Cyperus* and *Kyllinga*) must have occurred along the margins of the lake.

Species of *Potamogeton* occur in lakes, puddles and in rivers with sedges, grasses and other herbs along their banks. A combination of this pollen group is indicative of riverain environment and suggestive of the past relation of these lakes with river channels. Some of these lakes are fed by river channels even today.

3. *The mixed xerophytic riverine thorn forest*

The presence of *Tamarix* pollen together with occasionally that of *Acacia* is indicative of this forest, occurring on a narrow belt of younger alluvium liable to inundation and on flat and hummocky areas upon sand, silt and gravel on either side of river channels together with several grasses, forbes (species of *Tephrosia, Solanum, Heliotropium, Boerhavia, Digera, Indigofera*), composites and sedges.

In the vicinity of Lunkaransar this forest had existed about 10,000 years ago and since reduction during 6000-4000 years ago has been non-existent there. At Didwana it expanded between 5000-4000 year ago but appeared at Sambhar between 4500-3000 years ago. It appears that these lakes in the past were fed by flood streams like the Sambhar lake at present (the Band and Namdana streams). Along side stray pollen of *Tamarix, Ficus, Acacia, Prosopis, Salvadora,* and *Capparis* form significant pollen curves in the Pushkar lake diagram. Perhaps *Capparis* and *Syzygium* also occurred here. The lake is fed by the Gordi stream.

4. *The psammophytic scrub desert*

Occurring on deep calcareous sands on the dunes-crest, sides and flanks; undulating hummocky older alluvial plains; interdunal areas and the fresh sand deposition, this community is recognizable by *Calligonum polygonoides* the most characteristic element with *Aerva* as the other important member.

The scrub had occurred in the vicinity of Lunkaransar about 10,000 years ago but at Kanod in south-west Rajasthan either it was locally poor or distant. At Lunkaransar it expanded from its modest occurrence about 5500-4000 years ago and considerably in the recent past when the low dunes comprising shallow sandy deposits with rocky substratum as indicated by *Maytenus* built up in size. The moving sands carried the psammophytic scrub in the vicinity of Didwana by about 6000 years ago, prior to that *Maytenus* and *Capparis* had occurred here. *Maytenus* dwindled long before 3000 years ago and the increasing *Prosopis* with *Zizyphus* was associated with *Calligonum* in higher frequencies.

Only stray pollen of *Calligonum* reached Sambhar around 3000 years ago.

Calligonum in the vicinity of Pushkar had invaded the *Anogeissus* forest about 3,000–4,000 years ago and frequented with *Maytenus* and *Capparis* until *Anogeissus* forest recovered. The shrubby vegetation at Budha Pushkar was sparse during the last 4,000 years.

5. *The lithophytic scrub*

This scrub is indicated by the expansion of *Capparis* and *Mimosa* in the vicinities of Didwana and of *Capparis* alone in the vicinity of Sambhar between 3500-2500 years ago. Possibly the natural succession was deflected by biotic interference, and the scrub occurred on eroded rocky surfaces, gravelly and piedmont plains.

HISTORY OF HUMAN INFLUENCE UPON DESERT VEGETATION

The charcoal fragments met with since 10,000 years ago, excluding the natural agency, are attributed to the slash and burn practice for cultivation by Mesolithic man from 10,000 years to 5000 years ago and to the Neolithic and the Harappans thereafter (Singh *et al.*, 1974). The pollen evidence for cultivation is not conclusive (Vishnu-Mittre, 1974). The survey of modern shifting cultivation in eastern Rajasthan (none in the desert area) by *bhils* and other *adivasies* and in other parts of the country (Kaith, 1958) shows that it is confined to the Teak and dry deciduous forests which were non-existent in the desert during Holocene. Some dunes are under cultivation even today and millets and pulses are grown. Pollen of these millets is much below the cereal type pollen.

Besides being hunter and food gatherer, the Mesolithic man in Rajasthan also practised animal husbandry dating from 7000 years (Misra, 1971). The Mesolithic man inhabiting desert savannah found the tall perennial harsh grasses with piercing burrs unpalatable and injurious to his domesticated sheep and goat. To induce fresh growth of tender annuals he resorted to the slash and burn practice. This also helped him to concentrate on wild animals for easier capture to control ligneous growth and to maintain grass cover. The increase in livestock population by about 4000-3000 years ago and increased grazing pressure prevented grasses from attaining perenniality. With this the waning slash and burn practice had vanished.

The discovery of food grains from Kalibangan, the Harappan site, reveals that cultivation commenced here not much before 5000 years ago (Vishnu-Mittre, 1974; Vishnu-Mittre and Savithri, 1975; Savithri, 1976).

CONCLUSION

The environmental analysis of mosaic of Holocene pollen has enabled reconstruction of five plant communities occurring on various geomorphological situations. The halophytic scrub shows gradual expansion since 6000 years ago. The psammophytic scrub had invaded the extreme west of the desert about 10,000 years ago immigrating near Didwana by 6,000 years ago, then turned south-eastwards reaching Pushkar region by about 3,000-4,000 years ago. The lithophytic scrub at Didwana and Sambhar came into existence about 3,500 years ago as a result of basic interference.

Both the aquatic, marsh vegetation and the mixed xerophytic riverine thorn forest strongly suggest that these depressions were fed by streams thus supporting the geomorphologic evidence of their origin from abandoned channels (Ghose, 1964). The saline depressions were formed about

10,000 years ago under an increasingly arid climate, though some were formed later (Didwana 1500 years later; Pushkar and Budha Pushkar 6000 and 8000 years later).

There is positive evidence of cultivation dated to about 5000 years ago. The burning of perennial grasses for fresh growth of annuals by early man who practised animal husbandry was a widespread practice. The practice vanished with the increasing grazing pressure caused by increase in livestock population. This also leads us to conclude that aridity had already occurred here since Weichselian times but the biotic factor has exercised increasingly powerful influence more particularly since 3000 years ago when iron had been invented.

In the study of history of desert vegetation hitherto completed, pollen of *Salvadora* has not been encountered before 3000 years ago suggesting that *Salvadora* reached here much late in history. This has a great bearing upon the concept that *Prosopis-Salvadora* comprises the climatic climax in the desert. Is it an introduction by man in the recent past?

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I. 2.1

SEMI-ARID AND ARID AREAS OF RAJASTHAN - A PHYSICIST'S VIEW

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Features of normal rainfall

It is well known that west Rajasthan and the adjoining parts of the Punjab, East Rajasthan, North Gujarat and Pakistan have an annual rainfall between 50 cm and 10 cm (India Meteorological Department, 1968). Incidentally, it is less well known that the annual number of rainy days with a rainfall of 0.3 mm or more a day, over these areas also varies between fifty and ten (Rao *et al.,* 1976a). More than 90 % of this annual rainfall occurs during the short period-end of June to the middle of September.

In addition to the above average rainfall parameters, these areas experience high temperatures and moderate to strong winds during summer, and rather dry conditions during winter. Consequently, there is large evaporation not to speak of an even larger potential evapo-transpiration (the water need of plants). The potential evapo-transpiration over these parts varies from 160 cm to 200 cm (Rao *et al.,* 1976b); thereby causing a great deficit in water, even if no water is allowed to run off. The ratio of the water deficit (rainfall minus the potential evaporation) to the water need, is usually taken as a measure of the aridity. This aridity can be computed season by season or month by month, and is obviously large during the non-rainy months.

These "normal" parameters of the rainfall occur along with another additional troublesome parameter, - the year to year variations in the rainfall. In areas of large rainfall, such variations are small; but they are large in areas of poor rainfall. A measure of this variability is the coefficient of variation-the *ratio* of the standard variation of the year to year rainfall to the mean rainfall expressed as a *percentage*. In the areas now under consideration, this coefficient of variation is 50 % or more. A coefficient of variation of 50 % just describes, that out of every twenty years, there will be three or four years in which the annual rainfall will be only 50% or less of the mean annual rainfall. This is a very precarious situation, when the mean rainfall itself is as low as 30 or 40 cms.

Trends in the rainfall

There have been several studies looking for a systematic change in the rainfall over these parts during the last hundred vears, for which some rainfall records, although not strictly homogeneous, are available. The general conclusion is that there are no systematic trends, and that the rainfall variations have been practically stochastic. Power spectrum analysis have shown several peaks with several periodicities; but they have been found to be of no forecasting value. Decade rainfall means have not remained the same; they have shown fluctuations; but none that could be anticipated.

Impact of man

However, due to the continuous increase in the pressure of population, the land use in these areas have undergone changes. Agriculture has been extended into more and more marginal lands; animal husbandry has been more and more intense in that the number of animals per unit area has steadily increased. These have led to the soil becoming poorer, the vegetative cover continuously decreasing due to over grazing, and the top soils being lost by wind and water erosion.

Therefore, when the season's rainfall records a low value, even when it is not lower than what has been recorded on a few occasions in the past, the impact is larger; more cattle die, the total reduction in food and agricultural production is greater, there are consequent severe economical impacts, and on the whole the social suffering is several times more than what it was in the past. It is as if the *total area* of the arid region has increased. There has been a *potential increase* in the drought.

Meteorological impact

This is not to say that there are no meteorological effects caused by the recent human activity in these areas. The decrease in vegetative cover produces an increase of dust in the atmosphere. This has radiative effects although we do not yet know precisely what they are. It is easy to presume, that the dust radiates out more heat, that the dust laden atmosphere cools more than otherwise, and then sinks. Such a sinking air suppresses cloud growth, increases the dryness, warms up the air, and so on (Bryson and Baerreis, 1967). On the other hand, it is also feasible that the dust laden air absorbs more heat. Computations have shown that air over Rajasthan is sinking on the average, during the monsoon season, but to say that it is due to increased dust load in the air is not based on adequate evidence.

The other effect is the increase of the albedo of the earth's surface due to decrease in the vegetative cover, attributed to the much maligned goat-the poor man's cow. This is true. Such an increase in the albedo, makes the corresponding part of the upper atmosphere cooler than usual and contributes to an increase in the sinking motion. Consequently, a year of abnormally poor rainfall, caused by some reason, increases the albedo for a longer period and therefore, has a tendency to continue the rainfall deficiency during the next year also (Charney, 1975). But this does not go on for ever; in the past such a persistence tendency did not last for more than three or four years at a stretch. Another large variation in the large scale atmospheric system occurred after this period, sufficient to overpower all the effects caused by man's impact on the albedo.

The large scale meteorological conditions

Poor rainfall, high summer temperatures, and strong winds during summer characteristic of west Rajasthan and adjoining areas are the consequences of the large scale, quasi-stable, quasi-stationary wind flow pattern, six to ten or fifteen kilometres east and west and a few hundred kilometres north and south of Rajasthan. This feature of the upper air repeats itself during the summer, year after year, with minor changes in intensity and location. This flow pattern leads to a gentle sinking motion or subsidence of air over these parts and a comparatively vigorous ascending motion or convection over north-east India and adjoining areas. Such an ascending motion is easily surmised from the abundant rainfall experienced by those geographical areas. The stability conditions of the flow and the thermal and moisture structure of the lower parts of the atmosphere permit such ascending and descending motions. Orography, solar insolation, distribution of the Asiatic land mass, and the thermal properties of the Indian and Pacific Oceans, all lead to the above mentioned quai-stable flow patterns.

What we would like to emphasise here is that the flow pattern is not determined by highly local conditions of the land surface or the adjacent atmospheric layers. Hence the variation of rainfall from one year to another or over one decade to another should not be attributed to the change in the local conditions.

Pre-historic (Archaeological) and early historic evidence do suggest that Rajasthan and adjoining Sindh had experienced abundant annual rainfall four or five thousand years before the present.* This would suggest that the upper air flow patterns were different from the present, and that they were then favourable for the occurrence of large scale convective motion over Rajasthan also. The laws of atmospheric physics do permit such a situation. The physical equations-hydrodynamical and thermodynamical-controlling the flow patterns on a rotating earth, appear to be *intransient* (Lorentz, 1967).

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*Ramaswamy (1968)

In other words, they are capable of having more than one kind of quasi-stable, quasi-stationary flow pattern and the associated three-dimensional velocities. And one flow pattern may more or less flip over to the other, over a comparatively short period of a thousand years or so. A recent study at physical Research Laboratory has shown that the formation and movement of monsoon depressions are sensitive to their location with respect to the troughs and ridges of wave number 2 ($\lambda = 180^\circ$) in the large scale flow patterns (Keshavamurty, 1978).

Apparently, we can do nothing to change the present quasi-stable large scale flow patterns over this part of the world into the one that prevailed a few thousand years ago—the one that gave abundant rainfall to Rajasthan and Sindh.

What can be done to harvest water

Soil moisture condition is the most relevant factor for agriculture. The rainfall, along with the temperature and wind enable us only to *infer* soil moisture. Soil moisture also depends upon several factors like tilling, mulching, etc. Hence, it is desirable that steps be taken to have regular measurements of soil moisture made at various places and the data reported to a central office in real time. Appreciation of actual soil moisture conditions can be had only this way. A technical development for this purpose is yet to be realised. I would urge that agriculturists demand such a technical development, if they agree.

It has already been stated that the mean rainfall over these parts is about 1 cm per rainy day; the actual rate per hour being much higher. 80 % of the rainfall is of the order of 25-50 mm/day. There is significant run off even with rainfalls of 12.7 to 25 mm/day.[*] It has been estimated that the intensity per hour, is about seven times higher than what it is in the middle latitudes (Blanford, 1889). Consequently the rain water does not have sufficient time to soak into the land, with the result that recharge rate is smaller than what it is in the middle latitudes (Europe, and America). Hence the usual estimate of 25 % as the recharge rate is not quite applicable to Indian conditions. A recent measurement with radio-isotope technique in the Sabarmati basin, carried out by Physical Research Laboratory indicated a value of about 10 %. In arid regions it seems that the recharge rate is sometimes as low as 5 %. This is often due to the formation of a surface crust (Arnon, 1972), and consequent surface run off. This run off is often in the form of sheet flow, which soon changes into linear flow with the slightest slope. The formation of the surface crust is very well revealed in the Landsat imagery through its large reflectance. The gullies observed in the semi-arid and arid lands is an evidence of large erosion, and therefore of a large run off and poor recharge. This is a factor not adequately realised.

Hence we should take better steps than we have taken so far, to have all the rain water conserved. Percolation rate increases when the land is vegetation covered. Even then, the trampling by animals decreases it, although it may appear

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[*] (Kanitkar, 1968).

to increase the percolation. The run off is reduced by 20 % and erosion by 18 % if the area is fenced, even without any significant increase in the amount of grass grown. Contour bunding, plugging of gullies, provision of numerous surface tanks, are some of the methods adopted by the Chola Engineers of South India since the 2nd or 3rd century A.D. The same methods were adopted in the eastern districts of Shri Lanka under the ancient Sinhalese rulers (Toynbee, 1934).

The Government of Gujarat has a Water Conservation Scheme, whereby the drought prone *talukas* will have their gullies plugged and farm ponds constructed for the harvesting of rain water. As an example in one project area of about 1000 hectares, it is planned to construct 20 farm ponds (Pathak, 1977). Each will have a surface area of 0.25 hectare, and a depth of about 5 metres; each is estimated to cost about Rs. 2,500/-. This will be done by the local people with only a nominal support from the government. (The concept of self-help has almost disappeared at all levels; the villager wants help from the State; the State wants from the Centre, and the Centre wants help from the Oil rich countries or from the World Bank). One need not worry about seepage from the tanks, it will only recharge the surface acquifer, from which water can be drawn by plants and by man through dug wells. The deep tube well system, is not a long term solution; the underground water in the deep acquifer was perhaps stored a few thousand years ago and is obviously limited. Recent measurements of the age of the underground water at a few places in the Sabarmati basin, indicated that it was several thousand years old. It was probably collected, when the rainfall was abundant (5000 years before the present). An analysis of the data obtained by the carbon dating methods applied to the lake deposits in Sahara has shown humid rainy climates there during the following periods.

8000-7000 years B.P.
6000-4700 years B.P.
3700-3200 years B.P.

(Geyh and Jakel, 1977).

What can be done with the available resources

Insolation is abundant in these areas; so also wind energy during the summer. Efforts may be made to tap them; perhaps products derived using these energy sources can be exported. The best method of using solar energy is by the production of biomass—not necessarily cereals or pulses. One of the features of an arid or semi-arid land subjected to pressure of population is the removal of every tree, bush and twig for fuel. There is a statement at the recent U.N.E.P. Conference held at Nairobi, attributed to an Indian Scientist: "You may be able to provide cereals to these people of arid lands of India, but with what will they cook it?". This is full of implications.

It appears that there are special kinds of grass or bush which can use as much as 6-7% of solar insolation for conversion into biomass. Normal vegetation can possibly use only 2 to 3%—I am told. The sophisticated silicon solar cells, may be more efficient but they are expensive, and cannot be used for tapping energy over large geographical areas. Once such grass or bush is grown, it may be highly compressed into "brickets", or "pellets" and used either as fodder or as fuel.

Hydroelectric power generators, are solar energy converters, where oceanic water is the working substance. A physicist would conceive appropriate biomass as the working substance. If enough biomass is grown the brickets of fuel can be used locally as well as exported. The energy necessary for driving the machinery for compressing it should be derived either directly from the insolation or from the winds. Our winds are not as strong as the winds in the extra-tropical latitudes. So none of the wind mills imported, or designed on the basis of imported know-how, will be found satisfactory. We have to design the wind mills which will work efficiently with wind speeds as low as 10 kmph.

Not being an agriculturist myself, I dare not make any suggestions regarding cropping patterns, agricultural practices, fertilisers, methods of irrigation etc. In a recent workshop on 'Drought and Man' held at Ahmedabad, I heard that horticulture in semi-arid areas may be advantageous compared to agriculture. This does fit in with what is happening in ISRAEL—an arid land being one of the largest exporters of citrus fruits.

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I. 2.4

IS THE INCIDENCE OF DROUGHTS INCREASING IN THE ARID ZONE OF NORTH-WEST INDIA ?

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INTRODUCTION

The sowing date of the crops in the arid region is determined by the date of commencement of adequate rainfall, growing season by the duration of the period of adequate rainfall and absence of droughts, etc. Therefore, any attempt to study the trend in the occurrences of droughts in the arid zone of north-west India should include not only the determination of the secular trends in the occurrence of deficit rainfall years, but also in the available growing period as well as moderate to severe drought periods as estimated by the weekly water balances occurring within the rainy season.

MATERIAL AND METHODS

Daily rainfall data for large number of years (1901-1970) of different stations in western Rajasthan have been utilised in this study. For computing weekly water balances, mean weekly potential evapotranspiration (PE) values were computed by Penman's formula. Successive weekly water balances were worked out for the period from 22nd to 44th standard week (26th May to 4th November) of each individual year. The water budgeting procedure of Thornthwaite and Mather (1955) was followed for determining actual evapotranspiration (AE) and the aridity indices (AI) (where $A.I. = \frac{PE-AE \times 100)}{PE}$. The drought free growing season under rainfed farming was estimated as the period for which AE$\geqslant \frac{PE}{2}$, the periods of moderate and severe drought were determined by the following criteria:

1. Moderate drought — Period for which $\frac{PE}{2} > AE \geqslant \frac{PE}{4}$
2. Severe drought —Period for which $AE < \frac{PE}{4}$

RESULTS AND DISCUSSION

In order to study the trends in the occurrence of deficit rainfall years, the decadewise occurrence of such years at different stations in western Rajasthan is presented in Table 1. It is seen from the Table that year with large deficiency occurred more frequently during 1901 to 1920 and again during the decade 1961 to 1970.

The spatial variability of decreasing trend in rainfall during 1962-1971 in western Rajasthan indicate that the decrease in rainfall during the recent decade is very marked (viz. negative departure exceeding 32.5%) in the regions with coefficient of variation values exceeding 60% and even in areas with coefficient variation values ranging from 50-60 % the same is quite high (—12.5 %). The areas with coefficient of variation values between 50 and 40 % show practically no variation during the decade. But, when we regroup them as 2 regions viz. north and south of 27° N latitude we get increase in rainfall during the decade in the northern portion covering Ganganagar, Churu and northern Nagaur districts and decrease in rainfall in the southern portion covering southern Nagaur, Pali and Jalore districts. The areas comprising mainly of Jhunjhunu and

Table 1 Years of occurrence of large deficit rainfall in western Rajasthan

District	1901-1910	1911-1920	1921-1930	1931-1940	1941-1950	1951-1960	1961-1970	1970-1975
Jaisalmer	3	2	3	1	3	0	4	3
Barmer	3	3	3	0	0	2	3	2
Bikaner	1	1	0	2	1	0	3	0
Jodhpur	1	3	2	0	0	1	3	0
Nagaur	1	2	0	1	1	2	2	1
Churu	0	1	1	0	0	2	0	0
Jalore	3	3	1	1	0	0	2	0
Pali	2	1	1	0	0	0	2	1
Sikar	3	1	1	1	0	0	3	1
Jhunjhunu	1	1	0	1	0	1	1	0
Ganganagar*	—	—	—	0	2	0	3	0

*Data available only from 1926.

Sikar districts with coefficient of variation less than 40 per cent shows actually an increase of 9.4 per cent during the decade. One possible reason for the differences in the above trends in these subregions may be, the tendency of the monsoon depressions for recurving more often along east Rajasthan during the above mentioned years. This aspect may have to be further examined.

The rainfall departure during the decade in various rainfall zones of western Rajasthan are as follows:

	Annual rainfall zone (mm)						
	<150	150-200	200-250	250-300	300-400	400-500	500+
Departure during 1962-71 (%)	—32.5	—25.8	—15.6	—31.0	—2.5	—5.3	—9.7

Thus the decreasing trend is well marked upto the annual rainfall zone of 300 mm.

Trends in the frequency of occurrence of highly deficit rainfall water within the rainy season

Assuming that a week as deficit rainfall period if it fails to receive atleast half of its normal value, the frequency of occurrence of such deficit rainfall weeks (drought weeks) were worked out for the 11 district headquarters of western Rajasthan for the period 1901-1970. The data of decadewise mean number of rainfall deficit weeks per rainy season during 1901 to 1970 indicate that there does not appear to be much variation in the total number of rainfall deficit weeks in different decades. Also, the total number of rainfall deficit weeks within the main rainy season as well as decadewise means of prolonged rainfall deficit spells (of 4 weeks duration or more) does not show any specific trend.

Aridity shifts in the arid zone of western Rajasthan

In the present study, weekly water budgeting analysis was carried out in respect of four typical stations in western Rajasthan, namely, Jaisalmer, Barmer, Jodhpur and Sikar. Table 2 gives the decadewise means of number of growing period (G) as well as moderate (M) and severe drought periods (S) in weeks, occurring in each crop growing season. Out of 20 weeks considered, the growth period as well as moderate drought period together comprised 3 to 5 weeks in Jaisalmer, 5 to 8 weeks in Barmer, 8 to 11 weeks in Jodhpur and 10 to 13 weeks in Sikar. There is very little trend in the occurrence of drought weeks within the growing season during 1901-1970. One observation however made was that in the recent decade of 1961 to 1970, there was a slight decrease in the growth period and increase in the severe drought periods from the values of previous decade.

Table 2. Decadewise means of number of growing periods (G), moderate drought (M), and severe drought (S) for the period 25th standard week (18-24 June) to 44 standard week (29 October to 4th November) of western Rajasthan

Year/station		1901-1910	1911-1920	1921-1930	1931-1940	1941-1950	1951-1960	1961-1970
Barmer	(G)	4	5	5	5	5	5	4
	(M)	2	2	3	2	3	2	2
	(S)	14	13	12	13	12	13	14
Jaisalmer	(G)	2	2	2	2	2	3	2
	(M)	2	2	2	2	1	2	1
	(S)	16	16	16	16	17	15	17
Sikar	(G)	7	9	9	9	10	10	8
	(M)	4	3	5	3	4	5	4
	(S)	9	8	6	8	6	5	8
Jodhpur	(G)	6	6	6	6	8	7	6
	(M)	2	2	4	3	3	4	3
	(S)	12	12	10	11	9	9	11

Five year's moving averages of aridity indices pertaining to the period 22nd to 44th week for each individual year in respect of Jaisalmer, Barmer, Jodhpur and Sikar showed that there were 5 to 6 spells of above normal aridity indices. Of these spells, one that occurred recently (1961 to 1970) is of much higher intensity in respect of all stations. This is in conformity with the earlier finding (Krishnan, 1977).

Decadewise means of aridity indices in respect of the above mentioned four stations are given in Table 3. This Table also shows the increase in aridity index value in the recent decade of 1961-1970.

Table 3. Decadewise mean aridity index

Years	Barmer	Jaisalmer	Sikar	Nagaur	Jodhpur
1901-1910	75.9	83.4	65.1	74.0	71.8
1911-1920	76.3	85.3	60.4	76.0	72.0
1921-1930	76.8	88.5	57.5	71.0	69.4
1931-1940	76.9	86.4	59.4	73.0	68.6
1941-1950	73.2	87.2	52.7	72.0	64.9
1951-1960	75.2	81.7	52.9	70.0	65.1
1961-1970	79.9	90.6	65.2	72.0	73.2
Mean value for 70 years	76.0	87.0	59.0	73.0	69.0

Droughts and crop yields

The data of mean yields of *bajra* and *kharif* pulses in the Jodhpur, Jaisalmer, Barmer and Sikar districts indicate that there was a gradual decrease in the mean yield of these crops in these districts during 1960-1969 period, decrease being more perceptible in the Jaisalmer, Barmer and Jodhpur districts in that order.

The drought free weeks (G) during the crop growing season at Jodhpur which varied between 7.3 to 7.4 weeks during 1951-1959 period, decreased sharply to 5.0 and 4.6 weeks during 1960-1964 and 1965-1969 periods respectively. Similar trend was observed at Jaisalmer also. At Barmer, however, the reduction in drought free period was more clear only during 1965-1969 period with a corresponding increase in the aridity index values.

An interesting feature however is that at Sikar the total duration of severe moisture stress in the crop growing season which varied between 4.7 to 5.6 weeks during 1951-1959 increased to 10.4 weeks during 1965-1969 period. Similar increase in the moisture stress period in the total cropping season was observed in the other districts also. The severe drought period within the growing season varied from 11.6 to 16.0 weeks at Barmer, 12.5 to 12.8 weeks at Jodhpur, and 16.4 to 18.0 weeks at Jaisalmer, indicating general drought condition in the region during 1960-1969 period. Thus, the water budgeting analysis has brought forth salient features in the trends which were not noticed in the rainfall analysis discussed earlier.

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I. 3.1

INTEGRATED NATURAL RESOURCES SURVEY - RETROSPECTS AND PROSPECTS

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Exploitation of natural resources will remain the dominant factor influencing the development of large parts of the earths' surface for many years to come, especially in developing countries. But scientific knowledge of environmental conditions which is an essential pre-requisite for effective land-use planning is grossly inadequate in most cases. Integrated surveys provide a base for land evaluation, that is to determine the usefulness of the natural environment for man and this was principally conceived in Australia, Canada and Russia. It was designed as a means of collecting environmental information preparatory to land assessment. Attention was concentrated mainly on those inherent land characteristics of most importance to land-use. These include particularly the topography and drainage, soils, vegetation including pasture, climate and sources of water for irrigation and stock use.

The basic mapping unit in the Australian approach was the "land system" defined as an area or group of areas throughout which there is a recurring pattern of topography soils and vegetation

(Christian and Stewart, 1953). Aerial photographs are an essential tool, for areas with similar land characteristics have similar photo-patterns. Land systems of large areas could be thus mapped quickly because the limited field data could be extrapolated on the basis of airphoto interpretation.

For this reason, the integrated natural resource surveys on the lines of Australian "land system" approach have been adopted at the Central Arid Zone Research Institute, Jodhpur since 1960. The application of "land system" approach under Indian conditions, however, bristled with difficulties because the natural conditions have been greatly modified by man. Nevertheless, it proved suitable as a foundation because the landuse pattern boundaries and land system boundaries were found to be closely associated (Satvanarayan, 1967) and certain modifications were called for to suit local needs.

Therefore, based on the land system approach and recognising the need to account for high biotic interference, a new composite mapping unit termed as Major Land Resources Units (MLRU) was developed by Abichandani and Sen (1977). The MLRU concept may be defined as an area or group of areas having:

a) the recurring pattern of soil, landform and vegetation,
b) recurring pattern of socio-economic condition, and
c) recurring pattern of human activities.

It is thus based mainly on the homogeneity of the conditions that affect the human life in a particular area.

One third of the area under Indian arid zone has been surveyed by CAZRI so far. About 43,917 sq km have been surveyed in a reconnaissance scale, 52,736 sq km in semi-detailed and 28,821 ha in detailed manner (Table 1).

LAND USE POTENTIAL

The surveys so conducted and the assessments made have enabled the formulation of land transformation plan. For resource management, land could be classified in terms of the characteristics of any of its various elements. However, because of the continuous interaction between elements, it was desirable to group them to form ecological units in which their combined effectiveness for various uses could be evaluated (Hills, 1961). This underlines the applied value of integrated surveys in planning the economy, for landscape studies were thus necessary in working out measures for the transformation of nature (Kalesnik, 1962).

But integrated surveys were not intended to provider a final assessment of landuse possibilities. They were conceived as the first step in the long and varied investigations which were unavoidable for effective development planning.

Again, establishing biological potentials and physical possibilities of land use did not in itself determine the development possibilities. As rightly observed by Wright (1971):

"There is still the need for economic data on likely returns and cost of production. . . . Research, experimental plot and pilot schemes are all necessary to

Table 1. Integrated survey in Indian arid zone : Area surveyed

Reconnaissance survey		Semi-detailed survey		Detailed survey	
A. Central Luni Basin	11000 sq km	A. Siwana block	2045 sq km	A. 14 Research farms and RM & SC area (Soil and Landuse)	2597.25 ha
B. Bikaner district	27336 ,,	B. Saila block	1455 ,,	B. Kitnod village	1000 ,,
C. Mahendragarh district	3514 ,,	C. Ahore block	1590 .,	C. Nokha & Roda village	4000 ,,
D. Challakere Taluk (Mysore)	2067 ,,	D. Jalore block	943 ,,	D. Mahajan village	1000 ,,
	43,917 sq km	E. Chohtan block	3164 ,,	E. Parasrampura	4341 ,,
		F. Luni block	2000 ,,	F. Rozu village	80 ,,
		G. Santalpur (Gujarat)	1356 ,,	G. 5 villages in Jodhpur for dryland farming (Soil & Landuse)	2191 ,,
		H. Jodhpur district	22515 ,,	H. 5 villages in Jodhpur for O.R.P,	7812 ,,
		I. Nagaur district	17668 ,,	I. Landuse in Daijar area	5800 ,,
			52,736 sq km		28,821.25 ha

reach this point. Even then there remains, the broader sociological, economic and political aspects which will determine whether or not the various forms of production . . . . can be welded into a cohesive and stable development. Not until that stage has been reached can the land use potentials of regions be finally assessed."

Resource surveys and assessments in our view require to be undertaken concurrently and there is an urgent need to reappraise the traditional uses of land, so that actual use or misuse of land can be pinpointed. Post-reconnaissance surveys should invariably follow all integrated surveys in order to perceive whether predetermined goals are being achieved or not and suggest mid-term corrections.

There are two distinct but closely allied limitations in the integrated surveys. Fundamental classificatory inadequacies are perhaps the most far-reaching of these. Little attempt is made in many cases to classify the land in the strict sense except for the differentiation as "recurring pattern of topography soils and vegetation".

But then these surveys were meant as land inventories rather than classification in which types of land are defined in terms of summation rather than a synthesis of their separate characteristics. Of central importance, therefore, is the need for clearly defined primary units to provide the taxonomic "individuals" needed for class construction. To this end the emphasis on "facies" as the basic and smallest unit in landscape science is noteworthy.

As early as 1968, Mabbut drew attention of this classificatory inadequacy of integrated survey and he argued that for reliability and quantitative output for predictive assessment there is need for a "parametric" approach based on measured values of selected attributes. Since it may take some time before parametric approach alone could be standardised to provide a sufficiently comprehensive and mappable definition of land for general purpose classification, it is perhaps desirable to combine both the landscape and parametric approaches for immediate needs.

Work in Central Luni Basin area in western Rajasthan clearly illustrate the actual achievements and problems. The integrated reconnaissance survey was carried out in 1962 and its report drew the attention of Rajasthan State Government as a useful base for drawing the Master Plan for Luni Basin Development in 1977 about 15 years after the publication of the report.

Obviously the suggestions and recommendations made then had little relevance to the changing technology and development needs generated in the intervening years and therefore, has outlived its value for implementation. Further it did not assess the land treatment aspects and cost-benefit analysis.

Keeping in view these limitations it has now been proposed to undertake a resurvey of the entire Luni Basin so that in addition to basic resources and socioeconomic surveys to be carried out in a five year period, concurrent investigations are proposed to be carried out by separate team of specialist in potential areas on land treatment aspects and production economics. In this way the data emerging from the latter studies can be gainfully incorporated in the recommendations of the survey report for drawing a more pragmatic and realistic development plan of the region.

The integrated surveys acquire supreme importance in the context of Integrated Rural Development programme underway in the country wherein one of three steps involved is "compilation of resource inventories that will identify natural resources, infrastructure and participants drawn from the rural poor". To this end, it is obligatory that integrated surveys should be carried out in conjunction with socio-economic investigations.

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I. 3.4

LANDSAT ANALYSIS FOR DETECTION OF GROUND WATER IN RAJASTHAN DESERT

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Ground water, besides being confined to the hard and soft rocks, is also associated with the buried and abandoned or fossil river channels which are commonly found in the desert environment. During the sub-humid climatic period of the Rajasthan Desert there was a good net-work of drainage system. Subsequently, with the onset of the desertification processes, most of these streams have either shifted northward and westward or hidden and buried under the aeolian sands or got filled with their own sediments due to change in base levels. Wadia (1966) and Uppal (1973) has reported that the present Jamuna was with one of the tributaries of the Indus in the Pleistocene and Recent times or flowed alongwith the Saraswati river course independently to the Rann of Kutch. Similarly, other present-day streams of Punjab and Haryana which once flowed through Rajasthan have shifted their courses mostly to the north and north-west. Their

Scar-marks are still traceable as linear belts and show symptoms of water saturated zones lying below the surface. They can be taken as groundwater reservoirs. These buried and abandoned streams can be identified and mapped from the remotely sensed multiband imageries available in small and large scales. Ghose (1965) and his colleagues prepared a map showing prior stream relics of the Central Luni Basin based on aerial photo interpretation on 1:25,000 scale. Similarly, an attempt has been made to identify and map the buried and abandoned stream channels on LANDSAT I multiband imageries on 1:1000,000 scale. One of the objectives of this investigation was also to find out how many such streams can be identified and mapped from LANDSAT imageries.

16 LANDSAT scenes of the pass during October, 1972, on 1:1000,000 scale covering the desert part of Rajasthan and adjacent areas in 4 bands ranging from 0.5 to 1.1 micron spectral bands were used for interpretation and delineation. Some of these were enlarged to the scale of 1:190,000 for detailed studies. The photo prints were used for interpretation and delineation of present and buried and abandoned channels, topographic exposures and their alignments, and lineaments, and their direction. Bands 4 (0.5 to 0.6 microns wave length) and 5 (0.6 to 0.7 microns wave length) of the scenes were used for delineation of vegetative coverage because these wave-lengths are very sensitive to plant reflectance. The tonal variations were also studied. Bands 6 (0.7 to 0.8 microns wave length) and 7(0.8 to 1.1 microns wave-length) were utilized for delineation of present and prior streams, topographic units and lineaments and these bands provide clear demarcation between land and water, and even dry and saturated land surfaces.

Buried and abandoned streams

The photographic tones of the buried streams are linearly grey and parallel to the present courses which have registered darker tones. In some cases, however, the dry beds of the ephemeral streams show white tone. As compared to the surrounding terrain having light grey tone indicating poor to almost no vegetation, the courses of buried and abandoned channels have moderate vegetative coverage in a linear fashion as seen from comparatively darker tones. In case of streams where their course is only partially buried, it has been possible with the help of the grey tone and vegetative coverage to trace and extend the courses further to the master streams.

It is known that the Rajasthan desert slopes generally from north-east to south-west barring the local minor configuration. The topographic maps were utilized to delineate buried and abandoned streams.

The major lineament drections particularly of the Aravalli hills are from north-east to south-west almost parallel to the strikes of the hills. The minor criss-cross fractures are multi-directional. The master streams have followed major lineament direction such as the Luni. However, its tributaries such as the Bandi, Sukri, Mitri and Jawai have followed the minor north-west to south-east lineaments. The lineaments are structurally weak zones which act as good conduct for water movement. Chatterji (1966) has studied the joint patterns and the ground water potentials in Jalore Granitic domes and inselberg from the aerial photographs.

Near about a dozen of buried and abandoned stream channels have been identified. The longest amongst them is one starting beyond Churu from the Aravalli hills and ending in Kanodwala Rann north-east of Jaisalmer. It has a tributary starting midway between Sikar and Churu and is meeting the former one between Bikaner and Jaisalmer. An independent buried stream originates from the Aravalli hills between Didwana and Sikar and ends in the Rann of Pokaran.

Rao (1975) observed that the fresh water areas having T.D.S. less than 2000 PPM and areas having T.D.S. between 2000 and 3000 PPM are more or less coinciding the courses of the prior drainage channels (buried and abandoned drainage channels). Rao (1975) has described that a linear acquifer of loose sands and conglomerates near Bikaner city yields 40 to 90 cu m of good water per hour. He has also identified linear aquifers from Sujandesar to Mukta Nagar via Kanasar and Shivbari. The gravelly beds associated with loose sand are yielding fairly good quality of ground water. There are several examples of such type in Churu, Sikar, Barmer, Jaisalmer and Bikaner districts.

CONCLUSION

It can be concluded that multi-band LANDSAT imagery can act as reliable tool in tracing buried and abandoned channels and therefore for getting a synoptic view of the ground water location. The interaction, co-operation and co-ordination between imagery analysers and ground water hydrologists through feed back process can obtain quick results for detection of ground water in the desert. The geophysical survéys may be conducted along these mapped buried and abandoned channels to locate the aquifers.

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I. 3.6

ENVIRONMENTAL STUDIES OF KUTCH AREA USING LANDSAT IMAGERY

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Despite the long coastal line, large cattle population, fairly extensive mineral resources and sizeable agricultural land, the Kutch district remains one of the most backward region in the country. The reasons are: (a) extraordinary high aridity, and (b) incursion of sea water during the monsoon months. Both of these lead to an acute shortage of fresh water. These considerations have prompted the inclusion of Kutch in the Integrated Rural Development (IRD) scheme of the Government of India. Space Applications Centre (SAC) is one of the institutions taking a keen interest in the IRD. The present study has been inspired by this interest as well as our interest in evaluating the usefulness of Landsat data for making an inventory of the natural resources of the whole state of Gujarat. Present work is confined essentially to the study of regional environmental geomorphology of the Kutch area using Landsat imagery. The district has a total area of 45,612 sq km. Out of this the Great Rann of Kutch and the Little Rann occupy an area of 22,400 sq km.

The present studies have mainly involved visual interpretation of multiband imagery using conventional methods and an additive colour viewer for studying the 23 cm colour composites. A special projection system was fabricated to enlarge the 70 mm format images to a scale of 1:250,000 thus facilitating comparison with the "quarter inch" survey of India toposheets. Inundation and recession of sea water in the Rann area was inferred from the study of multidate imagery of 1972 and 1975. Limited field checks were carried out by taking traverses through the areas of interest. These traverses were planned using the Landsat mosaic on a scale of 1:1,000,000 as the base map.

RESULTS AND DISCUSSION

Major landscape units of the area are two; one is the Kutch mainland which includes coastal wetlands, coastal plain, central hilly uplands, hills of Pachham area and wide alluvial plains of Banni, the other is the Rann of Kutch.

The Kutch mainland

Wetlands

Major facets of the coastal zone environment of Kutch are the marshy wetlands. These wetlands were studied using Landsat imagery in combination with the additive colour viewer. The land-water interface, wetland boundaries, vegetation, mudflats and salt affected lands were demarcated. This served as wetland inventory data base for monitoring natural and man-made changes as well as for further detailed vegetation mapping.

The wetland of Gulf of Kutch extend from Gandhidham to Surbari Railway bridge about 60 km lengthwise and 40 km in width. It has an interconnected network of tidal streams which have been delineated. This network of tidal stream was compared with that shown in Survey of India toposheets (surveyed in 1964 and 1966) and some changes in their course especially in that of the Hadkiya creek and the streams near Cherabali were noticed. Increase in wetland area and shift towards Little Rann was also observed. The wetland of Kori Creek, extends to the north of Kori Creek. At the mouth of the Rann, a major mudflat is observed whose boundary was demarcated from landsat 1 (1972) and 2 (1975). Results showed a shift towards the west. Wetlands of Narayan Sarovar, Jakhau and Mandvi—Gandhidham are low and muddy. These appeared in bluish tone on colour additive viewer. The formation of these wetlands seems to be associated with the tectonic disturbances.

Coastal Plain

Coastal plain with its low-relief showed a distinct tone on landsat imagery. Boundary between coastal plain and the highlands was clearly observable. It extends from Naliya to Anjar over a distance of about 150 km and has a width of 20 km. Major streams draining the coastal plain like Naiero, Kankawati, Kharod, Mithi, Sakra, Rukmavati and Bhukhi could be observed on the Landsat imagery. Many lineaments and linear features were observed along the coastal plain. Near Anjar, erosion of the coastal plain was noticed in the imagery. The coastal plain is a major cultivation area of the district.

Central hilly uplands

Central part of Kutch has hills of relict type with a maximum elevation of 387 m (Dhinodhar). Hills extend from Gadoli to Anjar parallel to the coast. Hills can be seen widely spread on the western side of the mainland, gradually narrowing eastwards.

Banni

Northern side of mainland has a low lying alluvial plain known as Banni. This is a major grassland and gets inundated by the northerly flowing streams. Banni supports a large cattle population.

Rann of Kutch

Submergence of Rann during monsoon is still not fully understood. An attempt has been made here to understand the phenomenon of inundation period using available post-monsoon multidate imagery from Landsat 1 and 2. The inferences are based on 3 scenes of the western part, 4 scenes of the eastern part and nine scenes covering the Little Rann area. These show that based on topography and the encrustation pattern, the Rann of Kutch can be divided into two main parts. The area lying to the west of Pachham island or the western Rann and the area towards east of the island or the eastern Rann.

Western Rann

There is a major depression formed by Allah Band on the north and mainland on the south. A very distinct salt encrustation pattern can be observed in the imagery of both November 1972 and February 1975. No salt encrustation is seen north of Allah Band in any of the imagery. An island in the middle of this depression is observed in all the images but is not indicated by any toposheet.

Eastern Rann

This is separated from the western Rann essentially by the Pachham island and the uplands north of the island. Unlike the western Rann, there are streams like Luni draining into this area. The salt encrustation pattern from Landsat 1 and 2 are quite different in this case. Whereas the eastern half has encrustation in the 1972 imagery, the western half of this Rann has some major encrustation patches in 1975 imagery.

Little Rann

Little Rann is connected with the eastern Rann. Salt encrustation pattern of the Little Rann could be studied from September 24, 1972 to February

15, 1973 (seven scenes) and then in February 14, 1975. Rivers Banas and Saraswati are draining into the Little Rann. The salt encrustation pattern showed two distinct patches on the eastern side and along the southern border of the Little Rann in Landsat 1 imagery which could be studied at various stages of evaporation. However, 1975 imagery showed a large area having a non-uniform salt encrustation towards east. The drainage is apparently towards west in this area.

Inundation of Rann

Gupta (1976) opined that both the Ranns get inundated (upto 2 m) during July to November not only by the rain and stream water flowing into them but also by the tidal water due to strong winds during south-west monsoon. At the end of the monsoon flood water either recedes or evaporates leaving a thick crust of salt that covers large areas of the Rann. Roy and Merh (1976) have also studied the geomorphology of the Rann of Kutch using toposheets and aerial photography. However, the sub-facets demarcated by them are not observed in the Landsat imagery.

Inundation is confined to the trench formed by Allah Band but the area north of Allah Band does not get inundated by tidal water. It may be inundated by minor streams which do not leave any salt encrustation in this area.

Lack of any stream discharging into the western Rann and similarity of encrustation pattern would indicate that this part of the Rann is mainly inundated by monsoon tidal water. February 1975 imagery shows standing water east of Pachham island which is not observed even in November 1, 1972 imagery. As remarked earlier, 1972 imagery showed the eastern part of eastern Rann having large encrustation patches which were not observed in the Landsat 2 imagery (February 1975). However, some large patches were observed in the western part which were not observed in 1972 imagery. These two different patterns indicate that tidal waters may not be responsible for inundation of the eastern Rann. One of the possible explanations could be that the inundation of this area is by fresh water (streams and rain). Lack of salt encrustation on the eastern side in 1975 imagery but presence on the western side can probably be explained by the dissolving action of fresh water Rann and accumulation on the western draining from east to west in the eastern side.

The inundation of Little Rann can be explained only by taking into account the contribution of tidal water as well as of the fresh water. The contribution by the latter results in a non-permanent salt encrustation in this area.

Soil associations

The information available on soils of Kutch is scanty and hence an attempt has been made to classify the soils of Kutch by visual interpretation of Landsat imagery. The Rann of Kutch is dominated by sandy saline soils devoid of vegetation. The interior area around Bhuj has mainly red sandy and sandy loam soils. The coastal area around Mundra and Mandvi consists of saline.

sandy soils. The western region comprising of Lakhpat, Nāliya and Nakhtrana, and Rapar in the eastern part has plain alluvial terrain with sandy loam soils. Medium black soil covers the area between Anjar and Mundra.

CONCLUSIONS

Landsat imagery has provided an opportunity to study the environmental geomorphology of Kutch area. Some preliminary conclusions could be drawn about the inundation pattern of the different parts of the Rann. These can be confirmed by the availability of rainfall and stream discharge data. Understanding of this inundation pattern can be extremely important for any possible plan to reclaim the Rann, particularly after the Narmada project has been taken up.

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I. 3.8

ENVIRONMENTAL ANALYSIS FOR LAND USE PLANNING IN THE ARID ZONES

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An environmental analysis approach, utilizing eco-system simulation modeling, is presented as a means for effective land use planning in arid and semiarid regions. Physical and biological parameters along with climatic conditions are analysed to evaluate the potential productivity levels of the area. Land uses such as agriculture, cattle grazing, mining, and urban development are assessed as potential practices in the area. Land is quantitatively rated in the analysis to its suitability for each of these practices. Spatial data arrays of land suitability are displayed as printer maps by a computer programme. The entire methodology is not environment specific; it can be used for analyzing other eco-systems.

CAPABILITY VERSUS SUITABILITY

Capability is a measure of the land's potential for production of either vegetative or animal material. The capability rating used here assigns a value to specific locations on the land to represent its ability to produce a given material.

On the other hand, suitability is a measure of the capability of the land when constrained by economic, social, and political factors operating in all land use decision systems. Suitability of a given parcel of land for a specific land use may be dissimilar to the capability rating of the land for that use. An area with a high capability rating for a land use does not, by any means, indicate it will be assigned that use.

CAPABILITY ASSESSMENT

The first step in the determination of the capability of the land for various uses involves the assemblage of a resource data base of the area. Physical and biological characteristics of the land are assembled along with the climatic factors representative of the area. Physical factors inventoried are slope, soil type, drainage network, sources of water, characteristics of the soil, and floodplain areas, to name a few. The nature of the biological parameters inventoried are represented by type, density, and condition of the vegetation, wildlife species, population of wildlife, and other similar items. Parameters such as daily temperature, humidity, percent cloud cover, percent of potential solar radiation, precipitation, and average runoff are typical of the climatic parameters.

Using the inventory parameters, the capability of the land to sustain certain types of vegetation or various species of domestic and wild animals can be computed or approximated. In the case of cattle, for example the potential vegetation condition of the area and associated resource parameters (such as availability of water) are used to determine the number of cattle which may be grazed on the area. Similar operations may be performed to obtain an ideal level of stocking of the area for several other species of animals.

The capability of the land for certain crops and other vegetation may be determined. Availability of water for irrigation, the physical and chemical parameters characterizing the soil, and other resource variables are used in the computation of agricultural capability of the land for a given crop. From such an analysis, certain crops will have higher production capabilities than others. This ordering, ignoring economic and other factors, may imply which crops to plant in an area. Admittedly, the planting of a high profit crop which is only marginal in performance in the area is often desired over production of a low profit crop which has excellent growth performance for the area. However, from purely biological capability considerations, the crops may be assigned some form of growth capability index to show its potential growth in the area.

Geologic and geophysical information allow an assessment to be made of the mineral capability of the area. The existance and extent of mineralization in the area are the main factors in the mineral capability rating.

ECOSYSTEM SIMULATION

Recent innovations in computer-assisted procedures for estimating the impacts of land management activities on a natural resource base have greatly improved environmental analysis for land use planning. In specific, a family of interactive modular components that facilitate decision-making with respect to land use planning in arid and semiarid environments in the south western United States are currently under development (Carder *et al.,* 1978). While progress in designing, refining, and verifying continues, an outline of the conceptual framework of this computer system will illustrate this general approach to ecosystem simulation.

As structured at this time, the family of modular components consists of the following items: a set of general modules that, in turn, include simulators designed to estimate specific ecosystem responses to management activities; an interactive command system through which users link selected modular components and retrieve source data to operate those modules; and associated data bases to be introduced into a simulation exercise as required. To allow continual up-dating, necessary in meeting user demands, maximum flexibility is insured within the framework of the system.

For purposes of illustrating the application of the family of modular components in an arid environment in the south western United States, a description of the general modules which estimate specific ecosystem responses to management activities will be presented. Particular emphasis will be placed on components which simulate the ecosystem responses that determined, in part, appropriate land use planning in the arid zone. As the complete array of modular components cannot be described in this paper, only the simulation of herbaceous understory, animal carrying capacities, water yield, and sedimentation will be highlighted.

An interactive modular component is under development to estimate production and (to some extent) composition of herbaceous understories from knowledge of competing shrub overstories, precipitation amounts, and if appropriate, the time since the implementation of a management activity which reduced the impact of competing shrub overstories. While initial efforts have. been directed toward the estimation of total herbaceous understories, subsequent additions to the component will allow the simulation and partitioning of herbage production into three general categories: perennial grasses and grass-like plants, forbs and half-shrubs, and shrubs. Such partitioning will provide better insight to land use planning for anticipated consumption of the herbaceous resource by domestic livestock and wildlife species.

In a modular component which has been structured to determine animal carrying capacities, the production of herbaceous understories (entered directly by the user or obtained through outputs generated by the abovementioned herbage production simulator) is analyzed with respect to usable forage components for cattle, sheep, goats, wildlife species, etc. Appropriate plant species for inclusion in each forage component were ascertained from existing literature relevant to the preferred foods for these animals. Proper use factors are introduced into the simulation exercise by the user in an attempt to meet specific management objectives. Similarly, the amount of usable forage required to support the animal species of concern is generally input by the user to achieve a desired end. Given the time which animals will actually be consuming forage on the tract of land under consideration, along with an identification of possible constraints which may affect the distribution of animals, carrying capacities are determined through simulation and then compared to actual stocking rates to assess and use planning in terms of animal grazing activities.

A simulation of the impacts of current and future management activities on the water budget in arid environments can dictate subsequent land use planning. Therefore, a prototype modular component has been formulated to estimate water yield from readily available inputs, i.e., precipitation amounts, soil characteristics, and densities of shrub overstories and to predict the amount of sediment load in steams.

To provide simulation opportunities for other natural resource considerations, modular components have also been synthesized to predict: growth and yield of forest overstories; development and accumulation of organic material on the ground; habitat quality for a variety of animal species, maximum concentrations and daily volumes of dissolved chemical constituents in streamflow; and asthetic values associated with different ecosystems and man's activities. Collectively, all of the components can be used to describe impacts of management practices for land use planning.

SUITABILITY RATING

Ecosystem simulation models allow predictions to be made regarding the possible effects of changing the dominant land use of an area. The environmental effects resulting from a change in land use are very important considerations both legally and public opinion wise, for most locations in the United States.

Suitability of the land for cattle grazing is calculated from: (1) the grazing capability, (2) the effects on the ecosystem, and (3) the economic, social, and political constraints imposed on this land use. These models allow the land manager to know before the implementation of a land use activity, the environmental consequences of it. An economic analysis is performed next to better define the suitability of the area for cattle grazing. In this analysis, political and social constraints are introduced in terms of costs. Output of the economic analysis is the suitability ratings of the area for cattle grazing.

In general, the suitability rating process may be thought of as the application of a suitability function to the resource data, outputs of the ecosystem models, and all economic data derived from an economic analysis. All these data sets are spatially distributed, i.e., the data item's value may change from location to location on the study area. The suitability function is then applied to each cell or component of the area to calculate a rating for that individual cell. The magnitude and distribution of cell values for the entire area are presented using computer printer maps. The total range of suitability values is often divided into ten sub-intervals on these maps, each of which has a unique symbol used to represent it. A cell location on the area is then portrayed by the symbol which represents the subinterval corresponding to its suitability rating. In the case of cattle grazing, the suitability function was applied to all the variables mentioned above, with a resultant suitability surface showing the spatial variation in the suitability over the area. Similar procedures were applied to generate suitability maps for the land uses of agriculture, mining, and urban development. The suitability map allows for the easy and rapid comprehension of the variations in suitability throughout an area.

Suitability rating for housing or urban development, agriculture or mineral extraction are a function of physical as well as economic attributes of the land items as engineering properties of the soil.

FUTURE CONSIDERATIONS

Trial applications of the family of modular components has begun (Carder *et al.,* 1978). Initially, tests will be conducted in conjunction with well-defined data bases to provide for rigorous verification. These initial tests will involve simulation exercises across a range of ecosystem conditions, including arid and semiarid. Subsequent applications will be extended into more humid environments to furnish greater flexibility in land use planning.

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I. 3.9

A STUDY OF AIRBORNE GEOPHYSICAL DATA FOR SELECTION OF POSSIBLE AREAS FOR GROUND WATER EXPLORATION IN SOME ARID ZONES OF RAJASTHAN

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INTRODUCTION

Airborne geophysical surveys employing electromagnetic, magnetic and radiometric (total count scintillometer) sensors were carried out during 1967-68 over selected areas in Rajasthan, under Project "Operation Hard Rock", primarily for base-metal exploration. A total of 58,386 line kilometres were flown in Rajasthan covering an area of 30,140 sq km. The survey in Rajasthan was carried out over three blocks namely Ajmer, Bhilwara and Jahazpur. The area lies between latitudes 24°35′N to 28°15′N and longitudes 73°30′E to 76°04′E. Almost the entire area is semi-arid to arid, the western part of which forms part of the great Thar desert.

The flight direction of the traverses in all the three blocks was N 52° W-S 52° E, almost transverse to the regional strike of the lithological formations. The flight lines were mostly spaced at half km interval. Tie lines were flown at intervals of 20 kms, or more, for tying up the magnetic data. In the Ajmer block the flying operations were carried out with a terrain clearance of about 400 ft above the ground.

The Airborne Electromagnetic System used in the Ajmer block was the Barringer (Mark V) Induced Pulse Transient System (INPUT). In this system the E.M. energy is transmitted from a horizontal loop around the aircraft in the form alternate polarity pulses of half-sine wave shape of 1.0 milli-sec, width at intervals of 2.0 milli-sec, dead time. The decaying secondary field is sampled over six sampling points during the off cycle of the transmission with the help of a receiver (vertical coil) mounted in a 'bird'. The bird is towed 75 m behind and 60 metres below the aircraft with the help of a cable. The e.m. pulses generate eddy currents in conductive bodies lying within the range of the E.M. system and produce secondary electromagnetic fields which decay after the abrupt termination of the pluse.

The sampling centres were arranged at 300, 500, 700, 1100, 1500, 1900 microsecs after the cessation of the primary (transmitting) signal. The rate of decay of the secondary induced field, depends on the conductivity-thickness product of the target. Faster the rate of decay lower is the conductivity of the target and vice-versa.

A proton precession magnetometer which measures absolute values of total geo-magnetic field was used on time sharing basis with the E.M. system. The magnetic measurements were made at intervals of one second during the dead transmitter time. The magnetic variations help to bring out the major structural features, trace the trends associated with the exposed geological formations into the covered ground and to extract information related to the basement relief.

A scintillation counter mounted on the aircraft measured the total gamma radiation. This provided additional information on radio-activity associated with geological formations and radioactive targets.

Other ancillary equipment used were; radio-altimeter, intervallometer and a continuous 35 mm film strip camera. The flight path recovery was done on photo-mosaics with the help of 35 mm continuous photograph.

The responses from all the sensors were recorded on nine traces of an analog strip chart recorder, The parameters recorded were the response from all the six channels of the E.M. (Input) system, total magnetic field values, total gamma radiation count, altitude (terrain clearance), and timing lines with a fiducial mark after every tenth timing line.

The E.M. amplitudes were read from an arbitrary base level (of each channel) on the analogue chart and were plotted on the analogue chart overlays indicating their width and altitude at the anomaly peak positions. The magnetic data were corrected for various sources of error, such as diurnal variation, instrumental drift, altitude variation etc., using the control (Tie) line data. The corrected magnetic data was plotted on the flight plan map and iso-gamma contour maps were prepared. The total count radiometric anomalies were also plotted along the flight lines but no isorad contour map was prepared.

The western part of the north Ajmer block covered under Project 'Operation Hard Rock' has been chosen for the present study on the feasibility of interpretation of the airborne geophysical data for selection of favourable zones for ground water exploration. The area falls in toposheets 44p and 45 m and covers parts of Jhunjhunu and Sikar districts (Fig. 1). The area forms the eastern fringe of the great Indian (Thar) desert and is mostly covered with blown sands. The western foot-hills of the Aravalli mountain ranges which extend in a NE-SW direction form the eastern limit of the area under study.

General geology

The area of study is mostly covered by Quaternary deposits which rest over the Precambriam basement rocks. The geological sequence of western part of Rajasthan as available from records, pertaining to the area, is given below:

Era	Period	Series/System	Lithological description	Acquifer properties
Quaternary	Recent to sub-recent pleistocene	Dune sand alluvium	Sand, river flood deposits and valley fill deposits.	Major acquifer in the area.
		Pebbles, cobbles and boulder beds	Pebbles to boulder and conglomerate.	
		Unconformity		
Proterozoic	Upper Precambrian	Delhi system	Acid volcanic rocks and granite.	
		Railo series	Mainly Quartzites and impure calcareous rocks.	Small quantities of water from fractured and weathered zones.
			Marble (Makrana marbles) schist.	
		Unconformity		
Azoic	Archean	Aravalli system	Metamorphic Schist, Phyllite, Quartzite marble, Gneiss Granites.	Small quantities of water from fractured and weathered zones.

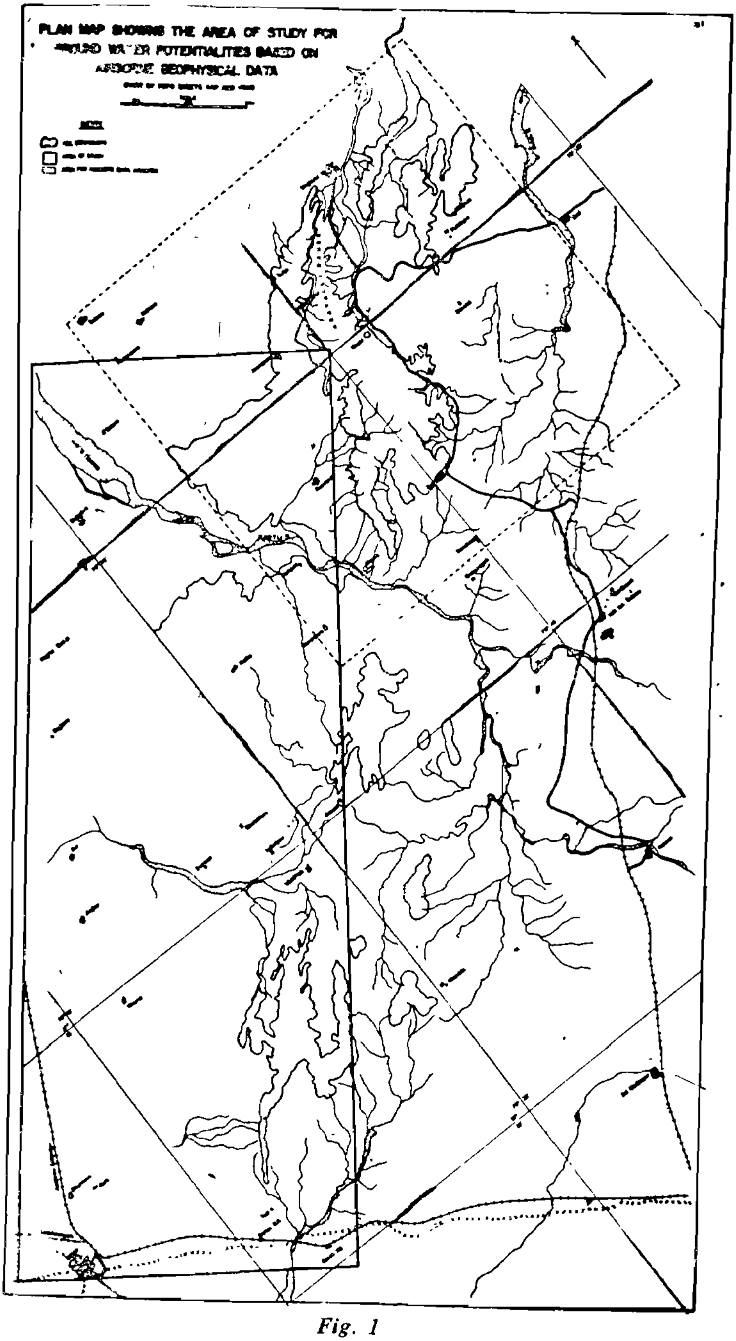
PLAN MAP SHOWING THE AREA OF STUDY FOR
GROUND WATER POTENTIALITIES BASED ON
AIRBORNE GEOPHYSICAL DATA

Fig. 1

Further west of the area, the Quaternary deposits rest over sedimentary formation of Tertiary and older age.

Physiography and ground water potentialities

The land surface is gently inclined towards the west and north west. There are two seasonal large streams flowing from south-east to north-west fed by a number of streamlets. A few streamlets originating from the hills flow westwards and disappear in the thick sandy cover. The thickness of alluvium or unconsolidated sediments overlying the Precambrian Hard Rock formations in the area generally vary from a few metres to about 100 metres.

The principal acquifer in the area consists primarily of sand (fine to very fine grained), lenses of silt, some clay beds and varying thicknesses of sediments containing calcareous concentrations and lenses which are locally known as *kankar.* The area of Precambrian terrain has its own characteristics of ground water occurrence. The rocks of basement complex are mainly granite, phyllite, quartzite gneiss and marble. The ground water movement is controlled by features such as fractures, joints and major shear zones. Generally the water yield in such environment is limited.

Over most of the area the depth to the water table ranges between 30 to 45 metres. The area under study has limited yield prospects (below 50 m^3/hr) and the water is generally saline except in some local patches. The movement of ground water in the region is towards west and north west from the Aravalli hill ranges. South west of the area is the known Sikar basin which is limited in the east by the impervious rocks of Aravalli mountains and in the south and west by structurally high sub-crops of the impervious basement. The acquifer in and around the Sikar basin area is reported to have best ground water potentials in the region. The reported thickness of the acquifer averages about 55 metres with a maximum of 80 metres near Sikar.

GEOPHYSICAL PRINCIPLES, PROCEDURE AND INTERPRETATION

In regional geophysical surveys the magnetic measurements play a vital role and provide a wealth of information which can be made use of for geological correlation and interpretation, related to various types of problems.

As the total earth's magnetic intensity contour maps represent the cumulative effect of the normal variation of the earth's magnetic field, anomalies originating from shallow sub-surface or outcropping features and those due to deep seated magnetic sources of large areal extent. It is necessary to separate these effects by quantitative method.

To achieve the above objectives, the magnetic data were digitised at regular grid intervals over the area around the Khetri Copper Belt (North eastern part of the area of present study). The data were first corrected for the regional variation of the earth's total magnetic field by applying the appropriate rate of change of variation along the latitudes and longitudes. The regional and residual anomalies were calculated using computer programme and the respective contour maps were prepared for detailed interpretation.

The magnetic 'Regional' generally represents the low frequency component associated with deeper and larger sources, as well as the nature of the basement topography. The regional map (Fig. 2) also indicates a slope of the gneissic basement trending SE from Sultana towards Padampura and Khatano. A zone of regional magnetic low is also observed in the area West of Tajiabeg. A few of the major NW–SE and E–W trending faults have also been indicated.

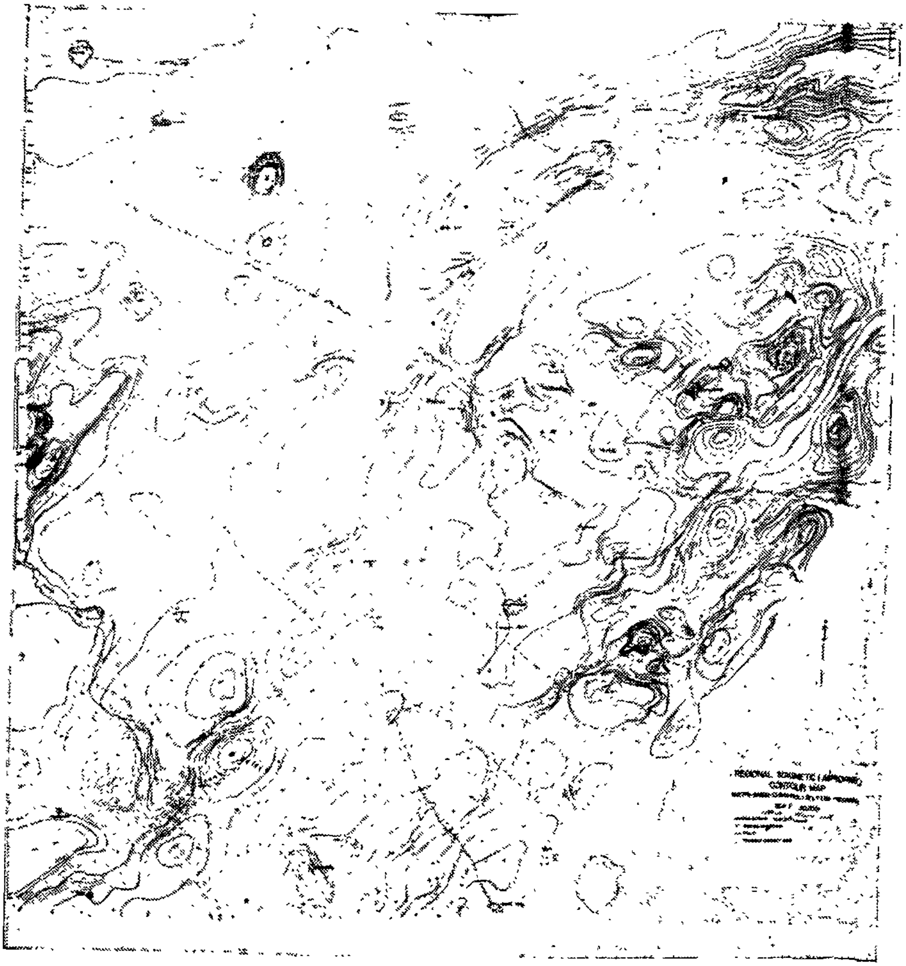

Fig. 2

The 'residual' anomalies generally represent the high frequency component of the observed magnetic field which is associated with the shallower causative sources and structure of small areal extent as well as local variations in the basement topography, wherever it is shallow. The magnetic residual map (Fig. 3) on the other hand shows a series of parallel zones near Sultana, trending NW-SE which may represent the undulations in the gneissic basement topography. The magnetic 'lows' in this region may be associated with depressions in the basement and as such may indicate a greater thickness of unconsolidated sediments. These depressions could be channels for the ground water recharge in the deeper region of the basement south-east of Khatano. Similar magnetic environment is noticeable in the region west of Tajiabeg, where the rocks of basement complex appear to be deeper with a system of magnetic lows orthogonal to the regional NE-SW strike of the Aravalli formations.

The Electromagnetic data were initially classified into bed rock conductors and surficial conductors. The bed rock conductors were further classified based on geophysical parameters like conductivity, strike length of the zone, magnetic association and geological setting. As the data were found to be more than 200 metres exploration, the bed rock conductors, considered significant for base metal exploration, were studied in detail and followed by ground investigations.

The rate of decay of the secondary electromagnetic field is slow in the case of good conductors and fast over poor conductors. It was observed that the presence of conductive surface layer above a good conductor tends to increase the overall response, but if the surface conductivity is very high, the transmitted energy is screened and it is difficult to identify the presence of conductors below such layers. The higher frequency component of the secondary field is generally related to the near surface region which is recorded in the earlier (1, 2 and 3 channels) while the response at the later channels can be related to the lower frequencies.

In general the presence of ground water in resistive formations tends to increase the conductivity. Moreover the ground water zones are generally represented by broad zones of higher conductivity. typical of a sheet like body (Fig. 4). The zones with surficial conductivity were taken up to study the nature of electromagnetic response in relation to the existing surface drainage system, known data on ground water acquifers in the region and regional geology published by various workers of the Geological Survey of India, as well as the maps compiled and published by the Central Ground Water Board.

For this purpose the EM data of the first and second channels of the INPUT records were digitised at regular intervals along the flight line and plotted on the flight plan. While digitising, it was noted that on some flight lines that the EM data were fast approaching zero (no response) as the aircraft had flown higher over the mountaneous region (Fig. 4).

The aircraft altitudes in these parts were found to be more than 200 meters above the ground, resulting in almost no penetration of the EM energy in the ground. It was also noticed that the first channel amplitude had more noise and hence second channel amplitude

ig. 3. Residual magnetic (Airborne) contour map, Khetri-Babai-Chinchroli belt (Rajasthan). Scale 1:

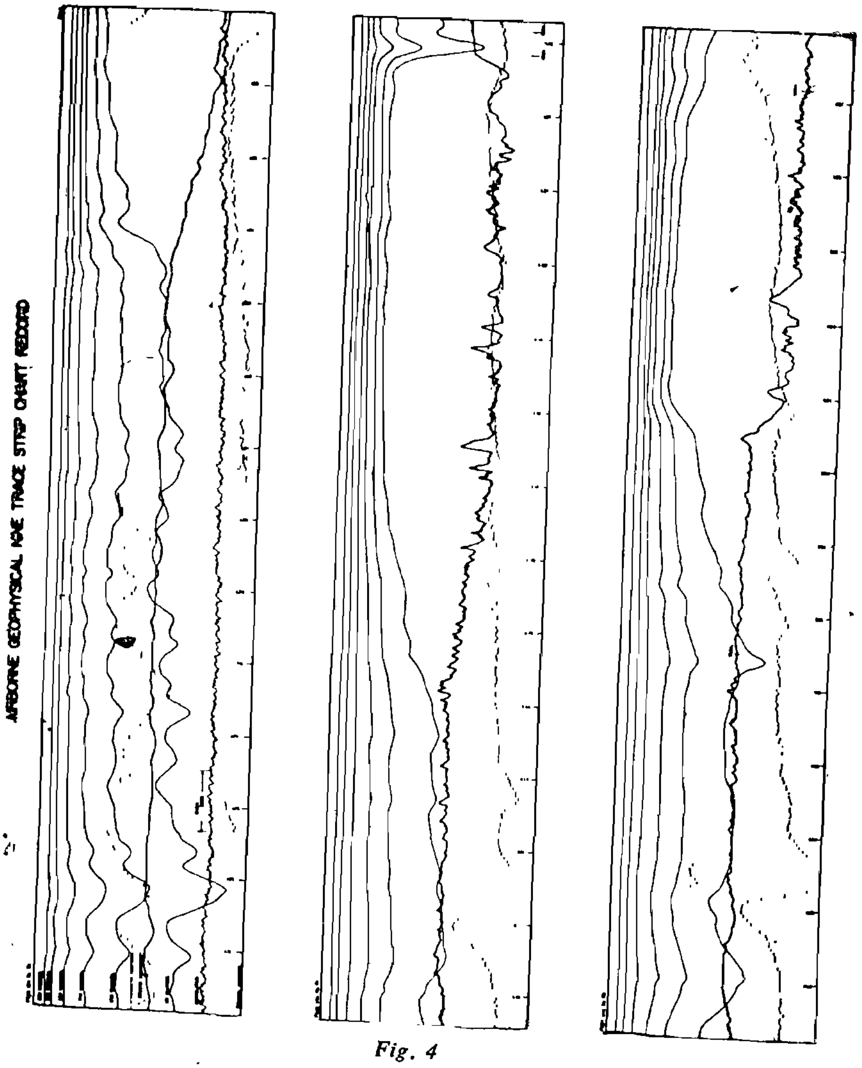

Fig. 4

(in arbitrary units) were contoured and the zones of relatively low and high amplitude responses were marked on the contour maps.

The major zones with high magnetic gradients (H.M.G.) were outlined on the magnetic contour maps. These are generally associated with lithological units of higher magnetic susceptibilities and can be differentiated from the zones of low magnetic gradient generally associated with the rocks of basement complex in this area. The major faults zones, contacts and basement, depressions interpreted from the magnetic regional and residual maps were transferred over the EM contour maps (Fig. 5) for correlation.

The salinity of water in this region tends to increase the surface conductivity. The zones with relatively less brackish water

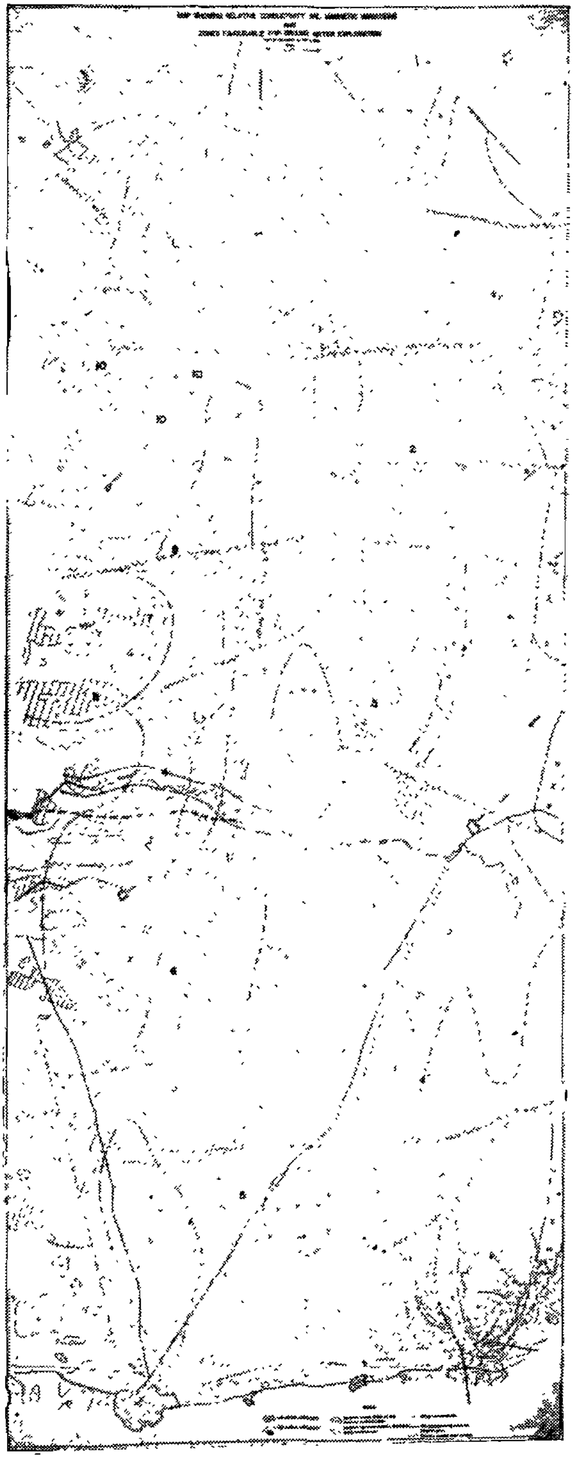

Fig. 5

are expected to show less conductivity and in turn, relatively low amplitude EM response. For example the amplitudes of the second channel EM response along Kantli river are in general lower (Fig. 4) compared to the zones on either side of it. Similar features were noted in the vicinity of other streamlets in the area.

The narrow zones of 'very low' amplitude responses observed in the area, appear to be closely associated with the shallow lithologic units, with poor conductivity. These have also been corroborated generally by the magnetic trends. It would appear that these features separate the acquifer on either side. Most of the EM zones also appear to be bounded by major faults or conform to them in the area. It is quite likely that the area in the vicinity of these faults and along them may prove favourable for tapping deeper sources of ground water. Even in hard rock areas with less thickness of the overlying sediments, these fault zones are indicative of fractures and shear zones favourable for ground water potential.

INFERENCES

Based on the correlative studies ten additional zones have been identified in the area of study as favourable zones for detailed ground water exploration besides the fresh water zones on either side of the Kantli river.

1. An elongated zone trending NE-SW between Salana and Padumpura near Kantli river.
2. A prominent zone west of Kishorepura extending from Mainpura towards south-west.
3. A broad zone of lower surfacial conductivity north of Udaipur (*Shekhavati*) beyond Dholakhera village.
4. Small zones of lower amplitude EM responses between Barwari and Bai corresponding to a low magnetic feature. This also suggests that apart from electrical conductivity the magnetic response should also be studied closely in interpreting geophysical data for delineation of favourable zones for ground water exploration. In the vicinity of this feature further south an elongated narrow zone of lower amplitude response has also been noted, the alignment of which suggests the possibility of its correspondence to an ancient river course.
5. A broad zone north-east of Gorian, from Todi village, extending through Kurli and Bhadwasi (NE of Sikar) in a NW-SE direction upto the western boundary of the area.
6. Some prominent elongated zones of Jhajhar, trending NE appear to follow the lithological contacts. These lie to the west of village Kheror.
7. A zone trending SE near village Baghera appears to lie in the centre of a large circular magnetic feature, which seems to be associated with an intrusive body possibly of granites.
8. A zone south-west of Baghera village along the periphery of the possible magnetic intrusive body.
9. A zone three kilometres to the NE of Baghera corresponding to a major fault zone inferred from the magnetic trends.
10. Several other smaller zones of interest lying to the north-east and east of Naglia Bas.

CONCLUSIONS AND SUGGESTIONS

The present study of the Airborne Electromagnetic and magnetic data reveals that it is feasible to carry out airborne geophysical survey for resistivity mapping and delineation of favourable zones for detailed ground water exploration, particularly in the arid and semi-arid regions as well as in hard rock areas.

With the improved version of the Input System designed and constructed by the National Geophysical Research Institute, Hyderabad, having enhanced capability of resolution and discrimination between horizontal and vertical conductive bodies as well as higher depth of penetration, it is expected that better data can be obtained for resistivity mapping. Also, the data obtained for other projects can be made use of, for delineation of ground water zones.

In order to achieve technically reliable airborne data it is felt necessary that:

(i) All the airborne geophysical data should be digitally recorded on Computer Compatiable magnetic tapes so that handling vast data and application of altitude corrections can be achieved directly and more accurately.

(ii) There should be provision in the instrument circuits for automatic correction of minor instrumental drifts to minimise chances of erroneous data recording.

(iii) If possible the E.M. data can also be corrected for altitude variations on board through mini-computer circuits before the output stages.

(iv) The E.M. channels should be calibrated accurately through reference signals to provide dependable inter-relationship from one channel to another.

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I. 3.10

PROBLEMS OF GROUND WATER RESOURCES OF WESTERN RAJASTHAN AND THEIR POSSIBLE MANAGEMENT

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INTRODUCTION

Over eighty per ent of western Rajasthan is covered by a blanket of sand and alluvium varying from a few centimetres to over two hundred metres thickness. As a result, many of the aquifers of this area have not yet come to limelight. Scientific investigations by various organisations within past 25 years have unearthed various new potential aquifers in this region. However, use of ground water resources has three major problems: (i) major proportion of the ground water reserves of this area comprises of saline water having total salt content of over 3000 parts per million (ppm), (ii) deep water table i.e. at depths of 60-100 m below ground level excepting the south-eastern region with water table at 15 to 30 metres, and (iii) generally the yield from the wells is poor ranging between

2 to 6 litres/second. High discharge wells are confined to very restricted areas like Borunda.

PRESENT UTILIZATION OF GROUND WATER RESOURCES

Due to the absence of major surface water resources and recurrence of drought, the inhabitants of this region have to generally depend on the ground water resources for their subsistence. As a result, the stress on ground water resources is increasing day by day. The index numbers of wells and tube wells have increased by 25 and 478 points from 1962-63 to 1974-75. Similarly, the index number of area irrigated by ground water and surface water (mostly canals) have increased by 116 and 147 points respectively during this period. Study of Table 1 indicates that out of the total annual recharge of 3950 mcm, 2607.4 mcm are being utilized. It will also be seen that we cannot depend upon the entire region to yield ground water of potable quality because sixty five per cent (65%) of the region is having ground water having total soluble salt (TSS) of over 3000 ppm.

Moreover, survey of Siwana, Ahore, Luni and Chohtan development block areas during the period 1962-67 has indicated that out of 8788 sq km area, nearly 4.79 and 13.1 per cent areas are over and sparsely exploited. The repeat observations of Luni development block area during the year 1976 has indicated that over exploited area within the block has changed to 76.8 per cent as compared with 6.2 per cent during the year 1966. Similarly, survey of Jodhpur district (1973-74) has indicated 2.8 per cent of the total area as over exploited within annual overdraft of 125 mcm Survey of Nagaur district (1976) has indicated 2.1 per cent area as over exploited.

The above stated estimates of the total reserves are, though tentative, but the trend of over exploitation clearly indicates that if the present rate of ground water mining continues, the situation may become critical within the coming few years.

MANAGEMENT OF GROUND WATER RESOURCES

In this region, the problem is to find water supplies for some places, and in other portions, the population must be protected against drought by way of planned utilization of available water resources. The best way is to tackle these problems depending on the conditions prevailing in a particular locality. However, planned resource utilization should get priority over search for new and untapped water resources for obvious reasons. One of the vital components of such a planned utilisation should be to regularly replanish the existing aquifers in the region by directing any excess surface or ground water which usually goes un-utilised and/or causes or likely to cause potential threat to the region.

(1) *Source of excess water*

There are three sources viz., (i) excess rain water, (ii) surplus river flood water, and (iii) excess ground water.

i) *The excess rain water*

The normal annual rainfall of western Rajasthan varies from 100 mm

Table 1. Ground water balance of western Rajasthan

District	Total area (sq km)	*Area having fresh water (percent)	*Area having saline water (percent)	*Annual recharge (mcm)	1975 Groundwater consumption (mcm)			Total	Difference
					Human population	Live-stock	Irrigation camps		
Barmer	29031	24.1	75.9	87	27.6	34.8	42	104.4	− 17.4
Bikaner	27102	19.6	80 4	314	21.0	14.8	23	58.8	+255.2
Churu	16261	19.3	80.7	80	32.5	53.0	1.4	~~8669.0~~ 86.9	− 6.9
Ganganagar	20384	5.0	95.0	538	82.4	20.4	1161	1263 8	−725.8
Jaisalmer	38475	30.7	69.3	910	6.0	15.9	0.4	23.3	+887.7
Jalore	10428	30.4	69.6	460	24 0	18 5	218	260.5	+199.5
Jhunjhunu	5648	96.3	3.7	222	34.1	12.9	43	90.0	+132.0
Jodhpur	22213	73.0	27.0	228	42.5	25.1	61	128.6	+ 99.2
Nagaur	17592	70 0	30.0	353	47.2	30.6	50	127.8	+225.2
Pali	11808	79.7	20.3	290	34.7	30.2	138	202.7	+ 87.3
Sikar	7658	95.7	4.3	285	38.0	20.3	98	156.3	+128.7
Sirohi	5127	ND	ND	183	15.1	10.2	80	105.3	+ 77.7
Total	211727	543.8	556.1	3950	405.1	286.7	1915.8	2607.4	+ 1342 6

*Based on the data provided by the Department of Ground water, Government of Rajasthan.

ND—Not determined.

Table 2. Water balance of the districts in western Rajasthan for surplus rainfall year expected once in 5 years

District	Total water received	Water used for cropping	Water used by forests	Water used by fallow and land not available for cultivation	Runoff	Total water used including runoff	Water available for recharge of aquifer	Water available for recharge of aquifer per sq km
Barmer	9545.600	3845.100	60.500	3048.6	234.92	7189.120	2356 480	0.08943
Jaisalmer	9014.350	161.000	76.500	7599.4	1.30	7838.200	1176.150	0.03046
Bikaner	7559.100	1470.000	39.500	4584.2	—	6093.700	1465.400	0.05387
Ganganagar	6506.900	4025.000	15.000	1838.0	—	5878.000	628.900	0.03035
Jodhpur	9374.800	3409.300	4.500	2594.0	134.64	6142.440	3232.360	0.14227
Nagaur	8880.100	3949.000	2.500	1308.4	26.93	5286.830	3593.270	0.20153
Churu	6780.200	3847.200	0.500	1123.4	—	4971.100	1809.100	0.10892
Jalore	7164.100	1963.800	9.000	1420.2	249.78	3642.780	3521.320	0.27661
Pali	7949.625	1929.900	308.500	1255.8	238.63	3732.830	4216.795	0.33979
Jhunjhunu	3270.700	1546.600	118.000	251.0	—	1915.600	1355.100	0.22929
Sikar	4664.100	1898.000	45.000	465.2	67.70	2476.400	2187.700	0.27904

All values are in million cubic metres.

in the N.W. sector of the Jaisalmer district to 600 mm in the south-eastern sector of Pali district. The general decreasing gradient is from S.E. to N.W. There is a considerable year to year variation and the value of coefficient of variation in respect to some portion of Jaisalmer district is 70 per cent or more. It has been observed that once in five years, the entire western Rajasthan can get more than 300 mm rains except for Jaisalmer district and western part of Bikaner and Ganganagar districts.

Out of the total annual precipitation over the region, 65.75 per cent is utilised for cropping, evaporation, deep drainage, etc., 1.91 per cent goes out as run-off and leaves behind 32.34 per cent, i.e., nearly 19000 mcm available for recharge. Out of the total precipitation utilised for cropping, only 10.1 per cent goes to the aquifers as natural recharge. However, every five years, there are possibilities of receiving rainfall of over 500 mm and during such periods, 22,000 mcm extra water would be available for artificial recharge (Table 2).

ii) *Surplus river flood water*

This region does not have many major rivers except river Luni and Jawai which flows in the S.E. part of the region. Out of 953.90 mcm run-off (Table 2) during normal rainfall from this region, only 44.56 per cent is being harnessed and utilized. The rest is available for adopting recharge activities.

iii) *Excess ground water*

Due to the introduction of the canal irrigation in sandy terrain of Jaisalmer and Ganganagar districts, the static ground water level is rising at an alarming rate. In the absence of adequate information, an approximate estimate of the water added to the groundwater storage under the various canal system is presented in Table 3. Apprisal of which could indicate, that, 784,080 mcm water has been already added to the aquifers, out of which, 196020 mcm can be recovered every year.

Table 3. Excess ground water resources

Canal system	Year of start	Command area (sq mile)	Average rise in ground water table (m/year)	Annual increase in ground water storage per year/ sq km (mcm)	Total water added to aquifer since start (mcm)	Annual recoverable ground water (mcm)
Gang canal	1927	55730	0.304	14.7	378231.00	94557.75
Rajasthan canal	1961	22590	1.5	1.25	31987.50	7996.87
Bhakra canal	1954	2690	1.5	13.5	373815.00	93453.75
Ghaggar flood water irrigation	1926-27	712.7	0.6	3.6	45.72	11.43
Total		7,9,022.7			7,84,079.22	1,96,019.80

In the Ganga canal area, the present static water level is at a depth of 20-27 metres b.g.l. Similarly, under the Rajasthan canal area, it is at a depth of 34 metres b.g.l. If six metre depth is considered as a critical limit, the acute problem of drainage can take place within 50 years or more, if the rate of rise in static, water level continues. Moreover scattered occurrences of parched water table have also developed as a result the lands becoming saline. To avoid this situation of drainage and development of salinity, it will be desirable to lower the static water level by mining it.

From the above discussion, it is very apparent that considerable excess water sources are available within this region which could be utilised for replenishing the aquifers for continued utilisation of ground water resources of this region and their rational management.

2) *Potential aquifers*

Water potentials of the aquifer are dependent on various natural parameters. Detailed knowledge of these for all of the aquifers known or yet to be discovered is lacking. However, the investigation reports available from the various organisations were critically analysed and the aquifers which are capable to receive recharge have been identified and classified into seven groups (Table 4).

3) *Methods of recharge*

Based on the various pre-requisites for adopting artificial recharge, the possible methods for the various aquifers of this region have been indicated in Table 4. To summarise in the region adjoining the source of surplus water, the flooding technique is considered to be the method of choice, whereas, in remote areas, digging of pits, trenches, injection wells, etc. could yield better results. Nevertheless, in order to make the maximum use of underground space, it may be necessary to lower the water level deliberately during the dry period to create space for fresh water to enter the storage during the period of availability.

However, before adopting any artificial recharge project, a systematic and detailed hydrogeological investigation for the particular area is of paramount importance. Such investigation should be undertaken on catchment basis rather than on the district basis. So, also to undertake pilot project to investigate the feasibility and relative economics of the various possible artificial recharge methods suitable for the particular area.

CONCLUSION

Adopting artificial recharge method will ensure a regular ground water supply over a prolonged period, check the gradual salinisation of ground water, minimise chances of land subsidence, salt water intrusion, over exploitation, reduced water depth, avert drought condition, etc. We need to draw inferences from the experiences gained in other countries which are at present investing huge amount of money in order to make good of the folly of excess ground water utilisation during drought period.

Table 4. Potential aquifers of western Rajasthan

Nature of aquifers	Location	Approximate area covered (sq km)	Present static water level (metre b.g.l.)	Natural recharge direction	Possible artificial recharge methods	Source of surplus water
Wind blown sand with younger alluvium	Narsa, Sun-ki-Dhani, Savar in Churu district.	193.143	30	N.E.	Flooding.	Rain water
Older alluvium	Sriganganagar, Tarapur, Rajgarh, Rawra, Balotra, Jalore, Jaisalmer, Pal-Zanwar-Doli, etc.	9505.134	Between 20 to>30	N.E. and West	Injection well and trenching, pitting, flooding.	Ground water
Vindhyan sandstone (fine to medium grained)	Balesar-Shergarh, Phalodi, Teori, Mathania, Nokha, Bikaner.	3597.01	20 to 30	N.E.	Flooding, trenching and pitting.	Rain water
Vindhyan sandstone (medium coarse grained)	Nagaur, Jodhpur and Churu districts.	2183.37	20 to 30	East and N.E.	Flooding and pitting.	Rain water
Limestone	Pinasar, Rol, Mundwa, Borunda, Khari, etc.	1369.97	<20	N.E. and East	Trenching and pitting.	Rain water
Tertiary sandstone (Lathi sandstone, Palana sandstone, Barmer sandstone)	Jaisalmer, Barmer, Palana & Bikaner.	4861.89	20 to 30	N.E. and South	Flooding.	Rain water
Quartzite (Delhi system)	Nagaur and Pali districts.	1400.61	20 to 30	East	Trenching, pitting and flooding.	Surface runoff
Malini-Volcanics and Granite.	Nagaur, Jalore, Barmer.	1837.41	<20	East	Flooding, trenching and pitting.	Rain water and surface runoff

In view of the considerable disadvantages, inherent in the enthusiastic over exploitation of water resources, especially in the arid and semi-arid regions, it is essential that immediate measures are taken to formulate a rational plan for efficient utilisation of such resources. It is hardly necessary to emphasise that such a plan should be operative before we reach a point of no return.

As stated earlier, already, several proved potential aquifers in the Luni basin, Jodhpur and Nagaur districts are showing the signs of over exploitation. Also, many of the aquifers like Rampura--Mathania, Pal--Janwar--Doli, Shergarh and alluvial aquifers of Sikar and Jhunjhunu districts, etc. have also started showing a declining trend of static water level. To avert such conditions, these areas should be given top priority for adopting artificial recharge to augment the depleting ground water resources.

I. 3.11

SIGNIFICANCE OF THEMATIC MAPPING FOR ENVIRONMENTAL ANALYSIS IN ARID ZONE

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INTRODUCTION

Significance of thematic mapping: classification

Regionwise distribution and the pattern of the resources can be well assessed if the existing information and available data are presented in the form of maps. Accordingly, thematic mappings on various aspects of arid zone problems are being undertaken by the Cartography section of C.A.Z.R.I. on the basis of the available information. Thematic generalisation technique is a problem of scientific classification and are of three fundamental types: quantitative, taxonomic and geographical or regional (Das Gupta, 1972).

Correct generalization can only be achieved with adequate data. If sufficient data are available they can be compiled and medium scale maps can be prepared which depict the actual distributional pattern of the resources and pinpoint the problem areas which need immediate attention for further investigations and developmental planning. The problems can be well visualised if the maps prepared are presented in the form of atlases.

The need for preparing such thematic maps and atlases for Indian Arid zone, was realised soon after the inception of Basic Resources and Human Factor Studies now being conducted by Central Arid Zone Research Institute, Jodhpur. So far four such atlases have been prepared: Agricultural Atlas of Rajasthan (1:2 million); Sheep Ecology of Rajasthan (1:2.5 million); Ground Water Atlas of Rajasthan (1:2 million); Agro-demographic Atlas of Rajasthan (1:2 million). Besides, the cartographic work on the compilation of Resources Atlases of N. W. Arid Zone of India (1:1 million) is also in progress. The significant value of some of the maps and atlases cartographed so far to pinpoint problem areas and evaluating resources are described next.

The information for mapping were collected from various published and unpublished official reports and statistical data. The data thus collected are hardly uniform and are of varied nature. These are compiled in the cartographic laboratory to make them mappable on uniform scale. Informations are also collected from large scale topographical sheets and aerial photographs.

Thus, a compromise of the three general types of thematic mapping--quantitative, taxonomic and geographic or regional are made to make the maps suitable for utility purposes.

AGRICULTURAL ATLAS OF RAJASTHAN

This atlas was published (Sen, 1972) by the Indian Council of Agricultural Research and contains 34 plates (1:2 million scale) representing mainly the agricultural problems of the state. 16 plates are of quantitative types. Five belongs to geographic or regional types. These are: crop belts; city regions; settlement pattern; agro-climatic regions and geographical regions. The rest are of taxonomic types. The atlas endeavours not only to portray the agricultural situation as at present prevailing in Rajasthan but also fill up some gaps in our knowledge regarding the future possibilities of a planned reorganisation of the agricultural front in the State.

This atlas incorporates vital information that have been collected so far on the physical and the biological and socio-economic aspects of tract which has led us to start the project on the compilation of the agro-demographic atlas of the Indian desert. Finally, the atlas admirably pinpoints the areas where there is an urgent need for the survey of the basic resources. Thus the atlas helped us to initiate the project on the terrain analysis and creep of the Indian desert and selection of the areas of integrated surveys.

GROUND-WATER ATLAS OF RAJASTHAN

The Cartographic work on the compilation of ground water Atlas of Rajasthan has been completed and the manuscript is ready for publication. Thirty maps were prepared on 1:2 million scale for the atlas. These are: (1) Factors affecting ground water (6 maps quantitative), Ground water potentials (9 maps geography), Ground water quality (9 maps quantitative) and taxonomic, Ground water utilization (6 maps).

The maps cartographed and the atlas in general, analyse in a fairly comprehensive manner the exploration, utilization and quality of ground water in different districts of Rajasthan with special reference to arid zone. A brief analysis of the maps prepared are given below:

In arid zone 1127.75 mcm or 47.78 per cent of the total exploitable potential is tapped leaving 1232.58 mcm or 52.22 per cent as surplus. In the sub-humid zone, which has four districts, 65.10%, (898.56 mcm) of the total exploitable ground water potential is tapped–the surplus being 34.90% or 481.63 mcm. In humid zone (4 districts) exploitable ground water potential and water potential tapped is the lowest-where only 33.93% (404.35 mcm) of the total exploitable ground water potential (1191.45 mcm) is utilized. Whereas in Rajasthan only 58.53% of the total ground water potential (8109.63 mcm) has only been tapped showing that most of the waters in arid zone, where it is mostly needed are yet to be exploited. Further, the quality of ground water in Rajasthan deteriorates along with the decrease of rainfall and in arid zone it is poor. It has been evident that the total dissolved salts in ground waters in arid zone, generally ranged from 180 to 7000 ppm. About 87 per cent of the total ground water exploited is utilized for irrigation in Rajasthan, about 13% for drinking, livestock, and other purposes. The utilization of exploited ground water for irrigation accounts for about 78, 90, 88 and 84 per cent in arid, semi-arid; sub-humid and humid zones respectively. In Rajasthan about 53% of the irrigated area is served by ground water. The figures account for 30, 73, 65 and 41 per cent respectively in arid; semi-arid; sub-humid and humid zones. But, in arid zone more than 99% of the total irrigated area in all the districts, except Ganganagar, is served by ground water (well) (Sen and Mann, 1976).

AGRO-DEMOGRAPHIC ATLAS OF RAJASTHAN

In all 30 maps have been prepared on 1:2 million scale to work out the levels of Agro and rural economic development and agro-demographic regions.

Sen and Gupta (1976) worked out some agro-demographic features in different agro-climatic regions of Rajasthan that have emerged in course of compiling the population maps (1:2 million) of the state. The rural population with percentage, density and decennial growth rate during the last census decade (1961-71) occupational pattern, agricultural population, per capita agricultural land, agricultural land per cultivator and pressure on land; production of cereals and pulses per cultivator; per capita production of staple food crops, per capita requirements of foods in different macro agro-climatic regions are cartographed in a series of 1:2 million maps.

On the basis of this map an attempt has been made to classify the surplus and deficit districts in relation to local supply of staple food crops (cereals and pulses). Considering different age groups and male-female composition of population it has been estimated that minimum per capita requirements of cereals and pulses in Rajasthan is 215 kg in a year. The districts of Churu, Bikaner, Jaisalmer and Jodhpur in the arid zone; Pali in the transitional zone; Jaipur and Ajmer in the semi-arid zone and Sirohi in the sub-humid zone form a compact group in deficit zone. Ganganagar of the arid zone in the north stands out as the granary of Rajasthan and forms a pocket showing a surplus zone. Three groups of districts, one formed by Alwar and Bharatpur of the semi-arid zone in the north-east; the second by Bundi and Chittorgarh of the sub-humid zone, all the four districts of the humid zone and Tonk of the semi-arid zone and the third by Jalore district of the transitional (arid-semi-arid) zone also belong to the surplus zone. The rest of the districts have per capita production between 215 kg to 265 kg and from the transitional zone between surplus and deficit zones.

The levels of rural and agro-economic development of the different districts of agro-climatic regions in Rajasthan state have been worked out on the basis of the efficiency of rural occupational structure and rural production. Both these aspects of development are in turn susceptible of further analysis. Accordingly fourteen indicators are selected for deducting a synthetic index to work out and map the rural economic and agro-demographic development. These consist of four *structural indicators* relating to rural population; eight *occupational indicators* relating to rural working population and rural economy and two *productivity indicators* relating to per capita production of food crops.

Following levels of rural and agro-economic development are identified and mapped (Sen & Gupta 1978).

Levels of agro-economic development	Synthetic index or score	Number of districts included	Total area (km^2 and %)
Very poor	Below 3o	*One* Bikaner (arid)	27231 (7.95%)
Poor to very poor	30-40	*Ten* Churu; Jodhpur, Jaisalmer (arid), Jhunjhunu; Sikar; (transitional-between arid and semi-arid) Ajmer, Jaipur, Alwar (Semi-arid—arid), Sirohi (sub-humid), Banswara (humid)	132784 (38.80%)
Moderately poor to poor	40-50	*Eleven* Barmer, Ganganagar, Nagaur (arid), Pali, Jalore, (transitional), Sawai-madhopur, Bharatpur, Tonk (semi-arid), Udaipur (sub-humid), Kota (humid), Dungarpur	149125 (43.57%)
Moderately developed	50-57 Max-55.69	*Four* Bhilwara (semi-arid), Bundi, Jhalawar (humid), Chittorgarh (sub-humid)	33074

Three agrodemographic regions on the basis of synthetic index are recognised and mapped (Map 1).

Region I (lowest order of development 550).

The region includes 11 districts comprising 46.75% of the total area of the state. This occurs in a belt from Jaisalmer and Jodhpur in the west to Alwar in the north-east and Ajmer in the south. This belt includes 10 districts–mostly the arid zone except Jaipur, Ajmer and Alwar of semi-arid zone in the east. Sirohi and Barmer form two isolated pockets in this group.

Region II (second order of development 550 to 700).

Three belts one in the east (4 districts) along the Chambal; other in the south west comprising Dungarpur, Udaipur, Nagaur, Pali, Jalore and Barmer and the other in the extreme north (Ganganagar) are distinguished–total area is 149125 sq km or 43.57% of the total area (in all 11 districts).

Region III

This comprises 4 districts (33,074 sq km or 9.68%) in the south-east in humid to sub-humid climate (except Bhilwara which is semi-arid). This is the region of third order of development, synthetic score being 700.1 to 780.

EXPANSION AND DETERIORATION OF THE INDIAN DESERT

An attempt has been made (Sen and Mann, 1977) to examine the creep and deterioration of Indian desert on the basis of some physiographic and topographic parameters. The extent of the Great Indian Desert and its geographic limits have been defined. The Indian desert has been identified as a true desert. The creep of the desert has then been considered in relation to the increase and decrease of desertic sand-the extent of sand dunes-water table and climatic phenomenon-drainage system and soil. The study of the maps reveal:

(i) Fresh sand deposition is still going on in the desert.

(ii) The general trend of the increase is towards the N.W. in Punjab, and Haryana and also in the Jodhpur district of Rajasthan.

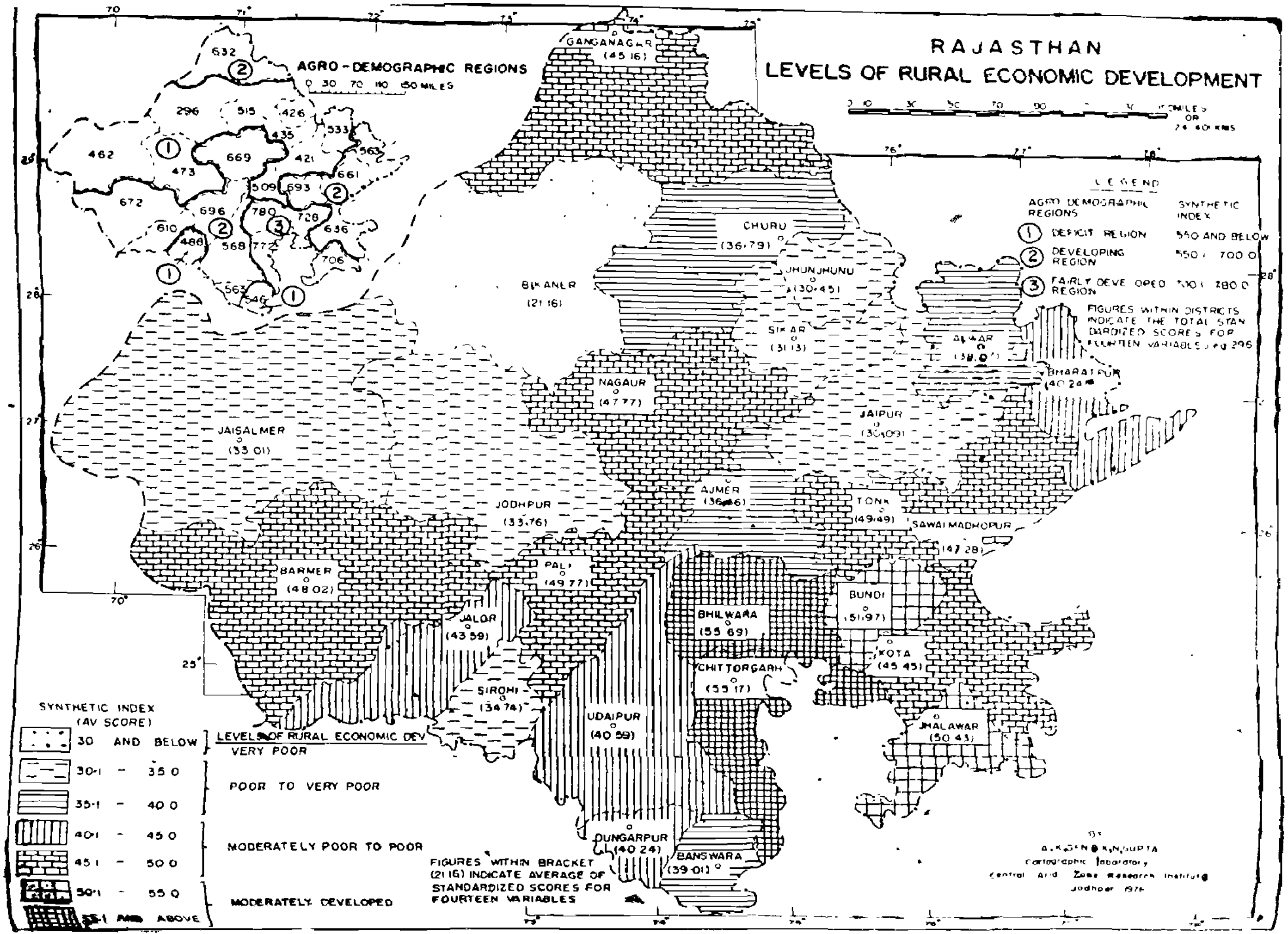
(iii) The creep of the desert is strong towards the west, i.e. in the desert itself than in the semi-arid districts.

(iv) Decrease of desert sand in an area is closely associated with an area of increased sand nearby causing deterioration of fertile lands.

(v) The effectiveness of the gaps along the Aravallis as a passage for the penetration of wind blown sand towards the east cannot be accepted as a conclusive proof of the advancement of the desert towards the east.

CONCLUSION

It is evident that the thematic maps depict a fairly complete physical and socio-economic character of the region. The maps thus are helpful to analyse the complete environmental or ecological-both biotic and abiotic-conditions of Indian desert. The significant value of the maps cartographed are accordingly-(i) they



RAJASTHAN
LEVELS OF RURAL ECONOMIC DEVELOPMENT

are helpful to delineate planning regions and regional pattern of resources, (ii) depicts regional characters and levels of economic and social developments in context of the development plans to be undertaken, (iii) bring out the problems of the desert and (iv) pinpoint the problem areas which need immediate attention. These are described in the text.

On the basis of the findings from the atlases prepared so far it is proposed that the programme of thematic cartography of arid zone problems will be intensified in the next five years.

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I. 3.13

GEOMORPHIC SIGNIFICANCE IN THE ENVIRONMENTAL PROBLEMS OF THE RAJASTHAN DESERT, INDIA

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Geomorphology being one of the vital element of the environment plays a significant role in the assessment of the physical potentials of the land and also to identify and pinpoint the environmental problems, related to landforms. Accordingly, researches on various geomorphological aspects of the Rajasthan desert have been conducted during the last seventeen years. The research findings of the geomorphological investigations carried out by the Central Arid Zone Research Institute, Jodhpur, have been compiled in a monograph (Singh, 1977) and are briefly discussed in this paper.

EVOLUTION AND GEOMORPHIC CHARACTERISTICS OF LANDFORMS

The present landforms of this region have resulted during quaternary period due to the fluvial and aeolian processes, under different climatic phases. In the Rajasthan desert, fourteen landform units viz., hills, rocky/gravelly pediments, flat buried pediments, sandy undulating buried pediments, piedmont plains, flat aggraded older alluvial plains, saline flat aggraded older alluvial plains, sandy undulating aggraded older alluvial plains, sand dunes, flat interdunal plains, sandy undulating interdunal plains, saline depressions, graded river beds and younger alluvial plains have been identified. The flat aggraded older alluvial and interdunal plains are quite extensive and are characterised by slope less than 1°, shallow to very deep alluvial sediments underlain by *kankar* pan, truncated and obliterated drainage channels and sediment particles of 0.06 to 0.59 mm diameter. These two units have good potentials for growing rainfed crops. Younger alluvial plains and flat buried pediments are nearly level with less than 1° slope and free from erosional hazards, the *kankar* pan is absent and the depth of the sediments varies from 3 to 15 m. These units and some parts of the flat aggraded older alluvial plains have good agricultural potentials for the irrigated crops due to the availability of groundwater at 10 to 25 m depth. The rocky/gravelly pediments lie at the base of the isolated hills which are often chracterised as inselberg are characterised by 1° to 2° slope, skeletal soils and dendritic and radial drainage patterns. These two units and some parts of flat aggraded older alluvial and interdunal plains underlain by hard *kankar* pan, can be developed into good desert catchments. Sandy undulating aggraded older alluvial and interdunal plains, piedmont plains and sandy undulating buried pediments are covered with sand sheets, hummocks and low dunes of 1 to 10 m and even 40 m height. The slopes of these plains are irregular varying from 1° to 3° and they are affected by severe to very complex erosional hazards. These units are suitable for good grasslands. The sand dunes of different types are suitable for grasslands and woodlands. The saline depressions are almost level, highly saline and unfit for cultivation. These are often suitable for extracting salts and evaporites.

GEOMORPHOLOGY AND ENVIRONMENTAL PROBLEMS

The landform units identified in this region are affected by different types of geomorphic problems like the erosional, depositional and salinity hazards; sand dunes and dearth of water.

(a) *Erosional depositional and salinity hazards*

The erosional, depositional and salinity hazards created by the geomorphic processes and/or accelerated by the human activities, are the major factors which limit the agricultural production in the Rajasthan desert. Such studies have so far been conducted in the Central Luni basin, Jodhpur and Bikaner districts and in parts of Nagaur district. Erosional, depositional and salinity hazards have resulted due to the interaction between man, land, water and wind. In all 10,190 sq km area has been affected in the Central Luni basin by these problems.

Salinity hazards

The salinity of soil is one of the major hazards affecting the agricultural production of the arid lands. It has now been evident that geomorphology plays a major role in the origin and distribution of soil salinity in the Raiasthan desert (Ghose and Singh, 1968). It has been proved that there are two types of salinity in the Rajasthan desert 'natural' and 'man-induced', and both the types are linked with the buried courses of the prior drainage channels (Ghose *et al.,* 1975).

The natural salinity in the Ranns and other saline depressions has developed due to the leaching of salts of different solubility downstream during past humid phases and their precipitation according to solubility, at the confluences and along the lower reaches of the prior drainage channels. Such salinity is of severe to very severe intensity at the Ranns of Thob, Pachpadra. Sanwarla, etc., while severe salinity is along the prior course of the Agaria Nala. The total area affected by natural salinity hazard is 348.6 sq km.

The man-induced salinity is a recent phenomena because of the construction of tanks and canals along the courses of the prior drainage channels. The construction of these irrigation network resulted into surface and subsurface water logging and rise of subsurface salts through evaporation and capillary action. A total of 613.5 sq km area of the basin is affected by this salinity hazard.

(b) *Sand dunes and related problems*

In the western Rajasthan, there are two major zones of sand dunes viz., eastern and western and they cover 58% area of this region. These dunes are also one of the major problems of the desert.

Types, origin and morphology of sand dunes

In the areas surveyed, six types of sand dunes have been identified which belong to the obstacle and free dune families. The major and minor (shrub-coppice) sand dunes which are formed by the topographical obstructions, belong to the family of the obstacle dunes. The common dune types such as parabolic, longitudinal, transverse and barchan, are originated by the winds without any influence of topographical obstruction and they belong to the free dune family. The major and minor obstacle dune are of 8 to 40 m and 90 cm to 5 m heights respectively. They do not have any definite orientation. The size of sand grains varies from 0.03 to 0.25 mm but the sand grains of 0.03 to 0.12 mm diameter are dominant. The sand dunes of free dune family are of 5 to 15 m and 10 to 80 m in height and the slopes of the leeward, windward and flanks vary from 15° to 22°, 8° to 14 and 2° to 4° respectively. The orientations of the parabolic, longitudinal and barchan dunes vary from N 40° E to N 48° E and the orientation of the transverse dunes ranges between N 48° W to N 52° W. The size of the sand grains in these dunes varies from 0.03 to 0.25 mm but the sand grains of 0.03 to 0.12 mm diameter are more dominant. The average diameter of the sand grains in these dunes ranges between 0.11 to 0.14 mm which is much below the average diameter of 0.3 mm for aeolian sands, reported by Bagnold (1941) for Libyan desert.

It may be concluded that the orientation of almost all the types of the sand dunes except transverse ones correspond to the directions of the southwest prevailing winds.

Sand dune systems

The studies on the dynamics of the

sand dunes revealed that there are two dune systems viz; old and new.

The dunes of old system are obstacle, parabolic, longitudinal and transverse. They are formed by intensive dune building activities during a prolonged arid climate phase. These dunes are of high relief, well stabilized, vegetated and have lime concretionary layers within them. The percentage of $CaCO_3$ varies from 3% to 10% in these dunes. Finger type lime nodules of 8 to 10 cm length and 2 to 3 cm width are exposed along their flanks, leeward and windward sides. The presence of tree vegetation like the *Acacia senegal* (20-40/ha), *Prosopis cineraria* (10-30/ha) indicate that the dunes are highly stabilized and do not need any plantation to ensure their stability, if they are protected from biotic interference.

The sand dunes of new system are of recent origin due to the renewed aeolian activities and are still in developing stage. The sands are loose, non-calcareous and have only 1 to 2% $CaCO_3$. Dunes of this system are the greatest menace to soil erosion affecting the agricultural fields, settlements, roads and railway tracks. If these are stabilized, the desert area will be protected from the danger of shifting sand, which provides favourable conditions for stabilization of these dunes. These sand dunes could be stabilised by planting locally adapted indigenous plant species like *Calligonum polygonoides, Zizyphus nummularia, Capparis decidua* and *Acacia senegal* (Saxena and Singh, 1976).

(c) *Dearth of water*

Rajasthan desert, due to low and erratic rainfall, high evaporation has very low water potential. Geomorphic researches are being carried out for locating, harvesting and exploring the surface and groundwater.

Location and evaluation of surface water resources in different landforms

Analysis of the morphometric characteristics of the small agricultural drainage basins in the Luni-Jawai and the Banas drainage systems. has revealed that drainage basins under different geomorphological settings have different surface water potentials. The drainage basins of phyllite-schist and rhyolite pediments have better surface water potentials than that of granite pediment and sandy aggraded older alluvial plain. The surface run off from these drainage basins could be harvested at suitable sites after calculating water yield, construction cost of dams and detailed contour survey. The mathematical models by establishing paired and multiple relationships between/among the morphometric characteristics of the drainage basins in different landforms (Singh and Ghose, 1973; Singh *et al.*, 1976).

From the study in the sandstone region of Jodhpur district (Singh and Sharma, 1979), it has been concluded that the mean annual runoff from the drainage basins is geomorphologically related to total basin area, total stream length, drainage density and first order stream frequency. These relationships, therefore, could be used to evaluate and predict the hydrologic and/or geomorphic characteristics of the new drainage basins of this region.

Location and evaluation of ground water potential zones in different landforms

Photogeomorphological studies in the different parts of the Rajasthan desert revealed the relics of the prior well integrated drainage systems which are at present disorganised and buried under the alluvial and aeolian sediments. These sediments are the good accumulators of groundwater and water here generally occurs at a depth of 5 to 25 m. In the central Luni basin, the alluvial material along the prior drainage channels acts as an aquifer and the depth of the water bearing riverine gravelly sand varies from 10 to 20 m. Groundwater along the prior drainage channels is mainly available in the flat aggraded older alluvial plains and flat and sandy undulating interdunal plains.

It is thus clear that the geomorphology plays a significant role in the location of the potential groundwater zones and desert catchments for harvesting surface water resources.

Palaeoclimate and desert spread

The investigations on the different geomorphic aspects of the Rajasthan desert have revealed that four sets of fluvial and aeolian landform features have superimposed on each other and they bear the imprints of the past climates, no longer operative at present.

There is a general apprehension that the Indian desert is spreading towards north and northwest but ths geomorphological investigations on the Rajasthan desert revealed that there is no evidence of desert spread beyond the existing desert boundary. Within the desert boundary, there are also two distinct zones of aeolian and fluvial activities. To the west of 300 mm isohyet, the aeolian activities are intense, reactivating and degrading the stabilised dunes and creating new active dunes. But to the east of 300 mm isohyet, the fluvial activities are more vigorous which have dissected the old existing landforms. All these recent morphological changes suggest that there is a small scale climatic amelioration in the recent period (Ghose *et al.,* 1977).

However, the over exploitation of the natural resources by man have set free retinue of hazards within the desert and have thus accentuated the desertic conditions.

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I. 3.14

SAND MOVEMENT STUDIES UNDER DIFFERENT LAND USE CONDITIONS OF WESTERN RAJASTHAN

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Though it is known that phenomena of sand movement and shifting dunes is operative over large parts of the arid zone, hardly any information is available on the quantum of this movement under different land use conditions and the effect that it has on nutrient loss. Therefore, the present study was undertaken at two places namely Beechwal and Udairamsar in Bikaner district of the western Rajasthan. At the former, three sites were chosen. These were: (a) bare sandy plain comprising of 4 hectare piece of land, (b) a 18-20 years old protected area dominated by grasses *Lasiurus sindicus, Cenchrus biflorus, Panicum turgidum* and (c) a sandy plain with a 10-15 cm high *bajra* stubble cover. At Udairamsar, the sites were: (a) bare unstabilised sand dunes and (b) stabilised sand dunes with grass and tree cover comprising *Prosopis juliflora, Calligonun polygonoides, Acacia tortilis, Leptadenia spartium* and *Crotalaria burhia.* The stabilised dune at Udairamsar was surrounded by an area with bare rolling sand dunes.

Measurement techniques

Sand movement was monitored by installing 25 iron pegs (100 cm×0.8 cm) at each of the above sites. They were installed in such a way that they formed a square with each peg at a distance of 6 metres from the other. Out of the total length, 40 cm of each peg was kept below-ground and the 60 cm above the ground level. This level was considered as a reference point. Sand deposition or removal was measured from the reference point with a scale. Sand samples upto 10 cm depth were collected before the start and after the end of the study for determining sand size distribution and the nutrient status.

Sand movement from a sandy Plain

Data presented in Table 1 show that from a bare sandy plain there was continuous increase in the removal of sand while both removal and deposition of sand was observed from grass cover and *bajra* stubble cover during the period of observation. Cumulative sand removal from bare sandy plain was 9.66 cm while it was only 0.17 cm from *bajra* stubble cover and no removal but deposition of 0.09 cm on grass cover during the 75 days period beginning from April to the end of June, 1977. From bare sandy plain the increase in depletion rate of sand with time can be explained with the increase in wind velocity. As there was no surface cover and the soil moisture status in top 30 cm depth was less than 1%, so there was no obstruction to the movement of sand. Working on wind erosion in southern Scania, Ahman (1975) reported a loss of 10--15 cm of surface soil in Vomb valley. Borsy (1975) observed a loss of 550 kg/m^2 in a period of 10 hours from a wind blown area in Hungary.

Table 1. Sand movement under different land use conditions

Treat-ments	Removal or deposition of sand (cm)					Total removal/ deposition (cm)
	5.4.77-20.4.77	21.4.77-9.5.77	10.5.77-25.5.77	26.5.77-9.6.77	10.6.77-24.6.77	
Beechwal						
i) Bare sandy plain	*−1.18	−1.47	−1.73	−2.37	−2.91	−9.66
ii) Grass cover	−0.04	+0.07	−0.16	+0.13	+0.09	+0.09
iii) *Bajra* stubble cover	**+0.22	−0.20	−0.16	−0.13	+0.10	−0.17

* − indicates sand removal.

** + indicates sand deposition.

The use of *bajra* stubble as surface cover was found very effective in reducing the movement of sand (Table 1). With stubble cover of 10-15 cm height and stubble to stubble distance of 15 cm, as much as 88% reduction in the movement of sand was observed. While working on the use of plant residues in checking sand flow, Bisal (1968) pointed out that the sand flow approaches zero at stubble rates ranging from 1200 kg/ha for a wind velocity of 5.36 m/sec to 7200 kg/ha for a wind velocity of 8.49 m/sec. Sinha (1970) also reported the suitability of stubble in checking wind erosion. He further pointed out that stubbles of 30 cm height were more useful than 15 cm height. Their effect on reducing the movement of sand is probably due to their action as barrier to the movement of sand--and also the binding of sand as a result of stubble roots.

There was no depletion but deposition of sand under grass cover. This was probably because of the binding of sand particles with grass roots, formation of surface crust and the reduction in wind velocity by the grass cover. In the present case surface crust formed with the combined action of silt plus clay and humus had crust strength of 1.5-2.0 kg/cm^2 and thus it was responsible for giving resistance to the wind action.

It has also been reported by Caldwell and Ellis (1936) that there exists a high correlation between the combined action of clay and alkali soluble humus and the size of water stable aggregates, and concluded that humus and clay are responsible for increasing the resistance of some soils to wind action. The deposition of sand in the present case might be because of reduction in the speed of wind carrying the finer fractions of sand over grass cover.

Sand size distribution in relation to its movement

Sand size distribution of an area and its understanding plays an important role in determining its erodibility or resistivity of wind action. Chepil (1943), reported that highly erosive soil grains vary in size approximately between 0.05 and 0.5 mm in diameter whereas the difficult erosive fraction vary between 0.02 and 0.05 mm and 0.5 and 1 mm in diameter. Sizes above 1 mm and below 0.02 mm were found to be non-erosive or some of them erosive only at an unusually high velocity of natural wind. Knottnerus and Peerl Kamp (1973) found that a soil consisting of loose sand particles of 100-500 mμ is highly susceptible to wind erosion.

In the present studies the sand soils dominated by erodible fractions (0.25-0.05 mm), poor in organic matter (0.03%) without any soil structure, therefore, were highly susceptible to wind erosion. The results (Table 2) showed an increase from the initial level in the percentage of grains > 0.25 mm and decrease of erodible grains of 0.25-0.05 mm and < 0.05 mm size under both bare sandy plain and stubble cover conditions. However, the magnitude of increase of coarser particles > 0.25 mm and decrease of finer fractions < 0.25 mm was higher under bare sandy plain condition compared to stubble cover condition. This shows higher rate of erosion of finer fractions of sand from bare sandy plain compared to stubble cover causing thereby an increase in percentage of coarser fractions. This also shows usefulness of stubble cover in checking the erosion of finer fractions. From this, it can be inferred that depletion of soil from bare sandy plain and stubble cover is mostly associated with the removal of finer fractions of sand less than 0.25 mm. Lyles (1975) also reported that during wind action finer particles like silt and clay are removed first leaving coarser sand and gravel behind. No significant change was observed in the initial and final grain size distribution of sand under grass cover. However, some increase in percentage of grain < 0.05 mm was noticed because of the deposition of these fractions over the sand under grass cover.

Table 2. Grain size distribution (%) of sand under different land use conditions

Treatments	Stage of sampling	% sand grains > 0.25 mm	0.25 – 0.05 mm	< 0.05 mm
Bare sand plain	Initial	16.10	73.98	9.55
	Final	37.71	56.53	5.23
Grass cover	Initial	9.25	74.03	16.13
	Final	9.66	73.66	7.33
Bajra stubble cover	Initial	14.31	75.71	9.35
	Final	20.99	69.70	8.65

Nutrients removal/addition in relation to sand movement

Wind erosion not only causes the removal of finer fractions associated with favourable hydro-physical environment of a soil but also the nutrients thereby making the soil infertile and unproductive. Table 3 shows the depletion of organic matter, nitrogen (total and mineral), total phosphorus and total potassium from bare sandy plain and stubble cover while addition of these nutrients has been observed in soil under grass cover because of sand deposition. The depletion of nutrients from bare sandy plain has been found much higher as compared to *bajra* stubble cover because the amount of sand removed from the former was higher than latter treatment. *Bajra* stubble cover was found useful in reducing the depletion of organic matter from 724 to 38 kg/ha, total nitrogen from 116 to 2 kg/ha, total phosphorus from 232 to 4 kg/ha and total potassium from 2159 to 35 kg/ha. This clearly shows the usefulness of surface covers in conserving soil and the nutrients associated with it. Daniel and Langham (1936) pointed out that loss of plant nutrients and organic matter and changes in soil texture resulting from wind erosion considerably lower the productivity of soil. Thompson (1957) reported a loss of 24.2 lbs of available nitrogen, 10.6 lbs of available phosphorus and 141.1 lbs/acre of available potassium annually by wind erosion. In the present studies, however, the loss of nutrients from the bare sandy plain seems to be higher, because of greater movement of finer fractions which are rich in nutrients.

Table 3. Nutrients depletion/addition as effected by sand movement under different land use conditions

Treatment	Nutrients (kg/ha)					
	Sand depletion/ addition (t/ha)	Organic matter	Total nitrogen	Mineral nitrogen (NO_3+NH_1)	Total phosphorus (P)	Total potassium (K)
Beechwal						
Bare sandy plain	*−1449.0	−724.5	−115.9	−44.9	−231.8	−2159
Grass	**+ 13.5	+ 33.8	+ 1.62	+ 0.4	+ 2.7	+ 22.4
Bajra stubble	− 22.5	− 38.3	− 2.25	− 0.7	− 3.8	− 34.9
Udairamsar						
Bare unstabilised sand dune	−5560.5	−2780	−333.6	−166.8	−1000.8	+6282.8
Stabilised sand dune	+ 151.5	+2121	+227.3	+ 30.3	+ 333.3	+1818

* − indicates depletion.
** + indicates deposition.

Sand movement from a typical sand dune

Fig. 1 shows the depletion of sand from a typical unstabilised sand dune and its deposition on the stabilised sand dune. Cumulative depletion rate from an unstabilised sand dune was found to increase with time upto 60 days after the start of observation beyond which it tended towards constancy. This was because of increase in wind velocity and its free action on loose sand of the sand dune. Decrease in depletion during the later period was probably because of decrease in wind velocity and increase in moisture status of the exposed portion of the dune. During 45 days period top 30 cm of the dune sand was removed and the exposed portion had 2-3% moisture. This increase in moisture status of dune from less than 1% to 2-3% was probably responsible for decrease in depletion rate. Bisal and Hsich (1966) while working in East Yorkshire reported that moisture contents of 4, 4.1 and 11.8% prevented erosion of particles < 0.84 mm in fine sandy loam, loam and clay respectively. In the present studies, cumulative depletion from a bare sand dune during 75 days period was as high as 37 cm while it was only 10 cm from a semi consolidated bare sandy plain surrounded by grass vegetation. Cumulative deposition on a stabilised dune at Udairamsar was also found to increase slowly with slow increase in average wind velocity. However, during 45-60 days period when the average wind velocity was maximum (16-18 km/h), there was sharp increase in deposition rate beyond which again slow rate was

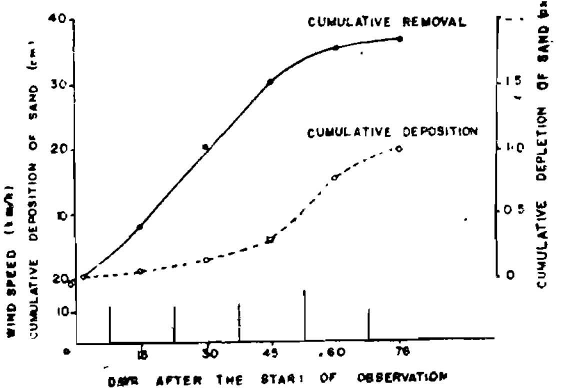

Fig. 1. Cumulative sand movement from a typical stabilized and unstabilized sand dune.

observed which moved towards a constant rate of deposition. This was possibly because of decrease in wind velocity. Cumulative deposition of sand on a stabilised dune with a cover of grass and trees during 75 days period was as much as 1 cm.

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I. 3.15

SALINE AND ALKALI SOILS OF DESERT AREAS

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The salinity of soils in desert may originate due to (1) capillary rise from subsoil bed of salt, (2) salt impregnated sand blown by sea wind, (3) *in situ* decomposition of soil material and (4) ingress of sea water in the coastal desert areas. The salts accumulating in top soil profile are chlorides, sulphates and carbonates of sodium, calcium and magnesium. In arid climate the salts do not leach down very much below the top horizon. Since the amount of rainfall is small, but the rate of evaporation is very rapid, the process of salinization is extremely rapid. In such areas under irrigated conditions excessive use of irrigation water accentuates the process of salinization. As the water from the surface evaporates, water brings up salts by capillarity, from the lower horizon to the upper horizon where they accumulate in quantities larger than can be dissolved by a flush of rain water.

Influence of geomorphological, hydrological and topographical conditions

The existence of a hot, dry climate is not in itself enough to set up salt accumulation and cause the formation of saline soils. When the ground water lies deep down, the moisture evaporated from the soil does not exceed the total atmospheric precipitation. With a deep ground water table (more than 10m), salinisation does not occur in the soil despite the dryness of the climate. There are however in all deserts, regions of salt accumulation. Such areas lie in deep depressions, sometimes wholly or partially encircled by mountain chains or uplands.

Some deep ancient underground waters are highly mineralized, while others are fresh. In large deep hollows, valleys, deltas and in regions marked by tectonic cracks, rising underground waters wedging out or drawing near to the surface become a very important factor in salinizing the waters and soils in depressions.

Thus, the most general and essential condition for the contemporary formation of active *Solanchak* soils in dry, hot climate is the existence of vast depressions. having, within their circumference, deltas, low river, marine or lake terraces, or some kind of water course or trough to act as centres of salt accumulation. Then there is the tendency of large stretches of saline soils to concentrate along the banks of streams of vast ancient alluvial plains.

Inside depressions, deltas and terraces, salinization processes are concentrated in secondary hollows. A relatively small difference in altitude is sufficient to make the soil salt content completely different from adjacent land. It is in fact in mesorelief hollows like this that *Solanchaks* and *Solanchak-like* soils are often formed; whereas the soil on the higher parts of the macro-and mesorelief is invariably less saline.

In deserts, special importance may be given to the process of transportation and redistribution of salts together with soil waters with little local discharge. After sporadic downpours there appear temporarily, surface and underground waters which wash down the residual saliferous rocks on the slopes and carry along easily soluble salts, together with the silt. The silt deposited by these waters, after the solutions themselves have evaporated is enriched with salts. Over long geological periods, this continuous inflow and evaporation of soil solutions causes the formation of *Solanchaks* on the low-lying parts of the desert areas.

Desertic soils in India consist of the following two groups:

1) Grey brown (desert) soils
2) Desert soils

1) *Grey brown (desert) soils*

Grey brown (desert) soils totalling an area of about 36,400 sq km, occur in Rajasthan in the districts of Barmer, Jalore, Jodhpur, Sirohi, Pali, Nagaur. Sikar and Jhunjhunu. The whole tract is a vast sandy plain including isolated hills and rock outcrops at places. The soils improve in fertility towards east and north-east. Usually the soils are saline and alkaline, with unfavourable physical conditions and high pH value. Water is scarce and occurs at greater depth from 30 to 120 metres from ground level. The phosphate content of the aeolian sand compares favourably with some of the alluvial soils, P_2O_5 ranging from 0.05 to 1.0 per cent. Total nitrogen is low, ranging between 0.02 to 0.07 per cent. The pH of the soil and sand varies between 7.2 and 9.2. The salt content is not in toxic doses. The soils and sand are calcareous in nature. Nitrogen occurs in the form

Table 1. Grey brown (desert) soil*

Location : About 23km south-west of Ajmer town, Rajasthan*
Elevation above mean sea level : 800 m
Annual rainfall : 625 mm
Topography : Level

Percentage constituents (oven-dry basis)

Depth (cm)	pH (1:2.5)	Clay	Silt	Sand	T.S.S.	Total N	Org. C	Si_2O	Fe_2O_3	Al_2O_3	Si_2O/Al_2O_3
0–30	8.18	4.44	3.84	92.09	0.300	0.016	0.120	45.76	10.74	34.24	3.20
30–60	8.17	4.20	4.16	91.56	0.057	0.013	0.126	46.39	8 57	26.59	3.01
60–90	8.66	5.34	3.54	91.52	0.050	—	=	47.32	10.54	25.41	3.16

*Tamhana, Shome and Raychaudhuri, 1953.

of nitrates which contribute to soil fertility. The analytical data of one characteristic profile of this class of soils is given in Table 1.

This class of soil also produces under irrigation a wide variety of crops, as in case of Pedocal Sierozem of alluvial origin and Pedocal brown soil of alluvial origin and grows rice, wheat, cotton, banana, tobacco and sugarcane.

2) *Desert soils*

Large part of the arid region belonging to Rajasthan and South Punjab, lying between the Indus valley and the Aravallis is affected by desert conditions. This part is covered under a mantle of blown sand which inhibits soil growth. These sands are partly derived from the disintegration of subjacent rocks but are largely blown in from the coastal regions and the Indus valley. Some of these soils, have low loss on ignition, varying percentage of calcium carbonate and are poor in organic matter. The description of one characteristic profile of this class of soil with analytical data is given below (Table 2).

Table 2. Desert soil*

Location	:	Suratgarh. District Bikaner, Rajasthan*
Elevation above mean sea level	:	224 m
Annual rainfall	:	290 mm
Topography	:	Level
Drainage	:	Well drained
Parent matérial	:	Alluvium
Depth (cm)		*Description*
(1) 0-18	:	D.7.5 YR 7/4; silty loam; weak blocky; tending to be weakly granular; dry and hard; good effervescence with acid.
(2) 18-58	:	D.7.5 YR 6/4; silty clay loam; weakly laminar developing to blocky and nutty; somewhat porous and dry; easily powdered under light pressure of fingers; good effervescence with acid; existence of some small shells of aquatic nature.
(3) 58-84	:	Pinkish to light brown; silty clay loam; compact and hard; somewhat more silty with a few grains of sand; somewhat gritty; medium effervescence with acid; other features as in (2).
(4) 84-127	:	Same as in (3) with slight effervescence with acid.

Percentage constituents (oven-dry basis) of soil

Depth (cm)	pH	T.S.S.	C_aCO_3	Clay	Silt	Sand
0-18	8.25	0.014	2.00	24.9	30.7	44.4
18-58	8.20	0.063	1.50	33.2	48.4	18.4
58-84	8.30	0.032	1.00	29.2	48.4	22.4
84-127	8.20	0.064	0.66	35 2	26.4	38.4

On this class of soil generally coarse millets are grown.

*Satyanarayana, 1956.

The data on the distribution of saline, saline-alkali and alkali lands in different states compiled by the Planning Commission (Appendix 17.2 of part V, Resource Development, Report of the National Commission on Agriculture, 1976) show that in the desert and grey brown soils of the districts Banaskantha, Mehsana, Ahmedabad and Surendranagar of Gujarat and of the the districts Ganganagar, Bikaner, Nagaur, Churu, Pali, Sirohi and Sikar of Rajasthan large areas are affected by saline conditions but not by saline-alkali and alkali conditions. However, detailed survey has not been made of such depressions in desert areas known as *playas* which consist of soils affected by saline-alkali and alkali conditions. Survey and demarcation of such areas and characterisation of these soils are urgently called for. The saline and alkali soils of the Little and Great Rann of Kutch represent typical saline and alkali soils of the desert in the coastal areas, subject to ingress of sea water. The Little Rann of Kutch has an area of 800 sq miles. Extensive areas of saline sodic soils and saline non-sodic soils are found in this tract. Normal or non-saline-sodic soils are found at a few places. The saline sodic soils contain large quantities of gypsum. The $CaCO_3$ content varies from 10 to 15 per cent. Rivers Banas, Rupen and their tributaries flow through it. The possibility of reclaiming the area by shutting off the encroachment of sea-water in Little Rann area and by leaching, is under study. The pH of these soils vary from 8.0 to 10.0. The soils are highly calcareous with low permeability. The texture varies from silty loam to clay loam. The underground water is highly salty, being under the influence of sea water. The soils are of low productivity.

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I. 3.17

SOIL RESOURCE APPRAISAL FOR IRRIGATION PROJECT OF RAJASTHAN LIFT CANAL COMMAND AREA

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The National Agricultural Commission in the interim report on Desert Development has suggested the possibility of irrigating certain areas on the left bank of the Rajasthan canal falling in drought affected districts of Bikaner, Jodhpur, Jaisalmer, Barmer, Ganganagar and Churu, by lift irrigation from the Rajasthan Main Canal. Therefore, pre-irrigation soil investigations were carried out. These comprised:

(i) Preparation of small scale soil map (1:100,000) using aerial photo-interpretation technique combined with limited field checks.

(ii) Interpretation of the soil map with analytical data of soil mapping unit for preparing a derived map showing land irrigability classes and subclasses.

The field work was completed with the help of three soil scientists within a period of six months between September, 1975 and March, 1976 and soil survey report alongwith soil map and derived land irrigability map was submitted by May, 1976.

General description of soils

Physiographically, major part of the proposed lift canal command area

Table 1. Soil map units, their characteristics and management needs (Proposed lift canal command area, Rajasthan)

Land unit	Soils	Irrigability class & sub-classes	Management needs
1	2	3	4
DESERT PLAIN (P)			
Undulating (P. 1) hummocky (P. 11)	Loamy fine sands to fine sands, 60 to 90 cm thick overlying unconsolidated permeable *kankar* layer (Calciorthids). & Fine sands to loamy fine sands, 100 to 150 cm thick overlying unconsolidated permeable *kankar* layer (Torripsamments).	IIIts; moderately good (III) with unevenness (t) and coarse texture (s) limitations.	i) Levelling. ii) Frequent irrigation.
With gravelly patches (P. 12)	Sandy/loamy, gravelly soil 15 to 25 cm thick overlying unconsolidated permeable *kankar* layer (Calciorthids). Sub-rounded and rounded quartz and sandstone gravels on the surface; 2 to 5 cm thick.	VIs; economically non-irrigable land (vi) due to gravelly nature and shallowness of soils.	Probably can be put under grass.
Without gravels (P. 13)	Fine sandy loams with a thin overburden (5 to 10 cm) of aeolian fine sands and loamy fine sands, 100 to 150 cm thick overlying unconsolidated permeable *kankar* layer (Camborthids).	IIIst; moderately good (III) with 3 to 5% slopes (t) and coarse texture (s) limitations.	i) Levelling. ii) Frequent light irrigation.

	& Fine sands to loamy fine sands, 100 to 150 cm thick overlying unconsolidated *kankar* layer (Torripsamments). & Loamy fine sands to loams, 60 to 90 cm thick overlying unconsolidated permeable *kankar* layer (Calciorthids).		
Duny (P. 14)	Fine sands to loamy fine sands, 150 to 200 cm thick underlain by unconsolidated *kankar* layer (Torripsamments). & Fine sands with more than 35 per cent *kankar* (skeletal), 60 to 90 cm thick overlying unconsolidated permeable *kankar* layer (Calciorthids).	IVts; marginally (iv) irrigable lands, scattered low and high dunes (t) and coarse texture (s) limitation.	i) Dune levelling. ii) Frequent light irrigation.
Very gently undulating (P. 2) with gravelly patches (P. 21)	Loamy fine sands to loams, 15 to 25 cm thick underlain by unconsolidated permeable *kankar* layer (Calciorthids), in	IVs; marginally (iv) irrigable lands, gravelly nature of the soil (s) on the surface and in the	Removal of surface gravels.

(*Continued*)

Table 1 (*Continued*)

1	2	3	4
	some areas the soil profile is gravelly throughout; 2 to 5 cm size gravels of quartz and sandstone on the soil surface. & Fine sandy loams to clay loams, 60 to 90 cm thick with 5 to 20 % of quartz gravels underlain by. unconsolidated permeable gravels of quartz and *kankar* (Haplargids) ; found only in area around Bap village.	soil profile, being the limitation.	
Without gravels (P.22)	Fine sands to loams, 25 to 70 cm thick (25 to 40 cm thick in Lathi-Baru area and 40 to 60 cm thick in Bap-Diyatra-Bijju area) underlain by unconsolidated permeable *kankar* layer (Calciorthids). & Fine sandy loams, 60 to 90 cm thick underlain by unconsolidated quartz gravels and *kankar* layer (Camborthids) found in Bap and north-west of Bap village.	IIIs; moderately good (iii) irrigable land; coarse texture and soil thickness are the main limitation (s).	Frequent light irrigation.

Shallow broad valleys (P.23)	Fine sandy loams to loams, 90 to 130 cm thickness, with textural increase (argillic horizon) underlain by quartz and *kankar* gravels (Haplargids). & Sandy loams, 90 to 130 cm thick underlain by quartz and *kankar* gravels (Camborthids).	II C; good (II) irrigable land.	
Gently sloping (P.3) crest (P.31)	Loamy fine sands to loams ; 5 to 15 cm thick; more than 35% gravels of quartz, sandstone and *kankar* present throughout the soil profile; the soil surface is also covered with gravel pavement of 2 to 5 cm thick; underlain by unconsolidated permeable *kankar* layer (Calciorthids).	VIs; economically non-irrigable (vi) lands due to gravelly nature of soil(s).	Can be put under grass.
Side slopes (P.32) with gravels (P. 321)	Loams; 40 to 90 cm thick; having 20 to 45% gravels of quartz and *kankar* throughout the soil profile; underlain by unconsolidated permeable *kankar* layer (Calciorthids).	IVst; marginally irrigable land (iv) due to gravelly nature of soil(s) and slopes 3 to 5% (t).	i) Removal of surface gravels, stones and boulders; ii) Levelling

(Continued)

Table 1 (*Continued*)

1	2	3	4
	The surface is covered by gravels of quartz and sandstone (and stones and boulders at places) to a depth of 5 to 10 cm. & Loams to clay loams with textural increase down the profile (argillic horizon) ; 60 to 90 cm thick underlain by quartz and *kankar* gravels (Haplargids). Soil Surface covered by gravels and boulders.		
Without gravels (P. 322)	Fine sands to loams ; 60 to 90 cm thick underlain by unconsolidated permeable *kankar* layer (Calciorthids). & Fine sands to loamy fine sands; 100 to 150 cm thick underlain by quartz and *kankar* gravels (Torripsamments).	III; moderately good (iii) irrigable land. Coarse texture (s) and slopes of 3 to 5% (t) are the limitations.	i) Levelling. ii) Frequent light irrigation.
LACUSTRINE DEPOSITS (L) (*Playas*)	Loams to clay loams; 100 to 200 cm thick; salinity increases and exceeds 2 % salts with depth (Salic horizon); poor drainage (Salorthids).	VIds ; economically non-irrigable (vi) due to poor drainage (d) and high salt content (s).	

ALLUVIAL PLAIN (A)	Loamy fine sands to fine sandy loams, 100 to 125 cm thick ; stratified layers of different textures throughout the soil profile (Torrifluvents). & Loams 60 to 100 cm thick with 20 to 40% gravels of quartz and *kankar* throughout the profile underlain by unconsolidated permeable *kankar* layer (Calciorthids). & Loams with textural increase in the soil profile (argillic horizon), 60 to 90 cm thick underlain by permeable quartz and *kankar* layer (Haplargids). Soils of alluvial origin found dominantly in Phalodi-Malar-Bap area in small patches.	IIIs; moderately good (iii) irrigable land, coarse texture and low fertility (s) are the main limitations.	i) Erosion control measures. ii) Frequent light irrigation.
HILLS (H. 1) Bare rock (H. 11). Partly covered with vegetation (H. 12) & Foot slopes (H. 2)	Fine sands and loams with gravels throughout the profile; 5 to 25 cm thick underlain by unconsolidated permeable *kankar* layer and sand stones. (Torriorthents and Calciorthids) with stones and gravels of 5 to 15 cm thick on the soil surface.	VIs; economically non-irrigable (vi) land; due to gravelly and shallow soils.	Can be vegetated with suitable species.

(Continued)

Table 1 (*Continued*)

1	2	3	4
DUNES (D) High (>2m) D. 1 Partly vegetated (D. 11) Bare (D. 12).	Fine sands to loamy fine sands, very deep (more than 200 cms) thick ; (Torripsamments) with 5 to 10 % of *kankar* gravels.	VIts : economically non-irrigable (vi) lands due to high dunes (t) and coarse texture(s).	Stabilisation required.
Low (<2m) D. 2 Partly vegetated (D. 21) Bare (D. 22)	-do-	IVts : marginally irrigable (IV) lands due to low dunes (t) and coarse texture(s).	i) Levelling. ii) Frequent light irrigation.
Interdunal, plain (D. 3)	Fine sands to loams, 60 to 90 cm thick with 20 to 40 % *kankar* gravels underlain by unconsolidated permeable *kankar* and sometimes gypsum layers (Calciorthids). & Fine sands to loamy fine sands 100 to 150 cm thick underlain by unconsolidated permeable *kankar* or gypsum layer.	IIIs ; moderately good (iii) irrigable land with coarse texture(s).	Frequent light irrigation and protection from wind erosion.
R-ROCKY AREA	Rocky		

Classification		Physiographic position	Brief description of the soils
Subgroup	Family*		
1	2	3	4
1. Typic Torripsamments		Dunes, interdunal plain, desert plain	Very deep, yellowish brown, excessively drained, sandy soils, calcareous.
2. Typic Torriorthents	Sandy skeletal	Hills	Deep, yellowish brown, excessively drained, sandy soils, calcareous, 60-80 % sandstone gravels and boulder.
3. Typic Torrifluvents	Coarse loamy over sandy	Alluvial plain	Very deep, yellowish brown to brown, well drained, coarse loamy over sandy soils, calcareous stratified.
4. Typic Haplargids	Clayey/Loamy	*Playas*, alluvial plain	Very deep, dark brown to yellowish brown, mod. well drained soils, calcareous, argillic horizon present.
5. Typic Salorthids	Fine loamy	Very gently undulating with gravelly	Very deep, brown to yellowish brown, well drained to mod. well drained, loamy to clay loam

(Continued)

Table 2 (*Continued*)

1	2	3	4
		patches, mottled tone, lacustrine deposits, *playas*	soils, calcareous, high salt content, salic horizon present. Clayey soils below 75 cm depth.
6. Typic Calciorthids	Loamy/ Loamy skeletal	Hills foot slopes, interdunal plain, desert plain, alluvial plain	Very deep, dark brown to yellowish brown, well drained, sandy loam to loam soils, calcic horizon present. Some soils have 40-80 % *kankars*.
7. Typic Camborthids	Coarse loamy	Desert plain	Very deep, dark brown to yellowish brown, well drained, sandy loam soils, cambic horizon present.

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*Mixed hyperthermic common to all.

comprises undulating to gently slopping desert plains having a thin aeolian deposit in the north-western and north-eastern parts. The soils are deep to very deep, calcareous, wind blown loamy fine sands to fine sandy loams underlain by a layer of unconsolidated permeable *kankar* layer. The dunes are restricted to the north-western, northern and north-eastern part of the survey area. Interdunal plains are predominant in Churu area. There are a few small scattered hillocks near Bap, Pokaran and south-west of Lathi area. These hillocks and the foot slopes are rocky and have moderately deep to shallow calcareous soils with gravel pavement.

Stretches of alluvial plains are mainly encountered in between Bap and Phalodi. They have deep to very deep calcareous reddish brown loamy soils.

Lacustrine deposits (*playas*) occur to the south of Bap and south-east of Pokaran. They have very deep saline fine loamy to clayey soils. The soil map units, their characteristics, irrigability classes and sub-classes and management needs are described in Table 1 and a brief description of important soil profiles along with analytical data are given in Table 2.

Suitability of the area for irrigated agriculture

The irrigability classification of the survey area is based on the principles and assumptions as given in the U.N.D.P./ F.A.O., Govt. of Rajasthan Report on Soil Survey and Land Classification (Technical Report, 1.1.1971, which is analogous to that described in the Soil Survey Manual, 1970). According to these, the lands are classified into six classes with class I as the best and class VI as the lands unsuitable for irrigation.

The area falling under different land irrigability sub-classes, system-wise, the irrigability sub-classes, the total irrigable area and economically non-irrigable area are shown in Table 3.

Table 3. Area of Land Irrigability sub-classes in different Lift Scheme Systems (hectares)

Lift scheme system	Irrigable land				Non-irrigable land	Total area within command boundaries
	IIc	ItI	IVts	IVds	VI	
I (Gajner)	—	61,500	6,200	1,500	1,800	71,000
I (Deshnok)	—	24,500	400	1,450	1,000	27,350
II (Kolayat)	1,400	85,700	4,200	8,300	7,500	107,100
II B (Bangarsar)	—	1,430	1,655	—	805	3,890
III (Phalodi)	835	47,010	6,560	15,080	7,465	76,950
IV (Pokaran)	95	101,210	6,435	9,805	10,715	128,265
V (Sahawa)	—	57,300	10,815	—	2,470	70,585
Total	2,330	378,655	36,265	36,135	31,755	485,140
Total irrigable land and non-irrigable land		4,53,385			31,755	

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I. 3.21

SOIL RESOURCE DATA AND MAPPING ACTIVITY IN THE NORTH-WEST ARID ZONE OF INDIA

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INTRODUCTION

Pleistocene alluvium and wind worked sands are by far the dominant parent material of the soils in the area. The alluvium is mainly light textured though in sizeable area namely to the east of Nagaur, Jodhpur and Jalore and then again in Saurashtra under the influence of fine grained sedimentary, metamorphic or basic igneous rocks, it is medium or fine textured. Pedogenic processes have caused a further slight to moderate argillisation of this alluvium but their vivid manifestation lies in redistribution and segregation of alkaline earth carbonates (Dhir and Kolarkar, 1977). During the succeeding highly arid phase(s) of the Late Pleistocene these alluvial plains got partially broken with generation of large masses of loose sand in the form of dunes and high hummocks. Sands from the Indus delta and Arabian sea coast may have contributed also to the latter. The extreme north-western part of arid zone is covered with old Indus system alluvium and far flood plain deposits (since partially covered with aeolian sand) of the river Ghaggar. Thus, this source rock variability of alluvium with moderate soil profile development and its differential break down have provided considerable hetrogeneity in soil cover of the area. This is manifested in extent of duniness, texture of soil, degree of development of lime concretionary layer and depth of its occurrence and salinity.

Somewhat belated in comparison to the rest of the country, studies in arid zone soils were started both by Central and State agencies in early fifties on a number of fronts. These include (i) pre-irrigation soil survey in project areas, (ii) soil survey as part of an integrated natural resources survey programme for macro level planning and development, (iii) detailed soil survey for formulation and execution of soil-water conservation programmes, and (iv) soil fertility investigations under farmers' advisory programme and for scientific pursuits. Extent of area covered under some of these programmes is shown in Fig. 1 and a brief account of achievements is as follows:

Pre-irrigation soil survey

This has been one of the most important application of soil survey. A rapid reconnaissance survey formed an integral part of a major irrigation project for utilization of Indus Basin waters, namely, the Rajasthan canal. Following this favourable preliminary report (C. W. P. C., 1952), a systematic survey was taken up of the gross command area of 16,080 km^2 by the Rajasthan State Govt. under assistance from UNDP and FAO. In this study, using 1/4 to 1 km grid profile examination, final soil map was prepared on a scale of 1"=1 mile (FAO, 1971; Mathur *et al.*, 1974-75). Based on physiography and profile characteristics, the soils of the area were classified into 25 mapping units. Assessment of these in terms of irrigability has shown that of the total command area, only 3.9% comprises of good irrigable soils. 40.5% and 8.4% of the area is made of moderately good and marginally irrigable soils respectively. Rest 47% comprising high dunes is non-irrigable. The survey has helped in bringing out the excessive deep percolation losses, salinity, perched water table formation are special problems needing attention in this precious irrigation project (Fig. 2).

Other important activities have been the survey of Jawai Canal command area in Rajasthan (38 km^2, Mehta, 1960) and the Jui Canal command (320 km^2) and the Gurgaon Canal command (4,606 km^2) in Haryana by the Haryana Agricultural University.

Soil surveys for regional resource inventory and land use planning

As part of an integrated natural resource survey programme, the CAZRI has been carrying out regular soil survey right from the year 1959 onwards. These surveys have mostly been carried out using aerial photo interpretation at a scale of 1 : 126,000 with a final map on quarter million scale. Such surveys have been carried out for an area of 79,000 km^2. The soil map shows series or their associations. In certain favourable situations, delineation of depth phases has been possible also.

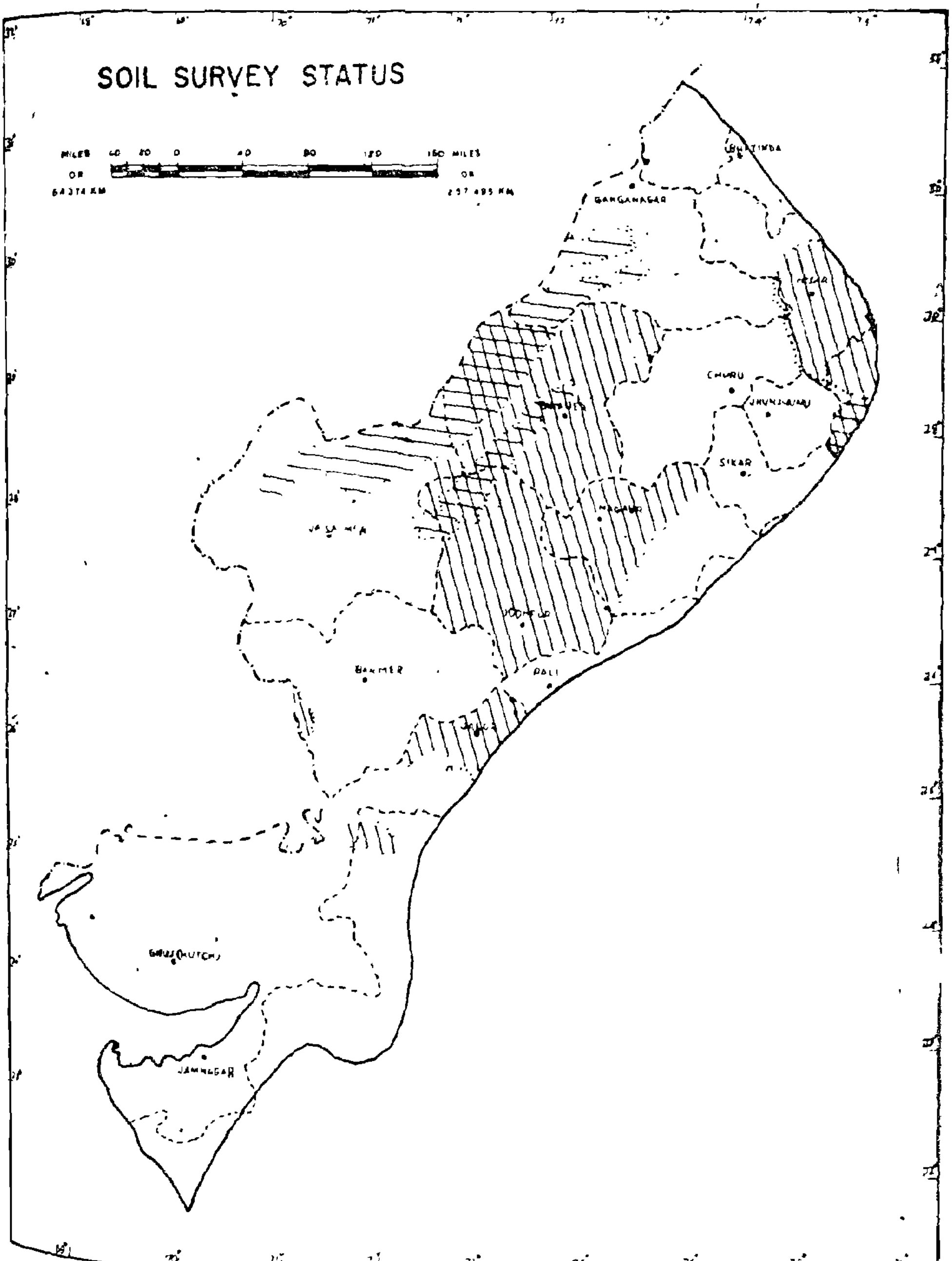
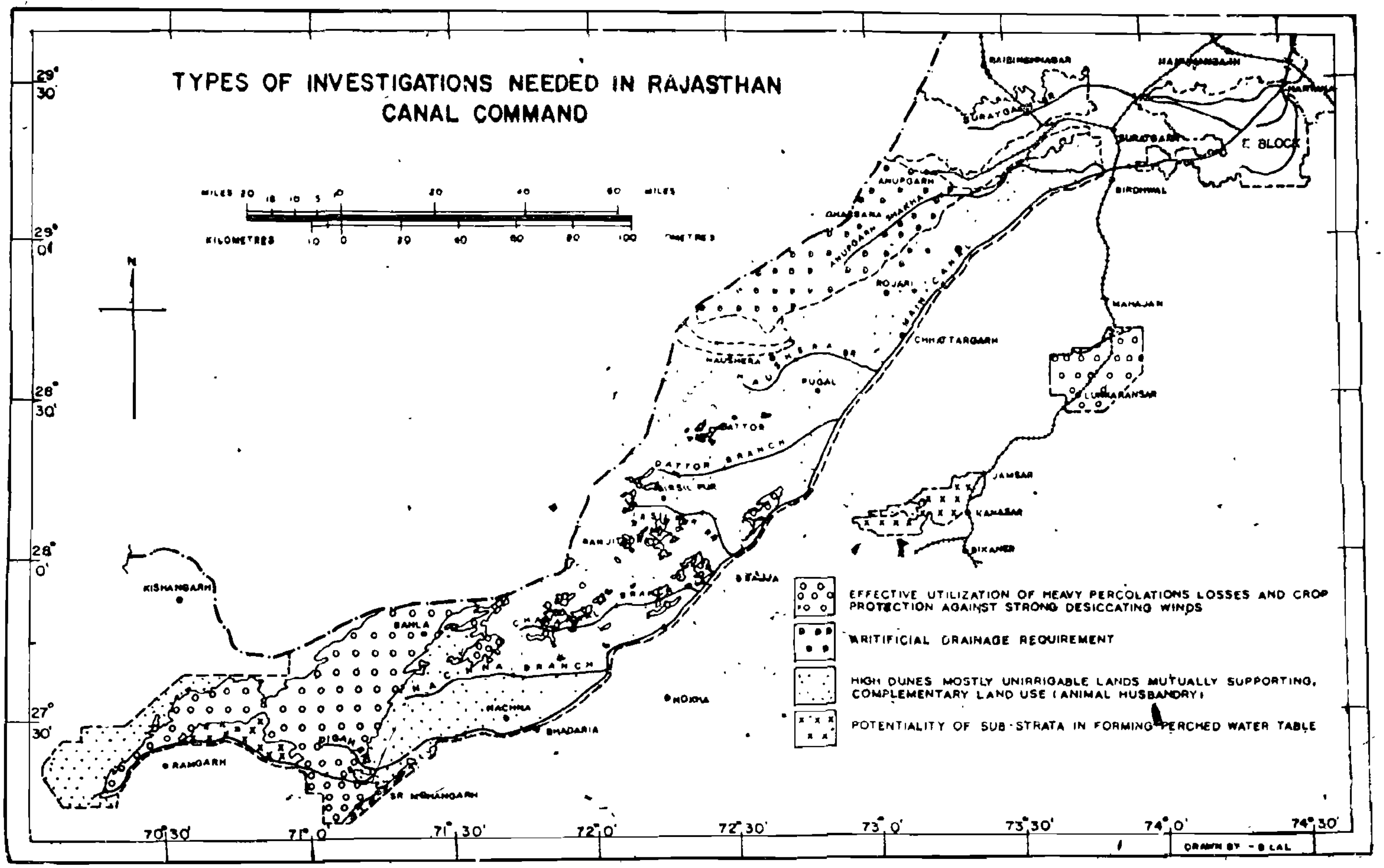


Fig. 1. Map showing extent of area surveyed in north-west arid zone of India. Hatchuring horizontal—pre-irrigation; inclined—resource inventory.



TYPES OF INVESTIGATIONS NEEDED IN RAJASTHAN CANAL COMMAND

Taking into account the soil characteristics and associated land features, the soils are interpreted in terms of broad landuse capability. Information in respect of one such surveyed area (Jodhpur district, 22,640 km^2) is presented below.

Distribution of lands under different land use capability classes in Jodhpur district

Land use capability	% area in the district
III_c and III_{cw} Lands well suited for arable farming. Scope exists for improved water conservation technology.	9.4
III_{ec} Lands well suited for farming but with simple wind erosion control measures.	19.7
IV_{ec} Lands suited for farming but with rigorous wind erosion control measures.	32.6
V_{sa} Salt affected lands suited for farming under specialised management.	0.7
VI_{ec} Lands suited for silvipastoral use.	13.1
$VI_{sh,\ e}$ Lands suited for pastoral use.	15.4
$VII_{sh,\ e}$ Lands suited for pastures but with soil water conservation practices.	7.9
VIII Lands of extremely limited use.	1.2

Information on present land use shows that large areas belonging to capability classes VI and VII are under cultivation. This in turn has lead to (i) considerable increase in incidence of wind erosion and generation of large masses of loose sand, (ii) reduced soil depth and expansion of bare areas.

Similar soil surveys have been undertaken also by other agencies, namely, National Bureau of Soil Survey and Land Use Planning and agricultural universities in Rann of Kutch and Hissar district respectively.

Soil surveys for micro-watershed planning

Arid zone landscape is dotted with hills and rock out-crops. Most of these are potential catchments, run-off from which presently goes under-utilized as deep recharge. Water erosion in form of gullies and rills is besides. Treatment of the entire catchment for soil and water conservation is an important activity under Drought Prone Area programmes. Detailed soil survey (10 inches to mile scale) forms a basis in preparation of these plans. Till to-date such surveys have been carried out over an area of 0.24 million ha in districts of Jodhpur, Barmer, Jaisalmer, Pali, Nagaur and Jalore.

Salinity-alkali problem in arid zone

Salinity in arid zone is fortunately a localised problem. It is confined to small inland depressions scattered throughout and to a marshy salt plain or Rann of Kutch (23,000 km^2). Besides these, there are two major tracts where salinity in soil assumes unusual proportions. One is in the extreme north-west in the far-flood plain of old Ghaggar system. Salinity is

Table 1. The available nutrient status of the major soils (Sanghi *et al.*, 1976). Percentage distribution of samples analysed

Soil group	The number of samples received and analysed	Organic carbon (%)			Available P_2O_5 (mg/100 gm)			Available K_2O (mg/100 gm)		
		Less than 0.5	0.5–0.75	Over 0.75	Less than 0.45	0.45–1.1	Over 1.1	Less than 5.2	5.2–12 5	Over 12.5
Desert calcic brown soils	144	89.10	7.90	3.00	25.13	44.43	30.44	23.60	50.70	25.70
Desert soils	4912	88.30	7.40	4.30	23.00	46.10	30.90	2.10	59.90	38.00
Grey-brown alluvial soils	12695	80.60	11.10	8.30	22.50	38.80	38.70	14.70	35.20	50.10
Brown soil (Saline phase)	2709	89.30	3.80	6.90	26.30	38.30	35.40	21.10	38.10	40.80
Non-calcic brown soils	1543	79.00	15.70	5.30	2.50	80.50	17.00	5.50	78.50	16.00
Hilly soils	2250	72.50	13.10	14.40	30.84	26.84	42.34	15.16	42.15	42.69
Total	24,253	82.33	10.00	7.67	22.54	41.80	35.66	12.37	44.02	43.61

dominantly sodium chloride-sulphate type with nearly one third samples showing significant amounts of gypsum. Survey under the Rajasthan Canal project has shown that the area of salt affected lands is about 0.14 million ha. The other tract with scattered saline patches is in the south-east in Jodhpur, Pali and Jalore districts. Salinity here also is dominantly of sodium chloride-sulplhate type (Mehta *et al.,* 1969). Salt affected areas are confined to down slope flat aggraded plains. The exact extent of such areas is not yet available but reconnaissance survey within this area (Pali Block, 1,400 km^2) showed that almost 25% of total area is so affected (Dhir and Singh, *l.c*).

Inherent fertility status of arid zone soils

Under soil testing programme as part of farmers' advisory service, valuable data have accumulated over the years on available nutrient status of soils (Sanghi *et al.,* 1976). This information for some of the districts in western Rajasthan is summarised in Table 1.

The results show that except for nitrogen as indicated by low organic carbon values, the arid zone soils are fairly well provided with major nutrients to meet the requirement of vegetative growth permitted by limited rainfall in the region.

From the foregoing, it would be seen that source rock variability and past evolutionary history have lent considerable variability to soil cover of the arid zone. The soils have considerable behavioural differences in erodibility, moisture retention, root zone limitation and salinity. Recognition and mapping of these soils, as illustrated from already surveyed area, provides a scientific basis for land use planning and identification of priority areas for specific soil and water conservation treatment. Fortunately, the inherent fertility status of soils in Indian arid zone is comparable, and possibly better than that of other arid zones in the world. This could precisely be a justification to check present irrational land use so that accelerated degradation of this precious resource is checked in time.

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I. 3.23

SOME ASPECTS OF SOIL CLASSIFICATION AND MAPPING AT INTER - COUNTRY (REGIONAL) AND WORLD LEVELS, WITH SPECIAL REFERENCE TO ARID AND SEMI-ARID ZONES

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INTRODUCTION

The objective of this paper is to throw light on some important aspects of soil classification and mapping, in relation to the following issues:

The need for inter-country (regional). and world soil grouping. The increasing need for a more detailed and precise soil classification.

The discussion in this text is confined to those soil characteristics most likely to be found under arid/semi-arid zones of the world where less attention has been given to regional and national soil mapping.

DISCUSSION AND ANALYSIS BASED ON AVAILABLE INFORMATION

If one reviews current literature on the subject, it becomes evident that in order to reach for regional and global soil mapping, apart from other major steps, scientists have endeavoured to:

Refer to seveal classification systems with special reference to U.S.D.A., soil classification system.

Work with observational and interpretational type of information.

Reach a compromise towards a form of Universal soil grouping.

Presently, a move which may require more detailed and more precise information is gradually taking shape. This is in relation to the evaluation of degradation of natural resources, which is of particular significance to those parts of the world namely arid/semi-arid, and tropical/subtropical zones, where relatively the minimum soil information is available.

The analysis that follows takes into consideration some of the diagnostic soil characteristics at higher category classifications, and their use and modifications for phase levels, with special reference to those that are relevant to arid/semi-arid zones.

U.S.D.A. soil classification differentiae at higher categories and phase level classification of the Soil Map of the World

Emphasis on climatic soil water regime

In the U.S.D.A. system of soil classification with reference to the 1975 Soil Taxonomy, diagnostic subsurface horizons, as well as other diagnostic soil characteristics function at almost all levels of higher category classification, but with varying degrees of specificity. However, it should be noted that in identifying properties of diagnostic subsurface horizons, one common active agent is recognizable, that is water. This can be more specified as climatic/soil/water regime. Its contribution is either directly, or indirectly. Its action is either physical, on colloidal material (clay or clay/organics) as such or on chemical deposits or a combination of both. The separation of diagnostic horizons shown in Table 1 is

Table 1. Regrouping of diagnostic horizons according to the possible effect of water climatic regime on mineral/organic and or chemical deposits

Mineral, mineral/organic	Chemical deposits	Mineral, mineral-organic and chemical deposits
Argillic	Natric	Spodic
Agric.	Calcic	Placic
Sombric	gypsic	cambic
	petrocalcic	duripan
	petrogypsic	fragipan
	solic	albic
	sulphuric	oxic

arbitrarily based on the dominance of the action of the climatic soil water/regime on mineral and/or chemical deposits. Similarly, such a grouping can be done in relation to the other diagnostic soil characteristics. Of the other diagnostic soil characteristics three types of contact are described, namely:

1) Lithic
2) Paralithic
3) Petroferric, of which only the lithic contact was characterised by depth in the (U.S.D.A.) soil classification.

However, soil moisture regime, with all its parameters, is considered in the soil taxonomy as an important diagnostic soil characteristic. Further reference to it will be made in the text.

At this point, it is important to note the use of such characteristics that are diagnostic at the phase level classification by the FAO/UNESCO classification.

As pointed earlier in the text that though the legend of the Soil Map of the World has carefully drawn and adopted the definitions and nomenclature of the diagnostic horizons of the soil taxonomy (U. S. Soil Conservation Service, 1974), it has not used a few epipedons and diagnostic horizons for various reasons, as follows:

1) Epipedons: (i) Plaggic
(ii) Anthropic

2) Diagnostic horizons: (iii) Sombric
(iv) Agric.
(v) Duripan
(vi) Fragipan
(vii) Petroclacic
(viii) Petrogypsic

It is understandable, in using a specific soil classification system (in this case U.S. Soil Taxonomy) at world or regional mapping level to omit some diagnostic horizons because of cartographic difficulties but not to use some diagnostic horizons as phases because of lack of information as was the case in the last four (5-8 inclusive) horizons. In addition, it is clearly stated in the Soil Map of the World that phases are based on management characteristics and certainly not diagnostic for the separation of soil units. This is not to mention the crude appromation adhered to in the cartographic presentation of such phases.

As much as the U.S.D.A. as a single system of classification defined and described its diagnostic horizons and other diagnostic soil characteristics, the FAO/UNESCO referred in many cases to ranges of characteristics of these diagnostic horizons specifying depth. Table 2 shows the FAO/UNESCO phase level classification and its corresponding U.S.D.A. high category classification.

Referring to Table 2 and with special reference to Arid/Semi-arid Zones one can almost limit the most common soil properties of diagnostic nature, regardless of any level pertaining to any classification system, to the following:

1. Lithic, and paralithic contacts

2. Salic, natric, gypsic, calcic, petrocalcic, petrogypsic.

3. Particle size classes

4. Phreatic.

Table 2. High/low level classification, relevant to arid/semi-arid zones

FAO/UNESCO phase level classification; Soil Map of the World	U.S.D.A. High category classification (Soil taxonomy, 1975).
Stony	(Particle size classes) 1
Lithic	Lithic contact 2
—	Paralithic 3
Petric	Plinthite 4
—	Gypsic 5
Petrocalcic	Petrocalcic 6
Petrogypsic	Petrogypsic 7
Petroferric	Petroferric 8
Phreatic	—
Fragipan	Fragipan a
Duripan	Duripan b
Saline	Salic 9
Sodic	Natric c
Cerrado	—

1 – 9 : U.S.D.A. Soil Taxonomy : Other Diagnostic Soil Characteristics.

a – c : U.S.D.A. Soil Taxonomy : Diagnostic horizons.

The significance of climatic soil moisture** regime soil classification with special reference to arid/semi-arid zones*

Climatic/soil moisture regime is not only the determinant of soil processes, but a vital characteristic in the arid/semi-arid zones of the world:

1. Its limited nature (amount and distribution), limits the economic use of the land.
2. It demands those conservation measures and practices that are still either beyond the recognition of the farming communities (in spite of all the efforts made), and/or require high level of costly management.
3. Failure to meet the above requirements (item "2" above), has contributed to the degradation of land in the arid/semi-arid as well as the tropical/sub-tropical zones of the world.

The methods of estimating soil moisture from meteorological records have their shortcomings, so has the judgment of depth of control section in relation to soil classification. Is the amount (cms) of water required to moisten a soil to a certain depth, from . 15 atm. but not air dry, as the soil taxonomy, 1975,

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* Climatic : strictly referring to climate.

** *Soil moisture : used synonymous to soil water.*

states, or is it the effective state of a moist soil that can maintain a crop(s) per year or per season? There is therefore a definite need to refine the soil moisture regime to separate its classes—(e.g. Xeric/Aridic).

The verification of the climatic (present climate) influence in maintaining the status quo of the soil to maintain a crop is of utmost importance in a pragmatic form of soil classification.

So far, in most cases in arid/semi-arid zones soil classifications used in conventional soil surveys have been confined to national projects of economic impact where, high investment costs for irrigation techniques are anticipated. Under these conditions, soil classification would go as far as the sub-group/series level, or to the phase level, whichever the case may be.

A conclusive broad outlook

In order to meet an international level of a soil classification and resource assessment both for development and anti-degradation planning, it is apparent that the regional and international organisations (with their available capabilities), should perhaps intensify their efforts towards the following directions:

1. Revise and improve soil classifications with a view of establishing a more comprehensive world/regional standardised units.
2. Standardise world and regional levels of classifications as first priority in order to feed back the national level details. This approach could perhaps be elaborated as follows:

a. A more comprehensive world zonation and intra zonation, with a plan to publish at regional level, at larger scale of (1—0.25 million) maps depending on the region.

b. At the Regional Level the comprehensive zonation should take into consideration:

—*Present climate*: the establishment and standardisation of world levels and patterns (with special reference to effective rainfall, and the directly available soil/water for a crop).

—*Geomorphological land units*: their establishment and standardisation, particularly in relation to definitions, nomenclature and association levels.

—*Soil taxonomic units*: using U.S. D.A. Soil Taxonomy classify to the subgroup level, establishing associations (with more specified components).

—Establish a Soil/Land/Climate Association scale, and use such a relationship as a mapping unit.

—Establish still at the regional level, the same association mapping units with sub-units (at scales, of one to 0.25 million), to include the same soil diagnostic properties, dominant to the region and specified by management parameters characteristic of the region.

This modification of the diagnostic properties by management parameters at the regional level, will furnish the gateway for the feedback of any soil classified information to the subgroup level at the national scale, as well as the link for land evaluation standards, regardless of the system of classification used so long as the diagnostic characteristics are specified.

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I. 4.2

SOIL-VEGETATION INTERRELATIONSHIPS IN THE NORTH - WESTERN COASTAL RANGELANDS OF EGYPT

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INTRODUCTION

The soil-vegetation relationships in the north-western coastal region of Egypt have received little attention by range ecologists. Except for reconnaissance soil survey and phytosociological studies, only general relationships between the semi-desert shrub communities and edaphic features were investigated (Tadros, 1956; Tadros and Atta, 1958a and b; Migahid *et al.,* 1963). This study was undertaken during 1965-1967 with the objectives to investigate and evaluate the edaphic characteristicis of seven plant associations, to isolate ecological factors that might contribute to plant distribution, and to develop vegetation-soil guides which could minimize soil survey problems throughout the western section of the Mediterranean coastal region.

DESCRIPTION OF STUDY AREA

The study area is located at Sidi Barani in the mid-western sector of the north-western coastal region of Egypt. The longitude 31° 35' W and latitude 26° 15' N cross at almost the centre of the area. The boundaries of the study area extend 20 km from east to west and from the Mediterranean coast on the north to 10-14 km southwards covering approximately 250 sq km. It includes most of the important range plant communities.

The area of investigation is more or less uniformally sloping from contour 70 m in the south to sea level in the north and has a slope of 5.4 m/km.

The rainfall occurs during winter and its annual average is about 150 mm. It is characterized by great annual fluctuation. The mean daily maximum temperature fluctuates between 17.5°C in January and 28.7°C in August, while the mean daily minimum varies between 6.9°C and 20.2°C in these two months respectively.

METHODS AND PROCEDURES

Selection of sampling sites

Phytosociological classification of the study area was carried out by Tadros *et al.* (1965) and Ibrahim (1968). Four major habitat types were recognized and several plant associations were identified. A vegetation map was produced.

Six plant associations and one sub-association belonging to the four following important habitats of the Mediterranean coastal regions were chosen for this study. Eight locations were randomly selected from 15 widely separated sites for each of the following associations:

1. Halophilous vegetation type occur close to the Mediterranean coast. The soil is sandy loam. The profile is occasionally accentuated and outcrops of sand-limestone are found:
   - 1.1 Association of *Salsola tetrandra—Suaeda fruticosa.*
2. Desert shrub type:
   - 2.1 Association of *Thymelaea hirsuta.*
   - 2.2 Sub-association of *Thymelaea hirsuta—Gymnocarpus decandrum.*
   - 2.3 Association of *Artemisia herba-alba—Asphodelus microcarpus.*
3. Inland dune vegetation type:
   - 3.1 Association of *Plantago albicans—Echiochilon fruticosum.*
   - 3.2 Association of *Uriginea maritima.*
4. Degraded desert vegetation type:
   - 4.1 Association of *Haloxylon articulatum—Anbasis articulata.*

Soil sampling

Trenches 200 cm long and 75 cm wide were excavated to the parent material to expose the entire zone or root penetration. The relief, degree and direction of slope and internal drainage, for each locations were recorded. Procedures outlined by the U.S., Department of Agriculture (1951) were followed in soil sampling.

Three soil strata were distinguished at each of 56 sites (8 locations X 7 communities). Soil samples from each stratum were dried and passed through a 2 mm screen. Field work was carried out during the spring of 1965.

Physical and chemical analysis of soil samples

Procedures used for chemical analyses of the soil samples were, with one exception, those recommended by the U.S. Salinity Laboratory (1954). The chemical analyses were electrical conductivity of 1:5 soil-water extract; total soluble salts percentage; soluble sodium, potassium, calcium, magnesium and chlorides; and cation exchange capacity. Lime content was determined by Schepler apparatus. All soluble cations and anions were determined as meq/100 g soil in 1:5 soil-water extract. Cation exchange capacity was determined for samples from four locations for each plant association.

For physical analyses, the determination of particle size distribution was by hydrometer except for the association of *P. albicans—E. fruticosum* and the association of *U. maritima* where sieving method was used because of the coarse texture. Each of the silt and clay contents for these two associations were rather low. Their total percentage was determined by subtracting the contents of both coarse and fine sand contents from 100. Moisture equivalent was determined as described by Piper (1950).

RESULTS AND DISCUSSION

The seven plant associations were distinctly different in their floristic composition (Tadros *et al.,* 1965). Field investigations showed that each vegetation type was associated with certain soil characters. Therefore, edaphic factors were considered of primary importance in the distribution of these vegetation units.

Table 1 shows percent total soluble salts, soluble sodium, potassium, calcium, magnesium and chlorides, lime; the coarse and fine sand fractions and their total; the silt and clay fractions and their totals; and moisture equivalent contents obtained from the entire soil profile in eight locations of the seven plant associations.

On the basis of results shown in Table 1, the four major vegetation types as well as the different associations and sub-associations within each type can be distinguished from one another as follows:

1. *Halophilous vegetation type*

This type is found close to the Mediterranean coast. The soil is sandy loam. This type has significantly higher values of total soluble salts, sodium, potassium, magnesium, chlorides and calcium than the remaining three vegetation types (Table 1). In the study area, only one association of *S. tetrandra–S. fruticosa* belongs to this vegetation type.

2. *Desert shrub type*

This type occupies flat to moderate slopes dominating sandy loam to skeletal soil which have the tendency to be compacted by run-off water. This type is distinguished by its silt and clay content which is significantly higher than that of the inland dune vegetation type but significantly lower than those of the halophilous vegetation and degraded desert vegetation types. The three plant communities belonging to this type are significantly different in the silt content of their soil. The association *A. herba alba–A. microcarpus* has a higher silt content (7.49%) than both of the sub-association of *T. hirsuta–G. decandrum* (5.24%) and the association of *T. hirsuta* (4.30%). The

Table 1. Mean values of the soil characters obtained from the entire soil profile in the association sampled

Vegetation Type	Halophilous vegetation	Desert shrub vegetation			Inland dune vegetation		Degraded desert vegetation
	S. tetrandra- *S. fruticosa*	*T. hirsuta*	*T. hirsuta-* *G. decander*	*A. herba-alba-* *A. microcarpus*	*P. albicans-* *E. fruticansum*	*U. maritima*	*H. articulatum-* *A. articulata*
Total soluble salts (%)	0.679 a[1]	0.078 b	0.080 b	0.162 b	0.061 b	0.068 b	0.130 b
Total soluble sodium (meq/100 g)	6.720 a	0.090 b	1.130 b	1.100 b	0.060 b	0.090 b	0.680 b
Total soluble magnesium (meq/100 g)	1.107 a	0.226 b	0.349 b	0.349 b	0.241 b	0.203 b	0.304 b
Total soluble calcium (meq/100 g)	0.825 a	0.565 b	0 500 b	0.481 b	0.476 b	0.418 b	0.437 b
Total soluble potassium (meq/100 g)	0.744 a	0.073 bc	0.680 bc	0.158 bc	0.016 c	0.050 bc	0.193 b
Chlorides (%)	7.603 a	0.142 b	0.158 b	1.272 b	0.113 b	0.105 b	0.503 b
Lime (%)	22.80 a	13.30 bc	17.80 ab	17.70 ab	6.60 cd	2.50 d	16.30 ab
Cation exchange capacity (%)	12.09 c	8.70 d	7.84 d	13.37 c	4.63 e	4.60 e	17.39 a
Coarse sand (%)	13.80 e	41.60 c	48.50 b	23.70 d	63.70 ab	66.20 a	13.40 e
Fine sand (%)	51.60 a	35.90 b	28.60 c	47.40 a	35.30 b	33.10 bc	47.30 a
Coarse + Fine sand (%)	65.40 d	77.50 b	77.10 b	70.00 c	99.00 a	99.33 a	60.70 e
Silt (%)	10.00 a	4.30 d	5.24 c	7.49 b	0.70 e	0.50 e	10.52 a
Clay (%)	24.63 b	18.27 c	17.68 c	22.54 b	0.30 d	0.17 d	28.74 a
Silt + Clay (%)	34.60 b	22.50 d	22.90 d	30.00 c	1.00 e	0.67 e	39.30 a
Moisture equivalent (%)	17.12 bc	10.40 d	10.22 d	15.00 c	2.84 e	4.24 e	19.74 a

[1] Within each line, means followed by a common letter are not significantly at the 1% level as determined by the multiple range test (Steel and Torrie, 1960).

latter association has a significantly higher fine sand content (35.90%) than the sub-association *T. hirsuta–G. decandrum* (28.6%). Also the association of *T. hirsuta* has a significantly lower coarse sand content (41.50%) and silt content (4.30%) than the use of the sub-association. *T. hirsuta–G. decandrum* (48.50% and 5.24% respectively).

3. *Inland dune vegetation type*

This type occupies the areas covered by relatively deep sand deposited by wind action. The sand surface horizon is always more than 50 cm deep and the sand is coarse and not very calcareous. This type has significantly lower values of cation exchange capacity, moisture equivalent and silt clay and lime content than the other three vegetation types. It is also characterized by having a rather high content of coarse and fine sand (99.00 to 99.33%). The two associations belonging to this vegetation type can be separated on basis of lime content. The association of *U. maritima* has a significantly lower lime content (2.50%) than that of *P. albicans-E. fruticosum* association (6.60%). But the soil of the latter association has significantly higher moisture equivalent (4.24%) than that of *U. maritima* (2.84%).

4. *The degraded desert vegetation type*

This type occurs on the rocky and shallow soil. The vegetation is very sparse and comprises of scattered sub-shrubs. The soil of this type has significantly high moisture equivalent, clay content and cation exchange capacity than the other vegetation types belonging to this vegetation type.

DIRECTIONAL CHANGES BETWEEN THE FOUR DIFFERENT VEGETATION TYPES

Since edaphic conditions varied to a greater or a litter degree within the study area, different habitats are formed. A number of plant associations are also developed within each habitat.

Figure 1 illustrates the syndynamic relationships between the different vegetation types and their associated soils. The syngenetical pattern is based on the successional and retrogressional changes that occurs to the desert shrub vegetation type.

The desert shrub type occupies the original desert soil which is composed of a mixture of residual and aeolian deposits. The main association is *T. hirsuta.* As soil gets deeper and more clay accumulates, the association of *A. herba-alba-A. microcarpus* develops. The sub-association of *T. hirsuta — G. decandrum* occupies soils having a slightly less clay and more lime content and also shallower and less developed than that of *T. hirsuta.*

In saline sandy clay loam soils which represent a fairly advanced stage of development with. desalinization of top layers, the main association is *S. tetrandra — S. fruticosa.*

Where the original desert soil is covered by aeolian deposits, sand dunes are developed. The association of *P. albicans–E. fruticosum* occupies sand dunes

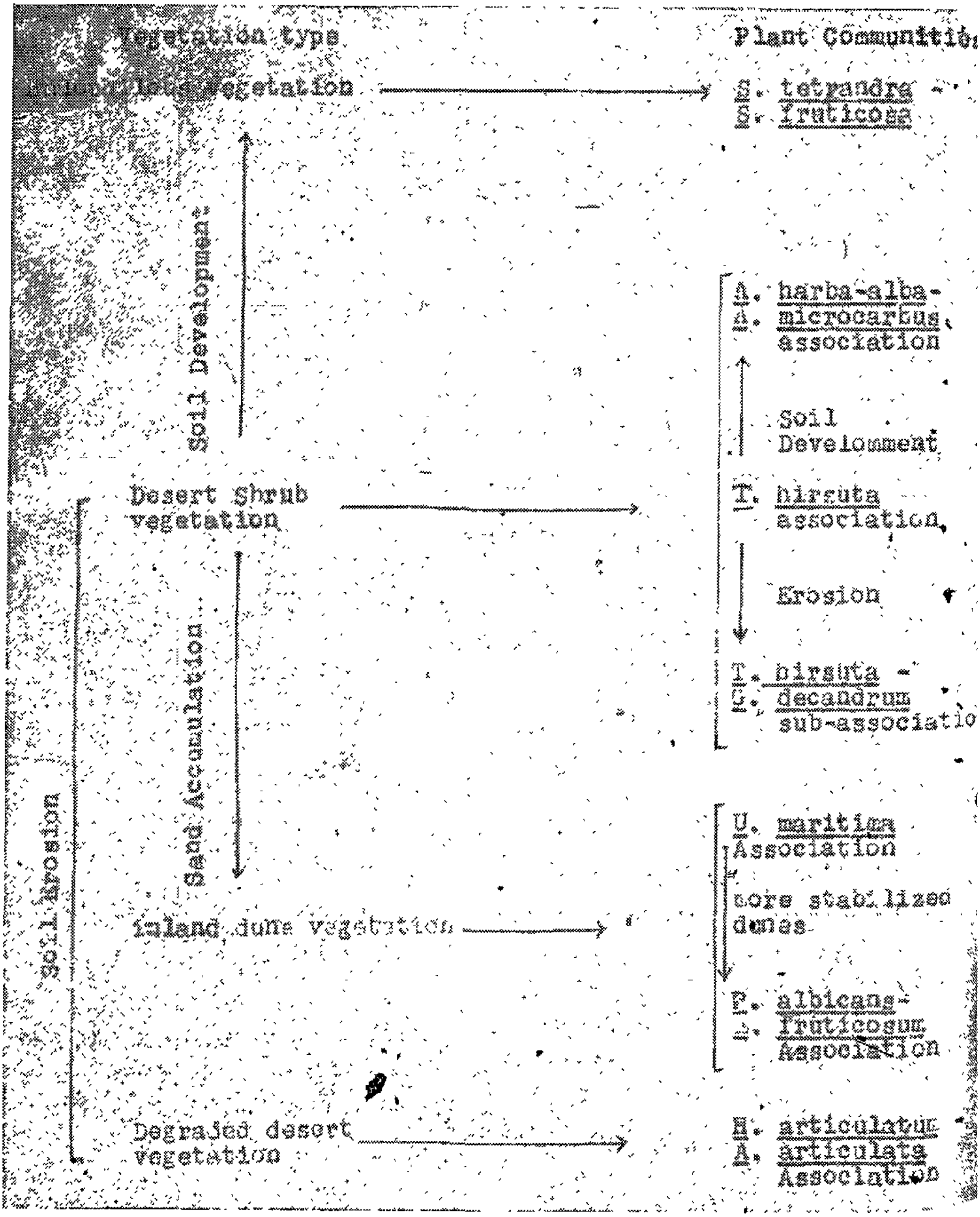

Fig. 1. Directional changes between the four habitat types and their plant associations.

more developed and stabilized as compared with those covered by the association of *U. maritima.*

Where the original desert soils are eroded and became shallow and rocky, the association of *H. articulatum–A. articulata* is developed.

The subdivision of landscape into its natural units referred to as vegetation types provides a better understanding of the landscape and subsequently enables a widespread application of econological knowledge to land management problems. Morevoer, the procedure undertaken in this study if followed in identifying the different habitats in other areas of the north western coastal region is likely to provide comparable results and valuable information for a better understanding of soil-plant interrelationships in the whole area. For range improvement and management purpose, the classification of rangelands into vegetation types, if it is accurately carried out, would reduce the amount of work invested in extensive phytosociological and soil analysis.

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I. 4.6

VEGETATIONAL ADAPTATION IN THE EXTREMELY ARID REGIONS OF THE INDIAN DESERT

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Extreme habitats have a fascination of their own. Usually in such habitats, one single factor is dominating and others are subsidiary. Evolution has occurred in all extreme environments so that plants within these areas are better adapted than they were previously to withstand the conditions of environment (Bradshaw, 1971).

Life-forms of plants reflect the major feature of the climate. It further provides a sound basis of natural ecological classification. Terrestrial communities represent large number of life-forms. Terms such as 'herbaceous' and 'woody' or the 'tree', 'shrub', 'grass' and 'forb' sequence have been widely used and provide the basis for the recognition of major terrestrial communities. Other terms such as hydrophytes, mesophytes and xerophytes have been used to refer adaptation along environmental gradients. But from the more detailed floristic point of view, one of the most widely used classification of life-form is that which was originally proposed by Raunkiaer (1934). Raunkiaer's life-forms are based on position of the renewal bud during unfavourable 'cold' or 'dry' periods, neglecting altogether the affinities of plants involved. Epiphytes, Phanerophytes, Chamaephytes, Hemicryphtophytes, Cryptophytes and Therophytes are the six primary categories which have been widely used. This series represents an increasing adaptation to adverse conditions–both of temperature and moisture (Cain, 1950; Stern and Buell, 1951).

Raunkiaer defined the life-form as the sum of the adaptations of the plants to the climate. According to him the plant climate could be expressed by the statistical distribution of life-forms in the flora of a region. He considered that heat was probably of the greatest importance in determining plant distribution. Since Raunkaier's pioneering work on the life-forms, many workers have attempted to classify life-forms, of course, mostly of temperate regions. Some attempts have, however, been made to classify life-forms in different hot deserts of the world (McDonald, 1937; Buell and Wilbur, 1948; Cain, 1950; Das and Sarup, 1951; Kanodia and Gupta, 1969).

Relationship of the life-forms with polyploidy, climate and ecology has been done mostly in the continental countries Hagerup, 1931, 1939; Larsen, 1960, 1963; Tischler, 1955; Polya, 1948; Felfoldy, 1948; Love and Love, 1943; Sokolovskaya and Strelkova, 1938,1940), Reese (1957) and Morton (1961, 1966) have worked out similar co-relations from North Sahara to Algerian region and east and west Africa respectively. However, on the Asian Flora, such studies have been made in the alpine region of Caucasus mountains, i. e. Altai & Pamir (Sokolovskaya and Strelkova, 1938,1940) and Eurasitic Arctic in USSR (Sokolovskaya and Strelkova, 1960). Baquar (1976) co-related the life-forms in the flora of Pakistan with the latitude, polyploidy and taxonomic groups. Earlier Gustafsson (1948) correlated polyploidy, life-form and vegetative reproduction. Ellenberg and Mueller-Dombois (1967) have recently revised Raunkiaer's classification. They have given this in the form of a key and have repeated it in Mueller-Dombois and Ellenberg (1974). Unlike Raunkiaer's original classification, these authors have considered plant behaviour during growing season as well.

There is a high degree of similarity in forms between the vegetation of arid and semi-arid zones throughout the world. The flora of the extreme arid regions is predominantly therophytic in rainy season. For the purpose of brevity of space, the classification of the life-forms of the 200 species of the extreme arid region, taken from the author's herbarium catalogue, has not been given again in this paper. Ninety eight species are therophytic (49%), although, they do not form stable associations. Hemicryptophytes are represented by 12 species (6%). Megaphanerophytes are entirely absent; only two species reach a height to be included under Mesophanerophytes and form only 1 percent of the total flora. Micro and Nanophanerophtes include 62 species (31%) and are represented by isolated stunted individuals, forming no forests. Compared with the general biological spectrum of the Indian Desert given by Das and Sarup, 1951 (Ph/22.1%, Ch/18.9%, H/15.5%, Cr/3.4%, Th/40.1%), these figures are striking in the higher percentage but lower numerical strength of Phanerophytes and small number of Hemicryptophytes, Cryptophytes (geophytes) and lianas of the region. The most characteristic life-forms of the region are Chamaephytes (9%) which are the leading species of most associations. Many of them, though attaining a height of 1-4 metres, cannot be classed under Phanerophytes because their upper branches die away and are replaced by shorter summer shoots in the dry season. The most important Chamaephytes are *Fagonia cretica, Tephrosia uniflora subsp. petrosa, Rhynchosia schimperii, Rhynchosia pulverulenta, Alysicarpus longifolius and Alysicarpus monilifer* among others.

Hemicryptophytes which are sparsely represented include 12 species (6%) such as *Chorchorus depressus, Seetzenia orientalis, Indigofera linnaei, Citrullus colocynthis, Glinus lotoides, Limeum indicum*. Moreover some Hemicryptophytic species become Therophytic in desert conditions or give off annual derivates. The commonly accepted notion that Cryptophytes (geophytes) are the most characteristic of the desert regions does not hold true; at least the area under present investigation is extremely poor in Cryptophytes since they are represented by only 4 species (only 2%). These species are *Corallocarpus epigaeus, Cistanche tubulosa, Dipcadi erythraeum* and *Cyperus atkinesonii.*

Therophytes, despite their abundance in number and coverage, hardly reflect the desert conditions. Their life-cycle is confined to few months of the rainy season and in years of extreme drought they fail to appear. Their dimensions vary greatly, depending upon the moisture conditions of the year.

Hemicryptophytes, Cryptophytes (geophytes) and Therophytes constitute a single ecological group, characterised by the interruption of life activities with the start of the dry season. They comprise about 57 percent of the flora, leaving 43 percent only for the forms permanently exposed to the difficult desertic conditions.

Flora of the region is dominantly Therophytic, since 98 species out of 200 species are Therophytes. Though these form no stable associations, they take a prominent part during the rainy season. Some Therophytes are weeds in the cultivated fields.

The normal spectrum given by Raunkiaer (*loc. cit.*), as based on calculations of all known flowering plants is:

$$\frac{\text{Mm/6, M/17, N/20,}}{\text{Ph/43}} \quad \text{E/3, S/1, Ch/9,}$$
H/27, G/3, HH/1, Th/13.

Calculations of the present area is as follows:

$$\frac{\text{Mm/1, M/9, N/22, L/2,}}{\text{Ph/34}} \quad \text{E/0, S/0, Ch/9,}$$
H/6, G/2, Th/49.

Comparison of Raunkiaer's spectrum with that of the present flora shows:

A. Therophytic percentage 49 is higher in the present flora than what has been estimated for the world flora.

B. The phanerophytic percentage (Mm, M, N, L) 34 is lower in the present flora than what has been estimated for the world as a whole (43).

A and B indicate less favourable conditions for vegetation in the present area in comparison to the world as a whole. It, however, compares well with that of the Egyptian desert flora (Hassib, 1954), where the Therophytes are represented by 50.3 percent. This is what should be expected in the extreme arid region.

Raunkiaer's life-form spectrum is most useful as an ecological descriptive device when the characters are weighed in a quantitative or community basis i.e. when number of individuals as well as number of species is considered. In the present area majority of species are annual but a few species of shrubs often make up the most important part of the vegetation.

According to Raunkiaer's concept there is a progressive increase of those species whose perennating buds lie near or within the ground as one approaches more severe climates. With this point in view a comparison of the flora of the extreme arid region with the life-forms of the entire Indian Desert including the semi-arid region shows interesting data, as given in Table 1.

Table 1. Comparison of life forms of the extreme arid region of the Indian Desert with other hot deserts of the world

Name of the region	Number of species	Percentage distribution of species among the life forms									
		Ph						Ch	H	Cr	Th
		Meg	Meso	M	N	L	Ph				
Extreme arid regions of the Indian Desert	200	—	1.0	9.0	22.0	2.0	34.0	9.0	6.0	2.0	49.0
				34.0							
Western Indian Desert (Das & Sarup, 1951)	538	—	2.3	2.2	4.6	7.8	5.2	18.9	15.5	3.4	40.00
					22.1						
Libyan Desert (Das & Sarup, 1951)	194	—	—	—	—	—	12.0	21.0	20.0	5.0	42.0
Cyrenaica Desert (Das & Sarup, 1951)	375	—	—	—	—	—	9.0	14.0	19.0	8.0	50.0
Death valley, California (Cain, 1950)	—	—	2.0	—	21.0	—	23.0	15.0	18.0	2.0	42.0
Ghardaya Desert, Algeria (Cain, 1950)	—	—	—	—	3.0	—	3.0	16.0	20.0	3.0	58.0
Ooldea Desert, South Australia (Cain, 1950)	—	—	19.0	—	23.0	—	42.0	18.0	4.0	1.0	35.0
Normal Spectrum (Raunkaier, 1934)	400	—	6.0	17.0	20.0	—	43.0	9.0	27.0	6.0	13.0

Ph-Phanerophytes; Meg-Megaphanerophytes; Meso-Mesophanerophytes; M-Microphanerophytes; N-Nanophanerophytes; L-Lianas; Ch-Chamaephytes; H-Hemicryptophytes; Cr-Cryptophytes; Th-Therophytes.

This comparison shows that the life-form spectrum changes progressively in the extreme arid region, the change being a shift towards emphasis on the more protected life-form classes. This is in accordance with Raunkiaer's thesis (1934).

In Table 1, the life-forms of this extreme arid region have been compared with the life-forms of the (1) Indian Desert, (2) the Libyan Desert, (3) the Desert of Cyrenaica, (4) the Desert of Death Valley, California, (5) the Ghardaya Desert, Algeria and (6) Ooldea Desert, South Australia, with the normal spectrum figures; the data have been quoted from Das and Sarup (1951), Cain (1950) and Raunkiaer (1934). Fig. 1 depicts the comparison of the life-forms of these areas.

A comparison of the life-forms in the Flora of the seven important hot deserts of the world shows that these areas mostly comprise of annuals. These life-forms are no doubt indicators of climate, the local edaphic factors, and the stage in succession also greatly influences the life-form composition (Cain, 1950). Raunkiaer's life-form spectrum is most useful as an ecological descriptive device when the categories are weighed on a quantitative or community basis i.e. when number of individual or number of species is considered.

This comparison of the life-forms of the several desert areas, which are climatically classified as 'hot deserts' reveals as many differences as there are similarities. The points in which they resemble one another are the pre-eminence of Therophytes (though the percentage values are variable) and the low proportion of Eryptophytes (geophytes). Nanophanerophytes (shrubs less than 2 m high) are well represented in most of the desert areas. Australian Desert stands out in having taller woody vegetation in abundance (19%) in comparison with only 1 to 2.3 percent in other desert areas.

While there is a sensitive correlation between the physiognomy and composition of vegetation and climatic parameters within each area, Raunkiaer's terminology is inadequate for the classification of the plant forms of the desert zones, it being primarily meant for the plants of temperate zones. Other systems have been suggested by a number of workers: Du Rietz (1931) for ground hugging plants; Weberbawer (1914) for the plants of the Peruvian mountains; Shreve (1942) for the arid zone of North-America and several others. Principal plant forms of the extreme arid region of the Indian Desert based on Du Rietz classification as modified by Cabrera (1952) have been depicted in Fig. 2 and summarised in Table 2. These are as follows:

1. *Haloxiles* (HL): Woody plants with persistent stem and boughs. The stem develops secondary structures from the second year of the plant's life.

A. *Arboriform* (A): With a main trunk either plain or ramified some distance above ground level.

a. Trees (T): Ramified trunk. The commonest types in arid zones are the Microphanerophytes or trees growing to a height of 1 to 8 metres. The commonest examples are: *Prosopis cineraia, Tecomella undulata* and *Acacia senegal.*

b. Rosulates (RO): Stem with no or few ramifications, the stem proper or the ramifications terminating in rosettes of leaves. This life-form is not represented in this region.

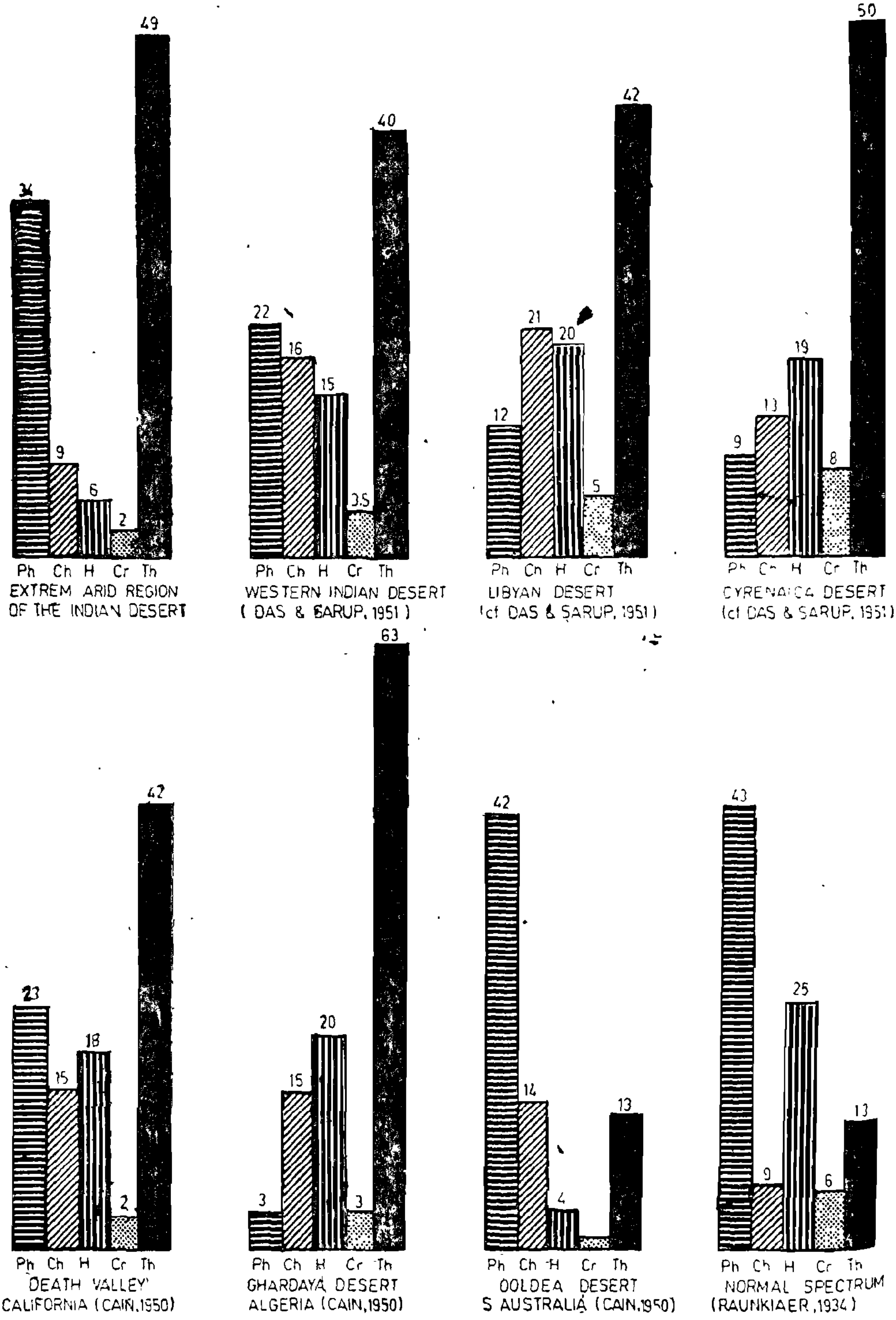

Fig. 1. Comparison of the life-forms of plants of seven hot deserts of the world.

Table 2. Life-forms of the extreme arid region of the Indian Desert on the basis of terminology given by Du Rietz and modified by Cabrera (1952)

Plant forms	Number of species	Percentage of species
1. Haloxiles (HL)	44	22
A. Arboriform (A)	14	7
a. Trees (T)	12	6
b. Rosulates (Ro)	—	—
c. Cereiform (Ce)	2	1
B. Arbustiform = Nanophanerophytes. (Arbu)	30	15
a. Upright shrubs (Us)	18	9
b. Creeping shrubs (Cs)	6	3
c. Pulviform shrubs (Ps)	4	2
d. Thick stemmed shrubs (Tss)	2	1
2. Hemxiles=suffrutices (Hx)	10	5
3. Herbs (Hb)	48	24
A. Hemicryptophytes (Hc)	40	20
a. Graminiform (Gr)	—	—
b. Rosular (Rl)	8	4
c. Caulifoliates (Cf)	20	10
d. Creepers (Cp)	12	6
B. Geophytes=Cryptophytes (Gp)	8	4
a. Rhyzomata (Rm)	4	2
b. Tubers (T)	—	—
c. Bulb geophytes (Bg)	4	2
d. Radicigemadas (Rg)	—	—
4. Therophytes (Th)	98	49

c. *Cereiform* (Ce): Tall plants with thick, leafless trunk and branches; also not represented.

B. *Arbustiform* (Nanophanerophytes) (Arbu): Woody plants with ramification starting at root level. This is one of the plant types most typical of the arid zones.

a. *Upright shrubs* (Us): This is the commonest type in the arid zones; the leaves are small in size and are lost in the dry season, whether winter or summer, at the slightest increase in humidity, they bud quickly. The commonest examples are *Calotropis procera, Capparis decidua.*

b. *Creeping shrubs* (Cs): Stem and branches hugging the soil.

c. *Pulviform shrubs* (Ps): Woody plants with very short branches closely interwoven to form an extremely thick pillow or cushion-shaped mass, sometimes almost rock-like in appearance.

d. *Thick stemmed shrubs* (Tss): Branches are thick and practically

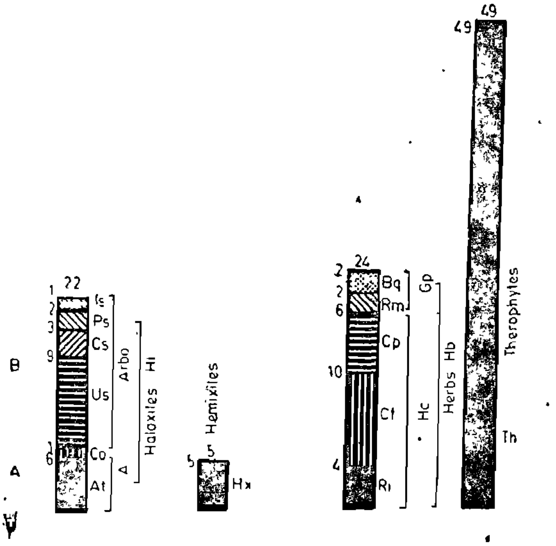

Fig. 2. Life-forms of the extreme arid region of the Indian Desert based on the terminology of Du Rietz (1931) and modified by Cabrera (1952).

leafless; *Euphorbia caducifolia.*

2. *Hemxilès suffrutices* (Hx): Plants in which the lower part of the stem is woody and perennial and the upper herbaceous and dying off yearly.

3. *Herbs* (Hb): Plants without a woody stem above ground.

A. *Hemicryptophytes* (Hc): Plants in which the annual resting buds are at soil level.

a. *Graminiform* (Gr): Plants with long, narrow, lineate leaves concentrated in the lower part of the stem.

b. *Rosular* (Rl): Herbs with a rosette of leaves at ground level from the centre of which the stalks or shoots spring. This type is relatively common in the arid zone, the foliage are on the ground and that protects the plant from the wind.

c. *Caulifoliates* (Cf): Hemicryptophytes without rosettes and with leaves growing direct from the stem.

d. *Creepers* (Cp): Hemicryptophytes with creeping stems. This is a frequent plant form in the arid zones.

B. *Geophytes* (Cryptophytes) (Gp): Herbs with subterranean resting buds, so that in the "dead" season no part of the plant is visible above ground.

a. *Rhizomata* (Rm): The resting buds are formed on rhizomes.

b. *Tubers* (T): The resting buds are formed on underground tubers but never reach the surface and fertilization takes place underground.

c. *Bulb geophytes* (Bg): The resting buds are protected by thick bud-sheaths forming bulbs, with the difference that the resperves are stored in the bud-sheath. Many arid zone liliflorales.

d. *Radicigemadas* (Rg): The resting buds are formed on the roots. Form which has been little studied of on occasion confused with rhizomed geophytes.

4. *Therophytes* (Th): Annuals without resting buds. On the conclusion of its short vegetative cycle the whole plant dies and the species only survives in the form of seed during the dormant period.

An analysis of Table 2 reveals that if the plants of the extreme arid region are classified according to Cabrera's concept, the Therophytes form the major bulk of plant components of the extreme arid region of the Indian Desert. This biological type–the Therophytes, is of frequent occurrence in the arid and the semi-arid zones and under certain extreme climatic conditions, is the only one capable of survival. The vegetative cycle of this life-form is very short (Ephemerophytes) and in many cases four to five weeks are enough to cover germination, growth, flowering, seeding and death. A short wet period, every few years, is all that such species need to survive, in such regions.

Herbs come next to Therophytes in the number of species. Haloxiles which constitute the characteristic permanent vegetation throughout the year from less than 1/4 of the total number of species (44), but their permanence gives the typical desertic character to the vegetation. Hemxiles form only 5 percent of the total species occurring in the area.

As in most other deserts, the majority of species in this extreme arid region are annuals and a major part of the vegetation consists of a few species of shrubs from the point of view of standing crop and annual production of dry matter. As a result the life-form spectrum of the vegetation community and the life-form spectrum of the flora do not necessarily coincide.

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I. 4.7

ANALYSIS OF STRUCTURE AND FUNCTION OF A BARCHANOID SAND DUNE ECOSYSTEM NEAR PILANI, RAJASTHAN

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INTRODUCTION

There has to be a systematic approach to understand the desert environment in order to exploit it for the fulfilment of some of our needs. In order to pursue such an approach, a barchanoid dune complex was selected for study.

DESCRIPTION OF THE STUDY SITES AND ITS ENVIRONMENTAL FACTORS

Study area

The study was conducted at a site located about 2 km from the Birla Institute of Technology and Science campus at pilani (28°23′N and 75°37′E with an altitude of about 350 m above the mean sea level). About 60 to 65% of the study site (total area 12,000 sq m) is covered with barchan dunes and the remaining 35-40% of the area is occupied by the interdunal lows. The heights of the dunes vary from 1 to 3.5 m.

The following sub-sites were selected for the detailed investigation carried out during May 1975 to April 1976: Site I: Windward sides of dunes, Site II: Crests of dunes, Site III: Leeward sides of dunes, Site IV: Intervening (interdunal) lows of dunes.

The perennial plant cover of the area comprises of *Prosopis, Acacia, Zizyphus, Capparis, Maytenus, Saccharum,* with a few scattered *Calotropis* and *Aerva* plants.

The area is exposed to stresses of severe grazing, and manual scrapping and cutting of the natural vegetation. Besides grazing and scrapping, hedgehogs, rodents (rats, squirrels), termites and insects also damage the vegetation at all stages of its growth and development. Beetles and mites are seen during rainy season.

Soil

The soils in the area are yellowish brown and sandy. The perpetual shifting of sand in these regions form these soils, which are azonal, alkaline, with low water holding capacity and organic matter (Table 1). Maximum gravimetric soil water at two depths (0.5 cm and 25-30 cm) was recorded in June (16.4%) in the interdunal lows. It has been observed that more moisture is retained by the soil at 25-30 cm depth than the surface soil. Lowest moisture (0.29%) value has been recorded in April in the surface soil of the crest of dunes.

Climate

The climate of the area is monsoonic. The computation of climatic data for the period 1959-75 reveals that the climatic formula for Pilani is EA$'_3$ a$'_2$ r. The formula shows that the climate is arid, third megathermal having water deficit around the year with no surplus. Based on the temperature and rainfall, the year can be divided into rainy (June to September), winter (October to February) and summer (March to May) seasons.

METHODOLOGY

For evaluation of phytosociological parameters, three 50 × 50 sq cm sample

Table 1: Physico-chemical properties of the soils

Parameters	Site I Windward	Site II Top	Site III Leeward	Site IV Interdunal lows
Colour	Yellowish brown	Light yellow	Light yellow	Darkish brown and yellowish
Bulk density (g. cm^{-3})	1.3	1.4	1.4	1.2
Coarse sand (%)	3.6	3.0	2.8	2 2
Fine sand (%)	94.4	96.0	95 7	87.8
Silt and clay (%)	2.0	1.0	1.5	10.0
Field capacity (%)	15.5	14.4	14.9	19.1
pH	7.3 - 8.4	8.1 - 9.0	7.4 - 8.6	7.0 - 8.1

plots were harvested of the ground level on each sampling date at each subsite. The samples brought from the field were separated and categorised into-(i) grasses, (ii) sedges, (iii) leguminous forbs and (iv) non-leguminous forbs. In the present study the phytosociological attributes for the above groups have been estimated from May 1975 to April 1976 following Misra (1968).

The samples from the harvest plots were further separated into green shoots and standing dead shoots. Litter was collected separately from each harvest plot and sifted in a fine sieve to remove the adhering soil particles. Below ground plant biomass was sampled by taking a monolith of 25 × 25 × 25 cm size in each harvest plot. Monoliths dug out were broken on the spot and roots were hand separated from soil before packing in polythene bags. The live green material, separated specimen wise, was washed and put in an oven at 80°C until constant weight was reached. Litter and standing dead materials were washed, oven dried and weighed. The belowground biomass was processed similarly for dry weight estimation.

Methods for calculation of production, accumulation and disappearance rates and system transfer functions as given by Singh and Yadav (1974) were followed.

The daily accumulation, transfer and disappearance rates were determined by dividing the material accumulated, transferred and disappeared by the number of days for respective seasons and the year.

RESULTS

Phytosociology

Detailed Tables showing the phytosociological record of the constituent species have been deleted and only the summarized observations have been dealt with.

Density

During the study period the maximum number of individuals m^{-2} recorded are: 44 on site I in November, 16 on site II in December, 60 on site III in July, and 176 on site IV also in July. The grasses are abundant on site IV (in the intervening lows) while the sedges are common on other subsites. Because of the biotic operations such as scrapping the density values are undoubtedly lower than the potentialities of the sites. The density would have been higher had the farmers not scrapped out the herbaceous vegetation during rainy season after cultivation of the land.

Importance value index (IVI)

The importance value indices recorded for various species during different months at various sites indicates that the values differ from site to site. The plant species showing highest IVI during rainy season include *Cyperus rotundus* (187) in June on site I, *Indigofera cordifolia* (280) in June, *Vigna* sp. (300) in July and August and *Pennisetum typhoides* (300) in September on site II, *Pennisetum typhoides* (229) in September on site III and *Boerhavia diffusa* (154) in June on site IV.

During winter season the dominant species with their IVI values recorded are: *Cyperus rotundus* (300) in January on site I, *Cyperus rotundus* (282) in January and February on site II, *Cenchrus ciliaris* (260) in January on site III and *Cyperus rotundus* (177) in February on site IV.

During summer season the species with their highest IVI values are as follows: *Cyperus rotundus* (300) in May on sites I and III and on site IV in March and April and *Cenchrus ciliaris* (300) in April on site II.

On yearly basis, among different plant categories, sedges have been found as the dominant plant group responsible for high IVI values.

Standing crop of green biomass

The green biomass on various sites varied from season to season. It shows an increase with the progress of rainy season on all the sites but due to human stresses the values fluctuate tremendously. In general, two potential growth periods occur-one in rainy season and the other in winter. The maximum biomass (g.m^{-2}.) was attained on all the sites in December in the following order: site IV (188.4)>site I (52.4)>site III (48.32)>site II (19.2).

Standing crop of dead shoots and litter

The standing dead vegetation fluctuates on all the sites. The peak of standing dead vegetation is seen in the month of January on all the sites in the following order: site III=site II (8.8 g.m^{-2}.)>site IV (8.0)>site I (4.0).

In the litter compartment also a season wise fluctuation was noted. Winter season exhibited maximum litter and the peak value reached in the month of December on sites II and III (4.0 and 8.0 g.m^{-2}.) respectively in January on site IV (14.0 g.m^{-2}.) and in February on site I (5.6 g.m^{-2}.).

Standing crop of total aboveground plant matter

The total aboveground standing crop (green biomass + standing dead vegetation + litter) was found to be maximum on site IV in all the months (Table 2).

Table 2. Standing crop of total aboveground biomass on different sites in different sampling periods from May, 75 to April, 76. (g.m^{-2}.)

Sampling months	Site I Windward	Site II Top	Site III Leeward	Site IV Interdunal lows
May (1975)	3.12	0	8.0	26.0
June	18.4	2.0	13.12	44.88
July	2.4	2.0	6.0	82.4
August	2.12	0.24	0.72	77.12
September	5.64	9.84	9.08	34.28
October	2.76	15.16	10.88	99.96
November	45.58	8.72	38.08	186.60
December	55.2	41.2	64.72	206.4
January (1976)	21.6	22.0	16.6	105.6
February	8.8	12.4	11.2	23.6
March	0	2.0	3.6	16.0
April	0	1.0	1.2	12.8

The peak value was reached in the month of December (206.4 g.m^{-2}.) and the minimum in April (12.8 g.m^{-2}.) on site IV. The peak values on site I, II and III were also reached in December (55.2, 41.2 and 64.7 g.m^{-2}.) respectively. On site I and III the minimum values were reached in April and on site II in May.

Standing crop of total belowground biomass

The total standing crop of roots (Table 3) showed an increase from June to December. The rainy season's peak (g.m^{-2}.) in the four sites was attained in the following order: site IV>site I> site II>site III. The peak biomass pattern in winter season was as follows: site IV> site I>site III>site II. Summer season however, displays a pattern of biomass production in the following order: site I>site IV>site II>site III.

Total standing crop of vegetation

The pattern of the total standing crop (g.m^{-2}.) of vegetation (above ground) Green + standing dead + litter + underground biomass was found in the following order: site IV (275.2)>site I (100.8)>site III (79.6)>site II (52.4). A definite pattern was observed here in the sense that the peak biomass is reached in December (Table 4).

Contribution of the constituent species and various plant categories to green biomass

During rainy season the major portion of the green biomass of the community was contributed by *Vigna* species and *Pennisetum typhoides*. The same species continued to contribute to the biomass of the system in winter also till they were harvested in December. After the harvest

Table 3. Standing crop of total belowground plant material in different months from May 1975 to April 1976 (g.m^{-2}.)

Sampling months	Site I Windward	Site II Top	Site III Leeward	Site IV Interdunal lows
May (1975)	7.36	0	0.16	<3.52
June	8.16	0.48	0.80	24.0
July	2.4	0.32	3.36	33.44
August	0.32	0.16	0.32	44.32
September	4.0	6.88	2.72	15.0
October	1.44	0.96	19.04	24.80
November	37.6	3.2	13.6	60.64
December	45.6	11.2	14.88	68.8
January (1976)	22.08	16.8	2.56	26.4
February	1.12	0.64	0.8	20.8
March	0.32	0.64	0.64	1.6
April	0.48	1.92	0.32	2.4

Table 4. Total standing crop of the vegetation on different sites in different months from May 1975 to April 1976 ($g.m^{-2}$.)

Sampling months	Site I Windward	Site II Top	Site III Leeward	Site IV Interdunal lows
May (1975)	10.48	0	8.16	29.52
June	26 56	2.48	13.92	68.88
July	4.8	2.32	9.36	115.84
August	2.44	0.4	1.04	121.44
September	9.64	16.72	11.80	49.28
October	4 20	16.12	29.92	124.86
November	83 18	11.92	51.68	247.24
December	100.80	52.5	79.6	275.2
January (1976)	43.68	38.8	19.16	132.0
February	9.92	13.04	12.0	44.4
March	0.32	2.64	4.24	17.6
April	0.48	2.92	1.52	15.2

of the crop, i.e. from middle of winter season to the end of summer the biomass contribution in the system was only by grasses (*Aristida mutabilis* and *Cenchrus ciliaris*) and by a sedge (*Cyperus rotundus*). On site IV during rainy season there were species other than the cultivated ones also which contributed to the biomass of the system. These species include: *Boerhavia diffusa, Convolvulus microphyllus, Corchorus depressus, Euphorbia thymiolia* and *Borrevia articularis.*

Monthly variations in aboveground (green biomass) net production (ANP)

The estimates of aboveground net production on all the sites during various sampling intervals were calculated through a change in biomass. The maximum growth of green biomass on all the sites was found during September, October, November and December which constitute the major growth period in this area. The peak increment in green biomass was maximum on site IV and least on site II. The pattern of the peak values varied in the following manner: site IV>site III> site I>site II. Summer had very low production compared with other two seasons.

Monthly variation in belowground net primary production (BNP)

Maximum production of belowground biomass was recorded in November on site I, in December on site II, in October on site III and in November on site IV. The peak of belowground net production on site II did not correspond with the peak of green biomass production while the other sites showed correspondence in the two peaks.

Monthly variation in standing dead shoots (SD)

The transfer to standing dead compartment on all the sites was calculated by change in the biomass of dead shoots.

Maximum standing dead material was recorded in November on sites II, III and IV and in December on site I. On all the sites the transfer to standing dead compartment was at its peak during winter season. All the sites started showing the disappearance of standing dead shoots in late winter and early summer. It was observed that there was no accumulation of standing dead shoots in any site till May. Some standing dead was found on site IV which disappeared in early August.

Monthly variations in litter deposition

Maximum litter accumulation on different sites was recorded in January on site I, in December on sites II and III and in November on site IV. Litter accumulation in summer season was recorded only on site I and in rainy season on sites II and IV. There was a continuous litter disappearance during summer season on sites III and IV. On sites I, II and IV there was a fluctuation in litter deposition during summer and rainy seasons.

Net primary production (NPP)

The estimates for aboveground net production (ANP), belowground net production (BNP) and total net production are given in Table 5. Both the aboveground and belowground net production are found to be maximum during winter season for all the sites in the following order: site IV>site I>site III>site II.

Table 5. Seasonal and annual distribution of net primary production ($g.m^{-2}$.) and its rate ($g.m^{-2}$. day^{-1}) in four study sites (from May, 1975 to April, 1976)

Seasons	Site I		Site II		Site III		Site IV	
	Windward		Top		Leeward		Interdunal lows	
	NPP	RATE	NPP	RATE	NPP	RATE	NPP	RATE
			Aboveground					
Rainy	19.00	0.16	11.60	0.10	15.08	0.12	52.96	0.43
Winter	50.44	0.33	25.00	0.17	47.88	0.32	160.12	1.06
Summer	2.92	0.03	1.00	0.01	7.2	0.07	19.6	0.21
Annual	72.36	0.20	37.6	0.10	70.16	0.19	232.68	0.64
			Belowground					
Rainy	4.48	0.04	7.2	0.06	5.6	0.05	40.8	0.33
Winter	44.16	0.29	15.84	0.10	17.6	0.12	53.8	0.36
Summer	7.04	0.08	1.28	0.01	0	0	1.92	0.02
Annual	55.68	0.15	24.32	0.07	23.2	0.06	96.52	0.26
			Total					
Rainy	23.48	0.19	18.8	0.15	20.68	0.17	93.76	0.77
Winter	94.60	0.63	40.84	0.27	65.48	0.43	213.92	1.42
Summer	9.96	0.11	2.28	0.02	7.2	0.08	21.52	0.23
Annual	128.04	0.35	61.92	0.17	93.36	0.26	329.2	0.90

The total net production and its rate was maximum during winter season for all the sites in the following order: site IV>site I>site III>site II. The total net production and its rates were minimum during the summer season on all four sites. In all the seasons the total net production and its rates were in the order: site IV>site I>site III>site II.

Net accumulation, transfer and disappearance rates

On all the four sites the rate of transfer of aboveground (green) net production to standing dead compartment was maximum during winter, and minimum during summer on sites I, III and IV and in rainy season on site II. The rate of transfer from standing dead to litter compartment was also maximum in winter on all the four sites and minimum in summer on sites I, II and IV and in rainy season on site II. On all the four sites the disappearance of litter was maximum during winter season and minimum in summer on sites I, III and IV and in rainy season on site II. The belowground biomass disappearance was maximum during winter season on all sites and minimum in summer on site I, III and IV and in rainy season on site II. The belowground net production was maximum during winter and minimum during summer season on all the four sites.

On annual basis, the rate of production is slightly more than the rate of total disappearance on site II. On all the other sites the rate of total disappearance is a little more than the rate of production.

DISCUSSION

From the phytosociological data it is found that the maximum number (176) of individuals m^{-2} were recorded on site IV during rainy season. The minimum number of individuals were recorded on site II. On all the four sites the density and IVI were seen to be maximum in either rainy or winter season. The reason for rich vegetation in early winter season, is the ripening of the crop plants and growth stimulation due to pre-winter showers. Thereafter, there is a constant disappearance of vegetation due to high temperatures and lack of moisture during summer. The low number of individuals and low IVI values on site II may be due to the topographic position and exposure as well as the microclimate which makes the soil unstable and poor in moisture content at this particular site. Apart from the sub-habitat conditions, the biotic disturbance considerably affects the composition of the vegetation. This explains the variation in the vegetational pattern of the four sites.

In rainy and winter seasons, legumes and non-leguminous forbs dominate in terms of IVI as compared to grasses and sedges. The low IVI values of grasses and sedges is due to human stresses. However, in late winter and summer season when there is very low moisture in soil, and inspite of other adverse conditions, some grasses and sedges are found to be surviving. These include: *Aristida mutabilis, Cenchrus ciliaris, Cenchrus biflorus* and *Cyperus rotundus.* In general it can be observed that the vegetation density is governed by the soil moisture and topographic features of the sites. The temporal vegetation pattern on the four sites exposed to various climatic conditions reveals that much of growth of ephemerals and annuals occur for a short period from

June to September. Further, due to pre-winter showers a limited amount of resprouting occurs. It is observed that winter season exhibits more production on all the sites. This may be due to the cultivated species which attain their peak biomass in winter. Further, the scrapping of the herbaceous vegetation by farmers in rainy season reduces the competition for cultivated species.

Normally, any natural ecosystem of sand and dune regions should show high rate of productivity, in aboveground (green) biomass compartment, during rainy season. This was not found so in the present ecosystem. Instead, winter season recorded the maximum productivity. The reason is obvious. This being a man-managed ecosystem, is cultivated during rainy season in the process of which all the natural herbaceous vegetation is removed and only the cultivated species are allowed to grow.

The system production and disappearance rates among the four sites vary seasonally and annually. The rates are found in order of site IV>site I>site III> site II.

The system behaviour as evidenced by the obtained results shows that maximum biological activity in terms of primary production, and inter-compartmental transfers of the site is limited to a short wet period of 4 months and early winter season. However, rainfall and available soil water seem to play a crucial role in the growth and development of vegetation in winter and summer seasons also. The results of the present study are in conformity with Joshi's (1978) account wherein he has designated such ecosystems as a 'Pulse System' where the rhythm of moisture seems to be more important than any other environmental variable.

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I. 4.9

TEMPORAL CHANGES IN THE VEGETATION OF EXCLOSURES ON VARIOUS DESERTIC HABITATS

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INTRODUCTION

The high pressure of the enormous livestock population coupled with other human use factors has resulted into excessive exploitation of the existing vegetation in western Rajasthan. Consequently vegetation is generally found in a highly degraded condition. Regeneration of the natural vegetation by certain efficient and economic methods has, therefore, been the major need. One of the methods that is generally suggested for this purpose is the protection of the degraded vegetation through exclosures for a certain period of time before the vegetation resources could be utilized once again. With this end in view, a chain of long term exclosures were established on a variety of habitats at the CAZRI Research Stations located in different eco-climatic zones of western Rajasthan. The experimental evidences gathered from the above studies are being described and discussed in detail.

SAND DUNES

Vegetation development in an 18 year old exclosure on coalesced barchan dunes at Udramsar (27°5′ to 28°4′ N latitude and 72°5′ to 74°0′ E longitude) was studied by Shankar and Dadhich (1977). Parallel observations were taken for the dune vegetation lying outside the fence line. Typical sand dune species (Shankarnarayan *et al.*, 1965; Satyanarayan *et al.*, 1966) were represented at this site. Vegetation analysis of the herb layer revealed comparative species richness and dominance of the species of higher ecological status i.e. *Panicum antidotale* and *Cenchrus prieurii* under protection. The mobile barchan dunes were devoid of grassy vegetation. As compared to the top and the slope, the base of the protected sand dune showed (Table 1) higher vegetal cover and herbage yield which were of correspondingly lower order in case of the stabilized but unprotected dune. The base of the stabilized but unprotected dune showed, however, higher crown cover as compared to the stabilized but protected and the mobile barchan dune. Protection favoured dominance (in terms of RIV) of *Calligonum polygonoides* and *Sericostema pauciflorum*. As compared to the stabilized dune the mobile barchan dunes showed preponderance of *Crotalaria burhia* and *Aerva persica,* which are reported (Kanodia and Gupta, 1969) to favour current fallows and fresh dunes. This may be related to the soil moisture status which is reported (Mann *et al.,* 1976) to be consistently more in unstabilized dunes than that of the stabilized dunes. The leeward side of the dune, both protected and unprotected supported greater (Table 2) vegetative cover. The flanks and the windward side came next in the order.

SANDY UNDULATING PLAINS

Vegetation development in the 12 years old exclosures on the sandy plains at Beechwal and Chandan was studied by Gupta and Saxena (1971). Their studies revealed improvement in the ground cover under protection. The unprotected area shows preponderance of shrubs and undershrubs. Basal cover of palatable perennial and annual species decreases considerably in the unprotected area which simultaneously show increase in the population of less palatable species with poor nutritive value e.g. *Tephrosia*

Table 1. Herbage yield and vegetal cover of the protected (P) and unprotected (UnP) dunes

Vegetation parameters	Sandy Plains	Stabilized dune						Mobile dune		
	(Unprotected)	Top		Slope		Base		Flanks	Windward	Leeward
		P	UnP	P	UnP	P	UnP	(Unprotected)		
Herbage yield (g/m^2)	46.44	24.3	28.0	61.0	49.0	228.8	20.5	—	—	—
Ground cover (per 1m length)	6.59	4.13	3.22	5.11	—	8.66	—	—	—	—
Bare area (per m length)	93.41	95.87	96.78	94.89	—	91.34	—	—	—	—
Crown cover (per 100 m^2)	—	21.80	11.31	11.84	11.84	11.78	30.8	6.13	1.75	0.95

Table 2. Relative Importance Value (RIV) of shrubs and under shrubs on various aspects of the protected (P) and unprotected (UnP) dunes

Species	Flanks		Windward		Leeward	
	P	UnP	P	UnP	P	UnP
Aerva persica	—	17.8	—	—	2.6	9.5
Calligonum polygonoides	72.1	3.3	79.6	—	60.5	—
Crotalaria burhia	11.7	76.1	6.3	91.5	16 0	90.5
Indigofera tinctoria	—	—	—	—	6.1	—
Prosopis juliflora	16.1	—	14.0	—	14.0	—
Sericostema panciflorum	—	—	—	—	4.9	—
Farseti hamiltonii	—	2.7	—	8.5	—	—

purpured, Crotalaria burhia, Aerva persica, Tribulus terrestris and *Oropetium thomaeum.* These may be regarded as indicators of overgrazed condition.

ROCKY HABITAT

Several studies (Bhimaya *et al.*, 1963; Saxena *et al.*, 1974) on the rocky habitat at Kailana, have been made to obtain information on the regeneration of the vegetation cover. More recently Shankar and Saxena (1976) recorded observations in the various compartments of the 20 years old exclosure at Kailana and also made parallel observations in the adjoining open area. This study, along with the earlier studies, clearly indicate the efficacy of protection of vegetation as a method of the improvement of the vegetative cover on rocky habitats. It was observed that IVI of the indicator species of higher ecological status e.g. *Eleusine compressa, Dactyloctenium sindicum* etc. was higher under protection than that in the open area. The reverse held true for the indicator species of lower ecological status e.g. *Melanocenchris jacquemontii* and *Oropetium thomaeum.* The ground cover was higher in the open area due to the rosette habit of plants and the thickets of *Oropetium thomaeum* which is a primary coloniser on weathered rocks. The herbage yield is much higher under protection. Similar trend can be seen (Table 3) in the regeneration of the woody species. Progressive increase in the density of the major trees and shrubs i.e. *Acacia senegal*, *Zizyphus nummularia* and *Grewia tenax* was observed (Table 4) under protection. In the open area the density of these plants was low and further decreased during the 20th year. Surprisingly *Zizyphus nummularia* showed trend of regeneration with higher density in the open area during the 20th year.

Table 3. Changes in tree and shrub vegetation of a rocky habitat (Kailana) due to twenty years of protection

	Protected			Unprotected		
	Top	Slope	Depression	Top	Slope	Depression
Acacia senegal	15.1	18.6	26.6	10.7	17.8	18.5
Grewia tenax	24.7	22.2	23.4	27.7	36.4	34.3
Zizyphus nummularia	38.4	36.9	15.6	37.4	16.8	15.1
Euphorbia caducifolia	4.1	3.0	4.8	6.2	15.6	14.3
Prosopis juliflora	4.4	9.2	6.3	13.4	10.0	7.5
Number of shrubs	12	16	18	5	4	6
Number of trees	4	3	4	2	3	3
Total number of species	16	19	22	7	7	9
Total crown cover/100 sq m	59.1	23.1	54.9	50.2	21.4	32.8

Table 4. Changes with time in the woody vegetation of a rocky habitat at Kailana

Vegetation Parameters	Protected compartments										Unprotected area	
	I		II		III		IV		V			
	10yr	20yr	10yr	20yr	10yr	20yr	10yr.	20yr	10yr	20yr	10yr	20yr
Density (per 100 m^2) of :												
Acacia senegal	1.6	2.5	—	3.7	2.8	1.4	2.7	3.7	0.6	1.5	0.8	1.0
Zizyphus nummularia	10.0	19.0	—	11.0	5.0	20.0	2.0	7.0	5.0	13.0	2.0	13.0
Grewia tenax	2.0	0.4	—	2.3	4.7	4.0	2.5	4.6	3.7	5.2	8.0	7.5
Total No. of species	11	8	—	12	10	11	11	14	9	14	6	9
Total No. of plants per 100 m^2	20	15	—	21	19	33	9	16	14	25	13	25

PEDIMENT PLAINS

Studies on the 18 years old exclosure at Bhopalgarh were conducted by Shankar and Sexena (1977). Within the exclosure four major plant communities i.e. *Dichanthium annulatum* on deposits of heavy soil, *Aristida-Eragrostis* on exposed gravelly surface with thin soil/sand deposition, *Eremopogon foveolatus* on loamy sand deposits and *Cenchrus ciliaris*, on heavy sandy loam deposits were identified and their cover and production compared with their counterparts in the open area lying outside the fence line. Results indicated improvement in their ground cover, forage and litter yield in the exclosure. The *Aristida-Eragrostis* community which is of low ecological status, showed dominance in the open area whereas in the exclosure plant communities of higher ecological status e.g. *Dichanthium annulatum* and *Cenchrus ciliaris* dominate. The herbage production was highest in the protected, *D. annulatum* community (4.1 t/ha) as compared to that in the open area (0.13 t/ha), followed by *Cenchrus ciliaris* (2.58 t/ha in the exclosure and 0.44 t/ha in the open). Higher litter production in the exclosure apparently helped in the soil built up that *inter alia* supported superior vegetation cover as compared to that in the open area.

The exclosure at Jadan (about 18 years old) also led to improvement (Gupta and Saxena,, 1971) in vegetation cover. Here, the cover of *Cenchrus setigerus* which is of high ecological status was higher (4.10) under protection as compared to that (0.18) in the open. The reverse held true for *Oropetium thomaeum* which is a primary coloniser (lowest status).

OLDER ALLUVIAL PLAINS

Seven exclosures of 1 ha each have been established on the older alluvial flats at Pali (Central Research Farm, CAZRI). Vegetation of these exclosures and of those lying outside (Tables 5 and 6) the fence line have been studied (Shankar and Saxena, 1977). As a result of nearly 18 years of protection distinct development of vegetation in the exclosures (Tables 5 and 6) exists. *Cenchrus setigerus* which represents the stable grass cover of this area had higher ground cover, botanical composition and herbage production than that in the adjoining open area. Only *Oropetium thomaeum* and other annuals of low productivity occurred in the open area.

The composition, density, canopy cover and the height of the shrubs increased in the exclosure. Large number of saplings of *Mimosa hamata* and *Zizyphus nummularia* were noticed (Table 6) in the excolsures and not in the open area. These shrubs had higher density in the exclosure forming an almost impenetrable thicket. Such a development of vegetation indicated the trend towards a scrub and then woodland stage. From the range management angle the succession of the vegetation need to be arrested at an earlier stage of *Cenchrus setigerus* grass cover with a sprinkling of shrubs that would provide leaf fodder e.g. *Zizyphus nummularia*.

In a separate study (Gupta and Saxena, 1971) on the vegetation development on the older alluvial flats at Jodhpur and Sojat, it was observed that cover of the perennial grasses i.e. *Eremopogon foveolatus, Eleusine compressa* and *Heteropogon contortus* was much greater in

Table 5. Changes in the cover, composition and herbage production of the ground vegetation of flat older alluvial plains at Pali

Species	Ground cover		Composition (%)		Herbage production (kg/ha)	
	P	UnP	P	UnP	P	UnP
Cenchris setigerus	2.85 (73.80)	0.23 (8.6)	24.6	3.1	580	40
Cenchrus ciliaris	0.03 (0.7)	—	0.1	—	10	—
Eremopogon foveolatus	0.21 (6.2)	0.02 (0.60)	4.6	0.5	140	10
Eleusine compressa	0.37 (11.4)	1.19 (45.1)	14.4	33.7	200	360
Oropetium thomaeum	—	0.22 (8.7)	—	10.2	—	180
Annual grasses	0.17 (5.2)	0.43 (31.3)	37.0	27 6	550	310
Forbs	0.09 (2.5)	0.52 (5.6)	18.9	25.0	250	—
Zizyphus nummularia (seedlings)	0.01 (.03)	—	0.5	—	20	—
Total	3.73	2.61			1750	900

Relative cover in parenthesis.

Table 6. Changes in the botanical composition of the woody vegetation of the flat older alluvial plains at Pali

Species	% Composition		Canopy cover sq m		Height (m)		Average density (0.1 ha)	
	Protected	Unprotected	Protected	Unprotected	Protected	Unprotected	Protected	Unprotected
Mimosa hamata	22.6	—	0.7	—	1.1	—	123.7	—
Zizyphus nummularia	27.8	33.3	1.2	—	1.4	—	150.7	29
Balanites aegyptiaca	2.8	12.6	1.1	0.1	2.9	0.3	12.2	43
Prosopis juliflora	0.3	33.3	—	—	—	1.6	1.3	21
Other species	3.1	20.8	—	—	—	—	14.1	6
Mimosa hamata (saplings)	27.4	—	—	—	—	—	151.0	—
Zizyphus nummularia (saplings)	16.0	—	—	—	—	—	92.0	—
Total	100.0	100.0	3.0	0.1	—	—	549.0	99

the exclosures. The cover of *Cenchrus setigerus* increased in the exclosures at Jodhpur but at Sojat the cover of this plant was slightly higher in the open area. By and large protection helped the regeneration of a perennial grass cover.

SALINE DEPRESSIONS

In saline depressions the dominant grass cover is typified by *Sporobolus helvolus*. Regeneration of this grass was noticed (Gupta and Sexena, 1971) in the exclosure at Bilara. The total ground cover in the exclosure and in the open area was 12.17 and 3.82, respectively. The cover of *Sporobolus helvolus* was 8.39 in the exclosure and 1.08 in the open area. The preponderance and the cover of annual grasses too increased under protection.

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I. 4.12

THE IMPACT OF CANAL IRRIGATION ON THE FLORA OF THE RAJASTHAN DESERT

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INTRODUCTION

A major event which has taken place in recent years in W. Rajasthan which is bound to have a profound influence on the ecosystem of N.W. part of the Rajasthan desert is the construction of the Rajasthan canal. The area to be served by this canal falls mainly in the districts of Ganganagar, Bikaner and Jaisalmer. The main canal when completed will be 445 km long with 7000 km of distribution system and will be one of the world's largest irrigation projects. The gross service area of the Rajasthan canal project will be over 2 million hectares of which the cultivable command area will be 1.3 million hectares (Sain, 1976; Kapoor and Rajvanshi, 1977). The irrigation facilities to be provided by the Rajasthan canal, the conversion of arid land into cultivable fields and the tremendous increase in population will have a great influence on the natural vegetation of this

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part of the Rajasthan desert. The changes that are likely to take place in the Rajasthan canal command area can be visualised by the study of the present day vegetation of Ganganagar district.

Ganganagar district lies in the extreme north of Rajasthan and is located between latitudes 28°40′ and 30°6′ N and longitudes 72°36′ and 75°30′ E. Prior to the construction of the Gang canal which was formally opened in October 1927, the entire district, which is a part of the Great Indian Desert, presented a picture of a typical desert. At present the western and the northern parts of Ganganagar district are irrigated by Gang canal, Bhakra canal and the Rajasthan canal systems. This has resulted in the transformation of a vast inhospitable stretch of arid land into a fertile land, famed for its agricultural produce. In the irrigated area the natural vegetation has considerably been destroyed by the farmers. Xerophytic plants, unable to tolerate excessive water, are getting eliminated from the cultivated area. The natural vegetation in the canal command area now exists only in wastelands and protected areas like reserve forests, as in Hanumangarh and Bijaynagar.

MATERIAL AND METHODS

Four botanical exploration tours were undertaken, namely in November 1976, October 1977, February-March 1978 and August 1978 and a total of 577 field numbers of plant specimens were collected. In addition, observations on the vegetation in different parts of the district were also made. All the specimens collected are deposited in the herbarium of the Arid Zone Circle, Botanical Survey of India, Jodhpur (BSJO) and in the Central National Herbarium, Howrah (CAL).

RESULTS AND DISCUSSION

The vegetation of Ganganagar district may be classified broadly under the following heads:

(1) Unirrigated areas,
(2) Ghaggar alluvial plain and
(3) Irrigated areas.

Unirrigated area

The eastern parts and the extreme western border of the district are unirrigated and are covered with sandy plains interspersed with sand dunes. These sand dunes may be unstabilised as in the region west of Anupgarh or may be stabilised. The soils here, in general, fall under the group 'Desert soils', which are poor in structure with low organic carbon content. These soils are normal in reaction and hence there is no problem of salinity or alkalinity (Vinod Kumar *et al.*, 1973). The species found here are almost the same as those found in similar habitats in the other parts of Rajasthan desert like Bikaner and Churu districts. The common trees in this area are Acacia raddiana Savi, A. senegal (Linn.) Willd., Capparis decidua (Forsk.) Edgew., Prosopis cineraria (Linn.) Druce, Salvadora oleoides Decne. and Tecomella undulata (Sm.) Seem. In addition, shrubs, undershrubs and herbs like Aerva javanica (Burm. f.) Juss. ex Schult, Arnebia hispidissima DC., Calligonum polygonoides

Linn., Calotropis procera R. Br., Clerodendrum phlomidis Linn. f., Convolvulus microphyllus Sieb. ex Spreng., Crotalaria burhia Buch.-Ham. ex Benth., Dipterygium glaucum Decne., Farsetia hamiltonii Royle, Haloxylon salicornicum (Moq.) Bunge ex Boiss., Heliotropium strigosum Willd., Indigofera argentea Burm. f., I. cordifolia Heyne ex Roth, I. hochstatteri Baker, I. linifolia (Linn. f.) Retz., Leptadenia pyrotechnica (Forsk.) Decne., Polygala erioptera DC., Sericostoma pauciflorum Stocks, Tephrosia strigosa (Dalz.) Sant. & Mahesh., Tribulus longipetalus Viv., Zizyphus nummularia (Burm. f.) Wt. & Arn. etc. are also found. The root parasite Cistanche tubulosa Wt. is found as a parasite on Aerva javanica (Burm. f.) Juss. ex. Schult., Calligonum polygonoides Linn. and Calotropis procera R. Br. The grasses and sedges frequently met with are Aristida adscensionis Linn., A. funiculata Trin. & Rupr., A. hirtigluma Steud. ex Trin. & Rupr., Cenchrus biflorus Roxb., C. ciliaris Linn., C. prieurii (Kunth) Maire, C. setigerus Vahl, Cymbopogon jwarancusa (Jones) Schult., Dactyloctenium aegyptium (Linn.) P. Beauv., D. sindicum Boiss., Desmostachya bipinnata (Linn.) Stapf, Eleusine compressa (Forsk.) Aschers. & Schweinf. ex C. Christensen, Eragrostis ciliaris (Linn.) R. Br., E. tremula Hochst. ex Steud., Lasiurus hirsutus (Forsk.) Boiss., Latipes senegalensis Kunth, Panicum antidotale Retz., P. turgidum Forsk., Cyperus arenarius Retz., C. conglomeratus Rottb. etc. The common creepers here are Citrullus colocynthis (Linn.) Schrad., C. lanatus (Thunb.) Mansf., Cucumis melo Linn. var. culta Kurz etc. Among the common climbers, mention may be made of Momordica dioica Roxb. ex Willd. and Mukia maderaspatana (Linn.) Roem.

Ghaggar alluvial plain

The soils here fall under the type "Reverine soils". Alkalinity and salinity problem in these soils is comparatively greater and the organic carbon status is also slightly higher (Vinod Kumar *et al.*, l.c.). The natural vegetation here is sparse, especially in low lying saline tracts. The common plants found here are Ammannia baccifera Linn., Argemone mexicana Linn., Echinops echinatus Roxb., Eclipta alba (Linn.) Hassk., Haloxylon recurvum (Moq.) Bunge ex Boiss., H. salicornicum (Moq.) Bunge ex Boiss., Launaea procumbens (Roxb.) Ramayya and Rajagopal, Peganum harmala Linn., Phyla nodiflora (Linn.) Greene, Polygonum plebeium R. Br., Portulaca oleracea Linn., Pulicaria crispa (Cass.) Benth. and Hook. f., Salsola baryosma (Roem. and Schult.) Dandy, Sesuvium sesuvioides (Fenzl.) Verdc., Suaeda fruticosa (Linn.) Forsk., Trianthema portulacastrum Linn., Zygophyllum simplex Linn. etc. The common grasses and sedges include Cynodon dactylon (Linn.) Pers., Dactyloctenium aegyptium (Linn.) P. Beauv., Desmostachya bipinnata (Linn.) Stapf, Diplachne fusca (Linn.) P. Beauv., Echinochloa colonum (Linn.) Link, E. crusgalli (Linn.) P. Beauv., Eleusine compressa (Forsk.) Aschers. and Schweinf. ex C. Christensen, Eragrostis ciliaris (Linn.) R. Br., E. diarrhena (Schult.) steud., E. japonica (Thunb.) Trin., E. poaeoides P. Beauv., Polypogon monspeliensis (Linn.) Desf., Saccharum spontaneum Linn., Sporobolus coromandelianus (Retz.) Kunth, S. helvolus

(Trin.) Th. Dur. & Schinz, S. marginatus Hochst. ex A. Rich., Vetiveria zizanioides (Linn.) Nash, Cyperus alopecuroides Rottb., C. iria Linn., C. rotundus Linn., Scripus tuberosus Desf. etc. Beyond the halophytic zone, Tamarix dioica Roxb. and T. ericoides Rottl. along with Acacia nilotica (Linn.) Willd. ex Del. subsp. indica (Benth.) Brenan, Calotropis procera R. Br., Capparis decidua (Forsk.) Edgew., Prosopis cineraria (Linn.) Druce, P. juliflora (Swartz) DC., Salvadora oleoides Decne.,Tecomella undulata (Sm.) Seem., Zizyphus mauritiana Lamk., Z. nummularia (Burm. f.) Wt. & Arn. etc. are present.

Ghaggar river bed is used for cultivation, rice being the main *kharif* (rainy season) crop, while wheat, barley and gram are grown as *rabi* (winter season) crop. Many weeds of cultivation are, therefore, naturally found here.

Irrigated area

The extensive irrigation facilities made available by the construction of Gang, Bhakra and Rajasthan canals have resulted in agriculture being the main stay of the people of Ganganagar district. The soils in the irrigated area, in general, are of the type 'Sierozems soils". The pH, barring a few localities where it is normal, ranges from 8.0 to 8.5. This shows that the soils are tending to become alkaline (Vinod Kumar *et al.*, l.c.). This district contributes nearly 50% of the cotton and about 35% of the food grain produce of the entire Rajasthan state. Amongst the food crops, wheat is the most important cereal crop and gram (Cicer agrietinum Linn.) the most important pulse. The other crops grown are cereals and millets like rice, barley, maize, bajra (Pennisetum typhoides Stapf & Hubb.) and jowar (Sorghum vulgare Pers.), pulses like moth (Phaseolus aconitifolius Jacq.), urd (P. mungo Linn.), mung (P. aureus Roxb.) and arhar (Cajanus cajan Millsp.), cotton, sugarcane, tobacco, chillies, oil seeds like rape, mustard (Brassica juncea Czern. & Coss.), brown sarson (B. campestris Linn.), til (Sesamum indicum Linn.), groundnut (Arachis hypogaea Linn.), linseed (Linum usitatissimum Linn.) etc., fodder crops like guar (Cyamopsis tetragonoloba Taub.), different types of vegetables etc. Amongst the fruit trees grown notable ones are Citrus sinensis (Linn.) Osbeck. (Musambi), Grewia subinequalis DC.(Phalsa), Psidium guajava Linn. (Guava) and Punica granatum Linn. (Pomegranate).

A large number of weeds are found in the cultivated fields and orchards, namely Acanthospermum hispidum DC., Achyaranthes aspera Linn., Amaranthus hybridus Linn. subsp. cruentus Thell. var. paniculata Thell., A. tricolor Linn., A viridis Linn., Anagallis arvensis Linn., Anethum graveolens Linn., Antirrhinum orontium Linn., Arenaria serpyllifolia Linn., Asphodelus tenuifolius Cav., Astragalus tribuloides Del., Cannabis sative Linn., Carthamus oxyacantha Bieb., Celosia argentea Linn., Chenopodium album Linn., C. murale Linn., Cleome gynandra Linn., C. viscosa Linn., Commelina benghalensis Linn., Convolvulus arvensis Linn., Corchorus aestuans Linn., C. tridens Linn., Coronopus didymus (Linn.) Sm., Crotalaria medicaginea Lamk., Croton bonplandianus Baill., Digera muricata (Linn.) Mart., Euphorbia clarkeana Hook. f., E. dracunculoides Lamk., E. hirta Linn., E. prostrata Ait., Fumaria indica (Hassk.) Pugsley, Gastrocotyle hispida Bunge, Gisekia pharnaceoides Linn., Gnaphalium luteo-album Linn., G. polycaulon Persoon, Gomphrena globosa Linn., Heliotropium ellipticum Ledeb., Ipomoea sindica Stapf, Kohautia aspera (Roth) Bremek., Lathyrus aphaca Linn., L. Sativus Linn., Lepidium sativum Linn., Leucas cephalotes (Roth) Spreng., Malcolmia africana R. Br., Malva parviflora Linn., M. sylvestris Linn., Malvastrum coromandelianum (Linn.) Garcke, Medicago polymorpha Linn., Melilotus alba Desr., M. indica All., Mollugo cerviana Ser., Nicotiana plumbaginifolia Viv., Nonea pulla (Linn.) DC., Oxalis corniculata Linn., O. corymbosa DC., Phyllanthus fraternus Webster, P. maderaspatensis Linn., Plantago amplexicaulis Cav., Polygala erioptera DC., Polygonum plebeium R. Br., Portulaca oleracea Linn., Pulicaria angustifolia DC., Rostellularia quinqueangularis (Koen. ex Roxb.) Nees, Rumex dentatus Linn., Sesbania bispinosa (Jacq.) W. F. Wight, Silene conoidea Linn., Sisymbrium irio Linn., Solanum nigrum Linn., Sonchus asper (Linn.) Hill, S. oleraceus Linn., Spergula arvensis Linn., Stellaria media (Linn.) Vill., Striga angustifolia (D. Don) Saldanha, Trianthema portulacastrum Linn., Trigonella foenum-graecum Linn., Vaccaria pyramidata Medik., Verbascum chinense (Linn.) Santapau, Vernonia cinerea (Linn.) Less., Veronica agrestis Linn., Vicia sativa Linn., Vicoa indica (Linn.) DC., Zaleya govindia (Buch.-Ham. ex G. Don) Nair etc. In addition, sedges and grasses like Cyperus eleusinoides Kunth, C. rotundus Linn., Brachiaria ramosa (Linn.) Stapf, Cenchrus setigerus Vahl, Dichanthium annulatum (Forsk.) Stapf, Digitaria adscendens (H.B.K.) Henr., Echinochloa colonum (Linn.) Link, Eleusine compressa (Forsk.) Aschers. & Schweinf. ex C. Christensen, Eragrostis ciliaris (Linn.) R. Br., E. diarrhena (Schult.) Steud., E. japonica (Thunb.) Trin., E. pilosa (Linn.) P. Beauv., E. poaeoides P. Beauv., E. tenella (Linn.) P. Beauv. ex Roem & Schult., Heteropogon contortus (Linn.) P. Beauv. ex Roem. & Schult., Lolium temulentum Linn., Lophochloa pumila (Desf.) Bor, Oplismenus burmannii (Retz.) P. Beauv., Setaria verticillata (Linn.) P. Beauv., Sorghum halepense (Linn.) Pers. etc. are also found.

Vegetation along the canals

Along the banks of the canals which are generally marshy, plants like Alternanthera sessilis (Linn.) DC., Bacopa monnieri (Linn.) Pennell, Centella asiatica (Linn.) Urban, Eclipta alba (Linn.) Hassk, Phyla nodiflora (Linn.) Greene, Polygonum barbatum Linn., P. glabrum Willd., Ranunculus sceleratus Linn., Salvia plebeia R. Br., Typha angustata Bory & Chaub., along with sedges and grasses like Cyperus iria Linn., C. tenuispica Steud., C. triceps (Rottb.) Endl., Fimbristylis dichotoma (Linn.) Vahl, Arundo donax Linn., Echinochloa colonum (Linn.) Link, Eragrostis gangetica (Roxb.) Steud., Erianthus ravennae (Linn.) P. Beauv., Hemarthria compressa (Linn. f.) R. Br., Imperata cylindrica (Linn.) P. Beauv., Paspalum distichum Linn., Phragmites karka (Retz.) Trin. ex Steud., Saccharum bengalense Retz., S. spontaneum Linn., and Setaria glauca (Linn.) P. Beauv. are common. In addition, Equisetum ramosissimum Desf. and

Marselia minuta Linn., are also met with. The aquatic plants found here are Eichhornia crassipes (Mart.) Solms, Hydrilla verticillata (Linn. f.) Royle, Ipomoea acquatica Forsk., Potamogeton nodosus Poir., P. pectinatus Linn. and Azolla pinnata R. Br. Wherever the soil is saline species like Haloxylon recurvum (Moq.) Bunge ex Boiss., H. salicornicum (Moq.) Bunge ex Boiss., Salsola baryosma (Roem. & Schult.) Dandy, Suaeda fruticosa (Linn.) Forsk., Tamarix dioica Roxb., Trianthema triquetra Rottl. ex Willd., Zygophyllum simplex Linn. etc. are encountered. Trees and shrubs like Capparis decidua (Forsk.) Edgew. and Zizyphus nummularia (Burm. f.) Wt. & Arn. are also common along the canal. Further, a large number of trees have been planted along the canal, the more common ones being Acacia nilotica (Linn.) Willd. ex Del. subsp. indica (Benth.) Bernan, Albizzia lebbeck (Linn.) Willd., Dalbergia sissoo Roxb., Eucalyptus species etc.

NEW INTRODUCTIONS IN GANGANAGAR DISTRICT

A comparison of the flora of Ganganagar district with that of the flora of the rest of Rajasthan desert has revealed that quite a number of species found in Ganganagar district have not been reported from the other parts of the Rajasthan desert, except for Bikaner district, where a few species have migrated recently (Dhillon & Bajwa, 1972; Dhillon & Bhandari, 1974). Most of these species have come down to Ganganagar district from Punjab, many of them presumably through canal water or as contaminations of crop seeds and have either established themselves along the banks of canals or are found as seasonal weeds in the irrigated area. A few species are aquatic. Species which have migrated to Ganganagar district from Punjab include Antirrhinum orontium Linn., Arenaria serpyllifolia Linn., Astragalus tribuloides Del., Centaurium centaurioides (Roxb.) Babu, Eichhornia crassipes (Mart.) Solms, Gastrocotyle hispida Bunge, Hypecoum procumbens Linn., Imperata cylindrica (Linn.) P. Beauv., Kochia indica Wt., Lolium temulentum Linn., Lophochloa pumila (Desf.) Bor, Malcolmia africana R. Br., Malva sylvestris Linn., Medicago polymorpha Linn., Oenanthe javanica (Bl.) DC., Phalaris minor Retz., Phragmites karka (Retz.) Trin. ex Steud., Plantago amplexicaulis Cav., Polygonum lanigerum R. Br., Psammogeton canescens (DC.) Vatke and Rhynchosia capitata DC.

THE LIKELY IMPACT OF RAJASTHAN CANAL ON THE RAJASTHAN DESERT VEGETATION

The regions in Bikaner and Jaisalmer districts, through which the Rajasthan canal will flow, when its construction is completed, is at present covered with sand dunes, with interdunal areas and sandy plains. The main canal will pass by Chattargarh, Pugal, Dattor, Birsalpur and Charanwali in Bikaner district, and Nachna, Ghantiali and Mohangarh in Jaisalmer district.

The common plants found here are Aerva javanica (Burm. f.) Juss. ex Schult., Calligonum polygonoides Linn., Citrullus colocynthis (Linn.) Schrad., Crotalaria burhia Buch.-Ham. ex Benth., Dipterygium glaucum Decne., Haloxylon salicornicum (Moq.) Bunge ex Boiss. and Leptadenia pyrotechnica (Forsk.) Decne., along with grasses like Dactyloctenium sindicum Boiss., Eleusine compressa (Forsk.) Aschers. & Schweinf. ex C. Christensen, Lasiurus hirsutus (Forsk.) Boiss., Panicum antidotale Retz., P. turgidum Forsk. etc. and the sedge Cyperus conglomeratus Rottb. The most common tree in this region is Prosopis cineraria (Linn.) Druce. Capparis decidua (Forsk.) Edgew. is found scattered in some localities and occasionally Acacia jacquemontii Benth., Calotropis procera R. Br. and Indigofera argentea Burm. f. are met with.

The changes which have taken place in Ganganagar district due to increased irrigation facilities are bound to take place in the Rajasthan canal command areas in Bikaner and Jaisalmer districts also, perhaps on a much larger scale. As it has happened in Ganganagar district, there will be extensive cultivation, tremendous increase in weed flora, phenomenal increase in population and destruction of natural vegetation. The role the Rajasthan canal will play in introducing species from neighbouring districts/states is already becoming evident in Bikaner district and species like Myriophyllum spicatum Linn., Phragmites karka (Retz.) Trin. ex Steud. and Potamogeton nodosus Poir., not reported from Bikaner district earlier, are now found there.

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I. 5.1

OSMOTIC POTENTIALS OF PLANTS AND SOILS OF PACHPADRA SALT BASIN IN THAR DESERT

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INTRODUCTION

Plants obtain most of their water from soil along a water potential gradient. In saline environment soil has multiple effects on plants and among them prominent one is the osmotic effect of high salt concentration. High amount of soluble salts in soil solution form a considerable component of the total soil moisture stress (Slatyer 1958, 1967). In saline soil it is difficult to distinguish between the effects exerted on its water relations by the osmotic potential of the salt solutions from those exerted by the soil matrix potential. Various plant species are found growing in the saline area of Indian desert-Pachpadra salt basin and almost all the halophyte species growing there have the capacity to endure drought. Osmotic stress is also an important factor for growth, development and distribution of plants.

Steiner (1935) worked out at least ten halophytic species of eastern coast of USA; Repp (1939, 1963) worked out some plants of saline and non-saline habitats of Neusiedler sea region of Austria, Migahid and El Shafei Ali (1953) worked out five halophytic species from Egypt and Onal (1964, 1966), also studied some halophytic plants but no attention on the saline plants of the Thar desert have been given from this angle so far. The present study is concerned with the annual pattern of soil osmotic potential in relation to six characteristic halophytic species of Indian desert viz. *Cressa cretica, Haloxylon recurvum, Salsola foetida, Suaeda fruticosa, Trianthema triquetra* and *Zygophyllum simplex.*

MATERIAL AND METHODS

The study was carried out during the years 1976-77 at Pachpadra salt basin, situated at 26°, 56', 51" N latitudes and 72°, 11', 06" E longitudes, 100 km away from Jodhpur. The climate is arid with an average annual precipitation of 285.5 mm, so that this salt basin can be included in arid zone. The effective precipitation is received mainly during monsoon. Some important climatic data for Pachpadra salt basin are given in Table 1 and rainfall pattern of the area from June 1976 to October 1977 is presented in Fig. 1.

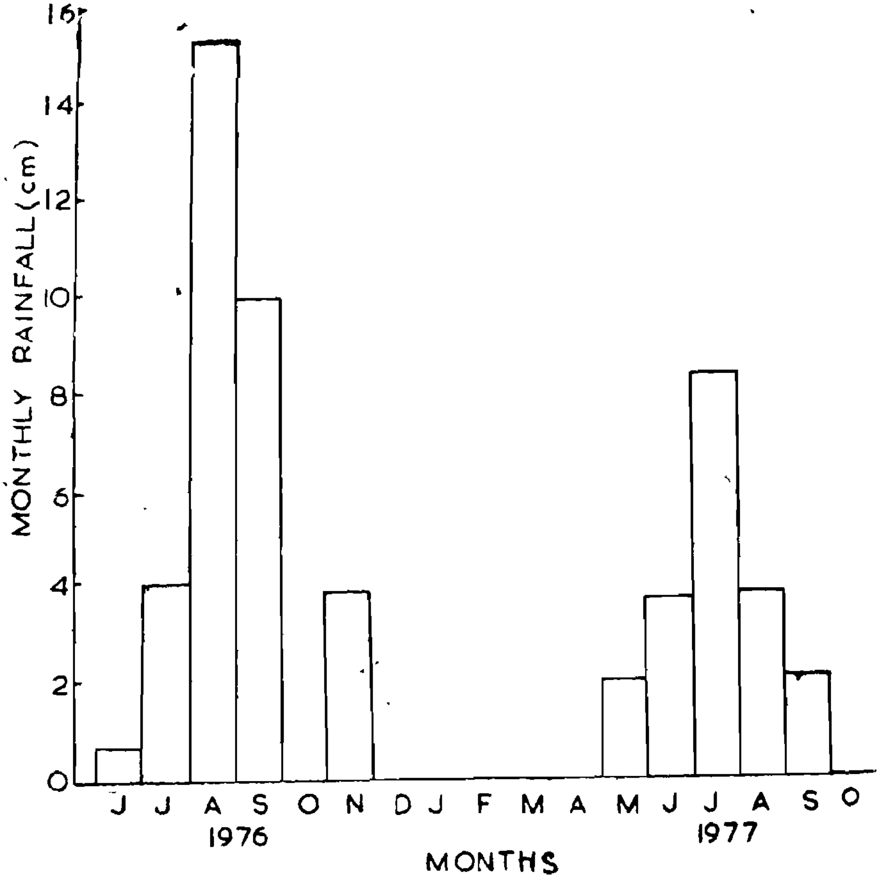

Fig. 1. Monthly rainfall at Pachpadra salt basin from June 1976 to October 1977.

Table 1. Climatic data of Pachpadra salt basin

Months	Mean maximum temp. (°C)	Mean minimum temp. (°C)	Highest maximum temp. (°C)	Lowest minimum temp. (°C)	Mean R. H. (8 hrs)	Mean wind velocity (km h^{-1})	Mean Rainfall (cm)	No. of rainy days	Maximum rainfall recorded in 24 h (cm)
January	25.50	7.00	33.90	−4.11	62	4.83	0.41	1.00	2.59
February	27.60	9.00	37.90	−3.55	57	5.31	0.38	1.00	1.96
March	34.20	15.00	45.00	−0.56	51	6.28	0.30	0.76	1.52
April	40.10	20.90	46.70	7.22	49	7.40	0.13	0.50	1.83
May	42.30	25.40	50.56	14.45	66	13.04	1.17	2.00	5.30
June	41.00	27.50	50.00	18.40	72	15.93	2.92	5.54	6.22
July	37.15	26.80	46.10	21.70	80	12.87	8.51	11.00	19.18
August	34.70	25.30	43.90	21.10	82	12.55	8.84	11.00	15.88
September	35.85	24.00	43.90	16.70	81	8.55	5.11	5.50	21.08
October	37.10	18.60	42.80	7.22	59	4.67	0.48	0.50	1.42
November	32.85	12.50	38.90	1.12	57	3.22	0.10	0.25	1.78
December	27.50	8.00	33.90	0.00	62	3.70	0.20	0.50	1.65
Year	34.70	18.35	50.56	−4.11	65	8.21	285.50	38.12	21.08

Soil samples from different depths viz. surface, 20, 50, 75 and 100 cm were collected during the last week of every month with the help of auger and brought to laboratory in air tight containers. Percentage soil moisture by oven dry weight was found out. Osmotic potential was found out by method of U. S. Salinity Laboratory Staff (1954) with the help of conductivity meter. Osmotic potential of leaves collected from the plants of the same area from which soil samples were collected was estimated by the method of Janardhan *et al.* (1975).

RESULTS AND DISCUSSION

i) *Soil osmotic potential*

The pattern of soil moisture percentage mainly affected by rainfall is given in Fig. 2. The data obtained for soil osmotic potential is shown in Fig. 3. It is evident from this figure that osmotic potential at surface decreased from October to May except in December where it increased because of the winter rain in November. The soil osmotic potential was higher in the months of June and July when the salts from the surface leached downwards. This period was suitable for the germination of seeds. At 20 cm the osmotic potential was higher than the surface in all the months except July and was maximum in rainy season, when compared with the soil at other depths. At 50, 75 and 100 cm depths, the osmotic potential was higher in the months of October, November and December than at 20 cm depth, while it was lesser in other months upto May due to upward movement of salts. The soil osmotic potential upto 50 cm increased in rainy season. The highest value was observed (-1.51 and -1.16 bars) in the months of June and July at 20 cm depths.

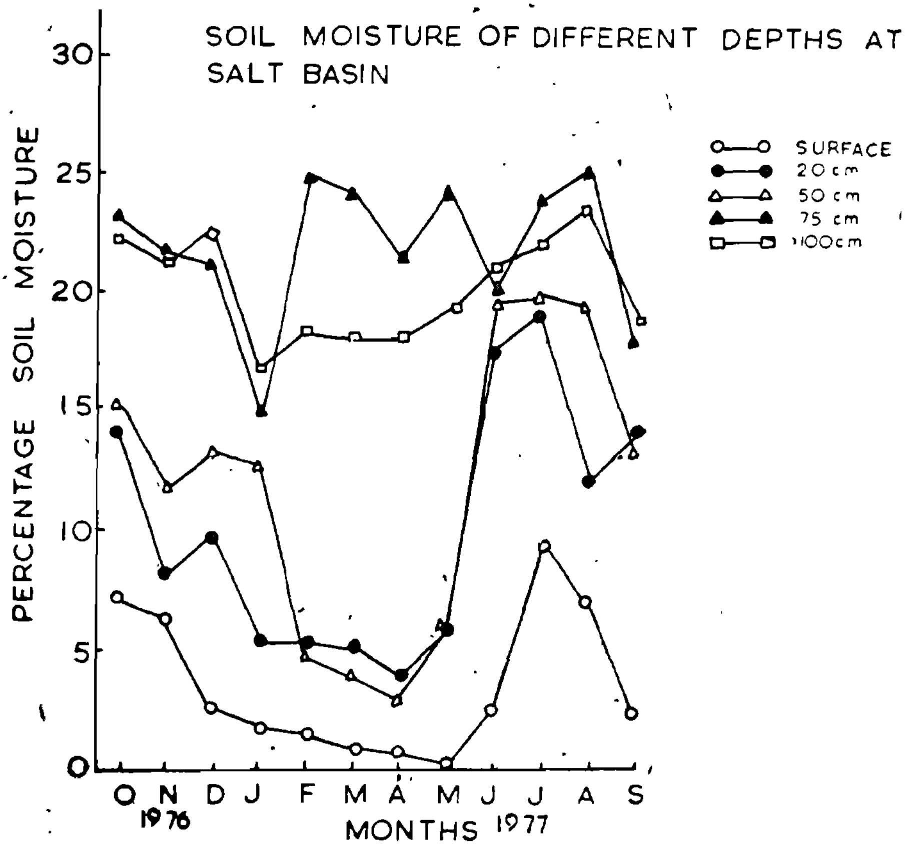

Fig. 2

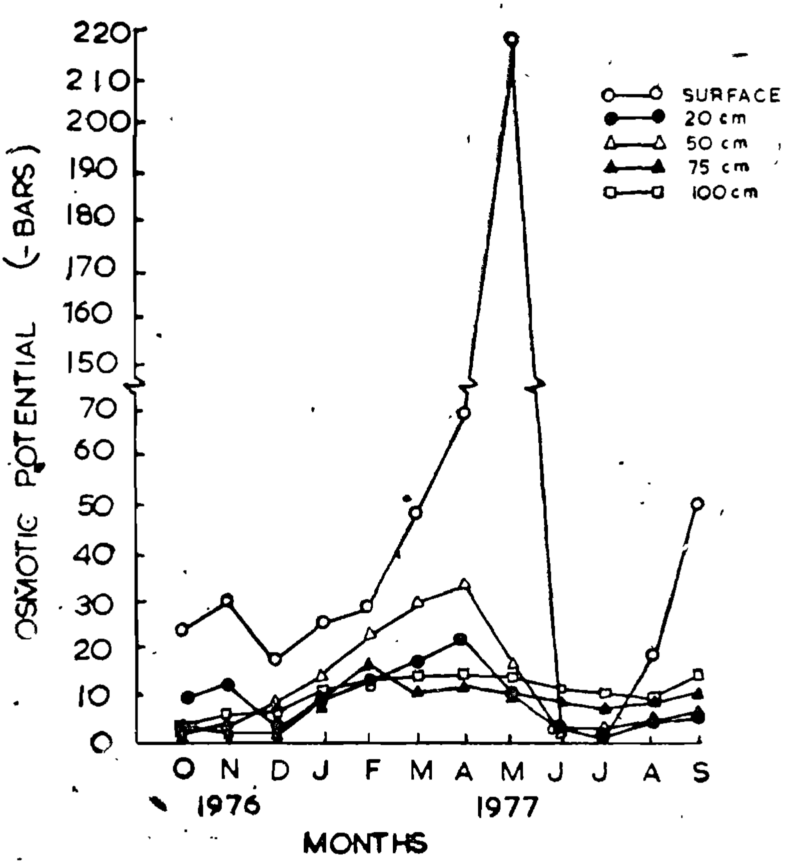

Fig. 3. Seasonal variation in osmotic potential of soil samples at Pachpadra salt basin.

ii) *Plant osmotic potential*

Osmotic potentials of the leaves of different saline plants are presented in Fig. 4. It is evident from this figure that the highest value of osmotic potential (-5.15 bars) was obtained in *Zygophyllum simplex,* an annual saline succulent in July, followed by *Cressa cretica* (June-August) and *Haloxylon recurvum* (June and July). In *Salsola foetida* the osmotic potential was the lowest (–69.11 bars) in the month of February followed by *Suaeda fruticosa* (-60.22) in January, *Haloxylon recurvum* (-54.35) in December and *Cressa cretica* (-53.44) in February. These lowered values in leaves were due to continuous uptake of soluble ions. In *Cressa cretica* osmotic potential decreased from October to February, then it again started increasing from March onwards because of the higher leaf water content, which was maximum in July and August.

In *Haloxylon recurvum* an abrupt decrease in osmotic potential was observed from November onwards upto March and then it increased in the remaining period

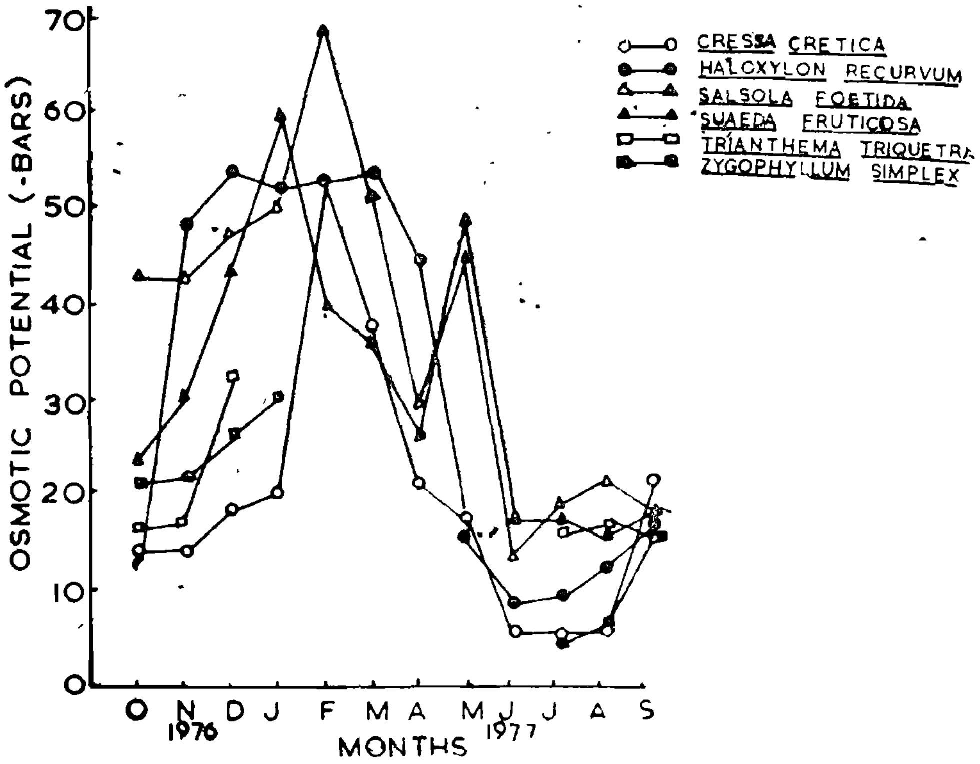

Fig. 4. Osmotic potential (-bars) in six saline plant species of Pachpadra salt basin.

showing maximum value in the rainy season. In *Salsola foetida* and *Suaeda fruticosa* the osmotic potential decreased upto February and January, respectively and then showed the increasing trend upto April and again decreasing in May due to higher salt content in the leaf tissues. Again the maximum increase was observed in the rainy season.

In *Trianthema triquetra,* the osmotic potential of leaves was nearly the same during their life span, except in December when it started drying, osmotic potential decreased upto the double of the original value. In *Zygophyllum simplex* with increase in dryness and age of plant osmotic potential decreased. The osmotic potential of plant leaves remained lower than that of soil osmotic potential in the effective root-zone upto 20 cm in *Trianthema triquetra* and *Zygophyllum simplex* and below 50 cm in other plants.

It is necessary for the plants growing under the saline conditions to maintain a high concentration of osmotic substances to overcome successfully with the water retaining forces of the surrounding soil. Halophytes growing in the saline soils are able to change osmotic potentials of their cell sap, whenever they require. Walter (1961) stated that halophytes which had moved into saline media showed osmotic adaptation of an average rate of 1 atm/day.

In the present study it was observed that osmotic potential of plant leaves always remained lower than that of the soil of root-zone and the results here could be compared with those of Ashby and Beadle (1957) and Black (1956, 1960) where the osmotic potential of Atriplex leaves was always lower (-bars) than that of the soil solutions. Von Faber (1923) calculated 148 and 163 atm osmotic potential for *Rhizophora* and *Avicennia* leaves. Harris *et al.* (1924) reported that the sap concentration may attain osmotic potential equivalent to 150 atm in *Atriplex confertifolia,* whereas Harris and Lawrence (1917) reported the osmotic potentials upto 50 atm in plants growing on saline and dry substrates. Montasir (1938) studied the halophytic species of Lake Manzala in Egypt and found that their osmotic potentials ranged from 43.15 to 78.46 atm. In the present investigation the lowest osmotic potentials were observed in *Salsola foetida* in the month of February (-69.11 bars), *Suaeda fruticosa* (-60.22 bars) in January, *Haloxylon recurvum* (-54.24 bars) in March, *Cressa cretica* (-53.44 bars) in February, *Trianthema triquetra* (-32.93 bars) in December and *Zygophyllum simplex* (-30.31 bars) in January.

All the six halophytic plant species studied here could also adjust themselve by changing their osmotic potentials rapidly with a greater range due to the change in osmotic potential of surrounding soil. This supports Waisel (1972) who stated that it is probably true that the great majority of the halophytic plants belong to the adjustable group and that their osmotic adjustment occurs rapidly Recovery from osmotic stress occur faster in salt accumulating halophytes than in salt enduring ones (Greenway, 1968).

Further, it emerges from the present study that during the rainy season due to higher moisture in soil and the leaching down of the salts resulted in the increase in osmotic potential of soil which leads to the increased osmotic potential of the plants. But, with the increase in salt concentration and decrease in soil moisture, plants try to adjust themselves to drought by the accumulation of salts. Thus the accumulation of salts in plants decreased their osmotic potentials upto the level of highest stress, so that, plants were able to take maximum water during the hot summer, which resulted in the gradual increase in their osmotic potentials.

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II. 1.1

CROPS OF THE ARID AND SEMI-ARID AREAS OF INDIA-PROBLEMS AND POTENTIALS

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Out of the total area of 326 million ha in India, 30 per cent has less than 750 mm rainfall, 42 per cent below 750-1,250 mm and 28 per cent more than 1,250 mm mean rainfall. In fact, all the areas with rainfall less than 1,250 mm can be considered part of the arid and semi-arid belt. The arid areas are mostly in North Indian belt in Gujarat, Rajasthan, Haryana, Punjab, Western U.P. and small areas of Andhra Pradesh and Tamil Nadu. In both the arid and semi-arid areas, the rainy season is short and dry period. Kampen and Krantz (1974) concluded that the semi-arid areas of India, or most of other 50 countries in the world which fall in this belt have 2-4½ wet months and the remaining dry months. The semi-arid areas of India mostly occur in Maharashtra, Karnataka, Andhra Pradesh, Tamil Nadu, Madhya Pradesh, some parts of Gujarat and Uttar Pradesh.

The rains are also erratic and often come in a few big storms of short durations which result in great runoff instead of charging the soil moisture profile. It is surprising that even at Jodhpur with

300 mm rainfall runoff is not uncommon. The vertisols (black soils) of the semi-arid tropics of India yield on an average more than 10 per cent runoff whereas alfisols (red soils) produce more than 25 per cent runoff under the same rainfall conditions. The evapotranspiration in both the arid and semi-arid belts of India is very high. A few typical examples from Hissar (arid), Jodhpur (arid) and Hyderabad (semi-arid) would clearly indicate that the evaporative demands for most part of the year are so large that unless supplemental irrigation is available, cropping becomes difficult. Suffice to say that water is the limiting factor in both the arid and semi-arid areas of India. Some of the arid areas of India lie in temperate cold regions such as Ladakh and Lahaul Valley. It is no wonder that in these regions, any agriculture is only irrigated agriculture.

The North Indian arid zone belt is also characterised by alternate hot and cold seasons, whereas the semi-arid belt has medium to high temperatures.

Under these harsh climates where water is the limiting factor, the erratic monsoons add to the harshness of the climate and make agriculture a gamble. Droughts are of common occurrence and drought prone areas occupy large acreage.

Man has fought nature and tried to modify some of these vagaries of nature by providing irrigation. Thus, irrigated farming has become most important in the arid and semi-arid belt of India. In fact, one of the most prosperous agriculture is in this region.

Notwithstanding man's efforts to develop irrigation large percentage of the area in this region remains unirrigated and practices dry farming.

When we think of the crops of the arid and semi-arid regions of India, we have to consider this factor whether we are talking of irrigated or partially irrigated or rainfed crops. If water were not a constraint, most of the important crops of cereals, pulses, oilseeds, fibre, sugarcane, forages, etc., can be grown in these regions. In the north Indian belt there being winter (cold) and summer (hot) season, generally two different crops have to be grown in the two seasons except for long duration crops like sugarcane and cotton which though start in the hot season but continue in a part of the cold season as well. However, in the semi-arid tropics of India, one can get two or even three harvests of the same crop, if water is not a constraint.

Interestingly enough, if one were to generalise, one finds that in the arid irrigated areas, cotton, sugarcane, rice, maize, pearl millets, wheat, groundnut, etc., become the dominant crops depending upon the economic factors. In the semi-arid tropics also depending upon irrigation intensity, generally, rice, sugarcane, cotton, maize, sorghum and groundnut become the dominant crops. Wheat is also becoming popular though its efficiency is rather low. The important crops of the arid and semi-arid areas of India are mentioned in Table 1.

The contribution of important crops of arid and semi-arid areas in India (based on data of 84 districts) of low rainfall unirrigated areas is given in Table 2. From this it may be observed that in case of sorghum, pearl millet, groundnut, cotton, ragi, pulses and other oilseeds, major contribution comes from the arid and semi-arid areas. Unless the yields of those crops under rainfed conditions increase, the real breakthrough in agriculture in India cannot come.

Table 1. Important crops of rainfed areas (arid and semi-arid) of India

Crops	Arid zone	Semi-arid zone
Cereals	Pearl millet, Wheat, Barley	Sorghum, Pearl millet, *Setaria*, Maize, Wheat, Ragi
Pulses	Chickpea, Pigeonpea, Greengram Moth	Pigeonpea, Chickpea, Greengram Blackgram
Oilseeds	Rapeseed, Mustard, Sesamum, Groundnut	Groundnut, Safflower, Castor, Niger, Sesamum
Fibre	—	Sisal, Cotton
Forage	Sorghum, Millets, Grasses, *Guar*	Grasses, Cotton

Table 2. Contribution of important crops of arid and semi-arid tropical areas of India (Based on data of 84 districts of low rainfall unirrigated areas)

Crops	Proportion of all India acreage in percentage
Sorghum	64.34
Pearl millet	51.39
Maize	19.19
Ragi	46.33
Wheat	30.66
Barley	21.38
Chickpea	31.51
Pigeonpea	47 24
Groundnut	74 06
Other oilseeds	36.22
Cotton	60.51

Source : A new technology for dryland farming, IARI, New Delhi (1970)

Cropping systems

Under dry farming conditions of the arid and semi-arid regions of India, intercropping is generally practised. Village studies conducted in Sholapur and Akola districts of Maharashtra and Mahboobnagar district of Andhra Pradesh by ICRISAT show that most of the small farmers under unirrigated conditions follow intercropping system. The number of crops included in intercropping system in a field is also very large. As soon as irrigation becomes available, intercropping gives place to sole cropping. The intercropping is the best mechanism for exploiting the environments, minimising risk and ensuring subsistence farming—pigeonpea-sorghum, groundnut-sorghum or millets, pigeonpea-groundnut, are common intercrops in semi-arid areas whereas pearl millet-greengram, pearl millet-*guar*, wheat-chickpea, wheat-sarsson-rapeseed are common in north Indian arid zone belt.

Since most of the pulses, oil seeds, and millets are produced in the arid and semi-arid unirrigated conditions, it is no wonder that the shortage of pulses and oilseeds becomes so pronounced in drought or low rainfall years. One cause of lower growth rate in Indan agriculture is the stagnant agriculture in many arid and semi-arid areas.

The cropping systems established by dry farmers are on large number of years' experience, they can only be substituted by more efficient and productive systems, provided it is also based on critical experimentation and vast experience. The traditional approach of scientific research based on sole cropping and optimum to high level of inputs does not seem to be suitable for the real world situation of the dry farmer. It is gratifying to note that All India Coordinated Dryland Agriculture Project and International Crops Research Institute for the Semi-Arid Tropics are developing techniques and philosophy to suit the conditions of the dry farmers of arid and semi-arid areas. It is realised that these farmers are working not only under climatic constraint but also under the capital constraint. The high input based technology does not suit them. The specific problems of crops of the dry farming arid and semi-arid areas are:

1) Moisture stress.
2) Poor crop standards, low yields and unstable production.
3) Non-availability of cultivars highly responsive to fertilisers, particularly, in oilseeds and pulses.
4) Low value crops hence low incentive for use of costly inputs.
5) Unsatisfactory marketing.

Prospects for arid and semi-arid areas

The potential for increasing yields in these areas of moisture constraint is vast. Even the results of trials conducted under the dryland conditions at 24 research stations of the AICRPDA have shown that if the technology which has been suggested by the scientists was adopted, the production can be increased many times. A reference to Table 3 based on the data of the above mentioned researches will make it abundantly clear that the scope is vast.

Table 3. Indicative potential of dryland agriculture as shown by achievement levels of various crops

Zone	Crop	Yield at research station (Q/ha)	Farmer's average yield (Q/ha)
ARID ZONE			
Jodhpur	Pearl millet	30	2
	Blackgram	10	1
Hissar	Pearl millet	15	5
	Guar	10	3
	Rapeseed/Mustard	10	5
Anand	Pearl millet	25	10
	Cotton	10	3
SEMI-ARID ZONE			
Hyderabad	Castor	20	7
	Sorghum	40	3
Bangalore	Finger millet	35	10
	Maize	45	34
Anantapur	Groundnut	15	5
	Pearl millet	10	3
Akola	Sorghum	25	5
	Cotton	10	1
Rajkot	Groundnut	15	6
	Pearl millet	20	7
	Cotton	6	1
	Sorghum	20	2
Kovilpatti	Cotton	7	2
	Pearl millet	25	7
	Sorghum	20	2
Bellary	Sorghum	10	2
	Cotton	3	1
Bijapur	Pearl millet	15	15
	Groundnut	10	3
	Sorghum	25	5
	Safflower	20	—
Sholapur	Pearl millet	30	2
	Pigeonpea	20	3
	Sorghum	30	3
	Chickpea	13	3

Sorghum : Dryland Agriculture Research Progress Report 1970-75.

At ICRISAT scientists in field scale experiments under rainfed conditions on the watersheds have observed that by the adoption of techniques such as improved variety, improved fertilizer application, broad bed and ridge system and proper rain water and soil management system, the production increased to about 300 *per cent* (Table 4).

In the Indo-British Project in Indore (Madhya Pradesh) it was reported by (Verma, 1977—personal communication) that on cultivated fields they are able to raise the yields of sorghum CSH-5 from 6.85 to 23.0 and of maize from 5.5 to 13.5 q/ha by proper soil and fertilizer management, using low doses of fertilizer and improving the surface drainage.

From these examples, it can be concluded that tradition bound agronomic practices followed in arid and semi-arid tropics require critical examination. In fact, the scientific knowledge which has been accumulated in the last decade, has brightened the prospects of increasing production of crops in the arid and semi-arid regions significantly. The hope of the *humanity for substantially increasing production* lies in the arid and semi-arid areas, as they have vast potential, which has not been exploited successfully. Water is a limiting factor but the arid and semi-arid lands suffer from both water stress as well excess. If man can learn to manage rainwater successfully, he can raise crop production from the arid and semi-arid areas many times.

Table 4. Additive effect of different factors in increasing crop production

Treatment	Variety	Fertilizer	Soil & crop management	Grain yield (kg/ha)	Increase (kg/ha)
1	Local	Local	Local	1190	–
2	Local	Improved	Local	1770	580 (2-1)
3	Local	Improved	Improved	2260	1050 (3-1)
4	CSH-5	Local	Local	1030	—
5	CSH-5	Improved	Local	2390	1380 (5-[illegible]
6	CSH-5	Improved	Improved	3450	2470 (6-4)

II. 1.2

STUDIES ON METHODS TO STABILIZE AND INCREASE FOOD CROP PRODUCTION IN THE MARGINAL RAINFALL AREAS OF KENYA

J. Ian Stewart[1] and Fred J. Wang'ati[2]

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INTRODUCTION

Over 80 per cent of Kenya's population derive their livelihood from agriculture and related enterprises. Unfortunately only 15 per cent of the land area receives 800 mm or more annual rainfall, and most of this land is already under intensive agriculture (Fig. 1). The remaining land area is classed as marginal in varying degree for unirrigated agriculture as a result of low and erratic rainfall. Nevertheless, it supports an estimated 4 million people out of a total of 14 million. At the current rate of growth, it is estimated that the resident population in marginal lands will increase to over 10 million by the year 2000, plus substantial immigration from the high rainfall area where land for tillage is now a major limiting factor. The task of feeding such a population will constitute a major economic and social problem for the government unless viable farming systems for the dry lands can be developed. A major component of such a farming system is the development of a cropping system that maximises water use efficiency on the farm. This is the background of the research project reported in this paper.

The problem

The areas of immediate interest are characterised by annual rainfall of 500 to 800 mm distributed between two rainfall seasons. In general, 60 per cent of total rainfall occurs during the "Long Rains" season which lasts from March to May. The "Short Rains" season which comes between October and December accounts for most of the rest. Throughout the study area, a combination of high rainfall intensity, shallow soils (60-200 cm), steep slopes and unstable surface soil structure makes the task of water conservation for crop production a delicate matter. The problem of water conservation is further complicated by high evaporative demands. With an average of 8-9 hours of bright sunshine daily and average daily temperatures of 20°C, most of the area has potential open water evaporation exceeding 6-7 mm per day.

Project objectives

Maize is the preferred staple food, so past research has been concentrated on development of maize varieties that combine short maturity to escape drought and reasonable yield potential. Sorghum and millet may often be better alternatives, but a screening programme for adaptation is required. It is also necessary to include legumes and such other crops as would encourage consumption of a balanced diet.

The broad objectives of the current project are therefore:

1. to develop through field experimentation water use/yield relationships for a number of important food crops, to match crops to water availability. The findings will be prepared for dissemination by extension staff;
2. to screen from available collections, varieties of cereals, legumes and oil crops for tolerance to drought, and physiological adaptation to conditions in marginal rainfall areas;
3. to develop cropping systems leading to reduced risk of total crop failure due to drought and at the same time maximise efficiency in use of labour and land resources.

FUNCTIONING OF THE RESEARCH PROJECT

Organization

This is a joint effort by the Ministry of Agriculture through the Agriculture and Forestry Research Organization of the Kenya Agriculture Research Institute and USAID. projected for a 5-year period, after which the research will continue under AFRO auspices. Offices are at KARI Headquarters, Muguga, located approximately 30 km N.W. of Nairobi.

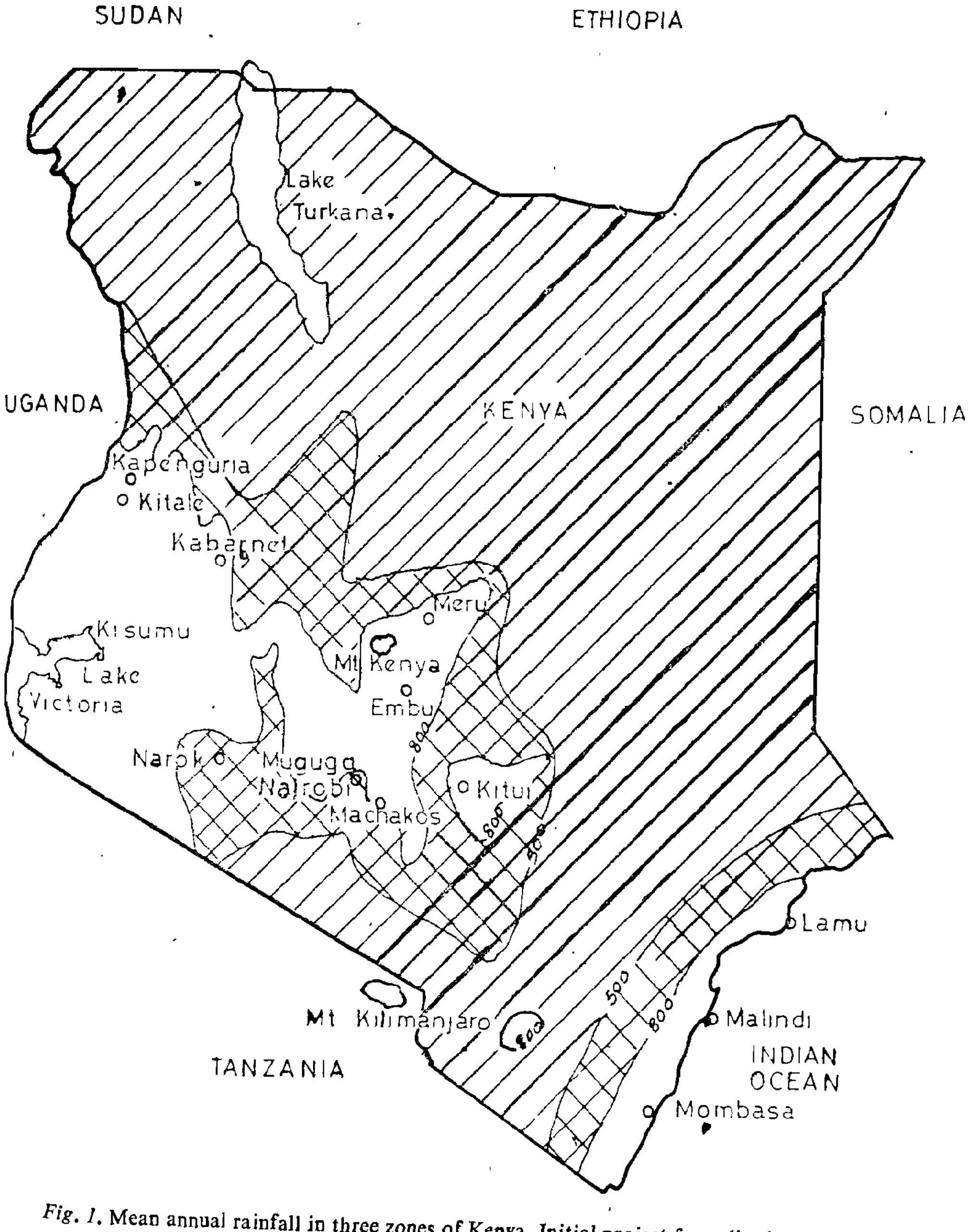

Fig. 1. Mean annual rainfall in three zones of Kenya. Initial project focus lies between 500 and 800 mm.

Americans presently active in the project are three USDA Scientists, seconded to USAID. They are an Agrometeorologist, an Agronomist, and an Agricultural Economist. An Electronics technician to maintain neutron scattering devices and other sophisticated equipment will join the study shortly. AFRO counterpart trainees have been assigned except for the agronomist position, also expected to be filled shortly. Trained AFRO technicians and staff as well as office and scientific facilities, are adequate to fill all needs. Cooperation with other research and action agencies of Government is excellent, and augmented by current policy, which ranks research and development activities in the marginal rainfall areas high in priority.

Long term goals

The action orientation of the research program is emphasised by Fig. 2 titled "Field Level Recommendation Sheet for Farm Planning". Key information developed in the research program will be coordinated with data from a number of other sources, to ultimately enable government to render a futuristic farm planning service to interested farmers throughout the marginal rainfall areas. Smallholders will benefit equally with larger growers of basic food crops, because, as the figure indicates, the farm plan will be evolved from recommendations developed on a field-by-field basis.

Figure 2 is a tentative example of information to be conveyed to the grower concerning each of his fields, say one month prior to the recommended date of planting. All recommendations on the sheet relate to the crop variety named near the top, selected using criteria developed in the research as among the best which might be grown in the given field soil, considering expected weather, management, and water supply conditions. Alternatives will be offered by development of perhaps three different crop recommendation sheets for each field. Each sheet shows the range of reasonable expectations for crop water supply (actual evapotranspiration or ET_A), consequent yield, and the net value of yield.

Obviously the numbers of field recommendation sheets to be developed and interpreted to the farmers will be very large in each cropping season when the program becomes operative. A computer service will be essential to bring together pertinent research data and environmental information, make necessary calculations and print out the field sheets. Conveying the recommendations to the farmers, and assisting in developing their farm plans will be the job of the District Agricultural officer, the agricultural extension service staff, and personnel of other agencies as appropriate.

Necessity for coordination with other agencies

Clearly, input data to the computer program will be required from a number of sources. Running briefly through the field recommendation sheet, the major needs are as listed below:

1. *Site descriptions* down to the field level will require a major survey and mapping effort by personnel of the Department of Agriculture and perhaps other agencies of government.

FIGURE 2 - FIELD LEVEL RECOMMENDATION SHEET FOR FARM PLANNING

Sheet No. ________ of ________

Date Computed ________________

SITE DESCRIPTION:

Field ____________ Farm ____________ District ____________ Farmer ____________

RECOMMENDED CROP & VARIETY ________________________________

WATER, YIELD, & RETURN ESTIMATES		LEVEL OF EXPECTATION		
		Normal	Lowest	Highest
Extractable Soil Water	(mm)	________	________	
Effective Rainfall	(mm)	________	________	
Effective Irrigation	(mm)	________	________	
Total Crop Water Supply	(mm, sum)	________	________	
Expected Yield (________/ha)		________	________	
Net Value at Expected Price		________	________	
(KSh/ha) at Lowest Price		________	________	
" at Highest Price		________	________	

RECOMMENDED PRACTICE:

Planting Date ________________ Seeding Depth ________

Row and Plant Spacing ________________ Fertilizer Rates ________

____

Soil and Water Conservation Measures ________________________

2. *Recommended crop and variety* is one of the major outputs of the project. Water relations and yield responses of a number of different crops will be quantified in experiments to be described later. In-depth research will be focused on only one crop type, perhaps two varieties, per year. Selecting crop varieties to undergo quantitative research itself entails a major research effort, the province of the team agronomists. They must evaluate ongoing programs of crop breeding and selection for drought resistance, extract the most promising materials from each, and carry out refined laboratory, greenhouse and field screening of the selected materials. Organizations with research programs already indentified as sources of plant materials adapted to marginal rainfall areas include AFRO (grain sorghum), FAO, Lanet, Kenya (grain sorghum and perhaps millets at a later date), Kenya Department of Agriculture Dryland Farming Research Station, Katumani (maize, grain sorghum. cowpeas, pulses, millets), University of Nairobi (pigeon peas, beans) and external sources such as CAZRI. ICRISAT, CIMMYT, IITA, the Rockefeller Foundation, and a number of prominent universities.

Additionally, recommending a given crop variety is based as much on economic and social factors as on production capability *per se*. To evaluate these factors the team agricultural economists must mount an equally intensive search for data quantifying all human factors affecting production capability on the farm, plus availability [illegible] all needed inputs, markets, cooperatives for machinery, credit, supplies, crop handling, storage, marketing, etc., as well as determination of labour requirements, costs and expected prices. A detailed monthly survey of some hundreds of small farm operations has recently been initiated by the Development Planning Division of the Ministry of Agriculture in conjunction with an EEC funded farm production loan program for the marginal areas. Data from this and other sources will be complemented by surveys personally conducted by project members, and utilised in making economic and social analyses for guidance of crop recommendations and many other aspects of farm planning.

3. *Return estimates* relate to economic research mentioned above, and require information primarily from the Central Bureau of Statistics and various Commodity Boards.

4. *Water and yield estimates* are based on transferable research findings on crop behaviour, coupled with site specific measurements and records of soil, climate, and management. Quantification of crop characteristics affecting water use and yield responses to deficits, lies at the heart of the research project, but considerable site data will be required from other agencies including the Meteorological Department, the Soil Conservation Service and the Soil Survey Department of the National Agricultural Laboratories.

5. *Recommended practices,* like recommended crops and varieties, will mostly be developed within the research project, but drawing heavily upon information developed by others, most notably the Katumani Drylands Farming Research Station, the Soil Conservation Service, and centres like ICRISAT.

Complementary research may be requested of other agencies, or initiated within AFRO, or jointly with other agencies. One of the more pressing needs is to assess the effectiveness of water conservation measures, and develop improved ones fitting the conditions of the marginal rainfall areas. Planning is underway for AFRO to cooperate closely with studies at the University of Nairobi on the simplest and cheapest methods of promoting rainfall infiltration and conservation. Related agricultural engineering research will be established within AFRO.

Research is also much needed on what constitutes on adequate meteorological network for prediction of rainfall and evaporative demands. Cooperative studies with the Meteorological Department are planned. Undoubtedly other important areas of study will soon become evident.

Training of personnel

Training of Kenyan scientists and technicians, both academically and in research techniques, is one of the most important goals of the project. Kenyan counterpart personnel will pursue higher degrees, mostly to the Masters level, at an American University where this line of research has been carried on. Those continuing to the Ph.D. will do their research work within the Project.

Additionally, opportunities will be offered to graduate students of the University of Nairobi, to satisfy their research requirements for either the M.Sc. or Ph.D. degrees within the project. Such research projects may be peripheral to the action orientation of the project, but will contribute information of much interest to the scientific community, and improve the ultimate project output.

WATER PRODUCTION FUNCTION RESEARCH BACKGROUND

Origins and concepts

The research program to be carried out in Kenya began at the University of California at Davis (UCD) in 1967 (Stewart, 1972; Stewart and Hagan, 1973; Stewart *et al.,* 1974), and has been continuous since. Field plot and lysimeter studies have been completed with grain sorghum and two varieties of maize (Stewart *et al.,* 1975; Stewart *et al.,* 1977a), pinto beans and alfalfa (Stewart *et al.,* 1976), pink beans and cotton (Stewart *et al.,* 1977b), light red kidney beans and the new UC-82A square-round processing tomato (unpublished). Principal sources of funding for these studies have been the United States Bureau of Reclamation, 1969-1973, the USDI Office of Water Research and Technology, 1974-1975, and the State of California Department of Water Resources, 1976-1977.

A key research concept is that, water being the limiting factor, increasing levels of water deficiency will result in a genetically controlled, reproducible pattern of yield reduction. Thus, for each crop variety a unique functional relation exists between yield and evapotranspiration. The relative value slope (or equation) of this "water production function" may be transferred to any site where the crop variety is adapted, and there combined with weather records and measurements of soil characteristics and cropping practices, to quantify the specific relationship expected between yield and ET at that site.

Genetic control of crop behaviour at the varietal level is not limited to yield and yield response characteristics, but also includes the effects of leafing characteristics on water requirements, and rooting characteristics on soil water extraction. Like yield response, these effects may be quantified respectively in lysimeters and field plots, then normalised with respect to research site weather and soil measurements. The results may then be transferred to any other site where the variety is adapted. When combined with environmental measurements made at the new site, quantitative predictions may be made of the actual evapotranspiration regime the crop is expected to experience, and the resultant yield. Details of these procedures are expanded by Stewart and Hagan, 1973; Stewart *et al.*, 1974.

Maize Research at Davis in 1974—Interpretation of findings

Studies at UCD in 1974 and 1975 were carried out jointly with researchers from the University of Arizona at the Yuma Field Station, Colorado State University at Fort Collins, and Utah State University at Logan, all member Universities of the Consortium for International Development. The experimental crop was maize,

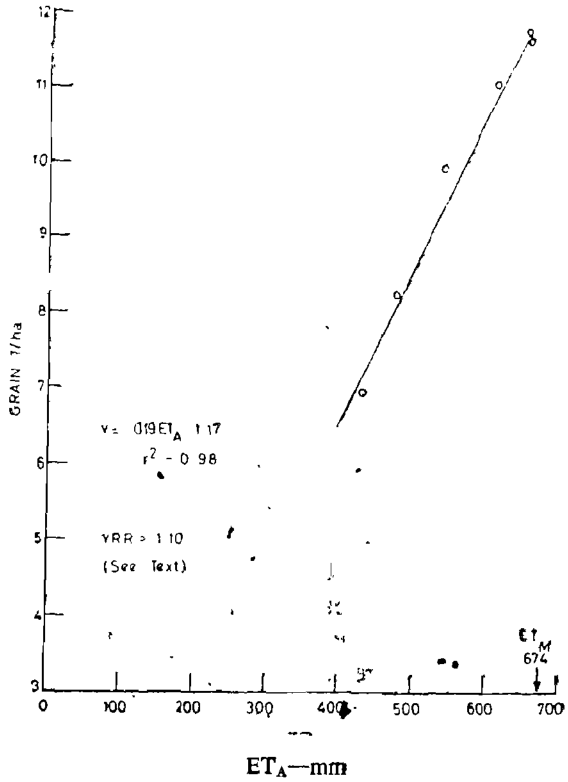

Fig. 3. Maize grain yields related to seasonal evapotranspiration depths (Davis, 1974.)

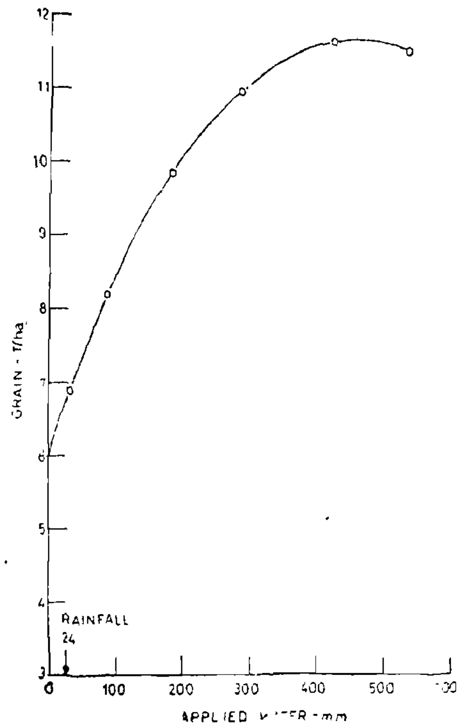

Fig. 4. Maize grain yields related to seasonal applied water depths (Davis, 1974).

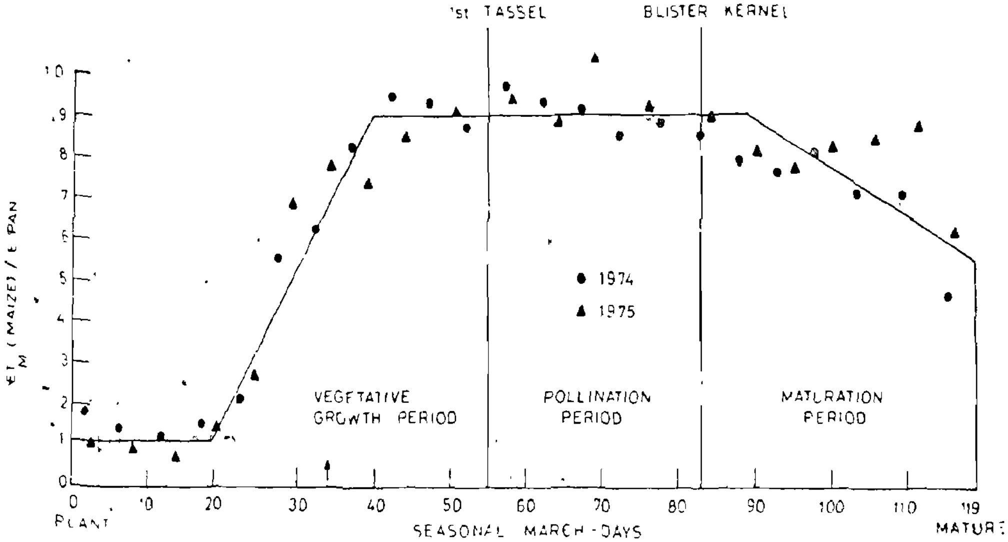

Fig. 5. Ratio of ET_M/Ep found at Davis in 1974 and 1975 respectively, daily measurements were made of ET_M from the large floating lysimeter and Ep from a class A evaporation pan.

SOIL DEPTH (cm)	DEPLETION BELOW FIELD CAPACITY - SOIL WATER UNITS										
	VEGETATIVE PERIOD				POLLINATION				MATURATION		SEASON
(0-15)	22	16	—	—	—	—	—	—	—	—	38
(15-45)	1	20	5	5	3	3	3	2	2	2	46
(45-75)	—	13	14	14	4	3	2	2	1	—	53
(75-105)	—	4	16	11	8	5	3	2	1	1	51
(105-135)	—	1	5	8	14	11	4	2	1	1	47
(135-165)	—	—	—	5	16	12	6	3	3	2	47
(165-195)	—	—	—	—	4	17	12	7	3	2	45
(195-225)	—	—	—	—	—	9	9	10	9	6	43
(225-255)	—	—	—	—	—	1	3	4	6	12	26
(255-285)	—	—	—	—	—	—	—	3	4	8	15
0-285	23	54	40	43	49	61	42	35	30	31	411

DAY 0 —— 20 —— 41 —— 55 —— 69 —— 83 — 90 —— 119

PLANT THIN LAI=3 1st TASSEL POL MILK MATURE

DAYS AFTER PLANTING AND GROWTH STAGES

Fig. 6. Time and depth function of soil water extraction by unirrigated maize Davis, California 1974. One "Soil water unit" equals 1% of field capacity of a 30 cm soil layer.

and all field procedures, data handling, analysis and reporting, etc. were standardized at the four sites (Stewart, *et al.*, 1977a).

The "line source" design developed at Utah State University (Hanks *et al.*, 1974), was utilized throughout, and has been used since at Davis for water production function studies on beans, cotton and tomatoes. This design is now being employed in the studies in Kenya. An example will be shown and discussed later.

Figures 3, 4, 5 and 6 show actual findings at Davis in 1974. These will serve as examples of the types of information to be developed in Kenya.

The yield versus evapotranspiration function and critical period effects

Figure 3 shows the relationship found between maize grain yield and total actual evapotranspiration for the season. This is termed the *Y vs ET* function. Typically, for all crops studied to date, it is fitted well by a straight line. This raises the question of "critical growth stage" effects which were also studied. Interested readers are referred to Stewart *et al.*, 1977a.

Figure 3 shows results from a single line source plot, labelled III, meaning it was irrigated in three major growth periods. Irrigation began 4 weeks after planting (the land had been preirrigated to assure field capacity to a depth of 3 m) and continued weekly thereafter until 9 applications were made. Thus 4 applications were made in the Vegetative Period which ended at first tassel, 8 weeks after planting. Similarly, 4 applications were made in the Pollination Period, which ended at blister kernel, 12 weeks after planting. A final irrigation was then applied to refill the profile close to the sprinkler line, and carry the crop to maturity. The application depth at the sprinkler line in each of the first 8 irrigations was 50 mm, shown by the lysimeter to be more than adequate to meet ET requirements in nearly all weeks.

Water measurements were made in every 4th row of maize, hence every 3 m, beginning 1½ m from the sprinkler line. Six "water application levels" were measured in all, five within the sprinkler pattern and one beyond its reach. Actual water application levels were nearly identical on both sides of the sprinkler line, and two separate water measurement bands were established across each plot, so there were a total of 4 replicates of each water application level in the plot. Hence, combining the 4 replicates in each instance, Fig. 3 contains 6 data points.

The results in Figure 3 and those developed in coordinated studies in Utah, Colorado and Arizona, have been used to develop yield models for different actual ET levels (Stewart *et al.*, 1977a; Hanks *et al.*, 1977). These models may be applied either at a simplified level in which prediction of yield is based on the III treatment regression line alone, or a more complicated level which requires quantification of separate growth period sensitivities. An important finding is that the simplified model predicts as accurately as the complicated model in nearly all circumstances. This becomes more true as more drought resistant maize varieties are selected for production.

Expanding briefly on selection for drought resistance, Figure 3 contains the notation "YRR = 1.10". This refers to the "Yield Reduction Ratio" defined as the percentage reduction in yield per percentage ET deficit, i.e., the relative value slope of the regression line, as it falls from the maximum yield and ET point. The greater the value of YRR, the more sensitive are certain growth stages, hence the less drought resistant the variety. Therefore, a single plot irrigated on the III schedule may be used to determine the YRRs and relative drought resistances of a number of varieties. By way of example, the YRR of a maize variety studied at Davis in 1969-1972 is 1.26, versus 1.10 for the variety in Figure 4. But the sensitivity of the Pollination Period of the former variety is 3 to 4 times as great as that of the latter variety (Stewart *et al.*, 1975; Stewart *et al.*, 1977a).

Relationships between yield and applied water

Figure 4 shows data from the same experiment as Figure 3, but relates grain yields to applied water (irrigation plus rainfall) rather than evapotranspiration. If "applied water" were different seasonal depths of rainfall rather than irrigation, the picture would look much the same.

Predicting crop water requirements

Figure 5 shows ratios of maximum rates of ET by maize to rates of evaporation from a class A evaporation pan, as found at Davis, California in the 1974 and 1975 growing seasons. Growth periods are indicated and the Figure covers the entire season from planting to maturity.

Such ET_M/E_P ratios, or crop coefficients, may be viewed as forming 4 distinct straight line segments as the season progresses (Stewart *et al.*, 1974; Doorenbos and Pruitt, 1977). Initially, after planting, the ratios are low, representing mostly bare soil evaporation for a period of 3 weeks. Rainfall in this period will increase the ratio. Over the next 3 weeks the leaf area development is rapid and the transpiration portion of ET becomes dominant. The rate of ET reaches a maximum and levels off when leaf area index reaches a value of about 3. At this time leaves will shade 70-80% of the ground.

Maximum ET rates pertain for the next 7 weeks, ending approximately at the milk stage. After that, as maturity approaches, the coefficient declines in more or less linear fashion as a result of leaf senescence.

Crop coefficients like those in Figure 5 are quite reproducible from year to year, and at different sites, and often fit several if not most varieties of a species. Adjustments between varieties are required mostly to account for different maturities. Figure 5 and others like it, to be determined in Kenya, provide a means of estimating the water requirements of major food crops in the different marginal rainfall areas.

Predicting both amount and sequence of extraction of stored soil water

Figure 6 shows the pattern of stored soil water extraction by maize at Davis in 1974 from a deep, well structured soil profile. The water content throughout was initially at field capacity. No water was applied save 24 mm of rainfall in the growing season. However, due to the high water holding capacity of the soil (nearly 100 mm of water per 30 cm of soil) the actual ET was about 430 mm, and yield about 7 tons/ha (Figure 3). Thus, although under water stress all season, growth was healthy, and root system exploration of the profile was maximised.

Figure 6 represents soil water extraction as "soil water units" rather than absolute amounts. A soil water unit is defined as 1% of the water which can be stored at field capacity in a 30 cm layer of soil.

As explained, Figure 5 is a device for predicting ET_M or crop water requirement. Similarly, Figure 6 is a device for predicting ET_A, i.e., the actual ET regime a crop is expected to enjoy. Both are to be predicted as sequences related to growth stages as well as for the entire season.

Many studies have included predictions of rainfall on a stochastic basis, and its expected contribution to actual ET. The research program in Kenya includes this type of study also. But the expected contribution of stored soil water to ET_A, and particularly its time sequence, has never been adequately evaluated insofar as the authors are aware. Charts like that in Figure 6, determined for good crops in Kenya, will be used for that purpose.

The suggestion is, that soil depth and structure permitting, a given crop variety (and likely several similar varieties) will exploit stored soil water repeatedly in the same time and depth pattern. Actual water quantities to be extracted are predicted by measuring field capacities of the different layers of the planning site soil (a 1–time measurement) and estimating the actual soil water content at the start of each cropping season.

KENYA FIELD EXPERIMENTATION

Operational levels

Field experiments with each study crop will be carried out at three levels of sophistication. These are: (1) The basic level at which all of the transferable information on crop water use and yield responses will be quantified, as exemplified by Figures 3, 4, 5 and 6. Muguga will be the site for these studies. (2) The secondary level will have experiments designed to recheck the basic findings and relate them more closely to actual conditions in the field. Research stations having an irrigation capability, and located within the marginal rainfall areas will be used for this purpose. Growing season will correspond to local practice. (3) The third level will closely approximate conditions faced by small holders in the marginal rainfall areas. Experiments will be simplified, and designed to check our ability to predict actual crop water regimes and expected yields in different environments.

Experimental features

Basic experiments at Muguga will include both field plot and large lysimeter studies. These will be carried out with irrigation in the hot dry season from mid-December to mid-March in order to maximize both water control *per se,* and the range of water regimes over which yield responses are studied. The deep red (alfisol), open-structured soil at Muguga has a high water holding capacity, and is ideally suited for studies of maximum rates and extent of root expansion, hence maximum extraction of stored soil water.

A large hydraulic lysimeter (3 m square by 2 m deep), recently completed at Muguga will be used for determination of crop water requirements. A complete and well tended meteorological station has been in operation there for 25 years. The line source experimental design will be utilized to determine both yield reduction ratios under chronic water deficits, and sensitivities of known "critical stages" to acute water deficits.

Secondary level experiments will be carried out at the Katumani Dryland Farming Research Station in Machakos District, and at other suitable GOK Research Stations as the study develops. The irrigation capability at Katumani has recently been augmented for this purpose. The meteorological station there includes a rain gauge, and screened Class A evaporation pan with green grass surroundings. A second evaporation pan will be installed in dry surroundings to determine effects of pan environment on crop factors. Such factors will be essential as a basis for estimation of crop water requirement at new planning sites. The initial field experiment of the study is presently in progress at Katumani. It is described in detail later.

Third level trials will be carried out concurrently with those at the second level, but will be located either on outlaying research stations or on private farms. Rain gauges and screened Class A evaporation pans will be installed if not already present. Experimental soils will be representative of the area, and no irrigation will be provided. Primary measurements will be periodic soil water content (hence soil water extraction), rainfall and crop yields. Variables will include, but are not restricted to plant population and tillage practices.

Initial maize experiment at Katumani

Maize was selected at the initial study crop. Accordingly, two short maturity cultivars developed locally were planted at Katumani on November 16, 1977. The first is "Katumani maize", a white seeded dent-type which matures in 100-120 days and is currently the most popular in the area. The second is an unreleased flint-type composite, lightly yellowish which matures as early as 90 days.

The experiment is well advanced as this symposium convenes. The Katumani maize is in the soft dough stage and the new composite is in the hard dough stage. Harvest will be during the latter half of March. Figure 7 shows details of the experiment.

The overall dimensions of the plot are 44 m wide by 56 m long, a total of .25 ha. Row spacing is 90 cm, and 48 rows make up the total plot, i.e., 24 rows on each side. Water measurement sites are in every 3rd row, and there are 7 "water application levels" measured on each side of the line, leaving three guard rows.

Water levels 1 and 7 represent the extremes of dryness and wetness respectively. No water is applied to water level 1 near the sides of the plot, hence this represents the rainfed condition. A known

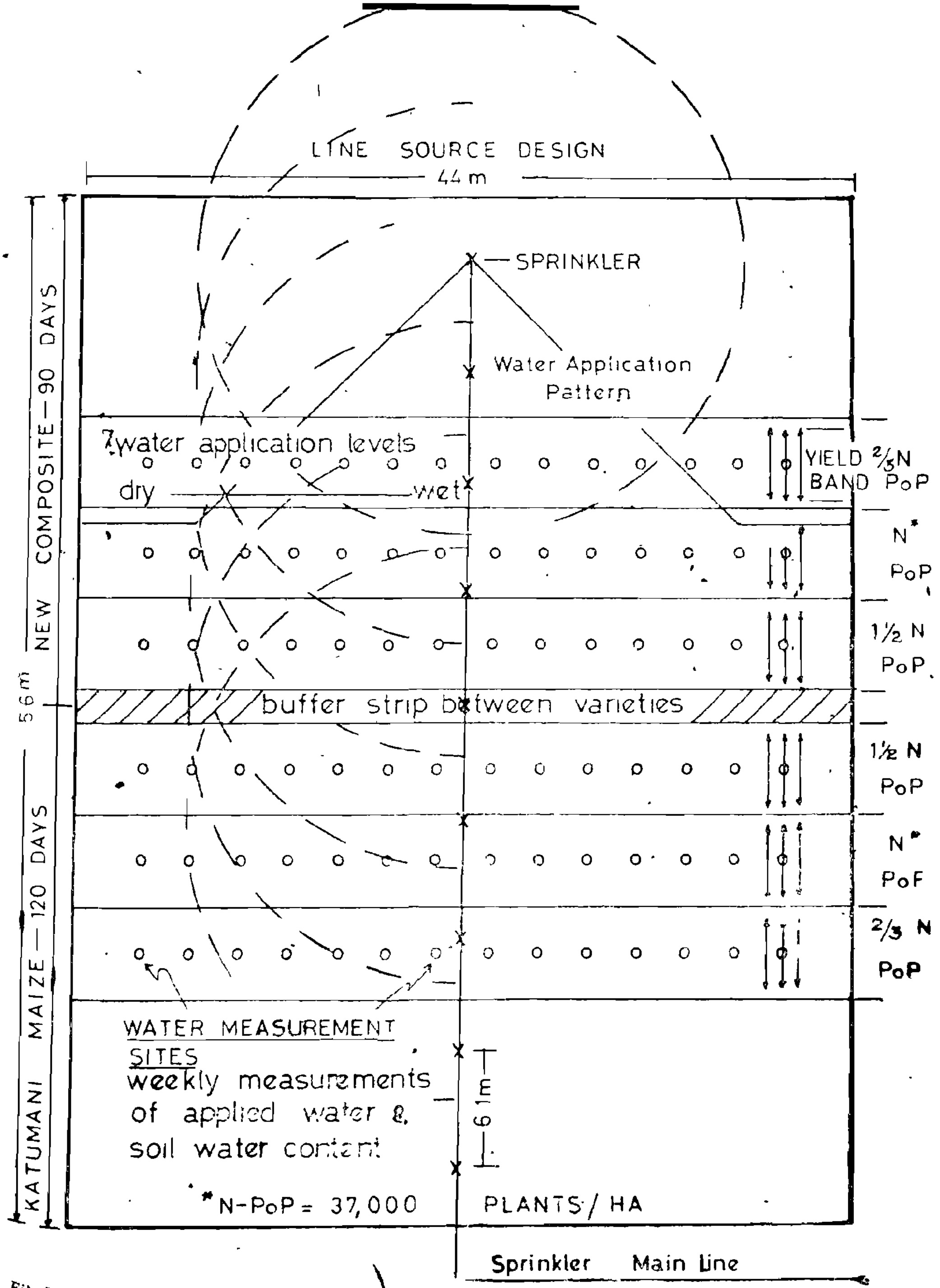

Fig. 7. AFRO/USAID maize water production function experiment at Katumani Dryland Farming Research Station. Planted 16th November 1977.

excess of water is applied to water level 7 near the sprinklers line. Adequate water is applied at level 6 to fulfil the crop requirement (ET_M), and levels 5, 4, 3, 2 and 1 represent increasing water deficiency.

There is only a single sprinkler line, so no overlapping water application from the sides, but with sprinklers close-spaced at 6.1 m along the line there is considerable overlap that way. To be valid, all measurements of applied water and corresponding yields must be made within the fully overlapped area. This area begins approximately 9 m. inside of the end sprinklers.

A total of water and yield measurement bands cross the plot, with 3 different plant populations. The normal (N–PoP) has 37,000 plants/ha. The others are higher (55,500) and lower (24,650). All rows are spaced 90 cm apart, with normal plant spacing 30 cm. Thus treatments are comprised of 2 varieties, 3 plant populations, and 7 water application levels, for a total of 42. Each is replicated twice.

Completion of maize studies

In March 1978 additional maize experiments with the same two varieties will be planted at all three experimental levels. Respective locations will be Muguga, Katumani and Kampi ya Mawe substation. Irrigation is not yet installed at Muguga, so the rainv season will be utilized. By hand irrigating the lysimeter, the water requirement of Katumani maize will be measured, and crop factors determined as seen in Figure 5. Additionally, the deep soils at Muguga will permit determination of the time and depth patterns of soil water extraction by both maize varieties, to form diagrams like Figure 6 to use in prediction elsewhere.

The Katumani experiment will be a repeat of that pictured in Figure 7. The latter experiment was only irrigated once at the start of the Maturation Period, due to delayed installation of equipment. However, the equipment is now operative, and the new experiment should proceed smoothly. Nevertheless, the initial experiment has provided much valuable data on growth habits and soil water extraction patterns of the maize varieties under study, and has served as a training ground for the technical staff who are now well acquainted with the research design and procedures.

The third (farm) level experiment will not be irrigated. It will include the same two maize varieties at the same three levels of plant population as at Katumani. Soil water content will be measured weekly, and daily measurements of rainfall and Class A pan evaporation will be made. This experiment will provide "ground truth" data for formulation of the predictive estimation methodology.

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II. 1.3

SOIL - WATER - PLANT RELATIONS AND PRODUCTION OPTIMISATION FROM ARID AREAS

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INTRODUCTION

General shortage of water and prevalance of drought conditions are by far the most serious constrains for stabilisation or promotion of plant production in the arid and semi-arid area. The overall problem is extremely complex as the plants in the open system of the field are subjected to wide ranges of soil-water conditions and to diverse interplay of environmental factors. The soil component and the plant component of the overall soil-water-plant-environment complex, however, can be gainfully managed to a degree for improving the agriculture production.

Factors influencing the soil-water variabilities

Soil-water variabilities caused predominantly by rainfall variations, may be of different nature. It has generally been recognised that drought in nature may be of different types and may be broadly classified into four different categories. In one case, erratic distribution of rains may lead to sporadic drought conditions where plants may be subjected to soil water deficit at any stage of growth. In another situation, rains may completely fail and thus very low soil moisture may prevail throughout the growing period of the crop. In the third situation, early rains followed by prolonged dry period may progressively dwindle the soil water reserve and thus plant growth and yield may be severely restricted. In the fourth situation, soil moisture stress, particularly at the critical reproductive phase of the plant may reduce the yield of the plant. Apart from these, delay in the onset of monsoon, sometimes may also adversely affect the rain-fed crops.

It is also necessary to reckon that soil moisture conditions may also vary widely depending on topography, vegetation, slope, soil depth and soil character. Wide differences in the moisture status of stabilised and unstabilised dunes (Mann *et al.*, 1976) and the relative influences of different tree vegetation on soil moisture status (Gupta and Saxena, 1978) are significant pointers to the need for evaluation of diverse factor of the arid ecosystem which modulate soil water condition.

Principles of insulation under sporadic droughts

Under the sporadic drought, it may be recognised that there will be 'wet' and 'dry' phases during the growing period of the plant and thus the stress condition is not likely to prevail indefinitely. It has been found (Lahiri and Kharabanda, 1966) that irrigation after a period of water stress induces high transpiration potential. It was therefore reasoned that after a single period of drought (till wilting), higher water and nitrate uptake at the post-drought stage may normalise the nitrogen status of the plant. It was further observed (Lahiri and Singh, 1968) that the protein synthesis increased sharply on watering at the post-drought stage, although there may be restriction of protein synthesis, and even its hydrolysis, at wilting. It was further observed (Lahiri and Singh, 1970) that the rate of nitrogen uptake remained virtually unaffected over a wide range of tensions (F.C. to 1 atm and F.C. to 8 atm) and impediments in uptake occurred only when plants passed through repeated cycles of F.C. to 15 atm tension. Our unpublished data again indicated that rewatering after a drought period sharply increased the nitrate reductase activity of plant tissue, particularly when nitrogen was limiting in the soil. These evidences suggested that adequate fertility may help in increased nutrient uptake during the 'wet' phase of the sporadic drought and may thus stabilise the crop yield despite the intervening 'dry' spells.

It could be experimentally demonstrated thereafter (Lahiri *et al.*, 1973) that performance deterioration of pearl millet crop caused by phasic drought could be substantially evaded under high soil fertility condition. This phenomenon has been found to be true in studies conducted with a number of other crops like wheat, *guar, moong* and *moth.*

Investigations on wheat and pearl millet indicated that adequate soil fertility helps to maintain a higher activity of plant enzymes under conditions of water shortage and temperature stress (Lahiri and Kathju, 1973, Kathju and Lahiri, 1976).

The foregoing account suggests that in rain-fed areas, where total precipitation as such is not low, adequate soil fertility may help in stabilisation of crops under sporadic drought.

Improvement of soil moisture conditions

Under other conditions of drought, effective methods are necessary for enriching soil moisture for yield stabilisation. A number of studies have been undertaken in this Institute for developing such methods. Prajapati *et al.* (1973) have indicated the methods of water harvesting from rocky catchments. Singh *ét al.* (1973) and Singh (1974) have defined the optimum proportion of catchment to cultivation areas for runoff farming in sandy flat plains. Misra (1966) in this context indicated the prospects of yield stabilisation of gram (*Cicer arietinum*) by bunding in sandy loam soil in years having low rainfall. It has also been found (Mann and Lahiri, 1979) that use of soil amendments (like pond silt and vermiculite), use of sub-surface barrier and different mulches improve the soil moisture conditions with associated increase in water use, water use efficiency and growth and yield of crops.

Effective use of the conserved moisture

It may be considered that the water enrichment of the cultivated area will be largely limited by the water holding capacity of the profile invaded by roots and thus may be rather low in sandy soils. In such a condition improvement of moisture recharge has to be linked with measures for improvement of soil physical conditions conducive for larger moisture retention.

In other condition where crops are grown in the conserved moisture the merit of use of fertilizer is often debated. It largely stem from the problem of early exploitation of moisture which often leads to increase in soil moisture stress at the later stages of development with an associated decrease in the yield. However, it is necessary to reckon that improvement of soil moisture during vegetative phase in any case will normally increase the consumptive use. Addition of fertilizer like nitrogen will deplet the moisture faster but its absence will decrease the efficiency of water use and thus may have deleterious effects. One way to overcome the difficulty may be to breed for earliness of maturity but the high yielding character has to be associated. The other possibility is to breed for features of the plant which have a direct influence on water relation. Increasing the sensitivity of stomata to water stress so that they close at higher leaf potential may not help, as the plant may lose the capacity to draw moisture from dry soil. Again, explorations of the use of antitranspirants have not yielded promising results suitable for large-scale application. A more attractive alternative is to identify plants having high hydraulic root resistance and high harvest index. Deeper root system may also be of advantage for tapping water from the deeper regions of the profile. Considerable effort is presently being directed towards the identification of crop varieties which are endowed with these characters.

Optimum use of limited irrigation water of arid areas

Research efforts (Singh, 1976) have also been directed towards maximising yield with a minimum of irrigation water. Among other things, it has emerged that lower average yield over a larger area could bring about a higher total benefit in the dry region, than most profitable yield from a small region. It therefore seems that it may be advantageous to spread a given quantity of water over a larger area. In this context a question arises as regards the role of inputs like nutrients on the water use efficiency. It will be a desirable strategy to induce in the plant system a higher level of efficiency so that the available water resources are utilised to the best of human advantage. It is very meaningful in the arid and semi-arid areas where a general paucity of irrigation water exists. Our findings (Lahiri, 1975) suggest that substantial production may be achieved with less water by optimising the inputs like nutrients. As a matter of fact one can obtain different levels of production, at the same level of water use, under irrigated conditions by a progressive optimisation of inputs. Thus it may be possible for a farmer of this area, having well irrigation of limited discharge, to expect a reasonable yield. Again it may be possible to divert the limited water resource over a larger area.

Improved methods of irrigation, like the drip irrigation has also helped in optimum use of minimum water. Singh (1974) reported from this Institute that trickle irrigation has produced 55.79, 12.03, 33.38, 82.33 and 40.61 tonnes/ha of bottle-gourd (*loki*), ridge gourd (*tori*), potato, water melon and round gourd (*tinda*) respectively and the percentage increase in yields of these crops, over the sprinkler and furrow methods, varied from the lowest of 32 in round gourd to the highest of 65.4 in potato. These increases in yield were associated with higher water use efficiency. It has also been found that the yield of potato, under trickle irrigation, was of the order of 31, 26 and 14 tonnes/ha with sweet water and water having 3 and 10 millimhos of conductivity while under furrow irrigation with sweet water it was about 19 tonnes/ha. Despite these advantages of trickle irrigation, the cost of installation is rather high. Reduction in the number of laterals by evolving suitable planting pattern may be one of the means for reducing the cost. The total expenditure in inputs like fertilizer may again be reduced by their application only in the wet zone which has relevance in this system. These aspects are presently being examined.

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II. 1.8

INTERCROPPING SYSTEM FOR DRYLANDS

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INTRODUCTION

In the arid regions of Western Rajasthan, mixed cropping has been in vogue since ancient times. However, the practice of intercropping perennial forage crops with annual crops is almost non-existent, despite the availability of well adapted and high yielding desert grasses and animal husbandry being the mainstay of the economy of this region. Since the farming community has not evinced any interest in the cultivation of grasses so far, it is surmised that any intercropping system which guarantees the optimum forage production per unit area and moisture, besides giving satisfactory yield of grains, is likely to find favour with the farmers.

Research efforts initiated in 1966 at this Institute yielded useful results indicating that green gram (*Vigna radiata*), dew gram (*Vigna aconitifolia*) and cluster beans (*Cyamopsis tetragonoloba*) were quite compatible for intercropping with *Cenchrus ciliaris, C. setigerus, Lasiurus sindicus* and *Dichanthium annulatum.* These companion crops yielded 2-3 q/ha of additional grain yield without impairing the productivity of the principal crop

(Daulay *et al.*, 1969, 1970, 1972). Having been encouraged with these results, research efforts on intercropping systems involving *Cenchrus ciliaris* grass were intensified in 1973.

MATERIAL AND METHODS

An experiment on the intercropping of annual grain legumes with *Cenchrus ciliaris* (358) was conducted for three consecutive *kharif* seasons (1973 through 1975) at the Central Research Farm, Central Arid Zone Research Institute, Jodhpur, in a strip plot design with four replications. Perennial grass was established during the second week of August 1973 by planting rooted slips in strips, in uniform (60 cm) and paired row systems (40/80 cm) and four grain legumes viz., green gram (S 8), dew gram (local), cluster beans (FS 277) and cowpeas (FS 68) were sown with one row in uniform and two rows in the paired row systems in the inter spaces of the grass rows. In 1974 and 1975, the companion legume crops were inter-cropped with the receipt of rains. After the establishment of the legumes, grass cuttings were regulated to avoid shading effect on the companion crops. On maturity, legumes were harvested for grain and forage. However, in 1974, intercropped legumes failed at the seedling stage due to prolonged drought spell of 26 days duration beginning 24 July.

Soils of the experimental fields were loamy sand to sandy loam in texture with more than 85% sand and pH. ranging from 7-8. The soil depth, total moisture storage capacity, bulk density were of the order of 90-100 cm, 125-135 mm and 1.5 to 1.65 g/cc, respectively. Soils were low in organic matter (0.4%), low to medium in available phosphorus (13-18 kg/ha) and medium to high in available potash (200-250 kg/ha).

The rainfall received during the cropping seasons is given week-wise in Table 1.

Table 1. Weekly rainfall (mm) during 1973, 1974 and 1975 cropping seasons

Meteorological week	Period	YEARS		
		1973	1974	1975
28	9 – 15 July	8.7 (1)	44.7 (1)	21.6 (2)
29	16 – 22 July	58.9 (2)	43.4 (3)	117.2 (5)
30	23 – 29 July	4.3 (–)	17.0 (1)	8.6 (1)
31	30 – 5 August			
32	6 – 12 August	87.3 (3)		47.5 (5)
33	13 – 19 August	108.7 (5)	1.5 (–)	48.2 (5)
34	20 – 26 August	9.5 (1)	15.0 (1)	7.1 (2)
35	27 – 2 September	161.7 (4)		12.7 (1)
36	3 – 9 September	59.5 (4)		172.7 (5)
37	10 – 16 September	9.0 (1)		63.4 (5)
38	17 – 23 September			5.8 (1)
39	24 – 30 September		36.1 (2)	
40	1 – 6 October			15.0 (2)
41	7 – 13 October		2.5 (1)	
42	14 – 20 October		2.3 (–)	
TOTAL		507.6 (21)	162.5 (9)	519.8 (34)

Note : Figures in parenthesis indicate number of rainy days.

Of the 3 cropping seasons, 2 seasons viz., 1973, 1975 were good rainfall years, whereas 1974 was a drought year. The total rainfall in 1973 and 1975 seasons was more than 500 mm, however, the distribution in 1975 season was more favourable to crop growth.

RESULTS AND DISCUSSION

Results of this study are presented under the 4 main heads viz., (i) green forage yield of the grass and seed yield of the legumes, (ii) dry matter production of the various intercropping systems, (iii) moisture use and moisture use efficiency as influenced by intercropping treatments, and (iv) economic analysis of the various intercropping systems.

Green forage yield of grass and seed yield of legumes

Data on green forage yield and seed yield of legumes as influenced by different planting systems and intercrops are presented in Table 2.

Green forage yield of the grass was not significantly influenced by systems of planting either in the pure stand or mixed stands during *kharif* 1973 and 1975. However, in 1975, the mean yield of green forage obtained from the pure and mixed stands in the paired rows showed 15 q and 3.5 q/ha higher yield over the uniform row system, the yield being 100.6 and 108.3 q/ha, respectively. Similar were the trends during *kharif* 1973 and 1974 but the differences were marginal. These observations are in agreement with the observations of Talamucei (1975) who also obtained marked increase in forage yield with alternate paired row planting of white clover/tall fescue mixture over the broadcast and alternate row planting systems.

Mean green forage yield of the *Cenchrus ciliaris* obtained under pure and mixed stands revealed that the forage yield was not adversely affected by intercropping of annual grain legumes during 1973 and 1975. However, during 1973, intercropping of cowpeas and cluster beans with *Cenchrus ciliaris* reduced the forage yield significantly while reverse was the case during *kharif* 1975. Tetteh (1972) also observed similar reduction in the yield of *Andropogon gayanus* grass by its mixed culture with forage legumes.

Seed yield of companion/intercrops was not markedly influenced by systems of planting in both the years (1973 and 1975) except that cluster beans which gave 4 q/ha higher seed yield under the uniform row system of planting over the paired row system of planting in 1975. Among the companion crops, cluster beans and dew gram gave almost similar but distinctly higher seed yield than green gram and cowpeas in 1973 season. Whereas, in 1975, cluster beans produced the highest seed yield (17.6 q/ha) followed by dew gram (7.8 q/ha), cowpeas (4 q/ha) and green gram (3.7 q/ha). Cluster beans and dew gram being comparatively long duration crops were greatly benefitted from the extended monsoon season of 1975 and resulted in markedly higher seed yield than green gram and cowpeas. Whereas, the yield of the latter two crops was adversely affected due to rains at their maturity causing

Table 2. Mean green forage yield of *Cenchrus ciliaris* (C C) and seed yield of legumes (q/ha) under different systems of planting

Treatments	Y E A R S												Mean			
	1973 (338 mm)				1974 (162 mm)				1975 (542 mm)							
	Uniform		Paired		Uniform		Paired		Uniform		Paired		Uniform		Paired	
	BC	CC	BC	CC	BC	CC	BC	CC	BC	CC	BC	CC	BC	CC	BC	CC
C.C. + green gram	19.2	3.7	19.9	4.0	45.2	—	48.8	—	90.3	3.7	114.6	3.6	51.9	2.5	61.1	2.5
C.C. + dew gram	18.9	4.4	18.5	4.1	45.2	—	48.8	—	105.6	7.4	102.7	7.8	56.6	3.9	56.6	4.0
C.C. + cluster beans	17.0	4.1	16.5	4.7	45.2	—	48.8	—	109.0	17.6	107.6	13.5	57.1	7 2	57.6	6.1
C.C. + cowpea	16.2	2.5	18.9	3.3	45.2	—	48.8	—	128.4	4.0	123.6	3.5	63.3	2.2	63.8	2.3
C.C. pure stand	19.5	—	21.7	—	45.2	—	48.8	—	100.6	—	115.3	—	55.5	—	61.9	—
Mean yield of C.C in mixed stand	17.8	—	18.4	—	45.2	—	48.8	—	108.3	—	111.8	—	57.1	—	59.7	—
't' test for green forage yield of grass																
1) Systems of planting		NS								NS						
2) Pure mixed cropping		Sig.								NS						

Note : BC stands for base crop; CC stands for companion crop.

delay in harvesting and threshing. Studies by Prasad and Chaudhary (1975) on suitable plant types of green gram for intercropping with *Cenchrus setigerus* also showed no adverse effect on the forage yield of grass by intercropping of green gram (288-8) and gave additional seed yield of 3 q/ha. Similar studies carried out at this Institute in 1973 revealed no reduction in the forage yield of *C. ciliaris* by intercropping cowpeas (K 11) which gave 5 q/ha additional seed yield (Anon. 1973).

Dry matter production under various intercropping systems

Total dry matter yield was estimated based on the air dried forage of grass, grain and straw yield of legumes. Since there was no significant difference in the dry matter yield between the two system of planting, data on the mean yield of the two systems of planting under different seasons are presented in Table 3.

There was no marked difference in the dry matter yield of the grass component between the pure and mixed stands both during 1973 and 1975 seasons when the intercrops were successful. However, in 1973, contribution of grass to the total dry matter production was comparatively lower than legumes and the reverse was the case in 1975 season. Among the intercrops, contribution to the total dry matter production was the highest by cluster beans, followed by dew gram, green gram and cowpeas both during 1973 and 1975 seasons. Based on the mean of three seasons, mean dry matter yield of the mixed stands was 65 per cent higher than grass alone. Combination of *C. ciliaris* + cluster beans resulted in the maximum increased dry matter yield over the grass alone (97%), followed by *C. cilliaris* + dew gram (62%), *C. ciliaris* + green gram (52.5%) and lowest (46%) in *C. ciliaris* + cowpeas intercropping systems. These findings are in agreement with the results of intercropping studies carried out at Gujarat Agricultural University Anand where combination of *Dichanthium annulatum* + cluster beans also showed maximum increase in dry matter yield over the grass alone (Anon. 1976). Mixed stands of green panic/perennial legumes also showed 100% higher forage production than grass alone (Subramanya *et al.*, 1976). Patel *et al.* (1973) also observed 30%higher dry matter production from the mixed stands of Guinea grass + lucerne over the pure stand of grass and this intercropping system resulted in 1.5 times as great the total efficiency of land utilization. Whereas, Tetteh (1972) reported reduction in dry matter yield of mixed sowing of *Andropogon gayanus* + forage legumes as compared to grass alone.

Moisture use and moisture use efficiency

Based on the moisture estimations at sowing and harvest of the crops/grass and the effective rainfall during the crop growth, total consumptive use for each of the intercropping system was worked out for 1975 season. Whereas, for 1973 and 1974 seasons, it was computed based on the effective rainfall and residual moisture in the soil profile at the end of the growing season. Data on moisture use and moisture use efficiency as influenced by different intercropping systems are presented in Table 4.

Table 3. Total dry matter yield (m tons/ha) as influenced by different intercropping systems

Treatments	1973			1974			1975			Mean			Percent increase over the pure stands of grass
	BC	CC	Total	BC	CC	Total	BC	CC	Total	BC	CC	Total	
C.C. + green gram	0.78	0.94	1.72	1.88	Failed	1.88	3.07	2.38	5.45	1.91	1.11	3.02	52.5
C.C. + dew gram	0.74	1.03	1.77	1.88	,,	1.88	3.13	2.86	5.99	1.92	1.29	3.21	62.1
C.C. + cluster beans	0.67	1.11	1.78	1.88	,,	1.88	3.28	4.77	8.05	1.94	1.95	3.90	97.0
C.C. + cowpeas	0.70	0.59	1.29	1.88	,,	1.88	3.78	1.72	5.50	2.12	0.77	2.89	46.0
C.C. pure stand	0.82	—	0.82	1.88	,,	1.88	3.24	—	3.24	1.98	—	1.98	—
Mean of the mixed stands	0.72	0.93	1.65	1.88	,,	1.88	3.32	2.93	3.52	1.97	1.29	3.26	64.6

Note : 1. *C.C.* = *Cenchrus ciliaris* grass.
2. BC stands for base crop and CC stands for companion crop.

Table 4. Gross monetary returns, consumptive use and moisture use efficiency as influenced by different intercropping treatments

Treatments	Monetary returns (Rs/ha)			Consumptive use (mm)			Moisture use efficiency (Rs/mm/ha)		
	1973	1974	1975	1973	1974	1975	1973	1974	1975
C.C. + green gram	1092	470	1943	218	122	333	5.00	3.85	5.84
C.C. + dew gram	1059	470	2525	218	122	347	4.85	3.85	7.30
C.C. + cluster beans	912	470	3923	218	122	350	4.18	3.85	11.22
C.C. + cowpeas	708	470	2255	218	122	336	3.25	3.85	6.72
C.C. pure stand	206	470	1081	218	122	335	0.98	3.85	3.23
Mean of the mixed stands	943	470	2662	218	122	342	4.33	3.85	6.06
SEm ± for types of cropping	19.05	—	58.62						
SEm ± for intercrops	19.29	—	78.84						
CD 5% for types	60.83	—	187.48						
CD 5% for intercrops	55.09	—	224.35						

Notes : 1. In *kharif* 1973, seeds of green gram, dew gram, cluster beans and cowpeas @ Rs. 205, Rs. 177, Rs. 137 and Rs. 180 per q respectively. Whereas, in 1975, green gram, dew gram, cluster beans seeds @ Rs. 140/q and cowpeas seeds @ Rs. 180/q.
2. In both the years, green forage of grass @ Rs. 10/q and straw of various legumes @ Rs. 20/q.
3. Consumptive use values for *kharif* 1973 and 1974 are computed ones.

Although 1973 and 1975 seasons received more than 500 mm rainfall but the consumptive use during 1973 was comparatively much lower than 1975 because of planting of grass and crops late in the season. During *kharif* 1975, there were no marked differences in the consumptive use of mixed stands and pure stand of grass. However, the total dry matter production of the mixed stands was 93% higher than pure stand of the grass. These observations are in full agreement to the suggested concept of Donald (1963) that two species of contrasting habit with respect to growth characters, mineral uptake or other morphological or physiological characters, will together exploit the total environment more effectively than monoculture and will thereby give increased over-all yield.

In 1973, green and dew gram combinations with grass resulted in comparatively higher moisture use efficiency than *Cenchrus ciliaris* + cluster beans and *C.ciliaris* + cowpeas and all these grass legume mixtures gave 3 to 5 times higher moisture use efficiency than grass alone. In 1975, moisture use efficiency was maximum under *C. ciliaris* + cluster beans (Rs 11.2/mm/ha) followed by *C.ciliaris* + dew gram (Rs 7.3/mm/ha), *C.ciliaris* + cowpeas (Rs 6.7/mm/ha) and lowest in pure stand of *C.ciliaris* (Rs 3.2/mm/ha).

Economics of intercropping systems

In order to have precise comparisons of different intercropping treatments, the yield data were transformed to gross monetary return and data of the successful intercropping seasons (1973 and 1975) were statistically analysed (Table 4).

Mean gross monetary returns from the mixed stands were significantly higher than pure stands of grass both during 1973 and 1975. Among the various intercrops, green gram and dew gram gave almost similar returns but green gram resulted in significantly higher gross returns than cluster beans and cowpeas during *kharif* 1973. In *kharif* 1975, treatment trends were almost similar to the one observed in 1973 except that intercropping of cluster beans gave significantly higher gross returns than dew gram and the same in turn was significantly superior to cowpeas which was also significantly better than green gram. Higher returns from *C.ciliaris* + cluster beans and *C.ciliaris* + dew gram intercropping systems during 1975 were mainly due to high, well distributed rainfall and extended monsoon season. From these studies it is indicated that intercropping of green gram with *Cenchrus ciliaris* in normal rainfall or short growing seasons and cluster beans during well distributed high rainfall seasons, is more remunerative.

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II. 1.9

PRODUCTION POTENTIAL OF VARIOUS WINTER SEASON CROPS UNDER DRYLAND CONDITIONS IN SOUTH - WEST HARYANA

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INTRODUCTION

Some degree of water stress during the growing season is a normal phenomenon in winter season dryland crops in semi-arid Haryana. Since there is no systemic account of winter crops in relation to soil moisture balance, crop yield and net return, therefore, as such, the experiments reported here were carried out on several dryland crops for yield superiority grown on stored soil moisture.

MATERIAL AND METHODS

Field experiments were conducted at the Dry Farming Research Centre, Haryana Agricultural University, Bawal (Mohindergarh) during 1972-73, 1973-74 and 1974-75. The experiment comprised of six crops in 1972-73 viz., barley (variety C 138), gram (C 235), sunflower (EC 68415), brown sarson (BSH 1), *taramira* (ITSA 1) and *raya* (L 18) while in 1973-74 wheat (C 306) was added. In 1974-75 sunflower crop was deleted because of its poor yield. In all the years the treatments were replicated four times in randomized block design. The gross plot size in each case was 8 × 3 metres.

The soil was loamy sand having available phosphorus 14 kg per hectare, available potassium 285 kg per hectare, organic carbon 0.39 per cent, E. C. 0.21 mmhos/cm, and soil pH 7.7. The profile soil moisture at —0.3 and —15 bar was 13.0 and 4.8 cm per 90 cm soil depth. The apparent specific gravity was 1.4.

the time of sowing, 39 to 42 per cent of the rainfall was stored in the root zone. The total rainfall received during the crop season (October to April) in 1972, 1973 and 1974 was 34.0, 36.3 and 95.3 mm respectively. In 1973-74 the second half of December was marked with the relatively low temperature, cloudy weather and very dense fog for a period of about 15 days, this was followed by again a fortnight of dry and frosty weather in the middle of January. Recommended package of practices were used. The soil moisture was measured gravimetrically from 0-90 cm depth periodically.

Table 1. Rainfall (mm) at Bawal

Months	1972-73	1973-74	1974-75
July	33.4	160.1	317.1
August	374.5	235 7	136.9
September	16.3	95.5	34.6
Total	424.2	491.3	488.6
October	6.0	2.3	31.7
November	9.0	—	—
December	—	—	33.6
January	19.0	22.0	—
February	—	7.0	—
March	—	5.0	30.0
April	—	—	—
Total	34.0	36.3	95.3

Total rainfall (Table 1) received during 1972 summer was 424.2 mm, normal but erratic, while 1973 rainfall was normal (491.3 mm). In 1974 the rainfall was above normal (488.6 mm). At

RESULTS AND DISCUSSION

Soil moisture

Soil moisture in 0-90 cm depth was measured at planting in various crops at an interval of about a month and at harvest. Soil moisture in root zone was favourable at the time of planting. It was reduced with time. There was practically very little soil moisture use in the first month after planting in almost all the crops except in wheat (C 306). Soil moisture depletion during reproductive phase was very slow but constant. All the crops depleted the soil moisture upto —15 bar value upto harvest (Table 2). Seasonal water use was minimum with the *taramira* (9.1 and 8.2 cm) and maximum in *raya* (11.6 and 12.1 cm) followed by gram. Higher water use in *raya* and gram (Fig. 1) appears due to the deeper root system. Water-use-efficiency showed marked variation with crops, both barley and *taramira* showed higher water-use-efficiency as compared to gram, brown sarson and *raya* (Table 3).

Amongst various crops, barley gave the

Table 2. Soil moisture as affected by different treatments, 1973-1974

Treatments	Soil moisture from 0 - 90 cm depth									
	Dates of sampling									
	3/10	18/10	2/11	2/12	2/1	28/2	2/3	9/3	14/3	23/3
Barley (C 138)	—	11.0	10.4	8.2	7.3	6.8	—	5.3	—	—
Gram (C 235)	12.3	—	11.2	6.6	6.2	5.1	—	—	—	4.0
Sunflower (EC 68415)	11.2	—	10.4	9.3	8.6	7.0	6.0	—	—	—
Brown sarson (BSH-I)	12.7	—	11.1	9.5	7.5	7.0	—	—	—	—
Taramira (ITSA-I)	11.3	—	11.1	7.5	7.3	6.2	—	—	—	—
Raya (L-18)	12.4	—	11.2	8.6	7.5	6.9	—	—	3.9	—
Wheat (C-306)	—	—	11.2	8.5	5.3	5.0	4.5	—	—	—

Table 3. Consumptive use of water and water-use-efficiency of various winter season crops

Treatments	Consumptive use (cm)		water-use-efficiency (q/ha-cm)	
	1972-73	1973-74	1972-1973	1973-74
Barley (C 138)	11.1	9.3	1.7	1.0
Gram (C 235)	8.5	11.9	1.6	0.4
Brown sarson (BSH-1)	11.3	8.8	1.4	0.4
Taramira (ITSA-1)	9.1	8.2	1.3	1.1
Raya (L 18)	11.6	12.1	0.8	0.4
Wheat (C 306)	—	7.7	—	0.7

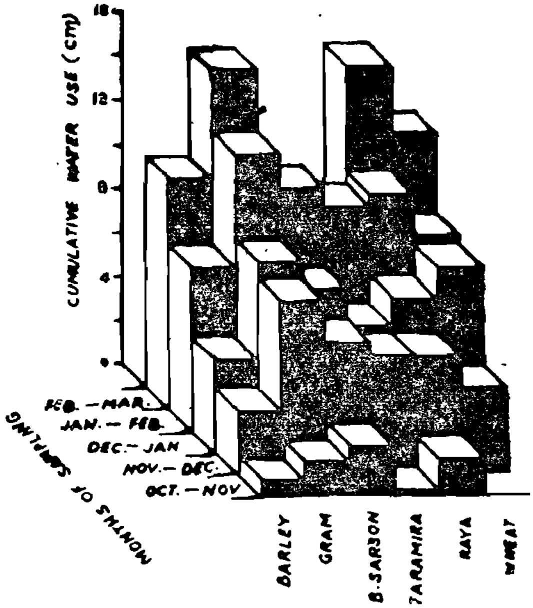

Fig. 1. Cumulative water use in various winter season crops, 1973, Bawal.

maximum grain yield (19.9 q/ha) followed by brown sarson, *taramira,* gram and wheat respectively. Wheat and sunflower practically failed in 1972-73 and 1973-74 due to depletion of available soil moisture in root zone.

There was marked variation in the grain yield of various crops due to prevailing weather condition. In 1973-74, there was unfavourable weather from mid of December to mid of January marked by low temperature, cloudy weather and very dense fog for a period of 20 days. The frost combined with the rainless winter caused serious damage to gram, brown sarson and *raya* (Table 4). *Taramira* on the other hand showed practically no reduction in the grain yield.

Table 4. Grain yield and economics of various winter season crops

Treatment	Grain yield (q/ha)			Average yield (q/ha)	Mean net return (Rs/ha)
	1972-73	1973-74	1974-75		
Barley (C 138)	18.6	10.1	31.0	19.9	633.0
Gram (C 235)	15.7	4.6	8.33	9.5	438.2
Brown sarson (BSH-I)	15.6	4.0	21.5	13.7	2015.5
Taramira (ITSA-I)	11.9	9.8	18.4	13.3	1645.0
Raya (L 18)	9.6	4.8	30.1	14.8	2060.0
Wheat (C 106)	—	5.6	15.2	5.4	—408
Sunflower (EC 68415)	6.4	0.8	—	3.6	
S. Em. ±	2.14	1.52	2.4	—	—
C. D. at 5%	5.99	3.62	6.8	—	—

Based on the net returns, *raya* and brown sarson were found to be most remunerative crops of the dryland at Bawal, [illegible]uth-West Haryana.

On an average, barley gave the maximum yield followed by oil seeds. *Desi* wheat and sunflower practically failed in the normal rainfall years due to the soil moisture deficit in the root zone during the reproductive phase of the crop. *Raya* was the most remunerative crop followed by brown sarson. *Taramira* may be mentioned as the most stable winter crop of dry land due to both drought and frost resistance. High production of *raya* and *taramira* have also been reported (Anonymous, 1976) under dryland condition. These results suggest that there is a scope to increase the conservation of summer rainfall to increase the stored soil moisture from winter dryland crops. Rao *et al.* (1978) have reported maximum net return of Rs. 1802/- with pearl millet under similar condition. It is apparent that it is more profitable to grow rape and mustard in winter season on conserved moisture as compared to rainy season crops on the same land.

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II. 1.10

IMPROVING THE MOISTURE STORAGE IN SANDY DESERT SOILS BY SUB - SURFACE MOISTURE BARRIER

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The wind erosion is a well identified problem of sandy soil management. The problem of poor moisture storage of sandy soils in arid and semi-arid plains of the world, has hitherto received only little attention. This paper deals with the concept and methodology of sub-surface moisture barrier as a means of improving moisture storage in sandy soils of the desert.

The concept of moisture barrier

The concept of moisture barrier originates from the observation that sandy soils with clayey sub-soil are the world's most productive agricultural soils. In order to duplicate this natural soil condition, Erickson *et al.* (1968a) used bentonite clay and plastic films placed to a depth of 60-70 cm in soil. Later, they switched over to the use of liquid asphalt as moisture barrier and it was this development that stirred world-wide interest in the technique.

This followed a series of field experiments conducted in different parts of the U.S.A. A technique for placing a

2-3 mm thick layer of asphalt to 60-70 cm soil depth was perfected. Erickson *et al.* (1968a) reported 200% increase in moisture storage capacity of the root zone by this technique which resulted in 40% and 32% higher yield of cabbage and cucumber, respectively. Earlier, Hammond *et al.* (1967) reported an increase in root zone moisture storage by 24 mm. In Florida, Saxena *et al.* (1968, 1971) also recorded higher yields of cabbage, potato and tomato from the barriered plots as a result of higher moisture storage and lesser leaching of nitrogen. The moisture storage in the 60 cm soil profile of Florida fine sand increased by 50 to 75 mm. Scarbrough and Liebhardt (1973) found that the barriered soil retained more moisture and also nitrates, and recorded more than 100% increase in yields of snapbeans, peas and tomato.

Amobar has been useful for field crops too (Erickson *et el.*, 1968a, 1968b). In paddy, barrier placement to only 15 to 20 cm depth proved highly effective. In the sandy soils of Taiwan barrier increased the yield of sugarcane. Corn, however, did not respond to barrier incorporation (Robertson *et al.*, 1973).

The success of field experiments as discussed above, generated considerable interest in the technique resulting into its commercial introduction in the U.S.A. A prototype of the asphalt barrier machine developed by the International Harvester Company was since perfected and introduced for field usage by Amoco Moisture Barrier Company (Anon. 1974) at Chicago. The company claims that Amobar costs about $ 700-750 per hectare and all or three-fourth of the expenditure is returned by the additional yield harvested in the first season itself.

Moisture barrier in context with the problems of Indian Desert Soils and climate

Soils in large part of Rajasthan are sandy, shallow to moderately deep, with a high rate of infiltration. Similar soil conditions also exist in parts of the adjoining states of Gujarat and Haryana.

A characteristic feature of the scanty rainfall that is received in the desert region is the occurrence of high intensity showers. At times bulk of the season's rainfall is received in a short spell resulting in deep percolation of moisture to the *Murrum* (partially decomposed bed rock material impregnated with calcium carbonate) strata. Other than few instances where soils are underlain by loose bouldary strata, *murrum* stores considerable moisture. However, moisture stored in *murrum* seldom moves upto the root zone for want of adequate moisture potential gradients. In winters, nevertheless, a portion of *murrum* moisture does move to the root zone in vapour phase along the reversed soil temperature gradients and contributes, to water needs of mustard and gram grown on stored moisture in localized pockets. If uncropped, this moisture is used by weeds and thus, little if at all is left till the next cropping season.

Sandy soils with clayey or cemented bouldary strata and sandy loam soils with sandy (dune like) sub-soil, are also met with though in small pockets, in this region. In such cases deep percolation is low due to steep differences in the hydraulic conductivities of texturally different layers and therefore barrier incorporation is not warranted. The work of Palta and Blake (1974) bears this fact out. They found that Amobar was not effective in a loamy coarse sand underlain by a coarse gravel layer. On the contrary in a homogenous fine sand the barrier increased the available water in the root zone and the crop yield.

Dryland agriculture

In arid Rajasthan, dryland crop production assumes priority over irrigated one with respect to reducing deep percolation, for the issues involved in the two cases are entirely different. Whereas under irrigation the objective is to bring economy in water use, on drylands it is the crop itself that has to be saved from oft occurring droughts.

In situ runoff concentration during the last decade, has made an impact on crop production in drylands. In years marked with high intensity showers concentrated in a small duration, runoff from the catchments exceeds the storage capacity of the soil in cropped area and is lost to deep drainage. Deep percolation, therefore, is a serious limitation of runoff concentration technique in such soil-climatic conditions.

Irrigated agriculture—Rajasthan Canal Command area

In arid Rajasthan, the ground water in general is brackish. As such, the use of moisture barrier technology with a view to economising water use cannot possibly be made in tube-well command areas owing to secondary salinisation-alkalinisation hazards. However, in canal command areas having good water quality the moisture barrier technique can be made use of, though with caution in view of arid climate indicative of salt accumulation. Large areas in Bikaner, Ganganagar, Jaisalmer and Jodhpur districts will be brought under irrigation in the coming few years by the Rajasthan Canal Project. Most of these areas fall into sandy, hummocky and duny classes of land of aeolian origin barring some alluvial soils in pockets.

The irrigation in such areas may lead to or associated with the following problems:

1) Excessive losses of water in deep percolation
2) Leaching of plant nutrients particularly nitrogen
3) Soil salinisation-alkalinisation as a result of salt movement to the root zone from deeper soil strata having a salt source.

The last of the above cited problems, i.e. salt accumulation, is not one of instant nature as the first two, and hence may arise only at some later stage of the irrigation programme. In Punjab a large area once productive as dryland turned saline-alkali after being brought under irrigation. In some instances this kind of soil degradation was noticed even when the water quality was good and the ground water table was also below the critical level. It was later revealed that some such soils had underlying salt strata that got linked to the root zone during repeated wetting and drying cycles under irrigation—a process that otherwise did not take place under rainfed agriculture. The resultant was salt transport, though at a slow pace, to the root zone which progressively built up to a level above the tolerance limit of most plant types. Same phenomenon is likely to operate at some later stage in the command areas of Rajasthan canal project too, in the event if indiscriminate irrigation is practised disregarding the soil-climatic conditions, especially on lands having a salt source. Besides controlled irrigation and use of systems like drip and sprinkler, sub-surface moisture barrier may prove to be a fool-proof measure against this hazard as well. It has previously been dealt that moisture barrier may lead to salt accumulation in soil in the event of irrigation with poor quality water. But if the water quality is good and the soil has a salt source below the root zone, the barrier may arrest soil salinisation by blocking the upward salt path-way.

Efforts underway to overcome the problem

In India the use of sub-surface moisture barriers is rather new. A modest beginning on the use of bitumen layers for reducing deep percolation in low land paddies was made under the Coordinated Project on Water Management and Salinity (Anon. 1971-1972). The results were encouraging but no significant headway could be made to popularise this practice. Recently, in Tamil Nadu efforts were made by the Cement Service Bureau (Anon. 1975) to develop cement soil mixtures for use as sub-surface barrier in coastal sands. The technique, however, did not meet much success in view of high price and non-availability of cement for such use. Moreover, the barrier approach in coastal areas may be questionable in view of the potential hazard of salt accumulation from the sea in cyclic salt and sea mists etc.

A systematic study on sub-surface moisture barrier was initiated in 1971 at the Central Arid Zone Research Institute, Jodhpur. Bentonite clay which is a natural resource of Rajasthan State was introduced for use as moisture barrier. As barrier is a costly input, we limited our choice of crops to vegetables. that respond to the availability of low tension water and fetch good returns. Furthermore, vegetables are grown in relatively smaller portion of the holdings, and therefore are all the more suitable for moisture barrier approach which we feel cannot be implemented over large areas at this stage of technological development. Round gourd (*Citrullus vulgaris*) was, therefore, selected for initial trials. Since it was not possible to incorporate barrier on whole field basis, a partial field moisture barrier technique was resorted to. Pits of 50 cm diameter were dug by tractor auger and bentonite clay was placed to 75 cm depth. Pit walls were thoroughly dusted with bentonite in order to reduce lateral movement of moisture during saturated flow. The results showed that this technique yielded 49% higher yield of round guard than for conventional system (Singh *et al.,* 1975).

Later, it was felt that in years of low rainfall the barrier may be rendered unnecessary in view of negligible or no deep drainage. Earlier, Gardner (1972) made similar observation and questioned the validity of barrier for dryland crop production. In order to overcome this limitation, the moisture barrier technique was integrated into a runoff concentration system in 1974. Inverted 'V' shaped microcatchments of 1.25 m width on each side with a 5% slope were provided between two rows of pits. Incidentally, the 1974 season turned out to be a drought year with only 136 mm rainfall during the season (July to September). The moisture barrier-runoff concentration technique in that year therefore resulted in 222% higher yield of round gourd than for conventional planting (Singh and Singh, 1975). The moisture storage in the profile was 90 to 103 mm as against 46 to 62 mm for no barrier-flat. The barrier in the flat plot did not make difference in moisture storage, since deep drainage was negligible.

In 1975, barrier incorporation by digging trenches was also introduced with a view to increasing the barriered area and thereby the moisture storage. Trenches (75 cm deep and 50 cm wide) were dug manually after an initial trenching to 30 cm depth by the inversion plough.

The experiment was carried out for three consecutive seasons (1975, 1976 and 1977) receiving 520, 548 and 326 mm of rainfall (July to September), respectively.

Data on soil moisture for barrier and no-barrier treatments recorded during the 1977 cropping season are presented in Table 1 and that for yield in Table 2.

Moisture stored in barrier-runoff concentration plots was much more than for no barrier-flat plots. In later part of August, the differences in stored moisture became narrow because of less rainfall in that period.

The data reveal favourable effect of bentonite barrier on vegetable yield inspite of normal to high rainfalls in all years. This lends support to the findings of Erickson (1972). He reported that barriered plots (asphalt) sometimes yield more than even the best irrigated plots for vegetable crops respond better to low tension water in the root zone. Another reason besides higher moisture supply, could be sizeable reduction in the leaching losses of nitrogen.

The additional yield of 37 q/ha

Table 1. Moisture storage (mm) in 60 cm soil profile during crop growth

Treatment	Dates of samplings							
	1/7		27/7		9/8		19/8	
	Trench	Pit	Trench	Pit	Trench	Pit	Trench	Pit
Barr. runoff conc.	95	118	87	113	107	126	56	66
No barr. flat	68	92	66	78	86	96	54	53

Table 2. Yield of round guard (q/ha) (Average of 1975, 1976, 1977)

Treatment	Runoff concentration		Flat	
	Trench	Pit	Trench	Pit
Barrier	107	92	94	83
No Barrier	84	70	85	70

obtained by barrier (trench)—runoff concentration technique, could pay off about two-third of the cost on barrier right in the first year besides reducing the risk of crop failure. Apparently, the economic analysis has to be based on a long range performance for the barrier once incorporated would remain effective for several years.

In 1977, other vegetable crops like lady's finger, chillies and tomato were also tried with the barrier-runoff concentration technique. The crops were planted late in the end of July in unreplicated observation plots. The yields from barrier-runoff concentration plots were 2.3 q/ha and 93 q/ha as against the conventional planting yields of 0.25 q/ha and 26 q/ha for chillies (ripe dry) and lady's finger, respectively. In chillies the bearing of the second flush is almost ready for harvest and this may yield about half the yield already harvested. In tomato there was considerable mortality at planting but the plants that survived are undergoing fruiting.

The partial field barrier technique thus developed, however, does not completely check the deep percolation, lateral movement of moisture off the barrier edge does take place at higher moisture levels. It was observed that some 14 to 15% moisture could be retained in the root zone (30-75 cm soil depth) of the barriered profile, which is 30 to 40% more than the normal storage capacity of 10 to 11%. For increasing moisture storage further, the lateral movement of moisture has to be reduced. This being the objective, a technique for vertical incorporation of barrier layer around the pits and in the sides of trenches was developed.

Two hollow cylindrical frames made of thin iron sheets are required for this purpose. The length of cylinders should be the same as that of the pits, and diameter such to fit the cylinders one inside the other, with a gap of about 2 cm.

The cylinder set is lowered into the pit and after placing the bentonite layer at the bottom, the 2 cm space between the cylinders is filled with 50% bentonite-soil mixture and the inner cylinder space, with the dug-out soil. The cylinders are then easily taken out thereby placing a 2 cm barrier layer vertically all around the pit. Same method can be used for placing vertical barrier lining in trenches by using frames of the desired specifications.

Moisture profiles taken 3 days after watering to saturation a plot having barriered and non-barriered trenches reveal the effectiveness of the technique (Table 3).

This technique can also be used to

Table 3. Effect of moisture barrier on soil moisture profiles three days after watering to saturation on February 16, 1977

Treatment	Moisture content (mm) in soil depths (cm)				Total storage (mm)
	0-15	15-30	30-45	45-60	
Barrier at 75 cm depth and vertically	28	40	40	40	148
Barrier at 75 cm depth	23	23	24	28	98
No barrier	11	20	23	25	79
0.3 bar retention	19	21	22	24	86

support the initial establishment of tree plantations in the arid region.

Future lines of work

From the problems uncovered and results obtained at this and other research centres of the world, the following aspects should come in the main stream of research on barrier approach to the problem of moisture storage in arid Rajasthan soils.

1. Partial field bentonite barrier-runoff concentration technique thus far developed, has proven to be promising for dryland crop production. There is a need, however, to develop low cost equipment to facilitate opening of trenches for barrier incorporation. Also, the runoff concentration component of the technology has to be further studied for catchment characteristics, viz. size, slope, length of run etc. in relation to water requirement of different plant types and rainfall conditions. Crops most responsive to the technique have also to be identified. Indications are that chillies and lady's finger in adjoining areas of Jodhpur and watermelon and muskmelon in lower rainfall areas like Bikaner, may be promising for production with moisture barrier technique. However, this needs further verification.

2. Asphalt moisture barrier is a well proven technique. It may initially be tried under irrigation in the Rajasthan Canal Command area. Most responsive crops from among different vegetables and other cash crops like chillies and sugarbeet etc. need to be identified. Studies in depth need also to be carried out under irrigation on the role of barrier in respect of both salt accumulation as well as prevention of salt transport from lower soil strata, besides the aspects of increased moisture storage and reduction in the leaching losses of nutrients.

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II. 2.2

THE TRANSPIRATION OF CORN (*ZEA MAYS* L.) AND ALFALFA (*MEDICAGO SATIVA* L.) AS AFFECTED BY PETROLEUM MULCH IN KUWAIT

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INTRODUCTION

Kuwait is a dry country. The rainfall averages 100-120mm/year. Mean maximum and mean minimum air temperatures reach 44.3 and 28.9°C and 15.2 and 5.2°C in August and December, respectively. Monthly average global radiation (R_g) reaches 700 langley/day in summer. Yearly evaporation amounts to 4075 mm and 6860 mm, from a Class-A pan and Pitche atmometer, respectively.

The soil is sandy in texture, about 6 per cent clay content, with low water holding capacity. Ground water is the only source for irrigation. Surface flooding is the main method for irrigation used in Kuwait. Due to the high permeability of the soil, more than 90 per cent of the water applied for irrigation is lost by deep percolation before it reaches all corners of the flooding basin. Farmers irrigate twice a day in summer in order to keep the soil moist. This practice not only caused the leaching of nutrients from the soil, but it has also helped in the rapid replenishment of reserved ground water. For this reason, irrigation water must be used more efficiently.

Transpiration of corn and alfalfa has been studied in Iraq by Al-Nakshabandi and Ismail (1972) and in the Central Province of Saudi Arabia by Al-Nakshabandi and Al-Samman (1975). The combined study included 'the calculation of potential evaporation from a hypothetical water surface (E_o), calculation of the empirical coefficient K_b in the Blaney-Criddle formula, the study of the effect of advected sensible heat on actual transpiration (E_t) of corn and alfalfa, net and total water use efficiency of corn and alfalfa, and the relation between transpiration and leaf area index (LAI) for corn, transpiration and rate of growth for alfalfa. Comparisons between the results of these studies with the present study are discussed.

EXPERIMENTAL DATA

Two lysimeter tanks, 2×2×2 m in volume were used in this study. After the tanks were installed, soil was inserted into them. Each lysimeter was surrounded by a plot 12×12 m. A weather station was installed between the two lysimeters. Meteorological measurements of this station and tables prepared by McCulloch (1965) were used for the calculation of Penman's estimate of potential evaporation from a hypothetical water surface (E_o). The transpiration of corn and alfalfa was measured by the inflow-outflow method inside the lysimeters, and by soil moisture sampling before and after each irrigation at the surrounding plots.

The soil was manured at a rate of 8m^3/donum* before planting; it was also treated with 15 kg/donum of ammonium sulfate in two stages, the first at planting time and the other when plants reached 30 cm in height. Corn was planted on August 27, 1977 by a row spacing of 0.5 m and within a row spacing of 0.2 m. Thinning to one plant per hill was done when plants were 0.15 m in height. Leaf area was measured weekly and LAI was calculated.

In order to study the effect of mulch on the actual transpiration of corn, petroleum mulch as prepared by Kittani (1973) was sprayed on October 17, 1976 to form a layer 0.3 mm in thickness on soil surface of one lysimeter and its surrounding plot.

To study the transpiration of alfalfa, the soil was ploughed and treated with manure at a rate of 8 m^3/donum. Alfalfa was sown on February 23, 1977. The lysimeter and its surrounding plot, which was sprayed with petroleum mulch during corn growing season, was also sprayed right after alfalfa sowing, making a layer of 0.3 mm in thickness on soil surface.

The same irrigation treatment was given to both lysimeters and their surrounding plots during corn and alfalfa growing seasons. Irrigation of both crops was performed whenever soil suction at a depth of 30 cm below soil surface reached 6-8 centibars on a gauge type tensiometer. A garden hose was used for irrigation and it was shifted from one spot to another in order to eliminate deep percolation and to ensure as even a distribution of water as possible over all the plots.

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*One donum = 1000 m^2.

The potential evapotranspiration of short grass (*Cynadon dactylon*) was measured during alfalfa growing season in a lysimeter tank 1×1×1 m in dimensions, installed with a rim 10 cm above ground level. The outflow pipe was connected to a container with which a ground water table was maintained at a depth of *50 cm below soil surface inside the lysi*meter, thus keeping soil at its optimum moisture condition.

RESULTS AND DISCUSSION

The determination of the transpiration of corn and alfalfa by the soil moisture method was unreliable, although many soil samples were taken. The cause could probably be attributed to the high permeability of the sandy soil resulting from deep percolation and subsequent uneven distribution of water. Therefore, it appears necessary to replace the flooding *irrigation method used in Kuwait with* the more modern sub-surface irrigation method to ensure an even distribution of water over the field.

Daily average transpiration of corn inside the lysimeters, leaf area index (LAI) and irrigation is presented in Figure 1. Maximum transpiration rate of

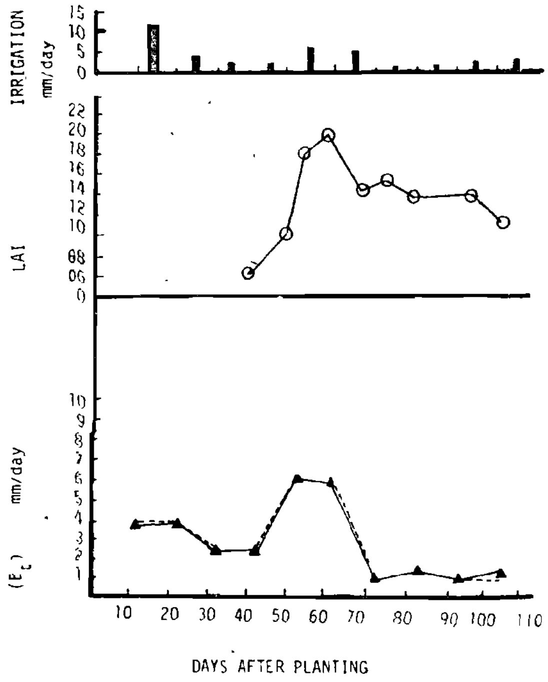

Figure I

10 - DAY AVERAGE ACTUAL TRANSPIRATION (E_t) OF CORN UNDER PETROLEUM MULCH (△--) AND BARE SOIL (▲—) IRRIGATION (■). AND LEAF AREA INDEX (L.A.I.)

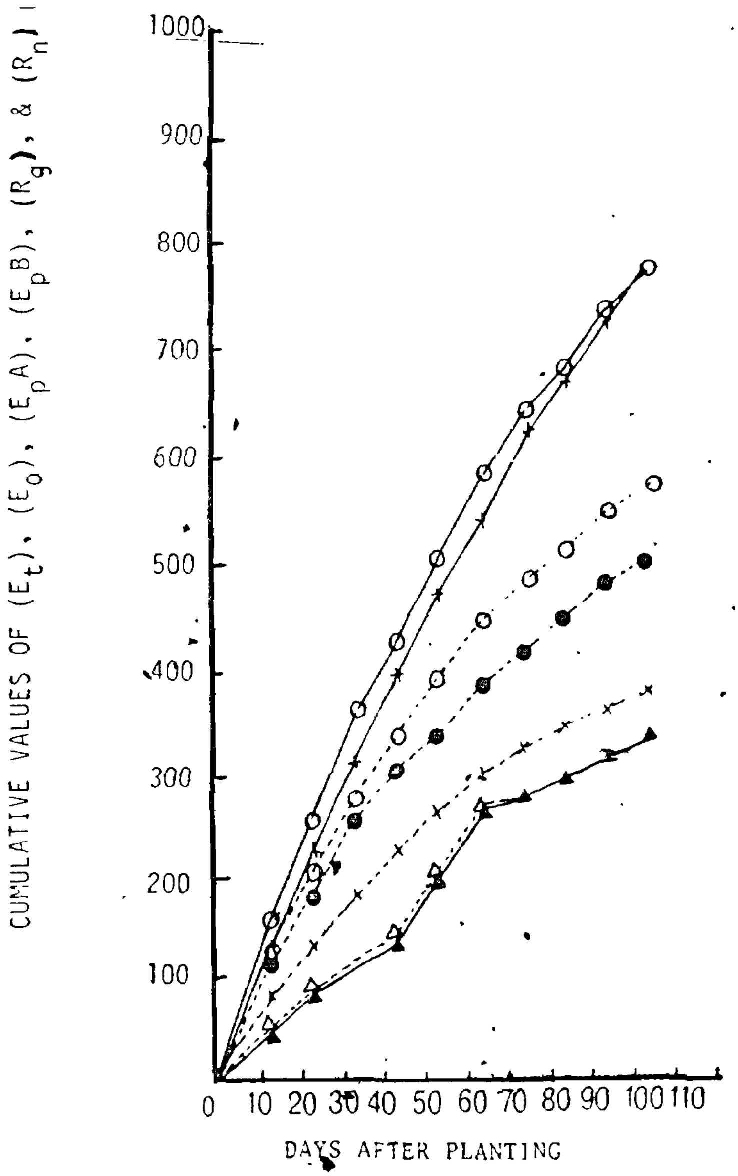

FIGURE 11

ACTUAL TRANSPIRATION (E_t) OF CORN UNDER MULCH TREATMENT (△-→)
AND BARE SOIL (▲—), PENMAN'S ESTIMATE
OF POTENTIAL EVAPORATION (E_o ○-→ EVAPORATION FROM A CLASS-A PAN
(E_pA ○—), EVAPORATION FROM A CLASS-B PAN (E_pB ●-→
GLOBAL RADIATION (R_g X—) AND NETRAITION EVAPORATION EQUIVALENT (R_n X-

6.0 mm/day was recorded after the elapse of 60 per cent of the growing season. This is probably due to the increase of land cover as leaf area index reached its maximum value of 2.0 when 60 per cent of the growing season had elapsed. The decreased rate of transpiration towards the end of the growing season is probably due to decreased irrigation and crop maturity. A similar trend was obtained by Al-Nakshabandi and Ismail (1972) for Baghdad. Figure I shows that petroleum mulch had no effect on the transpiration of corn. Although the mulch reduced evaporation of water through the soil surface (Kittani, 1973), thus increasing soil moisture content, this was subsequently offset by enhanced transpiration (Al-Nakshabandi and Ismail, 1972; Al-Nakshabandi and Ismail, 1975; Grimes *et al.*, 1969).

Seasonal volues of transpiration (E_t) under bare and mulch treatments, global radiation (R_g), evaporation from a Class-B pan (E_pB), evaporation from a Class-A pan (E_pA), Penman's estimate of potential evaporation (E_o), and net radiation (R_n) during corn growing season amounted to 335, 777, 509, 777, 575, and 381 mm, respectively (Figure II). The seasonal ratio of E_t/E_o was 0.58. However, the seasonal ratio of E_t/E_o at 1.26 for Baghdad (Al-Nakshabandi and Ismail, 1972) was related to the advected sensible heat from the surrounding dry uncultivated land, as shown from the E_t/R_n ratio of 1.92. The ratio of E_t/R_n of 0.88 for Kuwait, in the present study, shows no contribution from the advected sensible heat. The seasonal value of E_pB of 900 mm for Baghdad (Al-Nakshabandi and Ismail, 1972) was higher than for Kuwait, probably due to the advected sensible heat and high energy factors R_g for Baghdad (which amounted to 843 mm).

Daily average transpiration of alfalfa under bare soil, mulch treatments and irrigation is shown in Figure III. There is a general increase in transpiration with

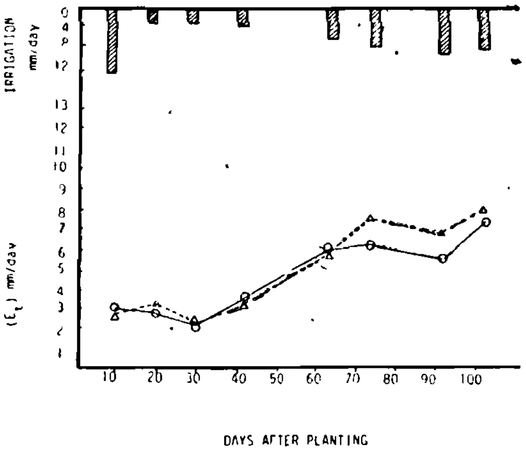

FIGURE III

10 DAY AVERAGE ACTUAL TRANSPIRATION (E_t) OF ALFALFA UNDER MULCH (△) AND BARE SOIL (○) TREATMENTS AND IRRIGATION

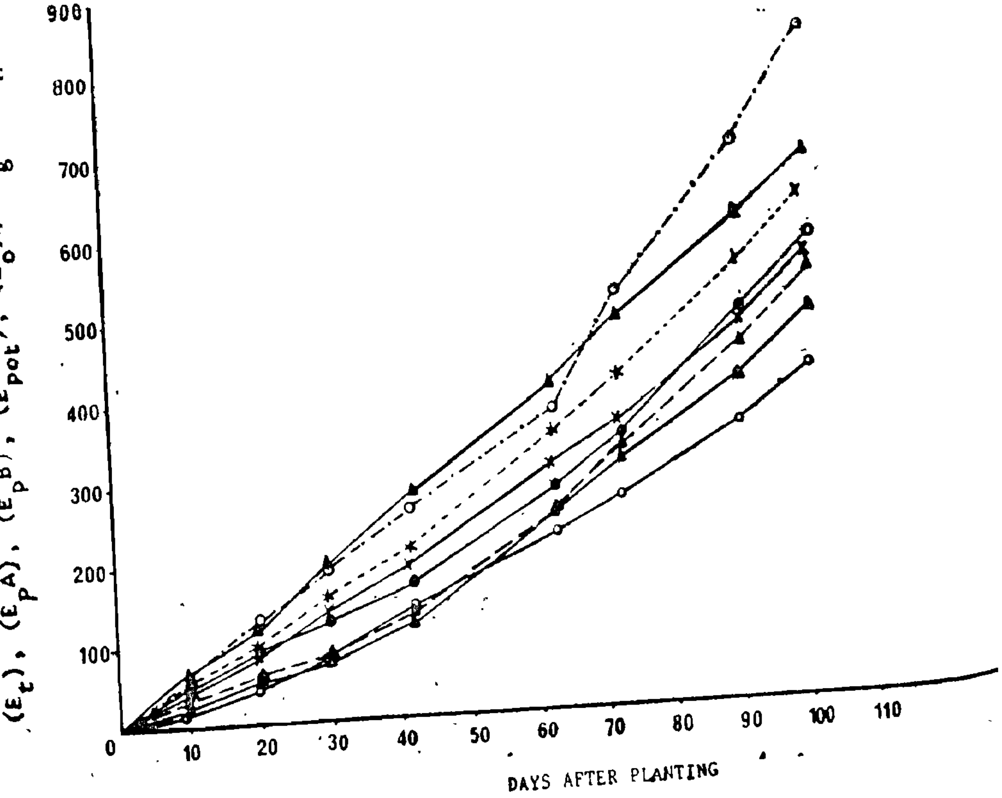

FIGURE IV

ACTUAL TRANSPIRATION (E_t) OF ALFALFA FOR KUWAIT UNDER PETROLEUM MULCH (△—) AND BARE SOIL (▲-·-) EVAPORATION FROM A CLASS-A PAN (E_pA○), EVAPORATION FROM A CLASS-B PAN (E_pB●—) PENMAN'S ESTIMATE POTENTIAL EVAPOTRANSPIRATION (E_{pot} ✶—) POTENTIAL EVAPORATION (E_o ✶-·) GLOBAL RADIATION (R_g ▲—) AND NET RADIATION (R_n ○

time. A similar rate of transpiration was recorded under both treatments during the whole growing season, except for the last month, when transpiration averaged 9.49 and 8.02 mm/day, respectively, for bare and mulch treatments. The small difference in the transpiration rate of alfalfa under the two treatments derives from the reasons mentioned above.

For, alfalfa, the seasonal values, under mulch and bare soil, for E_t, R_g, E_pB, E_pA, E_{pot}, E_o and R_n amounted to 488, 530, 690, 574, 834, 546, 650, and 418 mm, respectively (Figure IV). The ratio of E_t/E_pA was 0.59 and 0.64 for bare and mulch soils respectively, compared with a ratio of 0.78 for Riyadh (Al-Nakshabandi and Al-Samman, 1975). The higher E_t/E_pA for Riyadh is probably due to the higher global radiation there, which amounted to 950 mm. The ratio of E_pA/E_pB was slightly higher for Kuwait (1.45) than for Baghdad (1.39) (Fahad and Al-Nakshabandi, 1974), and is due to higher global radiation (595 mm) in Kuwait than in Baghdad. The higher potential evapotranspiration (E_{pot}) than (alfalfa) transpiration in Kuwait is probably related to the higher soil moisture of the lysimeters planted with short grass (*Cynadon dactylon*) than soil moisture of the lysimeters planted with alfalfa, particularly since the former was kept at field capacity during the whole season.

The empirical coefficient K_b for corn and alfalfa is shown in Table 1. The average K_b for corn was 0.63, which is very close to the value 0.65 as recommended by Blaney and Criddle (1950). Higher K_b values of 1.1 and 1.0 for corn during September and October, respectively, were recorded for Baghdad by Al-Nakshabandi and Ismail (1972) and were related to the advected sensible heat. Average K_b value of 1.30 for alfalfa for Kuwait is lower than the average value of 1.4 obtained by Al-Nakshabandi and Al-Samman (1975) for Riyadh. The higher value for Riyadh is related to higher energy factors. However, both values are higher than the one recommended by Blaney and Criddle (1950), which itself is probably related to high energy factors and advected sensible heat (evident from the observation that $E_t/R_n > 1$).

Table 1. Empirical coefficient K_b for corn and alfalfa in Kuwait

Month	K_b	
	Alfalfa	Corn
March	1.17	—
April	0.89	—
May	1.85	—
September	—	0.56
October	—	0.91
November	—	0.43
Average	1.30	0.63

Yield of corn and alfalfa, net water use efficiency* and total water use efficiency** for Kuwait are presented in Table 2.

Table 2. Yield, net water use efficiency (NWUE) and total water use efficiency (TWUE) of alfalfa and corn under bare soil and mulch treatments

Variables	Alfalfa treatment		Corn treatment	
	Bare	Mulch	Bare	Mulch
Yield (Ton/Acre)	3.28	3.62	0.28	0.28
NWUE	0.60	0.59	5.48	5.48
TWUE	0.81	0.70	7.67	7.67

Table 3. Yield of corn for Baghdad (Al-Nakshabandi and Ismail, 1972), yield of alfalfa for Riyadh (Al-Nakshabandi and Al-Samman, 1975), net water use efficiency (NWUE) and total water use efficiency (TWUE) for corn and alfalfa

Variables	Corn Treatment		Alfalfa
	Wet	Dry	
Yield (Ton/Acre)	1.5	1.3	7.80
NWUE	4.4	4.0	0.86
TWUE	5.1	4.4	1.06

Table 3 shows the yield and net and total water use efficiencies for corn in the vicinity of Baghdad (Al-Nakshabandi and Ismail, 1972) and for alfalfa in the vicinity of Riyadh (Al-Nakshabandi and Al-Samman, 1975). The lower corn yield for Kuwait than for Baghdad is probably related to soil texture and lower fertility in Kuwaiti soil than in Baghdad soil. However, these reasons, plus the higher energy factors for Kuwait, were responsible for the better net and total water use efficiencies for Baghdad. Greater net water use efficiency for Kuwait than for Riyadh is probably due to higher energy factors in Riyadh. However, lower total water use efficiency for Riyadh than for Kuwait is probably due to the deep percolation which took place in the Riyadh experiment.

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$$\text{*Net water use efficiency} = \frac{\text{(Amount of water consumed in Kg)}}{\text{(Grain or dry matter in gms)}}$$

$$\text{**Total water use efficiency} = \frac{\text{(Amount of irrigation water in Kg)}}{\text{(Grain or dry matter in gms)}}$$

S. Hussain in preparing the petroleum mulch is highly appreciated.

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II. 2.6

UTILIZATION OF LIMITED WATER RESOURCE FOR INCREASING CROP PRODUCTIVITY

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INTRODUCTION

The success of irrigation in cereals depends to a greater extent on weather conditions in middle Europe. Moisture stress from third week of May to second week of July; if coincides with warm and dry weather conditions, depresses the grain yield of cereals markedly (Klatt, 1967). Irrigation during such critical periods may increase the grain yield of winter wheat and spring barley upto 80 quintals and 65 quintals per hectare respectively (Klatt, 1963). However, when cereals show good response to irrigation, the availability of water becomes a limiting factor during most of the seasons and thus major proportion of water is diverted from cereal crops to other more profitable industrial units and vegetable and. garden crops. Results of several experiments have revealed that a short time water spray on plant foliage during warm sunny mid-day hours may increase the water use efficiency significantly of many vegetable and plantation crops (Witte, 1954); Chamazaev and Dzafarov, 1969; Seemann, 1969; Peterson and Weigle, 1970). This type of irrigation was termed as air irrigation, mist irrigation, day sprinkling, impulse irrigation, foliar irrigation, air conditioning irrigation, etc. in the literature. It was considered essential, therefore, to compare the effect of small quantities of water used in spraying of foliage with the traditional soil moistening irrigation or plant water balance, evapotranspiration and water use efficiency of winter wheat and oats.

MATERIAL AND METHODS

Field experiments with winter wheat (var. Poros) and oats (var. Astor) were conducted during 1968-69 and 1969-70 on sandy loam soil (19.5% field capacity, 5.0% wilting point, 6.2 pH; 90.9 mg total nitrogen, 8.7 mg available P, 10.8 mg available K per 100 g soil) at the Agricultural Research Farm, See-hausen of Martin-Luther-University, Halle-Wittenberg (German Democratic Republic), under temperate climate with average annual precipitation 560 mm and mean annual temperature 8.7°C.

Winter wheat sown in the second week of October during both the seasons, received 60 kg N per ha in spring season (mid-April) at tillering stage and 40 kg N per ha in the fourth week of May at jointing stage of growth. Oats sown on April 6, 1970 received 60 kg N per ha at the time of sowing and 40 kg N per ha was top-dressed in the first week of June at jointing stage of growth. Wheat and oats were harvested during fourth week and second week of August respectively.

Irrigation at different available soil moisture (ASM) regimes (without irrigation, without irrigation plus water spraying, irrigation at 30-40%, 50-60% and 70-80% ASM) was applied through over head sprinkler system. Water spraying on foliage of unirrigated wheat and oats was done through sprinkler irrigation using fine nozzels of "Gela-Regenpilze" once a day between 12.00 and 14.00 hrs, when the air temperature on clear sunny days exceeded 20°C. Such days mostly coincided with atmospheric relative humidity lesser than 50 per cent. The number of such days, when water spraying was done were 11 and 23 during 1969 and 1970 respectively. As per observations 3.3 g water on an average was required to spray the foliage of a tiller of wheat and oats at ear emergence stage. Therefore, water spraying of 1.3 to 1.5 mm was required for spraying a crop of 400-450 tillers per square meter. This quantity of water spraying was not having any direct effect in moistening the soil surface in wheat and oats.

The plant water balance was determined with the help of refractometer ABBE Model-G Zeiss Jena (Singh, 1977) twice a week after 1½ hrs of foliage spraying. The sap was procured from 25-30 fully developed green leaf blades of same age and position on the stem for determining refractometer values (R-value) as per cent sum of sugars and non-sugars in cell sap at 20°C. Width of stomatal aperture was measured with microscope of collodium impressions (5% collodium solution in 1:2 ratio of alcohol and ether respectively) taken on both sides of fully developed upper 1/3 portion of leaf blades of same age and position on stem. For each treatment 100 stomata from five different leaves were examined. An increase in R-value of cell sap indicates a decrease of plant hydrature or plant water balance (Walter and Kreeb, 1970).

Evapotranspiration (ET) was determined from April onwards till harvest of wheat and oats from soil water balance studies, rainfall and irrigation data. Water-use efficiency (WUE) was estimated as the ratio of grain yield to the total depth of water used in ET.

RESULTS AND DISCUSSION

An increase in soil water supply and water spraying on foliage increased ET in wheat and oats (Table 1). Treatments with irrigation also improved plant water balance and width of stomatal opening in both crops significantly over without irrigation treatments. More flow of water from soil via plants to atmosphere due to greater soil-plant water supply and lesser stomatal resistance due to soil wetting irrigation and foliage spraying might have increased the rate of transpiration. Greater vapour pressure gradient between soil-plant surfaces and atmosphere would have increased ET more over irrigated plots of wheat and oats than over unirrigated plots. Similar results have also been reported by Cowan (1965) and Salim and Todd (1965).

Additional grain yield of winter wheat and oats per mm depth of water application (obtained over unirrigated treatments) reduced markedly with increasing soil moisture content (Table 2). WUE also showed similar tendency in irrigated wheat and oats. Stanberry *et al.* (1963) and Slatyer (1967) also reported that the yield might be increased with increasing frequency of irrigation, but yield per unit quantity of water applied remain rather low at high rates of irrigation, because the rate of photosynthesis influenced lesser than transpiration rate at certain degree of stomatal closure with water stress.

Table 1. Effect of soil moisture and water spraying on plant water status, stomatal opening and evapotranspiration in wheat and oats

	Wheat (1970)			Oats (1970)		
Treatment	R-value (%)	Width of stomatal aperture (μ)	Evapo-trans-piration	R-value (%)	Width of stomatal aperture (μ)	Evapo-trans-piration (mm)
Without irrigation	8.87	1.88	304	8.97	2.02	295
Without irrigation + water spraying	8.16	2.36	334	8.43	2.58	325
Irrigation at 30-40 % ASM	—	—	338	—	—	356
Irrigation at 50-60 % ASM	8.21	2.55	401	8.25	2.79	418
Irrigation at 70-80 % ASM	8.01	2.70	450	8.24	2.82	456
C. D. 5 %	0.34	0.40	—	0.31	0.36	—

Table 2. Effect of soil moisture and water spraying on depth of water application and water use efficiency (WUE) in wheat and oats

Treatment	Wheat (1969)			Wheat (1970)			Oats (1970)		
	Total depth of water applied (mm)	Additional yield/mm depth of water applied (kg/ha)	WUE (kg/ha/mm)	Total depth of water applied (mm)	Additional yield/mm depth of water applied (kg/ha)	WUE (kg/ha/mm)	Total depth of water applied (mm)	Additional yield/mm depth of water applied (kg/ha)	WUE (kg/ha/mm)
Without irrigation	—	—	12.9	—	—	17.7	—	—	11.7
Without irrigation + water spraying	15	44.0	14.2	30	10.6	17.1	30	13.6	11.9
Irrigation at 30-40 % ASM	17	25.8	13.4	34	5.8	16.5	61	8.8	11.2
Irrigation at 50-60 % ASM	67	5.5	11.7	97	3.0	14.1	123	4.3	9.6
Irrigation at 70-80 % ASM	121	4.6	10.9	146	−1.2	11.5	161	3.2	8.7

Treatment with water spraying during high evaporative demand maintained on an average maximum values of WUE in wheat and oats (Table 2). This might be due to the fact that the grain yield of wheat and oats was significantly higher due to air conditioning irrigation over unirrigated treatments. Water spraying gave maximum grain yield of wheat, and yield of oats was also statistically at par with the yields obtained under different irrigation treatments. Significant better response of cereals like wheat and oats to air conditioning irrigation might be due to its effect in reducing the leaf temperature and rate of photorespiration during warm sunny mid-day hours. Photorespiration was reported to be several times greater than the true respiration in C_3 plants like wheat and oats (Goldsworthy, 1975). Therefore, the increase in the total accumulation of photosynthates due to reduction in the rate of photorespiration and improvement in plant water status and width of stomatal aperture might be responsible for higher WUE with minimum depth of water application under air conditioning irrigation treatment. Significant increase in the yields of tea, lettuce leaves, early potato, cole crops, tomato, sugarbeet and grapes was also observed with intermittent wetting of foliage during high evaporative demand by Witte (1954); Brjukwin (1969); Seemann (1969); Peterson and Weigle (1970). There are also reports from semi-arid tropics on significantly higher water use efficiency in sorghum due to application of 6 to 15 mm of water in crop life saving irrigations (Vijyalaxmi, 1975). Since water stored by water harvesting in the reservoir would be limited in semi-arid regions, method of water application should aim at maximum possible return per unit quantity of water application. Therefore, the essential requirement would be to cut down the conveyance, deep percolation and evaporation losses.

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II. 2.8

WATER HARVESTING IN AUSTRALIA

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INTRODUCTION

Water harvesting in Australia has concentrated on the collection and storage of runoff from modified catchments for stock and domestic use on farms, and public supplies in country towns. Little or no work has been done on runoff farming, but there is growing interest in the potential of water harvesting techniques for augmenting supplies for mining in arid areas.

The main zones of water harvesting activity are in the south-west of Western Australia, and the Eyre Peninsula of South Australia. The former has a mediterranean climate, an average annual rainfall of less than 750 mm and an annual evaporation upto 2200 mm. In the Kalgoorlie area, where there is interest in water harvesting for mining use, the average annual rainfall is 240 mm and the evaporation 2400 mm. In Eyre Peninsula the rainfall is more uniform and ranges from about 625 mm to 200 mm with annual evaporation of about 1250 mm to 2000 mm. The runoff and erosion from compacted earth catchments depend to a large extent on the intensity/duration pattern of the rainfall. Figure 1 shows this for one and ten year recurrence intervals for all areas of

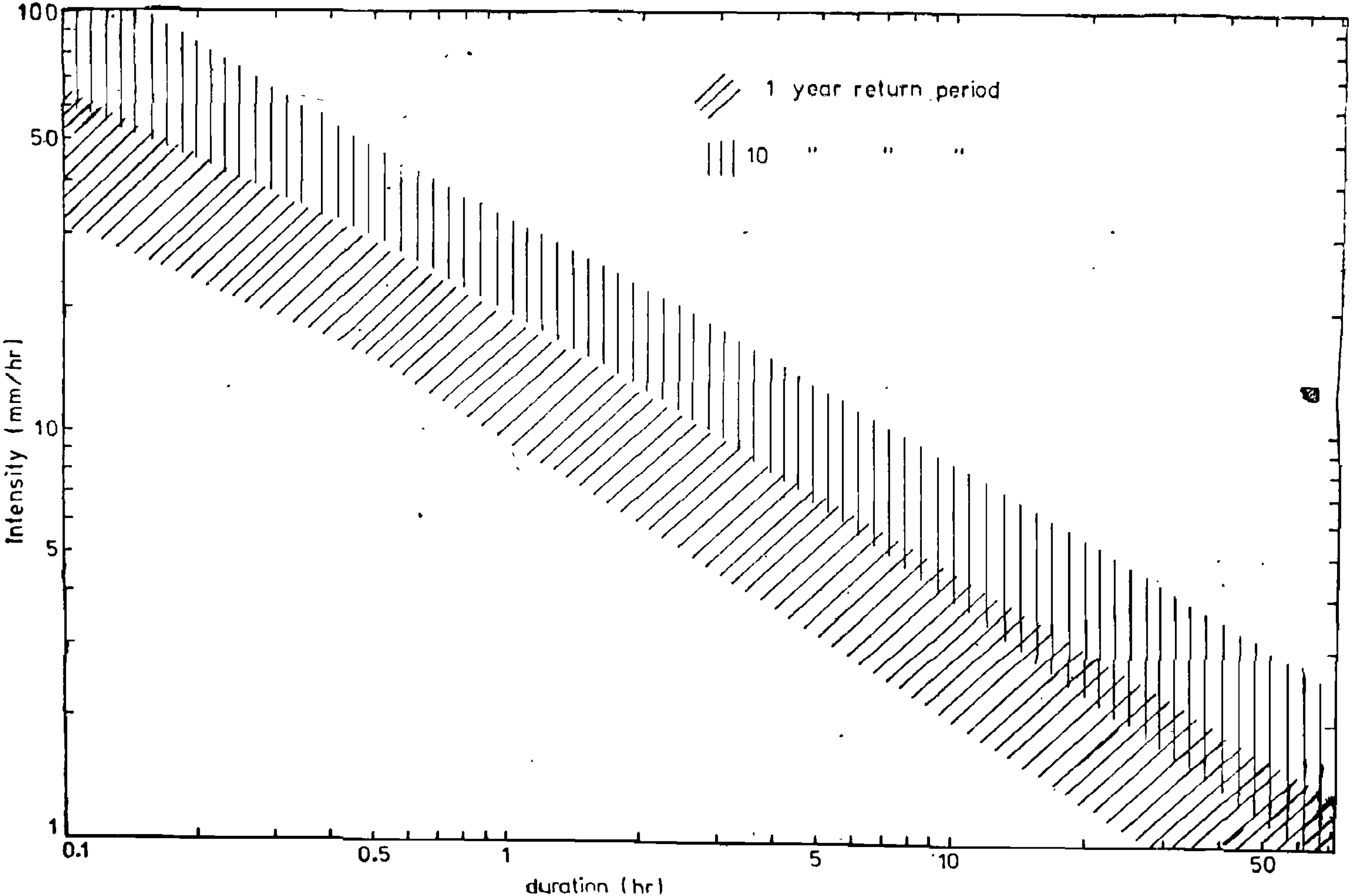

Fig. 1. Rainfall intensity-duration data for areas of water harvesting activity in Australia.

Western Australia and South Australia in which artificial catchments are widely used (Pattison, 1976).

In the south-west Western Australia remnants of the old plateau appear as ironstone capped ridges and lateritic soils are found on the valley sides and bottoms in association with red-brown podzols, red-brown earths and solonized brown soils (Burdass, 1974). In the Northcote (1971) system the dominant soils are described as hard setting loamy topsoils with red or mottled yellow clayey sub-soils. East and north of the 400 mm isohyet, the broad divides are covered with deep lateritic 'sand plain' deposits consisting of over 90 per cent of sand size fractions (Mulcahy and Bettenay, 1971). In association with these deposits are areas of hard setting loams with yellow clayey sub-soil while the valleys have calcareous loams (Northcote, 1967). Burdass (1974) makes the point that the presence of pallid zone clay, formed under the old lateritic cap, beneath many of the agricultural soils is, an important factor in water harvesting. In the Eyre Peninsula, the soils are porous alkaline red-brown earths frequently with some limestone nodules in the profile and a sub-soil with a higher clay content. Extensive surrounding areas have solodised solonetz soils with sand overlying clay at about 500 mm. In the north of the peninsula, where water harvesting catchments are being tried in a 200 mm rainfall zone, the soils are calcareous with sandy or loamy surface layers and increasing clay with depth; and shallow calcareous loams overlying calcareous shale or sandstone (Northcote, 1968, 1971).

Underground water sources are relatively scarce and often saline in both the south-west of Western Australia and the Eyre Peninsula. Low slopes in Western Australia and permeable surface soils and low intensity rains in both Western Australia and the Eyre Peninsula combine to produce little natural runoff. Thus both areas are largely dependent on surface water supplies for farm use, and experience difficulty in filling storages in below average rainfall years. An additional problem in Western Australia is that the drainage lines generally become saline following clearing for agriculture so that excavated tanks on the hillsides have to be used rather than dams.

WATER HARVESTING CATCHMENTS

Collection of natural runoff and seepage flows

Contour drains

The need to place excavated tanks on the hillsides where the natural catchment area is small, has led to extensive use of contour or grade drains in Western Australia. These are constructed on a gradient of about 0.5 per cent with a 2 m wide channel and 0.5 m high bank (Carder and Spencer, 1971; Spencer and Carder, 1964; Watson, 1963; Marsh, 1960).

Rock catchments

Granite bosses are quite common in some of the drier areas of the Western Australia "wheat belt" (300-350 mm annual rainfall). Runoff from some of these is collected by means of concrete or masonry walls built on a slight gradient around the lower slopes (Sutton, 1925; Davis, 1977). Storage may be provided by tanks built or excavated downhill of the rock, or by small dams across suitable hollows in the rock. Such catchments provide high quality water and are used for country town as well as farm supplies. Depending on the quality and size of the rock, runoff yields range from 60 per cent to 90 per cent and current costs are about A $2000/ha (Davis, 1977).

Intercepting seepage flows

Substantial seepage flows may occur through permeable surface soils above clayey sub-soils. These are sometimes collected by excavating a trench to the sub-soil and backfilling with material of low permeability. The trenches would normally be dug at the same time as the earth tank is excavated (Burdass, 1974).

Surface sealing techniques

Galvanised corrugated iron

Corrugated iron catchments have been used for many years (Kenyon, 1929) and give close to 100 per cent runoff. They are reputed to last over 40 years with little maintenance (Anon., 1969), but are seldom used because of the high initial cost of about A $3.00/m^2 (Hollick, 1974a). They have found some application on cracking clay soils which give little natural runoff, will not compact to an impervious surface; and which make construction of bitumen catchments very difficult (Morwood, 1972).

Bitumen and other surface treatments

The Public Works Department of Western Australia has been using bitumen catchments for country town water supplies for nearly 20 years. By 1973, 32 such catchments had been constructed covering a total area of 242 ha and ranging in size from 1 to 80 ha (Priv. Comm., P.W.D. of W.A.). Construction involves a 75 mm compacted gravel base course, soil sterilization, single coat cutback bitumen primer, and single coat bitumen emulsion sealer with a sand aggregate rolled into the surface (Kelsall, 1968). Maintenance consists mainly of weed control and respraying with emulsion approximately every seven years (Kelsall, 1962). Capital costs are about A $ 2.00/m^2 and around 90% runoff is achieved (Hollick, 1974b; Davis, 1977). In contrast with experience in other parts of the world, problems have not occurred with water discolouration or flavouring by bitumen oxidation products, but the reasons for this are not known.

Formed, compacted earth

Flat batter tanks

In areas of Western Australia where there is sand more than 300 mm deep overlying a clay sub-soil, excavated tanks are built in which the clay is spread out and compacted to form an apron around the tank to act as a catchment (Burdass, 1974; Carder and Spencer, 1971; Prout, 1969).

Roaded catchment

An idealised roaded catchment is shown in Fig. 2. The concept was developed by

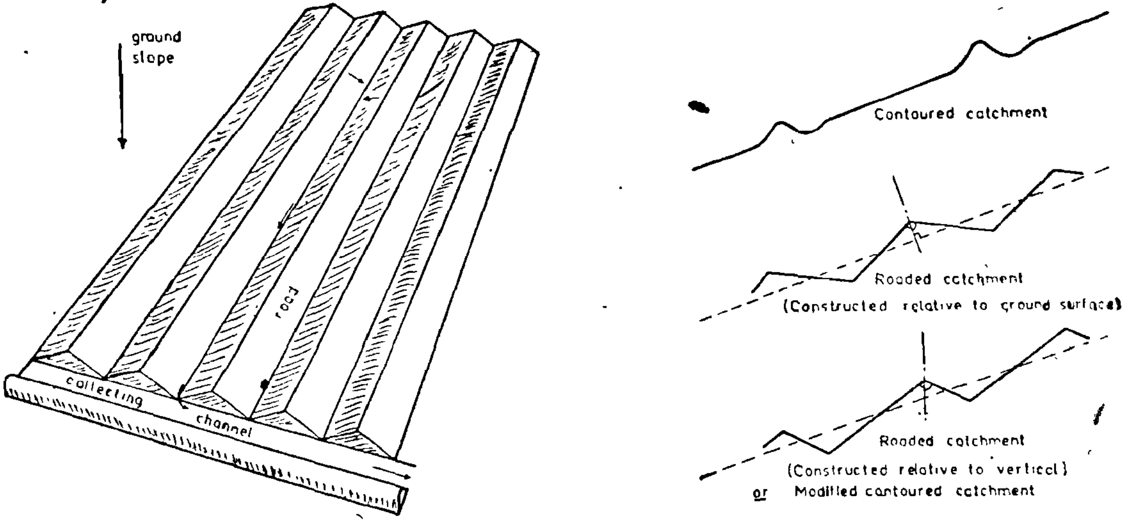

Fig. 2. Idealised roaded catchment and cross-section of roaded and contour catchments.

the Public Works Department of Western Australia in the 1950's for country town water supplies and by 1973, 21 catchments had been installed covering a total area of 707 ha and ranging in size from 12-71 ha (Prov. Comm.). At the farm level over 2500 farm roaded catchments have been built in Western Australia with an average size of nearly 1 ha (Prov. Comm., Dept. of Agriculture, W.A.). A number is also in use in South Australia, mainly on the Eyre Peninsula, including experimental installations in a 200 mm average annual rainfall zone.

The design of small roaded catchments has evolved from many years of field experience, coupled more recently with theoretical and experimental studies (Carder and Spencer, 1971; Anon., 1956; Carder, 1970; Frith and Nulsen, 1971; Frith, 1974, 1976a, 1976b; Hollick, 1974b, 1975, 1977). Recommendations regarding suitable channel gradients to prevent serious erosion are limited in their validity to the soil and rainfall conditions of the south west of Western Australia. Attempts to produce universal design methods have so far failed, due to the difficulty of measuring the erosion resistance of cohesive soils (Hollick, 1974 c, 1975, 1976, 1977).

The width and side slopes of the 'roads' are largely dictated by the soil conditions at the site, since it is important to bury all topsoil and pervious surface layers. Catchments have been built in recent years with side slopes of 1 in 5 and 'road' widths up to 20 m. However, rilling of these slopes has often been serious and it is now thought that slopes greater than 1 in 10 should not be used (Hollick, 1977). Computer simulation studies suggest that the consequent loss of runoff is minor (Hollick, 1974c, 1977). This restriction on side slope essentially places an upper limit of about 300 mm on the depth of overburden which can be buried during construction.

Computer simulation studies have shown that the optimum 'road' width is between 1 m and 8 m depending on site conditions (Hollick, 1974b, 1974c, 1975). However, the advantage of obtaining a blanket of lower permeability subsoil outweighs that of hydraulic efficiency, so that most catchments will continue to have 'roads' wider than optimum.

The shaded area in Fig. 3 shows the range of soil gradings found from analysis of 38 soil samples from 34 roaded catchments (Hollick, unpublished data). Also shown is the minimum grading curve recommended by the Public Works Department (Anon., 1956) and the grading curve for the soil used in W.A. plot experiments. For the soils studied by Hollick, the plasticity index ranged from 0 to 38 and linear shrinkage from 0 to 14%. Visual assessment of the catchment surface condition indicated that the majority of soils with a linear shrinkage greater than 6% showed extensive cracking and a tendency to become loose and powdery on drying, whereas those with a lower linear shrinkage generally did not. Those with a high linear shrinkage also tended to have lower surface clod bulk densities (about 1.5 g/cc) compared to those which formed hard, non-cracking surfaces (>1.7 g/cc). While Fig. 3 shows that soils with very low clay contents can be used provided the coarser fractions are well graded, the runoff would probably be much less than from higher clay content soils unless a crust is formed under rainfall.

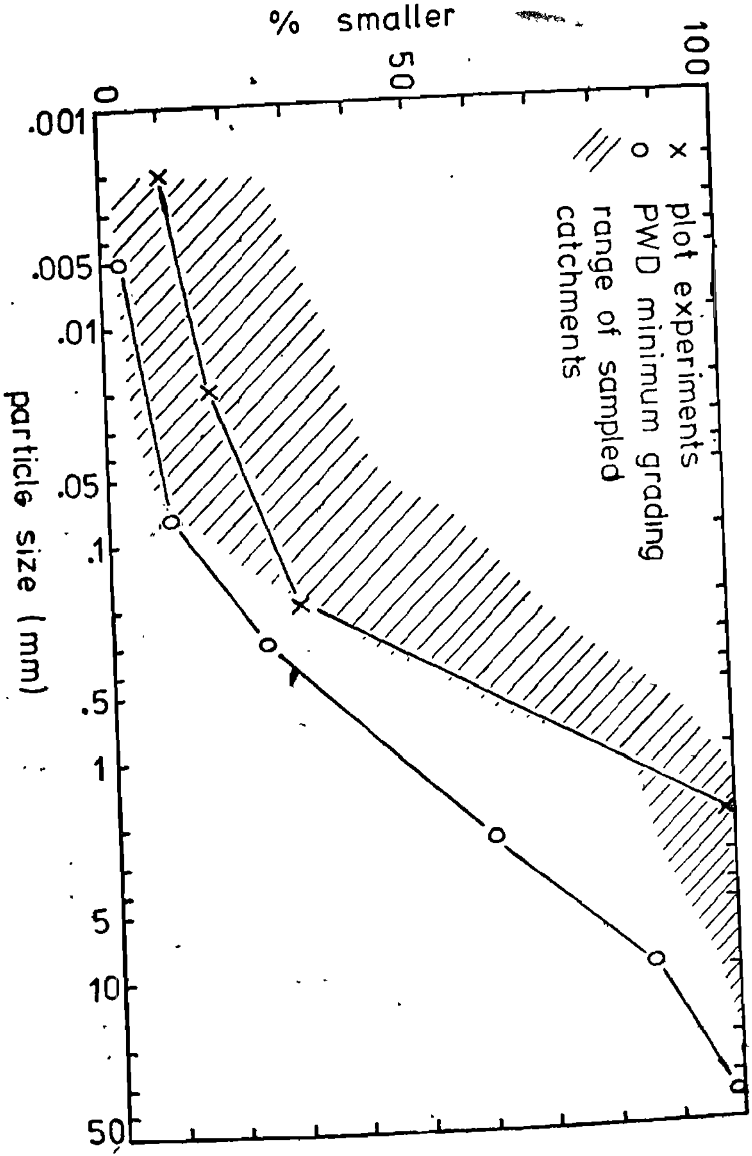

Fig. 3. Soil types used for roaded catchments and plot experiments in Western Australia.

Construction costs of roaded catchments range from about A $ 0.025—0.05/m^2 for farm catchments (Hollick, 1974a; Frith, 1976b) but the Public Works Department of W.A. estimates their current cost at A $ 0.11c/m^2 (Davis, 1977). Maintenance requirements include periodic spraying for weed control and the removal of any accumulations of sand or plant material from the channels (Pearce and Laing, 1976).

Contour catchment

The roaded catchment is best suited to ground slopes of no more than about 2-3%. In South Australia, a method known as the contour catchment was developed for use on steeper slopes (Young, 1965; Hollick, 1972). In this system the hillside is bared, smoothed and compacted and grade drains are constructed across the slope at intervals to prevent erosion and to guide the flow into the storage. Recently, the shape and spacing of the grade banks has been altered so that the catchment resembles a modified roaded catchment as shown in Fig. 2. A comparison of roaded and contour catchments on a 5% ground slope has shown the latter to be somewhat superior. This was attributed to the shorter overland flow distance (2 m v. 3.3 m); shorter channel distance to the storage (200 m v. 296 m); and steeper channel (Moore, 1976).

Water storage

Sealing excavated tanks

In most parts of Australia, excavated tanks lose little water to seepage. However, there are parts of the agricultural areas of south-west Western Australia where storage failure rates may be as high as 50%. Laing (1974) reported a number of experiments to seal leaking tanks. The methods tried were: Rivaseal (polyester film and fibre glass mat coated both sides with bitumen and talc); 0.2 mm black polyethylene sheet; bentonite; sodium tripolyphosphate; cultivation and compaction of tank surface. None of the soil treatments was found to be effective or economic where an alternative site for a new tank was available (Morwood, 1972) in Queensland.

Evaporation control

High evaporation rates in many areas of Australia cause very large losses from open storages. Despite the obvious value of an economical means of evaporation control, no such method has yet been found. Current recommendations in Western Australia to ensure stock water supplies in drought years are to build deep tanks served by improved, mainly roaded, catchments. Evaporation control measures are only recommended in emergencies to help eke out limited supplies.

DESIGN OF WATER HARVESTING SYSTEMS

Recommendations for the design of water supplies based on impervious catchment areas have been produced by the Australian Bureau of Meteorology (1968). In Western Australia a water balance model of a catchment/dam/consumptive use/evaporation water system has been developed that can predict least cost combinations of excavated tank capacity and artificial catchment area to give an assured stock water supply in a particular area. The model uses daily rainfall data to predict runoff using a simple threshold method that assumes the first Xmm of any rainfall are lost and the remainder becomes runoff (Frith *et al.,* 1974; Frith, 1976c).

APPLICATION TO DEVELOPING COUNTRIES

Water harvesting methods in Australia have been developed for use on large, privately owned farms with a relatively low return per hectare. Thus the area of land used exclusively for water supply has not generally been a constraint, but capital cost of any installation has. This has lead to the use of catchments that are less efficient than impervious ones and thus occupy more land, but which require few off-farm inputs other than earth moving. It has also resulted in almost exclusive use of unlined excavated tanks, and the provision of extra storage capacity or catchment area rather than evaporation control. This has been facilitated by the ready availability of bulldozers, graders and rollers in most areas.

By contrast, much of the water harvesting research in the U.S.A. has concentrated on capital intensive techniques, often for installation by government agencies in remote, inaccessible places to assist proper range management.

The scarcity of land and patterns of ownership vary substantially in arid and semi-arid regions of developing countries. However, it is probably reasonable to assume that capital for development projects is scarce but that labour is at least seasonally plentiful in most cases. Human and animal power, together with suitable implements, can be substituted for earthmoving machinery, so that Australian water harvesting techniques may well be more appropriate for developing countries than U.S. developments.

If daily rainfall records are available for a reasonable number of years a simple model such as described by Frith (1976c) could quickly indicate whether the catchment area and storage volume required are practicable.

Where available, rock catchments could be easily and cheaply installed using local labour and materials. Outside assistance would only be required for surveying, instruction, supervision and possibly the supply of cement.

Formed, compacted earth catchments could be built entirely from local materials using hand and animal labour. However, the design, surveying and construction supervision of such catchments requires considerable skill if they are to be satisfactory. Where rainfall intensity data are available, Figure 1 could be used to assess whether serious erosion problems would be likely to arise if Australian design specifications were employed. Design modifications to suit local conditions could also be made from limited field experience using the methods described by Hollick (1977).

Rising oil prices and limited foreign exchange probably restrict the extent to which bitumen catchments could be used in developing countries. Remoteness and the lack of technically competent people in the villages to instal and maintain them could also be drawbacks. Similar arguments apply to materials such as corrugated iron, butyl rubber and plastics.

With assistance in site selection and supervision, excavated tanks can be made without sophisticated machinery. Filling them with suitable aquifer materials to prevent evaporation is also possible, although expensive pumping equipment may be needed for water withdrawal unless the topography permits gravity drainage.

CONCLUSION

A wide range of water harvesting methods has been developed in Australia. Many of these would appear to be appropriate for other arid and semi-arid regions of the world. In particular the roaded catchment, excavated tank and artificial aquifer seem suitable for developing countries since they can be constructed with simple equipment from local materials.

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II. 3.1

USE OF SALINE GROUND WATER FOR IRRIGATION

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INTRODUCTION

In large areas of arid and semi-arid regions in India, comprising the states of Rajasthan, Gujarat, parts of Haryana, Punjab, Uttar Pradesh, Madhya Pradesh, Maharashtra, Karnataka, Andhra Pradesh and Tamil Nadu, where annual precipitation is much less than the annual evaporation, the ground waters form the major or the only source of irrigation. Several studies have been made on the quality of well waters in the states of Rajasthan, Haryana, Punjab, Uttar Pradesh and Gujarat (Bhumbla, 1969; Manchanda, 1976; Mehrotra, 1969; Paliwal, 1972; Talati, 1969). The data indicate that ground waters in most of these areas are charged with varying quantities of soluble salts beyond a generally accepted permissible limit and can be considered unfit for irrigation according to the U.S.D.A. standards.

Since usage of saline ground waters for irrigation *encompasses* extensive areas especially in view of the urgent need for augmenting irrigation resource to achieve multiple cropping and higher yields per unit of area, it is of vital importance to know precisely the composition of the groundwaters, their effects on soil properties and plant growth, the tolerance limits of important crops and to develop suitable management practices for using saline waters for irrigation without much adverse effects on soil and crop. With these objectives in view, work has been conducted recently at a few places under the All India Coordinated Project for research on use of saline water in agriculture. This paper includes some of the data obtained on such aspects at Agra (Uttar Pradesh) and Dharwar (Karnataka) centres in the project, which represent two different types of soil conditions.

RESULTS

Quality of ground waters

Water samples were collected from 190 wells in five blocks of Agra district in Uttar Pradesh, and from 215 wells in four *talukas* of Dharwar district during 1975-76 and from 154 wells in one *taluka* of Bijapur district during 1976-77 in Karnataka State (Yadav, 1977). These samples were analysed for electrical conductivity, cationic and anionic composition. Frequency distribution of ground waters of Agra district in different ranges of EC, SAR and RSC are given in Table 1. Table 1 shows that about 95% well waters fall within the EC range below 4 mmhos/cm. Roughly, 27% well waters have SAR values in the range of 10 to 18 and almost 76% well waters are associated with RSC problem, the greatest number of waters having RSC in the range of 5-10 me/l.

From the mean chemical composition of ground waters of Agra district (Fig. 1) it is seen that amongst cations, Na is the most dominant, followed by Mg and then Ca. Among anions, HCO_3 and SO_4 ions are relatively in higher proportion than Cl ions. Thus, these waters could be designated as Na-Mg-Ca type and HCO_3-SO_4-Cl type. pH of waters ranged between 7.6 and 9.2.

Certain locations were selected during 1973-74 in Agra district to evaluate seasonal variation in the electrical conductivity and ionic composition of ground waters. Well water samples were drawn in February, June, December 1973 and February 1974. Salt content decreased from July to December presumably due

Table 1. Frequency distribution of underground waters of Agra district in different ranges of EC, SAR and RSC

EC (mmhos/cm)	No. of wells	SAR	No. of wells	RSC (me/l)	No. of wells
< 1.0	36	< 10	133	No RSC	45
1.0-2.0	110	10-18	51	< 2.5	32
2.0-4.0	35	18-26	5	2.5-5.0	46
4.0-6.0	8	> 26	1	5.0-10.0	55
> 6.0	1			> 10.0	12

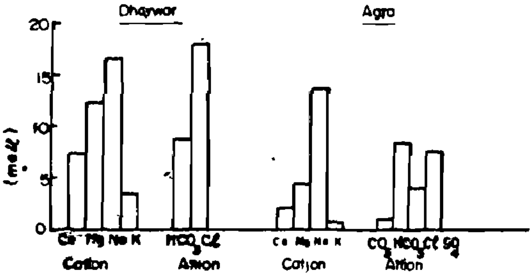

Fig. 1. Mean chemical composition of underground irrigation waters of Dharwar and Agra districts.

to the dilution effect of rainfall in the monsoon season. The salinity status of waters showed an increasing trend during post-rainy season in February and June owing to constant withdrawal of water for irrigation purpose and absence of dilution effect due to practically no rainfall (Fig. 2).

The analytical data of ground waters from Bijapur and Dharwar districts (Table 2) indicate that about 88% to 97% well waters fall in the EC range below 4 mmhos/cm. In general, the amount of Mg was greater than that of Ca particularly at higher EC values and showed a distinctly increasing trend with an increase in EC value of ground water. The amount of Na also increased with increase in EC value and constituted highest proportion among the cations. Among the anions the proportion of HCO_3 was more than Cl in waters having EC less than 2 mmhos/cm, while a pronounced reverse trend was discernible in waters having EC higher than 2 mmhos /cm. The pH values ranged between 7.2 and 8.5 in Bijapur

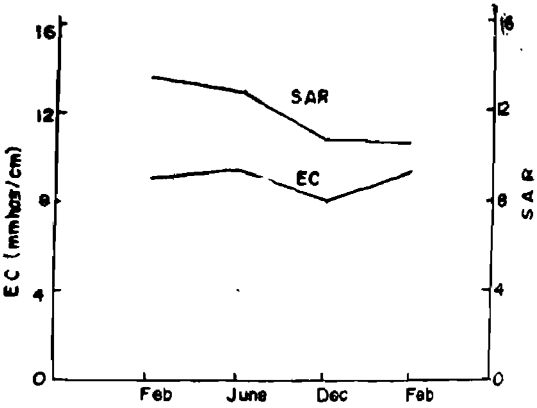

Fig. 2. Seasonal variation in the quality of ground waters in Agra district.

Table 2. Average composition of ground waters of Dharwar and Bijapur districts

EC range (mmhos/cm)	No. of wells	Cations				Anions (me/l)			SAR
		Ca	Mg	Na	K	HCO_3	Cl	SO_4	
				Dharwar district					
<1.0	96	2.0	3.2	3.9	0.7	5.7	2.8	NA	2.4
1.0-2.0	91	3.2	4.9	7.9	0.2	7.8	6.0	NA	3.9
2.0-4.0	24	5.1	8.4	11.9	1.4	7.0	14.1	NA	4.6
4.0-6.0	3	9.7	18.4	25.9	2.7	10.7	31.1	NA	6.9
>6.0	1	16.1	26.4	34.3	11.0	12.4	36.7	NA	7.4
				Bijapur district					
<1.0	39	3.2	3.6	3.5	NA	3.5	2.0	5.1	1.9
1.0-2.0	57	6.2	6.2	8.4	NA	5.8	3.9	8.3	3.4
2.0-4.0	44	9.2	11.7	15.7	NA	7.0	9.6	14.7	4.9
4.0-6.0	12	14.3	19.6	28.9	NA	6.9	16.4	32.5	7.0
>6.0	2	57.3	43.9	43.5	NA	4.0	80.5	57.8	6.1

NA = Not available.

district. The mean chemical composition of ground waters of Dharwar district is shown in Fig. 1.

Effect of saline water irrigation on soil properties and crop growth

An experiment was conducted in a quadruplicated randomised block design in 2.5×2.5 m plots, with a net size of 2×2 m. The soil used in the experiment was normal sandy loam at Agra centre and medium black clay at Dharwar centre. The different qualities of irrigation water used as treatments included best available water and artificially created waters having EC 2, 4, 6, 8, 12, and 16 mmhos/cm, keeping Cationic ratio as Na:Ca= 4:1 and anionic ratio as $Cl:SO_4:HCO_3$= 2:1:1, But, wherever SO_4 and HCO_3 ions exceeded 30 me/l and 10 me/l respectively, these were substituted by Cl. At each irrigation 6 cm of water was applied after cumulative open pan evaporation value of 6 cm.

Agra centre

Wheat (HD-1593)-*bajra* (HB-3) rotations was followed at Agra centre using NPK fertilizer application at 120-60-60 kg/ha. The data given in Table 3 indicate that on the whole, the grain yield of wheat showed very little decrease with irrigation waters having EC upto 8 mmhos/cm, but a significant reduction was recorded at EC 12 and 16 mmhos/cm. In case of *bajra,* no significant decrease in grain yield with different qualities of irrigation waters was observed in the first year i.e.

Table 3. Effect of saline water irrigation on grain yields of wheat and *bajra* crops on sandy loam soil at Agra

Water quality (EC × 10^3)	Grain yield of wheat (q/ha)					Grain yield of *bajra* (q/ha)			
	1972-73	1973-74	1974-75	1975-76	1976-77	1973	1974	1975	1976
No. of irrigations	4	4	5	5	4	1	3	0	0
Best water	39.0	34 5	34.8	44.2	37.4	35.5	7.4	24.8	41.8
2	42.2	32.2	35.0	42.8	37.4	35.9	7.6	23.0	39.0
4	40.5	32.7	31.2	40.7	37.1	41.8	7.3	21.3	36 3
6	38.4	33.7	27.3	40.7	37.3	35.7	6.2	18.3	36.0
8	36.2	33.2	29.8	42.7	39.4	35.9	7.2	18.5	31.3
12	27.7	31.3	9.1	28.4	36.0	33.2	4.2	12.5	24.5
16	12.2	29.4	3.8	26.9	28.5	28.4	3.8	3.3	18.5
C. D. at 5%	3.7	1.9	6.4	4.8	2.2	N.S.	2.6	—	9.0

1973, but there was a gradual reduction in yield with an increase in the salinity level of irrigation water in the subsequent years, the magnitude of reduction being more pronounced at EC 12 and 16 mmhos/cm, though no saline water irrigation as such was applied to *bajra* crop in 1975 and 1976. Very poor grain yield was obtained in 1974, probably due to greater number of saline water irrigations applied and therefore, no definite inference can be drawn regarding tolerance of *bajra* crop on the basis of the present data. These results, however, suggest that wheat crop could be grown on sandy loam soil under Agra conditions with irrigation waters having EC upto 8 mmhos/cm.

The data on soil salinity build-up (Table 4) at harvest of wheat and *bajra* crops reveal that there is a gradual accumulation of soluble salts in the soil with an increase in the EC value of irrigation water. The soil salinity build-up was more pronounced at higher EC levels i.e. 12 and 16 mmhos/cm than at lower levels and in the surface 0-15 cm layer *than in the lower depth. Much greater* accumulation of soluble salts took place at the harvest of wheat crop than at the harvest of *bajra* crop obviously due to more number of saline water irrigations applied and practically no leaching through rainfall during wheat crop season. It is further seen that the soluble salts which had accumulated during wheat crop season, were leached down substantially during rainy season when *bajra* crop was grown. Thus, the leaching caused by rains appears to be quite effective in reducing the salt concentration occurred during *rabi* season below the injury limit under Agra conditions. Nevertheless, the use of irrigation water with higher levels of salinity necessitates proper selection of tolerant varieties.

Dharwar centre

Sorghum (CSH-1 and CSH-5)-wheat (Hira and UP-301) rotation was followed, using NPK fertilizer application at

120-60-60 kg/ha in case of sorghum and 120-70-50 kg/ha in case of wheat. The data given in Table 5 show that the differences in grain yield of sorghum during the first two years were non-significant even at EC 16 mmhos/cm, but a significant reduction was observed with an increase in the EC value of irrigation water in the subsequent two years, especially at EC above 4 mmhos/cm as compared to best available water. In case of wheat also, there was no significant difference in the grain yield with different salinity levels of irrigation water in the first year, but in the subsequent years, a gradual reduction in grain yield was recorded with every increase in the salt content of irrigation water specially above EC 4 mmhos/cm. This is attributed to a gradual progressive build-up of salinity in the soil with saline water irrigation in the later years. In general, it can be inferred that sorghum and wheat crops can tolerate saline water irrigation upto EC 4 mmhos/cm on medium black clay soil under Dharwar conditions. The response of wheat crop indicating per cent reduction in grain yield at different EC levels of saline water irrigation at Agra and Dharwar centres is shown in Fig. 3.

The data given in Table 6 show that as in the case of Agra centre, accumulation of soluble salts has been greater in the surface (0-15 cm) layer than in the lower depth of the soil and has increased with an increase in the EC value of irrigation water. However, the leaching effect of rains in the heavy clay soil at Dharwar is much less than that observed in the light textured soil at Agra. This indicates a positive trend of

Table 4. Effect of saline water irrigation on soil salinity status (ECe, mmhos/cm) after *bajra* (*kharif*) and wheat (*rabi*) at Agra centre

Water quality (EC$\times 10^3$)	Soil depths (cm)	1972-73	1973-74		1974-75		1975-76		1976-77	
		Rabi (wheat)	*Kharif* (*bajra*)	*Rabi* (Wheat)	*Kharif* (*bajra*)	*Rabi* (Wheat)	*Kharif* (*bajra*)	*Rabi* (Wheat)	*Kharif* (*bajra*)	*Rabi* (Wheat)
B. A., W.	0-15	3.0	1.4	2.7	2.3*	2.7*	1.5	1.9	3 3	2.7*
	15-30	2.7	1.3	2.8			1.8	1.9	1.6	
2	0-15	3.2	1.4	5.3	3.1	4.1	1.5	3.2	1.3	5.2
	15-30	4.2	1.3	4.1			2.4	4.4	1 9	
4	0-15	5.8	2.6	4.5	4.0	6.2	1.8	4.5	1.3	6.1
	15-30	5.2	3.2	8.8			2.4	5.8	1.8	
6	0-15	6.5	1.4	11.9	4.7	8.1	2.1	6.5	1.4	8.2
	15-30	10.4	2.1	8.7			2.4	6.0	1.3	
8	0-15	9.6	1.5	15.3	5.5	9.1	2.4	10.3	1.6	9.4
	15-30	6.6	1.4	11.3			3.0	11.3	1.0	
12	0-15	17.5	2.3	7.9	6.8	12.3	2.7	18.9	1.5	12.7
	15-30	7.4	2.4	13.9			2.4	14.4	1.2	
16	0-15	23.5	1.8	30.9	6.9	22.5	2.3	25.1	1.5	17.7
	15-30	14.5	3.1	16.7			3.2	13.1	1.8	

*Values of EC refer to 0-30 cm depth of the soil.

Table 5. Effect of saline water irrigation on grain yields of sorghum and wheat crops on medium black clay soil at Dharwar

Water quality (EC × 10^3)	Grain yield of sorghum (q/ha)				Grain yield of wheat (q/ha)			
	1973	1974	1975	1976	1973-74	1974-75	1975-76	1976-77
No. of irrigations	2	4	3	5	7	7	5	7
Best water	81.0	80.8	88.8	88.1	18.3	36.0	28.4	35.9
2	74.1	73.8	75.5	75.2	16.7	33.2	26.5	32.2
4	74.8	73.3	73.8	72.8	16.4	30.8	25.9	29.1
6	72.2	72.9	65.0	63.1	16.2	28.8	25.2	27.3
8	75.1	71.5	52.5	50.6	16.0	28.2	23.9	24.7
12	77.2	70.5	36.3	34.2	15.3	26.5	19.9	23.1
16	74.3	65.3	18.8	21.2	14.9	22.5	11.4	17.0
C. D. at 5%	N.S.	N.S.		6.1	N.S.	2.1		4.0

Table 6. Effect of saline water irrigation on soil salinity status (EC_e, mmhos/cm) after crop harvest at Dharwar centre

Water quality (EC × 10^3)	Soil depth (cm)	1973-74	1975-76	1976-77	
		Rabi wheat	*Rabi* wheat	*Kharif* sorghum	*Rabi* wheat
B.A.W.	0-15	0.8	0.5	0.4	0.5
	15-30	0.8	0.3	0.3	0.4
2	0-15	1.7	1.0	0.6	1.0
	15-30	1.3	0.8	0.6	0.9
4	0-15	2.1	1.5	0.8	1.7
	15-30	2.1	1.1	0.9	1.3
6	0-15	1.9	1.9	1.0	2.3
	15-30	1.9	1.5	1.0	1.8
8	0-15	2.9	2.3	1.3	2.6
	15-30	2.3	1.4	1.3	2.0
12	0-15	3.4	3.6	1.9	4.0
	15-30	3.2	3.4	2.4	3.8
16	0-15	3.7	5.1	2.8	5.3
	15-30	4.5	4.6	2.5	4.9

Note : Data for 1974-75 are not available.

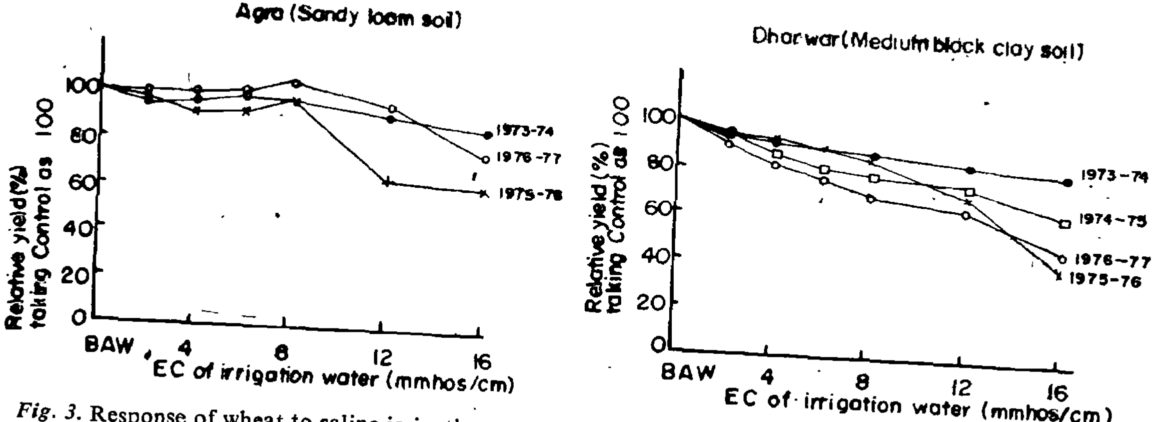

Fig. 3. Response of wheat to saline irrigation water at Agra and Dharwar centres.

accumulation of souble salts with saline water irrigation on heavy black soil and further suggests the need for developing suitable management practices and tolerant crop varieties for such conditions.

Successful use of highly saline waters for irrigation on well drained sandy soils has been reported by several workers (Kanwar, 1961; Satyanarayana *et al.*, 1967; Singh and Bhumbla, 1968; Singh *et al.*, 1967; Talati, 1969). On the other hand, the use of saline water having even relatively much less salinity level could cause accumulation of excessive salts in heavy-textured soils (Talati, 1969). Singh and Bhumbla (1968) reported a significant correlation between the soil texture and the effect of EC value of irrigation water on soil salinity. In view of such observations, Kanwar (1961) had included soil texture and crop tolerance in the triangular diagram proposed for evaluating the quality of irrigation water. These aspects have also been duly considered in a meeting of several scientists from India held at C.S.S.R.I., Karnal in 1972 to modify the standards for water quality.

CONCLUSION

The results reported above indicate a wide variation in the chemical composition of the under ground waters. The effects of such saline waters for irrigation on soil properties and plant growth are, however, modified considerably according to the soil texture, rainfall pattern of the area and the duration of their use. Besides, the crops differ in their tolerance characteristics and provide ample scope for selection for different qualities of irrigation waters and soil conditions. Depending upon these factors, certain qualities of saline ground waters can be used for irrigation with adoption of suitable management practices to produce satisfactory yields. These data, therefore, suggest the need for modifying the U.S.D.A. standards for judging the quality of irrigation waters for practical use under different agro-climatic conditions and for developing appropriate management practices. The modifications in the criteria for evaluation of water quality should take into account the various soil properties including depth, clay content, type of clay mineral, drainage characteristics, water table, climatic conditions, crop varieties and management practices. Further studies on these lines will help in development of scientifically sound criteria to suit the varied local conditions and ultimately, in optimum utilization of ground water resources for increased crop production in the arid and semi-arid areas.

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II. 4.5

A PROMISING MINOR MILLET *KANGNI* (*SETARIA ITALICA*) FOR THE ARID REGIONS OF RAJASTHAN

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The arid zone agriculture faces twin problems of low productivity and high instability. *Bajra* or pearl millet is the traditionally grown staple food crop in these regions, although some minor millets have also been under cultivation sporadically. The productivity of pearl millet is rather low largely because of diseases and pests not only in the improved varieties but also in local varieties. Besides, post harvest losses by storage pests are also substantial. Pearl millet being a crop of poor people, the marginal land and arid areas, cannot bear the cost of pesticides even we may have any.[1]

Under these circumstances, use of alternative food crops with better production prospects appears feasible. Minor millets

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[1] Kanwar, J. S. (1975), Downy mildew and ergot in pearl millet—an over view (cf. Anon., 1975).

constitute such a group of crops with a low cost of cultivation, they grow satisfactorily on relatively poor or marginal soils and can stand conditions of drought or low moisture availability. The keeping quality in storage is also good (to serve as famine reserves). Saxena (1975) analysed the yield data of minor millets and pearl millet in India for 21 years (1952-1972) and observed that yield per unit area of minor millets (318-388 kg/ha) was more than that of pearl millet (212-284 kg/ha) in normal as well as sub-normal years. The influence of unfavourable weather was more marked on pearl millet and the minor millets could give higher and assured yields. Under pearl millet, there was appreciable coverage (2.8 m ha) under high yielding varieties by 1973. Improved varieties of minor millets have yet to come under cultivation. Even then, minor millets yielded as good as or higher than pearl millet at national level, particularly so during the drought years of 1972-73 and 1974-75 when the minor millets yielded 364 kg/ha and 403 kg/ha compared to 333 kg/ha and 286 kg/ha of pearl millet respectively.[2] From the initial studies of breeding programme at CAZRI, Jodhpur since 1972, it was established that only two minor millets i.e. the foxtail millet *kangni* (*Setaria italica*) and the proso millet *chena* (*Panicum miliaceum*) can be grown successfully. Subsequent studies showed *Setaria italica* as having higher yield potential and shorter maturity period than *Panicum miliaceum* which, though grows quicker, has uneven maturity and grain shattering. Further, the insect pest incidence is comparatively high in *Panicum miliaceum* (AICMIP, 1975-76, 1976-77) and *Lonchura malabarica* is a serious bird pest under arid conditions (Verma and Rana, 1977).

Setaria italica, the promising minor millet crop

For human consumption at present only *Setaria italica* hold promise as a supplement to pearl millet crop in arid regions. It is not a season-bound crop and can also be taken up as a summer and post monsoon crop if irrigation facilities exist.

Adaptability, yield potential and maturity period

Of all the minor millets, *Setaria italica* has the highest yield potential and a good adaptability. It can be grown from hilly areas (upto 1800 m altitude) to near desert conditions. In season of severe drought, crop substitution is possible by replacing pearl millet with foxtail millet. According to Murty (1976) a large variability exists for different yield contributing characters in foxtail millet which can be exploited for improving the yield potential. It has also been found that production in foxtail millet is highly stable. A number of high yielding and early maturing strains have been developed and tested at CAZRI, Jodhpur (Table 1). Out of these, S. No. 1 yielded higher (18.99 q/ha) than the recommended pearl millet variety BJ 104

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[2] Directorate of Economics & Statistics, Govt. of India, 1975.

Table 1. Yield and maturity of some promising strains of *Setaria italica* developed at CAZRI, Jodhpur

Strain	Yield (q/ha) 1976	Yield (q/ha) 1977	Days to maturity
S. No. 1	10.84	18.99	60-65
S. No. 9	10.70	10.84	55-60
Se-21-1	6.70	13.97	50-55
S. No. 26	9.90	16.35	60-65
Arjuna (Check)	5.49	6.49	65-70
Co-3 (Check)	3.75	—	70-75
Pearl millet BJ 104 (recommended variety)	14.32	18.00	80-85

(18.00 q/ha) in *kharif* 1977. There is a considerable unrealized yield potential in foxtail millet which is yet to be fully exploited.

The strains developed at CAZRI are also early maturing which is a very important character considering the erratic rainfall pattern prevalent in arid zones. Variety Se-21-1 of this centre was found to be the earliest in maturity in all India trials at various centres. No variety of pearl millet matures in less than 70 days whereas the strains of foxtail millet developed at this centre mature in 50-55 days. This makes crops substitution possible in seasons of late onset of monsoon or drought.

Soil and fertility requirements

Foxtail millet does appreciably well in poor shallow soils. It is grown on all types of soils, ranging from very light soils, ashy grey types, red loams to even heavier clayey types (usually put under rice) in tracts of uncertain rainfall (Aiyer, 1954). Under conditions of low input management, it grows well and produces more than pearl millet. Fertilizer response trials conducted at CAZRI revealed that different varieties of *kangni* responded differently to various levels of nitrogen; the response was up to a maximum of 60 kg N/ha. There was no response to phosphate application.

Disease problems

Downy mildew (*Sclerospora graminicola*), ergot (*Claviceps microcephala*) and grain smut (*Tolyposporium penicillariae*) are serious diseases of pearl millet. Only a few lines have shown some promise for resistance to downy mildew, while definite sources for resistance to ergot and grain smut are yet to be found.

On foxtail millet, there are no serious diseases on record. The only disease of some importance is rust (*Uromyces setaria italica*) for which resistant strains have already been developed earlier (Guruswamy Raja, 1973). The other diseases of importance reported elsewhere on *kangni* are blast (*Piricularia* sp.), leaf spot (*Helminthosporium* sp.) and smut (*Ustilago crameri*); and none of these have been observed to occur under arid conditions. Variety Se-21-1 developed at CAZRI has been shown to possess multiple disease resistance against blast, rust, *Ephelis* and virus diseases. *Sclerospora graminicola* was reported to infect *Setaria italica* in the past (Nene and Singh, 1975) but physiological races virulent on this crop are not known to be present.

Pest problems

The number and severity of the insect pest problems in pearl millet are on the increase. Problems of shootfly and root-grubs are still under experiments for the satisfactory control. *Amsacta moorei,* which appeared in epidemic form in *kharif* 1977 and caused havoc in pearl millet, did not show preference for *kangni.* Of the other pests so far reported on *Setaria italica* (Nayar *et al.,* 1976), only two namely, *Peregrinus maidis* and *Myllocerus* sp. occur in this region. These are also pests on *bajra* and other *kharif* crops and have shown no specific preference for *Setaria italica.* Under AICMIP trials also, observations at different locations have established that pest incidence on all varieties of *Setaria italica* is low (AICMIP, 1975-76). Some shootfly incidence has been recorded on *Setaria italica* at various centres in India (AICMIP, 1976-77). Fortunately, shootfly does not occur as a pest in arid regions. However, a complete assessment of the pest problems and losses caused by them remains to be done.

Under identical conditions of storage, seeds of *Setaria italica* remained practically free of infestation by *Tribolium castaneum* and *Rhizopertha dominica* while pearl millet varieties supported heavy populations of these common storage pests.

Nutritional value

Nutritive value and essential amino acid contents of *kangni* have been compared with pearl millet in Tables 2a and 2b. Foxtail millet has higher protein, iron, thiamin and niacin contents than pearl millet. Other components are comparable or of a little lower order. The iron and calcium contents of foxtail millet are nutritionally better available due to low phytic acid content (Murty, 1976). This is of particular significance as the diet of poorer sections of society is deficit in available iron and protein. Considering the amino acid contents, foxtail millet has a comparable constitution with higher quantities of histidine, phenylalanine, lysine, methionine, leucine, isoleucine and valine.

Present problems and future work to be done

For improving the consumer acceptability of minor millets in all sections of people, suitable processing technology has to be developed by food experts. At present, there is no special processing industry for minor millets. Oil from *Setaria italica* can be of topical importance in view of the shortage of edible oils. Some initiation in these directions is becoming

Table 2a. Nutritive value (per 100 g) of foxtail millet compared with pearl millet (Gopalan and Balsubramanian, 1966)

Food stuff	Protein (g)	Fat (g)	Carbohydrates (g)	Calories	Calcium (mg)	Iron (mg)	Carotene (μg)	Thiamin (mg)	Riboflavin (mg)	Niacin (mg)
Foxtail millet (*Setaria italica*)	12.31	4.3	60.9	331	31	12.9	32	0.59	0.11	3.2
Pearl millet (*Pennisetum typhoides*)	11.52	5.0	67.5	361	42	5.0	132	0.33	0.25	2.3

Table 2b. Essential amino acid content of foxtail millet and pearl millet (mg/g of nitrogen)

Food stuff	Arginine	Histidine	Lysine	Tryptophan	Phenylalanine	Lysine	Methionine	Threonine	Leucine	Isoleucine	Valine
Foxtail millet	0.44	0.24	0.16	0.05	0.33	0.10	0.22	0.22	0.87	0.35	0.37
Pearl millet	0.47	0.16	0.23	0.09	0.23	0.08	0.13	0.21	0.58	0.31	0.34

evident (Thirumala Rao, 1976). Meanwhile, *kangni* should be taken up in cultivation in the operational research projects in arid and tribal areas of Rajasthan to fully work out the prospects of the crop as also the cost of cultivation with improved technology, the disease and pest problems, if any. New strains with higher expressed yields should be further developed.

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II. 4.6

PROBLEMS AND PROSPECTS OF *MOTH* BEAN [(*VIGNA ACONITIFOLIUS* JACQ. (MARECHEL)] IN ARID AND SEMI-ARID ZONES OF RAJASTHAN

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INTRODUCTION

Moth bean is a major and important pulse of arid and semi-arid zones of Rajasthan where erratic rainfall and dry atmosphere prevails during most of its growth period. In most of the driest parts it is a main crop, either taken solitary or as a mixed crop with *bajra.* It occupies approximately 1.8 million hectares producing 0.42 million tons with an average production of 237 kg/ha (Table 1). The low production per unit area is considered to be due to lack of suitable varieties, cultural practices, its susceptibility to diseases and pests. Inspite of its importance as a drought resistant, nitrogen fixing and protein rich grain, it has failed to receive scientific attention for its improvement. The problems associated with *moth* cultivation were studied to obtain firsthand information on this aspect. The results are reported in this communication.

Table 1. Area, production*, and average production of *moth* bean and rainfall** in Rajasthan (1970-71 to 1976-77)

Contents	YEARS						
	70-71	71-72	72-73	73-74	74-75	75-76	76-77
Total area (ha)	15,56,277	15,63,687	14,74,107	15,22,270	15,78,197	18,05,171	17,84,515
Total production (metric tonnes)	4,03,971	2,65,358	74,899	3,76,828	83,583	3,70,716	4,23,298
Average production (kg/ha)	259.54	169.70	50.81	247.54	52.96	205.36	237.21
Rainfall (cm)	62.54	66.48	40.10	78.06	47.13	82.74	75.64

*Director of Economics and Statistics, Govt. of Rajasthan, Jaipur 1977.
**Director of Agriculture, Govt. of Rajasthan, Jaipur 1977.

MATERIAL AND METHODS

Eight cultures from main *moth* growing districts were collected and evaluated at Asalpur Farm with a view to study their yield potential. The planting was done in RBD with five replications. Each plot consisted of 6 three-metre long rows spaced 30 cm apart. Data were recorded on grain yield and fodder yield per hectare, harvest index and 1000 grain weight.

Since no literature is available on fertilizer requirement of the crop, another experiment was planted to find fertilizer response of this crop. In this experiment, four levels of nitrogen viz., 0, 10, 15 and 20 kg/ha and three levels of phosphorus i.e. 30, 40 and 50 kg/ha were applied with and without rhizobium culture. The experiment was done in RBD with three replications. Each plot consisted of 8 five-metre long rows spaced 30 cm apart. Observations were recorded on grain and fodder yield, harvest index and 1000 grain weight.

A total collection of 815 lines, collected from Rajasthan and adjoining states were grown on SKN College of Agriculture, Jobner farm in a single 3 metre row. Screening was done against natural infestation of nematodes, yellow mosaic virus and leaf spot diseases.

RESULTS AND DISCUSSION

This crop is absolutely dependent upon rainfall. A critical evaluation of Table 1 reveals that the production has gone down in the drought years. However, in general, the area under *moth* crop has progressively gone up.

Variability in local collections

Eight different collections were evaluated for yield potential. The difference in yield were nonsignificant (Table 2),

Table 2. Local *moth* bean yield potential trial, *kharif*-1977*

Name	Place of collection	Grain yield (q/ha)	Fodder yield (q/ha)	Harvest index	1,000 grain weight (gm)
UUM-1007	Bikaner	6.55	31.44	18.39	21.04
UUM-1002	Jhunjhunu	6.26	28.52	19.59	23.24
UUM-1003	Nagaur	5.89	28.37	17.05	20.56
UUM-1001	Bikaner	5.85	25.26	18.35	21.84
UUM-1005	Ganganagar	5.65	26.74	17.51	21.00
UUM-1006	Sikar	5.59	24.59	17.69	22.44
UUM-1009	Merta	4.70	19.37	19.21	21.84
UUM-1008	Jhunjhunu	4 63	24.30	15.87	22.80
C. D. at 5%		NS	NS	NS	1.38

*Mean values of grain yield and other characters.

Table 3a. Fertilizer cum rhizobium trial of *moth* bean interaction table

Source	D. F.	Grain yield (gm/plot)		Fodder yield (kg/plot)		1,000 grain weight		Harvest index	
		M.S.S.	F value	M.S.S.	F value	M.S.S.	F value	M.S S.	F value
N	3	0.0732	8.13*	0.5145	9.1469*	91.539	1.337	6.49	3.21*
P	2	0.0206	2.28	0.0270	<1	9.394	<1	3.45	1.70
NP	6	0.0165	1.83	0.4591	7.755*	19.100	<1	4.34	2.14
C	1	0.0115	1.28	0.4516	7.628*	239.039	3.492	15.03	7.44*
NC	3	0.0075	<1	0.1456	2.459	90.675	1.324	2.44	1.20
PC	2	0.0059	<1	0.1116	1.885	75.543	1.103	1.64	<1
NPC	6	0.0034	<1						
P vs without P	1	0.0037	<1	0.2237	3.778	40.039	<1	0.90	<1
Between 'C'/ without Fert.	1	0.0005	<1	0.0204	<1	14.015	<1	0.06	<1
Error	50	0.0090		0.0592		68.448		2.02	

*Significant at 5% level.

Table 3b. Mean values for different treatments

Components	Grain yield (gm)	Fodder yield (gm)	Harvest index	1,000 grain weight (gm)
N_0	0.330	0.967	27.614	22.655
N_{10}	0.208	0.670	22.202	21.561
N_{15}	0.233	0.801	25.516	21.888
N_{20}	0.185	0.578	27.438	22.811
SE_m	0.0223	0.0032	0.1122	3.8026
C. D. at 5 %	0.0619	0.1589	0.9285	5.4052
P_{30}	0.2128	0.7658	25.869	21.795
P_{40}	0.234	0.781	24.998	22.391
P_{50}	0.271	0.716	26.211	22.500
SE_m	0.0003	0.0024	0.0841	1.6887
C. D. at 5 %	0.0536	0.1376	0.4398	4.6811
C_0	0.227	0.833	23.871	22.686
C_1	0.252	0.675	27.515	21.772
SE_m	0.0158	0.0405	0.2368	1.3788
C. D. at 5 %	0.0438	0.1120	0.6565	3.8221

N×P interaction of fodder yield

	P_{30}	P_{40}	P_{50}	Mean
N_0	0.964	1.044	0.894	0.967
N_{10}	0.751	0.636	0.623	0.670
N_{15}	0.691	0.936	0.777	0.801
N_{20}	0.659	0.506	0.571	0.578
Mean	0.768	0.781	0.716	0.754

SE_m = 0.0993.
C. D. at 5 % = 0.2753.

which indicates there is not much genetic variability. Perhaps each collection consists of a mixture of different homozygous lines. It is expected that development of pure lines through selections within those mixtures woud result into development of worthwhile varieties. Variability was also nonsignificant for fodder yield. Though 1000 grain weight did differ significantly, the amount of variability was very low.

Fertilizer requirement

While there was no response to phosphorus application the crop showed negative response to different levels of nitrogen (Table 3a). The addition of bacterial culture at the time of sowing could not have any significant effect on grain yield. However, effect of culture on fodder yield and harvest index was significant (Table 3b).

Diseases

Though quantitative data were not recorded in these experiments, it is seen that this important *kharif* pulse is highly susceptible to diseases like yellow mosaic virus, nematode infection and leaf spot of bacterial and fungal origin. Nematode infection is more serious problem than yellow mosaic virus. The infection is caused by *Melodogyae incognita* which is quite ubiquitous in Rajasthan soils. The soil population of the nematode larvae was 170/100 ml soil around the infested plant's root zone which may cause even complete devastation of the crop. It may therefore, be concluded that lack of suitable varieties, non-response of existing varieties to fertilizers and high incidences of disease and nematodes are the main problems to be tackled in this crop.

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II. 4.9

GENETIC IMPROVEMENT IN CLUSTER BEAN (*CYAMOPSIS TETRAGONOLOBA* TAUB.)

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Cluster bean is an important crop of *kharif* season in arid and semi-arid regions of India. Perhaps, there is no other leguminous crop which can be grown so successfully in soils of poor fertility and mild alkalanity and areas of erratic rainfall where severe drought is a rule rather than exception. It is being grown for vegetable, fodder, green manuring and seed purposes. Both forage and seeds are highly nutritive. The gum is used as food and in the textile and paper industry. This has opened a new avenue for agro-industrial development in the arid and semi-arid tracts and hence there is an urgent need for planned and systematic research programme with regard to yield and quality of forage, seed and gum content in this crop.

In the present paper, an attempt has been made to discuss the findings of the research work in progress and future plan of work with regard to genetic improvement in *guar*. Two main approaches employed were the mutation breeding and hybridization programme.

Mutation breeding

Mutation breeding has been found to be a potent tool for making genetic improvement in crop plants (Humphrey, 1954; Gregory, 1955; Gupta and Swaminathan, 1967). Micky (1975) has given an account of crop cultivars bred through induced mutations.

The dry seeds of two varieties namely: B5-54 and Pb T2 were irradiated with 10, 20, 40, 60, 80 and 100 kR of gamma radiation (Co^{60} source). From the segregating population of this treated material, selections were made for desirable plants in M-2 and M-3 generations.

These selections were further purified for three, four years and were evaluated against the check varieties like Pb T2 *durgapura safed* and F.S. 277 in yield trials during 1976 and 1977. The results of 1977 are presented in Table 1. Table reveals that the mutants M-2, M-5, M-6 and M-10 outyielded the checks. The yield of M-10 was significantly higher than all the checks. It outyielded the checks by 40 per cent. The increase in yield of M-2, M-5 and M-6 was 14 40, 13.99 and 14 09 per cent respectively The yield of M-7, M-4 and M-1 were, however, at par with checks. These mutants will again be evaluated and may be released for commercial cultivation if found superior. Due to adverse conditions and unfavourable environment, 1976 results were not so reliable. However, the yield trend of M-1, M-2, M-4, M-6, M-7 and M-10 was almost similar during 1976 also.

Table 1. Mean plot yield and per cent increase over mean of checks of some of the lines isolated from irradiated population in cluster bean

Lines	Grain yield per plot (kg)	Per cent increase
M-1	0.947	—
M-2	1.096	14.40
M-3	0.741	—
M-4	0.923	—
M-5	1.092	13.99
M-6	1.093	14.09
M-7	0.932	—
M-8	0.752	—
M-9	0.831	—
M-10	1.342*	40.08
Pb T2	0.987	—
F.S.277	0.947	—
Durgapura safed	0.941	—
Mean of checks	0.958	

*Plot size 6.75 sq m.

Dwarfing genes and determinate habit

Many scientists have stressed the need of plant ideotypes in different crop plants (Donald, 1968; Asana, 1965: Chaudhary and Singh, 1976), however, the success in this direction is very limited. In the present irradiated material, the possibilities of inducing dwarfness, earliness, photo-insensitivity and other desirable yield components were explored. With rigorous selection, dwarf and early plants of different height groups were isolated in the variety B5-54. These mutants are characterized by their determinate and non-branching habit, early maturity, reduced plant height and increased cluster size (Fig. 1 and Table 2). Though in cluster bean branch number per plant is positively correlated with seed yield (Chaudhary and Singh, 1976; Sanghi *et al.*, 1964). On the basis of path coefficient analysis studies, Chaudhary and Singh (1976) reported that branch number has very little direct effect on seed yield and thus is of less importance. On the other hand, seed weight and peduncle length have substantial role in grain yield. They suggested the model characteristic for cluster bean as the higher number of clusters with high number of pods, longer peduncle and bolder seeds. These dwarf and determinate have all these characteristics. Being unbranched, more plants can be adjusted in a given area and consequently increasing the total grain yield.

It was interesting to note that the time of determination had direct impact on plant height, earliness and peduncle length. The smallest plants were 20 cm high compared to 170 cm in control. These mutants were about one month early in maturity than F.S.-277 the standard variety. Since, there were several height groups (Fig. 2) the dwarfing habit seems to be under the control of polygenes. Studies on the nature of inheritance are in progress. Further, the plants of medium height (70-100 cm) appeared to be most desirable for seed yield (Table 3), since they had more number of clusters without any significant decrease in peduncle length. These mutants will be very useful in hybridization programmes aiming at breeding for lodging resistance, earliness and yield components in this crop, in case they are not of direct commercial use.

Table 2. Characteristics of dwarf mutants compared with F. S 277 variety of cluster bean

Characters	Mutants	F. S. 277
Growth habit	Unbranched and determinate	Unbranched and indeterminate
Plant height	Dwarf	Tall
Flowering	Early	Medium
Maturity	Early	Medium
Cluster size	Long	Medium
Leaf	Broad and thick	Medium in size and thickness

Table 3. Comparison of determinate plants with normal plants (non-determinate) of cluster bean

Material	No. of bunches		No. of pods		Seed yield (g)/plant		per cent increase in yield over	
	Mean	C. V.	Mean	C. V.	Mean	C. V.	F. S. 277	B5-54
Determinate								
I group (below 70 cm)	4.87 (3-6)*	45.13	81.67 (38-127)	27.69	17.22 (6-24)	30.99	105.49	8.98
II group (70-100 cm)	6.24 (4-8)	28.97	98.20 (56-149)	29.30	20.89 (14-32)	20.48	149.28	32.22
III group (above 100 cm)	6.65 (5-11)	22.44	72.78 (39-101)	26.49	16.74 (9-27)	24.48	99.76	5.94
F. S. 277	8.28 (3-12)	28.42	33.76 (8-84)	47.80	8.38 (2-21)	47.80		
B5-54	23.40 (6-44)	47.79	60.30 (16-114)	54.80	15.8 (5-32)	51.01		

*Range values are given in parenthesis.

Fig. 1. A determinate plant of cluster-bean.

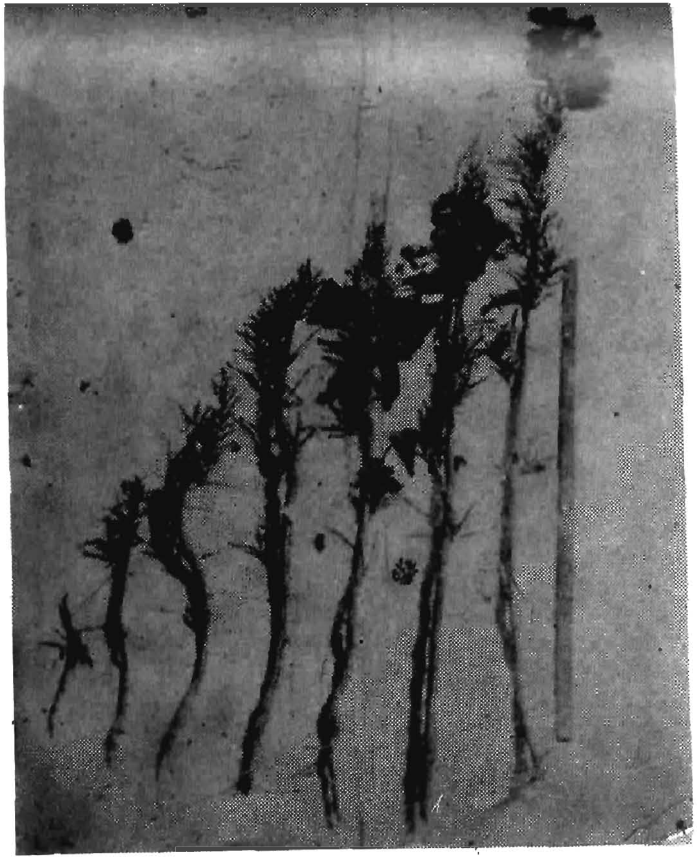

Fig. 2. Determinate dwarf mutants of different height groups of cluster bean.

Table 4. Gum and protein content of some of the lines of cluster bean

Lines	Gum content (%)	Protein content (%)
1-6-10	34.9	29.7
I C 9041	34.0	21.9
G S 1	26.5	26.7
I C 287	24.0	25.7
I C 9040	25.6	30.0
G S 55	29.1	21.2
2-1-8	29.4	29.8
No 320	31.9	21.6
I C 370	34.6	25.6
6-5-12	28.3	25.6

Hybridization programme

Eighty two lines of *guar* in our collection including mutants mentioned above, were analysed for protein and gum content for two successive years. The seed protein ranged from 18.37 to 31.50 and 19.70 to 31.50 per cent for 1975 and 1976 respectively. For gum content the range was 23.7 to 39.6 and 23.1 to 38.4 per cent for 1975 and 1976 respectively. The differences for genotypes were significant. The data of some lines which fall into low or high group of protein and gum content have been given in Table 4. The mutants M-2, M-8 and M-10 had fairly high protein content (29.31, 29.75 and 28.87 per cent respectively) while M-4, M-5 and M-6 showed quite high gum content (37.0, 35.1 and 35.7 per cent respectively). However, the gum and protein content were moderate in the determinate type.

To study the genetics of gum and protein content, the crosses were made between and within groups (Table 5). The material is in F2 generation which will be studied this year and the inheritance of these two traits will be worked out.

Besides, an active intervarietal hybridization programme is under way in this

Table 5. Details of crosses

1. High gum × Low gum
   1-6-10 × G S 1
   1-6-10 × I C 287
   I C 9041 × G S 1
   I C 9041 × I C 287
2. High gum × High gum
   1-6-10 × I C 9041
3. Low gum × Low gum
   G S 1 × I C 9040
4. High protein × Low protein
   1-6-10 × G S 55
   1-6-10 × I C 9041
   I C 9040 × G S 55
   I C 9040 × I C 9041
5. High protein × High protein
   1-6-10 × I C 9040
6. Low protein × Low protein
   G S 55 × I C 9041

department *inter alia* incorporating in otherwise desirable grain type, photoinsensitive genes from determinate type and *pusa navbahar* and other genetic stocks, the disease and pest resistance and earliness from the genetic stocks isolated for these traits

Interspecific hybridization in *Cyamopsis,* has not yet been reported and appears to be a challenge to the breeders and geneticists. If successful, one can exploit more genetic variability by attempting a few interspecific crosses. Our future work in cluster bean has been planned on these aspects. The crosses between different species of this genus will be attempted and the compatibility between them will be looked for. An attempt will be made to remove the crossability barriers, if any, between these species through various techniques including embryo culture and amphidiploidy.

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II. 5.3

IMPROVEMENT AND MANAGEMENT OF CULTIVATED FORAGES FOR INCREASED ANIMAL PRODUCTIVITY

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Importance of forages in India's agricultural economy is obvious from the very fact that inspite of the largest cattle wealth (34.3 crores), the animal performance is one of the lowest in the world. The obvious reasons for this is the lack of sufficient amount of good quality fodder (both green and dry) and the concentrates. We are short of concentrates by 6.0 times, of green fodder by 1.73 times and of dry matter by 2.77 times. This deficit is likely to increase further keeping in view the fact that the area under fodder crops is declining and the animal population is increasing every year by almost 2 per cent. During the last 25 years, the pressure of bovine population has increased from 74 to 98 animals per 40 hectares of arable land. In Rajasthan alone, livestock population has increased from 9.4 to 18.1 millions during the last 20 years, whereas area put to less intensive use has decreased by almost 25 per cent. This has created a situation where animals are unable to get even one-third of what they need for a maintenance ration of 4.53 kg of roughage per day plus 2.72 kg of green grass for a body weight of 227 kg, obviously, insufficient fodder results in poor cattle and, therefore, there is an urgent need to augment our feed and fodder resources of the country, which account for almost 60 per cent of the expenditure on a dairy farm, in case if the ultimate aim is to achieve 'White Revolution' in near future.

Importance of cultivated fodder crops is all the more in arid and semi-arid regions especially when economy of the farmer is based on mixed farming system. Maximization of forage productivity could obviously be possible through improvement and management of fodder crops especially when it is difficult to bring in more area under fodder cultivation due to pressure on land.

Breeding objectives

Simultaneous improvement in yield and quality is necessary to have increased animal production. Forages have little relevance until and unless evaluated for their quality especially in terms of intake, digestibility and utilization. Among quality characters, crude protein (7-8 per cent), and digestibility are of much importance, in addition to better intake value. Leafiness has been found to be the only criterion so far of voluntary intake. Leafiness has also been found to be associated with crude protein and digestibility. Hence, breeding for leafiness is of considerable importance in forages since it has also been established that leaves contribute more towards dry matter yield than the stem. However, there is need for simultaneously looking into the aspects like succulence, disease resistance and absence of toxicants (tannin, saponin, coumarin, HCN, oxalic acid, etc.) which otherwise affect the overall feeding value of the forage. Paroda (1973) considered that an ideal type of forage has to have leafiness for increased palatability and intake, low toxic constituents, better digestibility, stability for high dry matter production, good regeneration, resistance to diseases and insect pests, better seed production, and above all, suitability for a specific farming system. Therefore, efforts need to be made to achieve these objectives.

Improvement in fodder crops

Maximization of dry matter production in forages is necessary to ensure harvesting per unit area enough of digestible nutrients. It has been established that the difference in dry matter production can easily offset the minor losses in quality attributes and varieties with high dry matter production could often be at distinct advantage. The best way of achieving this is to breed varieties of high dry matter production combined with leafiness and palatability. Recently, new varieties of sorghum (PC 1, HFS 576, S 136 and PC 6), cowpea (HFC 42-1), *guar* (HFG 444, HFG 119 and B-19-1-55), lucerne (Anand-2) and oats (OS 7, OS 44, OS 54, HFO 54 and HFO 65) have been evolved which are both leafy as well as high in their dry matter production.

The other way for maximization of dry matter production is to grow multi-cut varieties. Multi-cut varieties find favour with the farmers because, in addition to their high yielding ability, these are also capable of producing fodder at frequent intervals. Striking examples of varieties like T-9 of lucerne, mescavi of berseem and NB 21 of napier x *bajra*-hybrid are well known. Concept of regeneration for increased yield has recently been adopted in non-traditional multi-cut forage crops like sorghum, oats and cowpea, and some promising varieties have been evolved at the Haryana Agricultural University, Hissar. These are SSG 59-3 of sudan grass, HFS 822 of sorghum, HFO 114 (*Haryana javi* 114) of oats and HFC 42-1 of cowpea.

The dry matter production in case of multi-cut varieties is 25-30 per cent more than the checks under the same management system. Also the same variety provides more dry matter in two cut management than in one cut management though at the cost of both protein and digestibility of dry matter. In all-India Coordinated forage sorghum trials, a multi-cut sudan grass variety (SSG 59-3) has shown its superiority at all the locations over the entries including *pusa chari*-1, giving an all-India average of 150 q/ha of dry matter as against 100 q/ha of best single-cut forage sorghum varieties. Similarly, HFO 114 of oats has been recommended by the All-India Coordinated Project on forage crops as first multi-cut variety of oats in the country. It is capable of giving about 129 q/ha of dry matter as against 89 q/ha obtained in case of check variety *weston*-11.

In Table 1 are shown the details of most commonly used varieties of forage grasses and legumes. Except a few, indicated above, most of these are of the result of direct selection from out of the genetic variability available. Breeding material, now being generated at leading forage research centres like IGFRI (Jhansi), HAU (Hissar), PAU (Ludhiana), IARI (New Delhi) and CAZRI (Jodhpur) is expected to provide high yielding varieties of forages both for increased yield and quality.

Management of fodder crops

Suitable management of cultivated fodders can lead to substantial increase in forage production per unit area and time. As is evident, area under fodder crops is rather limited (4 per cent only) and in view of pressure on land, additional area under fodder crops, as advocated by the National Commission on Agriculture, is perhaps not likely to materialise in near future. Therefore, alternatives like adoption of improved varieties and suitable management practices for higher forage production from limited land is advisable. Also production need to be oriented in such a way that the supply of fodder is regulated all the year round. Adoption of suitable crop rotations, including both annual and perennial crops with varying cropping intensity, can help in augmenting fodder supply throughout the year. Recent research in Punjab, Haryana, Rajasthan and Gujarat, and for that matter all over the country, have proved the efficacy of rotations like:

—Napier × *bajra*-hybrid intercropped with berseem, or

—Napier × *bajra* hybrid + lucerne, or

—Sweet sudan grass + berseem/lucerne.

These rotations are capable of producing high quality green fodder under

Table 1. List of improved varieties of fodder crops and grasses

Crop	Botanical name	Improved varieties
(A) *Kharif fodders*		
1. Sorghum	*Sorghum bicolor*	JS 20, JS 263, JS 29/1, Pusa-Chari-1, Haryana Chari, (JS 73/53), SL-44, CO 11, Vidisha 61-1, S 136, PC 6, Nilva and M.P. Chari, (J6, IS 4776, HFS 566 are new strains).
2. Sudan grass	*Sorghum sudanense*	Meethi Sudan (SSG 59-3), (HFS 478 and J 69 are new strains).
3. *Bajra*	*Pennisetum typhoides*	S 530, T 55, A 1/3 and F_2 generation of BJ 104 hybrid.
4. Maize	*Zea mays*	Ganga-1, Ganga-5, Deccan, Vijay composite and Bassi local.
5. Teosinte	*Euchlaena mexicana*	Improved teosinte.
6. Cowpea	*Vigna unguiculata*	HFC 42-1, IGFRI-S-450, IGFRI-S-457, Russian Giant EC 4216, FOS 1, CO 1 and No. 10.
7. *Guar*	*Cyamopsis tetragonoloba*	No. 2, FS 277, Durgapura Safed, AG 111, HFG 119 and B-19-1-55.
8. *Moth*	*Phaseolus aconitifolius*	T3 and Jodhpur local.
9. Napier X *bajra* hybrid	(*P. purpureum* X *P. typhoides*)	Pusa Giant Napier, Gajraj and NB 21.
(B) *Rabi fodders*		
1. Berseem	*Trifolium alexandrinum*	Mescavi, Tetraploid berseem and IGFRI-S-99-1.
2. Lucerne (Alfalfa)	*Medicago sativa*	Sirsa 9 (T-9), IGL 1, Anand 1, Anand 2, Sri Ganganagar, IGFRI-S-244 and IGFRI-S-54.
3. Oats	*Avena sativa*	Kent, Weston-11, Fulghum, FOS 1/29, Algerian, Haryana Javi (HFO 114), IGFRI-S-2688, OS 6 and OS 7.
4. *Senji*	*Melilotus* spp.	FOS 1.
5. *Methi*	*Trigonella foenum-graecum*	T-8.

assured irrigated conditions to the tune of 1500-2000 q/ha per year in a regulated manner covering even the lean periods. Napier × *bajra*-hybrid (NB 21) should be planted in these rotations at a distance of at least 2 metres. It has also been demonstrated by National Dairy Research Institute, Karnal and Amul Dairy, Anand that when these rotations are adopted simultaneously on farmers fields; one hectare land can sustain about 8 to 10 cross bred animals giving on an average 10 litres of milk per day-an ideal situation for a dairy industry to achieve.

Under limited irrigated conditions, rotation like '*bajra* + cowpea — *jowar* + cowpea – oats' is considered to be most suitable giving about 900-1200 q/ha. However, such rotations are unable to supply fodder all the year round. Crops like cowpea, *guar* and *moth* also hold good promise in water scarcity area as they are relatively drought hardy, and cowpea being quick growing, can provide quality fodder during summer and *kharif* months. Oat is another less water requiring fodder crop in *rabi* and can yield fairly comparable dry matter with that of high water requiring crops like berseem and lucerne. Sorghum is most important *kharif* fodder crop owing to its excellent hay making and silage making quality. Similarly, oat is another good crop for silage. As indicated earlier, crops like maize and teosinte are most suited under humid climate and should replace crops like sorghum and *bajra* in above rotations.

Role of legumes in improving the quality of cereal forage, when grown together, has amply being demonstrated and thus, legumes should invariably be adopted in forage production programme. This would improve intake, digestibility and utilization of forage. Even utilization of wheat straw and hay etc. can be improved substantially by adding leguminous green fodder in the animal ration.

Stage of harvesting is another non-cash input which can help in harnessing maximum nutrients per unit area. It has invariably been proved that in a single cut management, harvesting at 50 per cent flowering is the best stage both from yield and quality point of view. Advancement in age would affect the quality of forage adversely. Similarly, harvesting at earlier stages than flowering, would produce less of dry matter though quality will be better. In multi-cut system, harvesting at 10-15 cm above ground would help in better regeneration. First cut in sudan grass and oats should be taken at 55 and 70 days, respectively, whereas subsequent cuttings should be taken at an interval of 40-45 days. Interval of cutting in berseem and lucerne is frequent and generally 30-40 days interval is most desirable. Napier × *bajra*-hybrid should not be allowed to grow taller than 2-3 feet in order to have regeneration as well as good quality of fodder. For better regeneration, one thumb rule is to apply irrigation immediately after each cut coupled with fertilizer dose of about 40 kg N/ha in case of cereal fodders.

Application of phosphatic fertilizer to an extent of 60-100 kg P_2O_5/ha in legumes, especially in berseem and lucerne, has been found to be most beneficial and, therefore, must be adopted as a practice if maximum productivity from available land and resources is envisaged. Similarly, application of about 60-80 kg N/ha in case of sorghum, *bajra* and oats can enhance forage yield substantially. In order to economise on fertilizer, cereal fodders should invariably be raised in fields preceded by leguminous crops.

A well-charted programme of management of forages, application aside of cash inputs like fertilizer and irrigation, can lead to substantial increase in forage production of good quality mainly through adoption of practices involving non-cash inputs like improved varieties, suitable rotations, timely sowing, harvesting at appropriate stage and mixed cropping of legumes and cereals.

CONCLUSION

The early possible way of meeting the forage deficit is to produce maximum digestible dry matter per unit area especially when land under cultivated fodders is limited. For this, adoption of superior multi-cut varieties, which are capable of producing more digestible dry matter, and their suitable management would ensure supply of good quality fodder for a longer period. Also suitable management of pastures through reseeding improved varieties and appropriate agronomic practices coupled with rational utilization through suitable grazing systems would go a long way in improving the productivity of our animal population, especially in the arid region.

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II. 5.4

FORAGE PRODUCTION UNDER DIFFERENT SYSTEMS OF GRAZING ON RANGELANDS IN ARID REGIONS OF INDIA

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INTRODUCTION

Due to recurring and frequent droughts in arid regions, animal husbandry plays an important role in the economy of the region. Livestock of this region depend on natural rangelands for roughage supplies. Rangelands are highly denuded due to heavy stocking pressure. Land actually available for grazing per adult cattle unit (A.C.U.) is about 1 hectare out of a total geographical area of 3 ha/A.C.U. (Ahuja and Mann, 1975). About 80 per cent of lands in arid regions are in 'Poor' condition class. Under years of normal rainfall conditions, forage shortage, presently is about 40 per cent (Ahuja, 1977). Area of rangeland needed to maintain an adult cattle unit on year long basis for 'Poor', 'Fair' and 'Good' condition classes are 8, 6 and 5 hectares respectively (Bhimaya and Ahuja, 1969).

Therefore, a greater pressure exists on natural rangelands. Deferment to vegetation is considered as advantageous for establishment, growth, or seeding for a particular species within a plant community (Wilson, 1977). Present studies were therefore undertaken to evaluate forage production on different rangelands under different systems of grazing for 3-6 years, to find out suitable grazing management practices.

MATERIAL AND METHODS

The major grazing trials on different types of rangelands with growing cattle yearling heifers as grazing animals were undertaken viz:

I. Effect of different intensities of grazing stress on rangelands on forage production.

II. Effect of different systems of deferred rotational grazing on forage production.

Treatments adopted under above experiments are as under:

I. *Effect of different intensities of grazing stress on rangelands for forage production*

Studies were conducted in range substations, Borunda, Chandan, Sojat and Samdari, of the Central Arid Zone Research Institute, Jodhpur, with following intensities of grazing stress.

T1 Continuous controlled grazing on yearlong basis (one heifer per unit plot).

T2 Heavy intensity of grazing (4 to 5 heifers per unit plot).

T3 Moderate intensity of grazing (2 to 3 heifers per unit plot).

T4 Grazing as in T2 plus supplemental feeding to meet with D.C.P. and T.D.N. requirements of grazing animals from December to June.

T5 Grazing as in T3 plus supplemental feeding to meet with D.C.P. and T.D.N. requirements of grazing animals from December to June.

These five treatments were replicated thrice under randomised block design. During 1967-68, concentrate feeding was not given under T4 and T5 in all experimental stations.

During 1965-66, animals under T2 and T3 were withdrawn whenever forage on the concerned range plots got exhausted. From 1966-67 onwards, wherever forage on range plots got exhausted, animals were provided with post seeding stage (mature) hay harvested from nearby rangeland, at about 3 kg/animal/day. Animals under T4 and T5 were provided with post seeding stage (mature) hay harvested from nearby rangeland whenever forage from the rangeland got exhausted.

Botanical composition (based on vegetational maps and Parker's loop method) of each plot was kept similar as far as possible, in a sub-station.

Grazing was carried out during 1965-66, 1966-67, 1967-68, 1970-71 in Chandan, 1965-66, 1966-67, 1967-68 in Sojat, 1966-67, 1967-68, 1969-70, 1970-71 and 1971-72 in Borunda and 1966-67, 1967-68, 1968-69, 1970-71 and

1971-72 in Samdari. It could not be carried out during rest of the years due to unavoidable reasons.

Size of unit plot in Borunda, Sojat and Chandan sub-stations was 2.4 ha, while in Samdari, it was 4.0 ha. Number of heifers in Sojat under T2 and T4, and T3 and T5 were 5 and 3 respectively, while in rest of the range stations, it was 4 and 2 respectively. Size of unit plot was fixed mainly on grass species composition and forage production. During 1970-71 and 1971-72, the size of plot under T2, T3, T4, T5 was reduced to 1.2 ha in Borunda and number of grazing animals reduced to half in above respective treatments, due to unavoidable conditions.

II. *Effect of different systems of deferred rotational grazing on forage production*

Studies were conducted in range sub-stations, Jaisalmer, Beechwal, Maulasar, Jaswantgarh and Jabdinagar, with following grazing treatments using heifers as grazing animals.

T1 Continuous controlled grazing throughout the years.

T2 Deferred rotational grazing. Each plot was sub-divided into two equal sub-plots. Grazing was carried out for two months in rotation, for the whole year, giving a total stress of six months a year to each sub-plot.

T3 Deferred rotational grazing. Each plot was divided into two equal sub-plots. Grazing was carried out in rotation of 4, 4, 2, 2 months, thereby giving a total stress of six months a year to each sub-plot.

T4 Deferred rotational grazing. Each plot was divided into two equal sub-plots. Grazing was carried out in rotation of 2, 4, 4, 2 months, thereby giving stress of six months a year to each sub-plot.

Above treatments were replicated five times in randomised block design.

Size of grazing plot per treatment in Jaisalmer sub-station was 2.4 ha and in the rest, it was 2.9 ha. One animal was allotted per treatment.

Botanical composition (based on vegetational map and Parkers' loop method) was similar as far as possible in each treatment plot is a sub-station.

Grazing was carried out in Jaisalmer, Jaswantgarh, Jabdinagar, during 1965-66, 1966-67, 1967-68 and 1968-69; in Maulasar during 1965-66, 1966-67, 1967-68; in Beechwal during 1967-68, 1969-70.

Forage yield could not be recorded during 1966-67 and 1968-69 in Beechwal and 1966-67 in Maulasar and Jabdinagar sub-stations. Following procedures were common for both experiments I and II.

The forage yield was estimated by harvesting forage Estimation Quadrates (F.E.Q.) during middle of October every year, air drying the forage and weighing it species wise. Grouping of high perennials, low perennials, annual grasses, non-edibles, was based on classification of Bhimaya and Ahuja (1969). The F.E.Q. (3.3×3.3 m each) were effectively protected during growing season (June—October) every year. Harvesting of forage was done from a net area of 3.162×

3.162m leaving a rim to avoid border effect. Six F.E.Q. were randomly distributed in each of the experimental plot. Every year, the position of F.E.Q. was changed by rotation along random points in clock wise direction. After fourth year, the position of F.E.Q. was changed at random. Experimental year for the grazing purpose was extended from 1st July 1965 to 30th June 1966 and from 1st July 1966 to June 1967. Grazing beyond 1967 was carried out from 1st August to 31st July of succeeding years.

Yearling heifers of local breed, available in the nearby village with initial body weight of 80 to 90 kg were grazed (number depending on treatment) continuously for one year in each experimental plot. Body weight of each animal was recorded at fortnightly intervals. New set of animals (keeping breed of animal same in a sub-station) were selected for grazing every year. Grazing was carried out during day hours only. Water was available freely to animals in animal house of the range sub-station. Rainfall was recorded with standard rain gauge.

RESULTS AND DISCUSSION

Experiment I

In Chandan, a sub-station under low rainfall zone with light soils, total forage yield under different treatments and different years differed significantly, lowest yield being during the years of lowest rainfall (1968-1969). At moderate and high intensities of grazing stress (T3, T5, T2, T4), forage yields declined, while it was higher under light intensity of grazing (T1). Klipple and Costello (1960), Klipple and Bement (1961) recommended light grazing of deteriorated rangelands for progressive increase in forage yield and economics when compared to heavy and moderate stocking of ranges. Under higher intensity of grazing stress, decreased forage yield may be due to close grazing of animals, damaging the root stocks, thereby retarding their regeneration. Forage component of high perennial species i. e. *Lasiurus sindicus* was separated out and results revealed that contribution of this species was not affected by different intensities of grazing stress, but it differed during years, lowest being during year of poor precipitation (1968, 1969). Low yields of this species and also total forage yield during 1970 may be due to continuous effect of drought during 1968 and 1969. Hardy nature and deep root system of *Lasiurus sindicus* may be responsible for its escaping drought and withstanding heavy grazing stress (Ahuja *et al.,* 1976).

Total forage yield and that from climax species viz. *Cenchrus setigerus* on a rangeland with shallow soils and average annual rainfall of 336 mm (Borunda) did not differ significantly under different intensities of grazing stress. However, these differed significantly during different years. Least yields were during the years 1966 and 1972. Forage yields on rangelands was affected by total rainfall and its pattern of distribution. Low forage yields during 1970 and 1971 could be attributed to ill distributed and erratic pattern of rainfall. The contributions from climax species viz. *Cenchrus setigerus* were not affected by different intensities of grazing stress, but these differed during different years, as in the case of total forage yield. Perhaps the pattern of ill distributed rainfall during 1971 affected the production of *Cenchrus setigerus.*

On a rangeland (Sojat) with average annual rainfall of 574 mm, total forage yield and that from climax species *(Cenchrus setigerus)* were not affected by different intensities of grazing stress. However, higher total forage during first year (1964) may be due to very well distributed rainfall during the monsoon of the year. During 1965, lowest yield of *Cenchrus setigerus* is mainly due to poor distribution of rainfall. Good rainfall during July followed by poor precipitation during August 1965 proved congenial for annual species, while such type of rainfall did not allow sufficient growth in perennial species (*Cenchrus setigerus*), resulting in their lowest yields. All these indicated the pattern of distribution of rainfall (and not the absolute precipitation) and determines the production from different species. This is in agreement with the findings of Perry (1977).

On a rangeland (Samdari) dominated by annual species with average annual rainfall of 331 mm, total forage yield was not affected by different intensities of grazing stress. Yields during different years differed significantly due to rainfall and its distribution pattern. Unusually, yields during 1975 were low, although the rainfall was above normal. Unusually heavy rains during July, destroyed the young growing promising seedlings of grass species which resulted in poor yields. Thus, the pattern of rainfall determines the herbage production on range.

Experiment II

Forage yields, total as well as from different groups of species was not affected in different rangelands due to different rotational grazing systems while it differed between years.

In a rangeland (Jaisalmer) with mean rainfall of 181 mm, and *Lasiurus- Cymbopogon-Aristida* cover least total forage yield was recorded during the year when rainfall was erratic and ill distributed (1968). During the year of properly distributed rainfall (1964), yields were highest. Forage production from climax species viz. *Lasiurus sindicus* followed practically the same pattern.

In another desertic rangeland (Beechwal), with average annual rainfall of 211 mm with *Aristida-Eleusine-Lasiurus* cover, total forage yield and that from low perennial species were least during the year 1969 when precipitation was least and distribution was uneven. However, the yields from climax species (whose contribution due to low coverage was poor) was not affected during different years.

In a rangeland (Maulasar) with *Aristida-Cenchrus ciliaris* cover and mean rainfall of 461 mm, total forage yields were higher during the year (1967-68) when rainfall remained evenly distributed. However, the yield of high perennials viz. *Cenchrus ciliaris* were not affected by years presumably due to low population.

On a rangeland (Jaswantgarh) with saline (heavy soils) wherein salt tolerant grass (*Sporobolus helvolus*) dominates and has an average annual rainfall of 364 mm, least forage yield was during year of poor rainfall (1965) and highest when precipitation was evenly distributed and above normal (1967). Due to very low population of high perennial species, their contribution was not significantly affected during different years.

On a rangeland (Jobdinagar) with

heavy soils and *Dichanthium-Sporobolus-Aristida* cover, and mean rainfall of 473 mm, forage yield increased with the increase in precipitation and it decreased during the years of poor precipitation (1965) and the year when the rainfall was erratic and ill distributed (1968) when there were unusually heavy rains during July, 1968, followed by practically no rainfall. However, the contribution of high perennial *(Dichanthium annulatum)* was not affected by low precipitation or erratic rainfall, possibly due to high moisture retention capacity of soils and inherited characters of the grass. Yield from *Dichanthium annulatum* was the highest during the years when the precipitation was maximum (1967). These indicate that production from different grass species is dependent upon pattern of rainfall, soil types suiting different species, etc.

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II. 5.13

SALT TRANSPORT AND PERFORMANCE OF SOME GRASS SPECIES UNDER PRECIPITATION MANAGEMENT IN A HIGHLY SALINE SODIC SOIL

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INTRODUCTION

About 14 per cent of total cultivable area in Haryana is salt-affected (Anon., 1973). Several hundreds of hectares of crop land have been rendered unproductive by salinity and/sodicity problems in Hansi tehsil of Hissar district, Haryana. These problems are also associated with high water table conditions. The area is predominantly canal-irrigated for more than 50 years with no lined canals. As a result of this and poor water management practices as well as changed rainfall pattern of this region for the last several years, the water table has increased several folds. The geological formation and topography of this area is such that it forms localized valleys with no natural outlets of drainage. The underground water is generally moderate to highly saline (EC less than 2 to 30 mmhos/cm). Hence, there are a limited number of tubewells and artesian wells which do not cause enough depletion for lowering the water table. The ground water table generally remains within one metre depth in monsoon season and 2-5 metres in other seasons of the year (Agarwal, 1974). This seems to be the major cause for the development of salty soils in this area (Collis and Evans, 1964; Kulkarni, 1961).

The soils of this area are mostly sandy loam in nature and are moderately permeable. Inspite of almost flat topography, several gentle ridges and depressions have developed in the area due to moderate undulating microrelief. Runoff from ridges is frequently impounded in depressions in slightly to moderately affected land. Salts are concentrated on the raised stretches while the associated depressions are relatively non-saline.

The overall climate of the region is of semi-arid type with wet monsoon and dry to semi-dry winters. The mean rainfall is approximately 360 mm which is highly erratic and significant portion of which (about 70 per cent) is received in July to September (monsoon season) (Goyal *et al.*, 1974).

The objectives of the experiments were: (1) to evaluate the salinity and sodicity changes on a typical salt-affected soil that might be brought about when natural precipitation was impounded, or supplemented with additional water, compared to allowing runoff to adjacent depressions and (2) to evaluate long term responses of some salt tolerant grass species on thus partially reclaimed soil.

MATERIAL AND METHODS

In July 1976 an experiment was initiated on a salt-affected soil patch in a severely affected area at Haryana Government Agricultural Farm, Hansi. This farm is situated about 8 km from Hansi town on Hansi-Sisah road and about 34 km from Hissar city. Previous reports (Goyal *et al.*, 1974; Dahiya and Dahiya, 1977) indicate that the soils of the farm and adjoining areas are identified as coarse loamy and calcareous with continuous blackish-white encrustations on the surface, are developed from fine loamy, Indo-gangetic, alluvium parent material, and morphologically classified as Natric Camborthids. High salt (ECe=27.5 to 45.2 mmhos/cm) and exchangeable sodium (exchangeable sodium percentage-ESP=31.1 to 63.7) contents occur throughout the profile. Sodium, magnesium and calcium are the dominant cations and chlorides followed by sulphates and traces of bicarbonates are the chief accompanying anions. The soil is classified as a highly saline sodic (Richards, 1954). The EC of the underground water varies from 8 to 55 mmhos/cm which tends to decrease as water table nears the surface during monsoon season due to dilution effects of percolating rainfall (Dahiya, 1978).

The treatments chosen were: A=control, precipitation not impounded; B=precipitation impounded; C=precipitation impounded plus leaching with 15 cm of water; D=precipitation impounded plus 25 cm of water; and E=precipitation impounded plus 50 cm of water. Leaching water was applied only in the beginning of the experiment (July 1976). Each treatment which was replicated four times in 8×1 m plots embeded with polyethylene sheets upto 50 cm depth around each of them was superimposed with sub-treatments of four grass species in split plot design. The grass species taken were: rhodes grass (*Chloris gayana* Kunth.), guinea grass (*Panicum maximum* jacq.), para grass (*Brachiaria mutica* Stapf.) and *P. laevifolium.* The grasses were planted in the last week of July 1976 and fertilized with 40, 50 and 25 kg/ha of N, P and $ZnSO_4$, respectively. Farm yard manure at the rate of 2.5 t/ha was also applied.

Soil samples were collected prior and after each monsoon season as well as in winter seasons upto one metre depth at an interval of 25 cm. Soil salinity evaluation and other laboratory determinations were made following Richards (1954). Measurements on water table were obtained through five perforated observation wells installed around the experimental site. Grass cuttings were obtained at appropriate intervals for dry and green matter yield. The dry grass samples were analysed for protein content and *in vitro* dry matter disappearance (IVDMD) (Barnes *et al.,* 1971) in 1976 only.

RESULTS AND DISCUSSION

Fluctuations in water table depth during the period of experimentation are given in Table 1. The monthly figures given represent average water table levels from five observation wells. Monthly precipitation is also given. Water tables rose following periods of heavy precipitation. The deepest level of water table occurred in June or July, whereas shallowest occurred in August, September or October. The average level was 2.55 m over 20 months.

Table 2 summarizes effects of treatments on changes in soil salinity for one metre depth during two years. Initial application of 50 cm of water (treatment E) reduced salinity from 18.5 to 6.63

Table 1. Average monthly water table depths and rainfall

Month and year	Water table depth (m)	Rainfall (mm)	Month and year	Water table depth (m)	Rainfall (mm)
May 1976	4.05	—	March 1977	2.90	5.00
June 1976	4.18	—	April 1977	3.20	24.00
July 1976	3.60	12.50	May 1977	3.27	22.00
August 1976	2.12	360.50	June 1977	3.37	18.00
September 1976	1.33	77.70	July 1977	3.67	88.30
October 1976	1.74	—	August 1977	1.53	200.00
November 1976	2.02	—	September 1977	1.52	47.50
December 1976	2.31	2.50	October 1977	1.54	9.00
January 1977	2.49	21.00	November 1977	1.72	1.00
February 1977	2.64	—	December 1977	1.80	0.60

Table 2. Treatment effect on soil salinity and sodicity of 1-m depth over a two-year period (values are averages over 1-m depth for four replications)

Sampling date	EC of 1:2 soil-water extract (mmhos/cm)					Exchangeable sodium percentage				
	A	B	C	D	E	A	B	C	D	E
Before leaching (19th July 1976)	18.50	18.50	18.50	18.50	18.50	53.50	53.50	53.50	53.50	53.50
After leaching (28th July 1976)	18.50	18.50	13.25	12.13	6.63	53.50	53.50	44.70	34.50	19.40
After Ist monsoon (25th September 1976)	15:15	2.80	1.85	2.00	2.03	48.20	8.70	5.40	3.20	3.70
In Ist winter (7th December 1976)	16.31	3.43	3.55	2.58	2.18	50.80	18.30	13.70	14.80	14.10
Before 2nd monsoon (29th June 1977)	19.50	4.87	4.90	4.25	3.15	57.10	28.10	27.00	23.40	21.90
After 2nd monsoon (25th September 1977)	15.03	2.30	2.13	2.06	2.02	47.60	8.30	4.30	1.80	1.30
In 2nd winter (14th December 1977)	16.87	3.03	3.10	2.98	2.30	52.70	14.20	11.10	10.60	7.10

mmhos/cm and ESP from 53.5 to 19.4. Twenty five cm of water (treatment D), however, reduced salinity and ESP only to 12.13 mmhos/cm and 34.5, respectively. Similarly there was not much decerase in salinity and sodicity by 15 cm of water (treatment C). Thus, only 50 cm supplemental leaching water markedly reduced salinity and ESP. Considerable reductions were accomplished in two years by impounded precipitation (treatment B) alone (columns 3 and 6 in Table 2). Soil salinity and ESP were lower throughout the experiment for all treatments receiving impounded rainfall than for the check treatment which allowed runoff. The largest reduction of salts and exchangeable sodium for all treatments occurred during the first monsoon season (July to September 1976). This decrease was apparently due largely to 45.1 cm of rain which fell between July 1, 1976 and September 30, 1976 (Table 1).

Slight to moderate increases in salinity and ESP were observed to take place in winter and summer seasons (columns 4, 5 and 7 in Table 2). Movement of salts towards the surface is apparent and may be associated with upward moisture movement during these seasons. For example, in 1976 in treatment B, EC and ESP increased from 2.80 mmhos/cm and 8.7 on September 25, 1976 to 3.43 mmhos/cm and 18.3 respectively, on December 7, 1976. Corresponding figures on June 29, 1977, were 4.87 mmhos/cm and 28 (Table 2). By September 25, 1977, salinity and ESP were reduced to 2.3 mmhos/cm and 8.7 respectively, however, this reduction was partly off-set by the subsequent winter increase and on December 14, 1977, EC and ESP were 3.03 mmhos/cm and 14.3 respectively. This trend, observed for all treatments, was slightly greater where rain water was impounded alone.

Precipitation alone is apparently sufficient in the area to decrease salinity and sodicity appreciably. Since ESP decreases rapidly as desalinization progresses, there seems to be no need of adding gypsum, or any other amendment, to reclaim the saline sodic soils of this area (Table 2).

Data in Table 3 reveal that sprouting was significantly less in treatment A over other treatments; however, differences in sprouting amongst B, C, D and E were non-significant. The sprouting in *B. mutica* and *P. laevifolium* was significantly more than in other two species, which indicates that these two species are fairly tolerant to this kind of saline sodic condition. In general, there were no significant differences amongst treatments B, C, D and E (precipitation with or without additional leaching water) for green and dry matter yields in all cuttings as well as in cumulative yield for both the years. However, the yield with these treatments was significantly more over the check treatment (treatment A) where runoff was allowed.

Statistical analysis for species revealed that the differences were present amongst them for both green and dry matter yields. *B. mutica* consistently and significantly outyielded other three species in both the years (Table 3). The performance of *C. gayana* and *P. laevifolium* was more or less at par and both were significantly superior over *P. maximum*. This indicates that *B. mutica* seems to have better ability to withstand and yield in the saline sodic conditions prevailing in this area. We see that *C. gayana*, even after having poor

Table 3. Treatment effects on the performance of different grass species

Treatments/ species	Year	Sprouting (%)	Green fodder yield (q/ha)				Rank	Dry matter yield (q/ha)				Rank	Protein (%)	IVDMD (%)
			I-cut	II-cut	III-cut	Total		I-cut	II-cut	III-cut	Total			
A	1976	27.08	20.80	23.87	22.82	67.49	5	5.82	6.96	8.77	21.55	5	9.11	61.23
	1977	—	19.11	21.79	22.99	63.89	5	5.60	6.50	6.23	18.33	5	—	—
B	1976	75.00	95.70	94.48	94.26	284.44	4	25.42	28.37	26.66	80.65	4	9.57	62.50
	1977	—	125.20	121.59	118.68	365.47	3	33.80	35.50	39.23	108.68	3	—	—
C	1976	81.55	97.70	116.05	107.04	320.79	2	27.88	32.68	30.04	90.60	2	9.22	61.05
	1977	—	110.10	127.36	117.24	354.70	4	35.60	35.60	34.55	105.75	4	—	—
D	1976	83.73	103.80	115.08	109.42	328.30	3	31.17	33.41	32.30	96.88	3	9.17	61.30
	1977	—	129.04	130.05	122.23	381.32	1	35.50	37.60	40.78	113.88	1	—	—
E	1976	84.63	110.79	123.87	109.88	344.46	1	32.07	30.47	34.37	96.91	1	9.44	61.80
	1977	—	124.90	122.99	121.16	369.05	2	34.00	35.68	41.52	111.20	2	—	—
C. D. at 5 %	1976	11.00	24.05	36.09	22.25	69.33		7.55	9.30	5.58	18.33		N.S.	N.S.
	1977	—	16.77	16.68	11.98	31.18		5.56	4.93	10.04	13.28		—	—
Brachiaria mutica	1976	83.49	122.62	136.75	128.54	387.91	1	34.12	33.32	35.66	103.10	1	9.32	59.00
	1977	—	158.31	147.65	138.29	444.25	1	43.10	37.80	46.64	129 44	1	—	—
Panicum maximum	1976	46.19	54.61	102.95	73.96	231.52	3	14.41	24.99	22.83	62.23	2	8.75	66.53
	1977	—	69.68	65.03	59.42	194.13	4	18.40	18.30	21.50	58.20	4	—	—
P. laevifolium	1976	82.62	88.82	57.83	74.64	221.29	4	25.81	19.06	22.57	67.44	4	10.78	62.60
	1977	—	98.01	93.04	87.31	278.36	3	32.30	28.50	28.00	85.60	3	—	—
Chloris gayana	1976	69.29	82.97	77.27	75.42	235.66	2	23.90	25.79	26.81	76.50	2	8.54	58.50
	1977	—	92.78	103.18	114.84	310.80	2	25.50	29.60	37 92	93.02	2	—	—
C. D. at 5 %	1976	10.18	15.27	23.52	13.62	43.23		4.43	6.26	4.80	12.92		N.S.	N.S.
	1977	—	16.77	8.85	15.43	39.14		5.11	4.52	7.34	9.66		—	—

sprouting as compared to *P. laevifolium*, yielded more or less at par with the latter. This behaviour may be attributed to the better post-sprouting spreading ability of the former through its rhizomatous stems (Narayanan and Dabadghao, 1972). There were non-significant differences between the treatments, species and their interactions for protein and IVDMD (Table 3).

The interactions of treatment × grass species are presented in Table 4. It is seen that *B. mutica* yielded maximum during 1976 when precipitation with 50 cm of supplemental water (treatment E) was impounded. But the difference was significant only between treatments B and E. In case of *C. gayana*, highest yield was obtained in treatment D (precipitation plus 25 cm of water).

Table 4. Effect of treatment x species on green and dry matter yield (q/ha)

Species		Treatments				
		A	B	C	D	E
			1976			
Brachiaria mutica	GFY[1]	121.95	404.15	442.10	461.45	509 88
	DMY[1]	31.75	105.20	122.55	123.70	132.30
Panicum maximum	GFY	30.25	312.45	282.50	242.55	289.86
	DMY	7.45	84.65	72.95	69.55	76.55
P. laevifolium	GFY	35.00	217.70	305.45	270.60	277.71
	DMY	10.35	66.35	85.70	87.90	86.90
Chloris gayana	GFY	82.75	203.45	253.10	338.60	300.41
	DMY	36.65	66.40	81.20	106.35	91.90
C. D. at 5 %	GFY			96.67		
	DMY			28.45		
			1977			
Brachiaria mutica	GFY	101.60	551.43	529.85	557.09	481.28
	DMY	26.50	163.40	158.20	156.50	142.61
Panicum maximum	GFY	34.00	244.69	209.06	235.18	247.71
	DMY	9.00	71.90	62.50	74.60	73.00
P. laevifolium	GFY	37.45	339.10	322.28	357.68	411.56
	DMY	11.10	106.50	93.40	113.50	101.50
Chloris gayana	GFY	82.50	326.66	357.50	375.68	411.56
	DMY	26.70	92.90	108.90	110.90	125.70
C. D. at 5 %	GFY			87.52		
	DMY			21.62		

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[1] GFY and DMY stand for green fodder yield and dry matter yield, respectively.

However, yield from this treatment was only significant over that from treatment B where only precipitation was impounded. In case of all species, significant differences were observed between check (treatment A) and other treatments where precipitation was impounded. During 1977, such differences were not observed except that differences between check and treated plots were significant.

The results presented here clearly suggest that in arid and semi-arid areas, where enough good quality water is not available for leaching purposes either due to scarcity of canal water or unusable underground water, the impounded natural precipitation seems to be effective in partially reclaiming the salt-affected soils. Such partially reclaimed lands can be used for normal production of tolerant and semi-tolerant crops. Since most of grain crops are initially susceptible to such conditions, some grasses found to be tolerant to such conditions may be grown preferably during initial years of reclamation.

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II. 5.14

A RAPID METHOD OF SURVEYING AND MARKING CONTOURS FOR CULTIVATING AND SEEDING DEGRADED RANGELANDS

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INTRODUCTION

Regeneration of degraded and eroded semi-arid or arid grazing lands is a problem facing many countries of the world. In Western Australia parts of three major river catchment areas in the pastoral zone show serious pasture degradation and erosion. These are the catchments of the Ord, Gascoyne and Fitzroy rivers which have been reported by Fitzgerald (1967, 1968), Wilcox and McKinnon (1971) and Payne *et al.* (in press) respectively. Government organised rehabilitation programmes are now under way on all three catchments.

Remedial treatments are aimed at promoting the re-establishment of perennial vegetative-cover. In many cases pasture regeneration has been achieved by manipulation of grazing frequency and intensity. Unfortunately, in some cases, notably on the Ord river catchment, pasture degradation had reached the stage where there were so few desirable perennial species remaining that there was virtually no nucleus of seed available for natural recovery. In these circumstances complete protection from grazing and expensive cultivation and seeding operations have been necessary to facilitate recovery. A number of cultivation techniques involving specialised implements have been developed. These are described briefly later in this paper and in more detail by Fitzgerald (1967, 1968, 1976).

One of the problems confronting field workers was the need to ensure that all cultivation was carried out as near as possible to the contour. This paper describes a mobile hose level unit which enables relatively rapid surveying of contour lines over large areas. It was developed during the early stages of the Ord River Regeneration Project by officers of the Soil Conservation Service Branch and the former North West Division. It is based on the hose level developed in the early 1950's by the Soil Conservation Service for use in the agricultural areas of Western Australia.

THE ORD RIVER REGENERATION PROJECT

An estimated 3750 km^2 of the Ord River catchment has been subjected to varying degrees of pasture degradation and erosion. On parts of this area a regeneration project involving cultivation and seeding, coupled with complete protection from grazing commenced in 1960. It was not practical or desirable to mechanically treat whole area and a system was developed whereby about 20 per cent of the area was actually treated by discontinuous strip cultivation and seeding.

A range of implements including chisel ploughs, disc pitters and opposed disc ploughs with seedbox attached were developed for the work. All of these implements were relatively light weight with an operating width of 1 to 3 m and were three point linkage mounted on medium powered (up to 65hp) tractors.

In practice the cultivating implement was held in the ground for about 20 m and then lifted out for 6-7 m. Distance between furrow lines varied with location and slope but was usually about 5-6 m and each successive line coincided with the uncultivated gaps in the line adjacent to it.

Due to the bare soil, degree of slope, heavy intensity of summer rain and excessive runoff it was essential that all cultivation was as close as possible to being on the contour.

THE PROBLEM OF CONTOURING

As the project required many thousands of kilometres of contour cultivation there was an urgent need to develop a fast and reliable method of surveying contours. Initially this surveying was done with instruments and men on foot but this was slow and expensive. A tractor mounted hose level was developed which functioned satisfactorily but this fully committed a power unit which was required for cultivation and seeding.

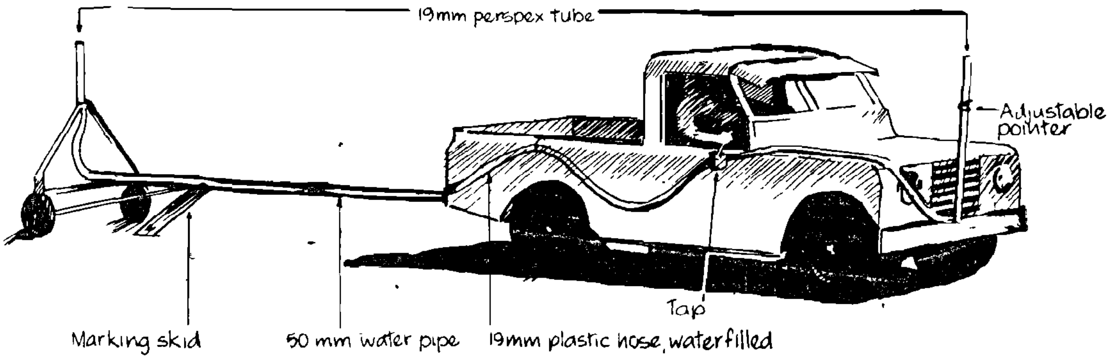

Fig. 1. Mobile hose level unit.

THE MOBILE HOSE LEVEL

The unit consists of a four wheel drive vehicle and trailing jinker assembly with two small (about 25 cm diam) solid rubber wheels. The wheels are mounted on a short cross axle at the extreme end of the jinker. The jinker is made from a 6 m length of 50 mm galvanised waterpipe and is attached to the vehicle by a standard ball hitch or close fitting drawbar pin.

Above the wheels of the jinker assembly a light triangular steel frame holds, in a vertical position, a 1 m length of graduated clear perspex tubing of 19 mm external diameter. An identical perspex tube is mounted rigidly on a steel upright attached centrally to a guard frame on the front of the towing vehicle. A length of 19 mm plastic water hose connects between the lower ends of the two perspex tubes by passing along the drivers' side of the vehicle and through the piping of the jinker. A tap is inserted into the hose near the steering wheel of the vehicle where it can be easily operated by the driver.

Plastic caps with a 3 mm diameter hole in their centres are screw fitted over the open top ends of both the perspex tubes. A vertically adjustable pointer is attached on the steel upright immediately adjacent to the front perspex tube.

The hose is water filled and each of the perspex tubes contains a small cylindrical float. The floats are identical and made of solid plastic or thin metal tubing. The length of the floats is 10-15 cm and the diameter slightly less than the internal diameter of the perspex tubing. The floats are weighted equally to float with only a small portion above the water surface. This ensures that there is no possibility of the float sticking to the sides of the tube above the water. The top and bottom halves of the floats are painted contrasting colours. The junction of the two colours is easily seen by the driver and provides the level indicator line.

A small skid or marker made of metal is pivoted loosely to the rear end of the jinker. This drags on the ground and leaves a mark indicating the contour line. The mark is followed by a tractor with a cultivating implement and seedbox.

The general layout of the hose level unit is depicted in Fig. 1.

OPERATING THE LEVEL

Before moving off it is essential to close the tap near the driver otherwise the water will surge and be lost out of the top of the rear perspex tube. Similarly the tap must be closed before stopping otherwise water will be lost from the front tube. Once the unit is moving at a constant speed the tap is opened.

The speed should be maintained steady at about 7 km/h. This is best achieved by driving on a fixed hand throttle setting. With a Landrover four wheel drive vehicle, second gear, low range was found to be most satisfactory.

The driver must maintain the centre of the front float at the zero slope mark indicated by the adjustable pointer. If the float level rises above this mark the driver must correct and return to the contour by turning upslope. Conversely if the float falls the driver must correct by turning downslope.

During operations the driver should check the float levels regularly to ensure that the original setting is correct. The most common problem is loss of water due to air bubbles in the line, leaking hose fittings or failure to close the tap when starting or stopping. Any loss of water requires resetting of the adjustable zero slope pointer.

With a little practice a driver can operate the unit accurately and 50 km or more of contour lines can be marked out in a day.

LIMITATIONS AND ACCURACY OF THE LEVEL

The level works most efficiently on relatively smooth bare ground. Some ground roughness can be tolerated but large bumps or sudden irregularities cause rapid fluctuations in the water level making accuracy difficult. Water level fluctuations can be damped somewhat by partially closing the tap in the hose line or by experimenting with the size of the hole in the caps at the top of the perspex tubes. The smaller the hole the greater is the damping effect. Topography on the Ord Regeneration Project area is gently undulating and the level did not have to be operated on slopes in excess of about 5 per cent. However, there is no reason why it would not function efficiently on greater slopes.

Numerous tests on the accuracy of the machine showed that, when set up as previously described, a slight but consistentlv downhill grade line was run. The reason for this is not certain but it could be due to the forward motion of the whole machine and it can be corrected. Tests showed that setting the adjustable pointer (i.e. the zero slope line) about 1 cm below the calculated setting virtually eliminated the downgrade error.

The error limit of the machine on smooth country is generally less than 0.1 per cent slope but may be up to 0.5 per cent on country with moundy or rough microrelief. These error margins were acceptable for the short lengths of cultivation used and did not cause water channelling or scouring.

CONCLUDING REMARKS

The mobile hose level described enabled rapid marking of contour lines over very large areas of the Ord River Regeneration Project area. It greatly assisted effecting the remedial treatments. In its present or modified form it may have application to other degraded rangelands where cultivation and seeding works are required.

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II. 6.2

SILVICAL STUDIES ON INDIGENOUS AND EXOTIC TREE SPECIES IN RAJASTHAN DESERT

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INTRODUCTION

The increase in human and livestock population in arid regions is the main reason for over exploitation of the natural resources leading to ecological imbalance mainly because of the limitations based on the potential productivity. As the demand is on the increase, the resources tend to become depleted under arid conditions. In order to keep up the balance, it is essential to develop the fuel-cum-fodder tree species so as to meet the demands for fuel and forage during lean periods for human and livestock respectively. The local tree and shrub species of the region are not only meagre in number but are also slow growing and, therefore, it was essential to study the adaptability and performance of various trees and shrubs of indigenous and exotic species from different isoclimatic regions of the world under arid and semi arid conditions.

INTRODUCTION AND EVALUATION OF TREES AND SHRUBS

Between 1958 and 1976, 112 species of *Eucalyptus,* 65 species of *Acacia* and 82 miscellaneous species of 44 genera from Australia, Israel, USA, USSR, South Rhodesia, Chile, Peru, Sudan, Kenya, Arizona, Venezuela, Mexico, etc. along with the indigenous species have been under trial in Jodhpur (deep sandy soils with mean annual rainfall of 350 mm) and Pali (shallow soils ranging from 15 to 22 cm in depth overlying hard calcareous pan with mean annual rainfall of 400 mm). The following species have been found to be promising viz., 16 species of *Eucalyptus,* 12 species of *Acacia,* 12 miscellaneous species of 8 genera and 13 indigenous species of 11 genera.

Eucalyptus is native of Australia and was first introduced in India in 1843 in Simla and the Nilgiris. Being a quick growing species with a wide range of adaptability it makes a valuable material for farm steads for meeting the domestic requirements of farmers in the form of fire wood and small timber. Besides these, fence posts, pit props, electric poles, etc. are being made out of the poles. Leaves of certain species are distilled for essential oils. Very superior charcoal is provided from the wood of *Eucalyptus* species which has been found to be superior to the mixed jungle wood. Some species which are most suitable for arid and semi arid regions also have been found to yield about 100 kg fuel wood per tree in a period of 10 years. Species namely, *E. camaldulensis, E. terminalis, E. melanophloia* and a plantation of such species could be managed by coppice system, being good coppicers. Apart from its role of fuel wood and fast growing characters, it has a strong aesthetic appeal, its variety in colour, branching pattern, foliage, smooth whitish grey bark in many species add beauty to the plant and some of the species are renowned for their beautiful flowers.

The studies on the techniques of raising *Eucalyptus* seedlings at this Institute have revealed that seeds sown in October gave higher germination and plant per cent as compared to July-August sowings owing to damping-off disease. Better seed germination is obtained when the seeds are sown in sand 3 parts and sterilized leaf mould 1 part filled in shallow saucer shaped earthen trays of 30 cm diameter and 9 cm depth with 3-4 holes of 1 cm diameter at the bottom to facilitate bear two to three pairs of leaves i.e. when the seedlings are about a month watering by percolation. When seedlings and a half old, they are pricked out into galvanised iron tubes or polythene bags. The containers are filled with a fine mixture of sand, clay and farm yard manure in equal parts. By July, the plants would attain height of 30 to 45 cm which is the right size for transplanting them at site in pits of 45×45×45 cm immediately on receipt of a good soaking shower. Watering is desirable immediately after transplanting as that would facilitate to give a firm hold for the plants and also give the plant a good start. For *Eucalyptus* plantation 4×4 m espacement would be ideal. Weed control in the plantation should be taken care of for nearly 3 years.

The most promising *Eucalyptus* species are listed below in the order of their performance:

1. *Eucalyptus melanophloia,* 2. *E. coolabah,* 3. *E. terminalis,* 4. *E. tereticornis;* 5. *E. camaldulensis,* 6. *E. ochrophloia,* 7. *E. populnea,* 8. *E. intertexta,* 9. *E. populifolia,* 10. *E. sideoxylon,* 11. *E. tessillaris,* 12. *E. oleosa,* 13. *E. bicolor,* 14. *E. siderophloia,* 15. *E. stracklandi,* 16. *E. hybrid.*

In comparison to all these exotics, *E. hybrid* of Madras has given the best height growth and m.a.i. of 119 cm whereas the best *Eucalyptus'* species from Australia has given the m.a.i. of 75.3 cm. Some of the experiments conducted on water requirements of plants have indicated that *Eucalyptus* species require 1300-1400 gms of water for manufacturing one gram of dry matter whereas xerophytic plants require 250-350 gms of water and other plants as much as 600-800 gms of water. Therefore, in arid zones, where moisture precipitation is less and absorption of water in the soil is also less, there is always scarcity of water for the plants, hence it is implied that *Eucalyptus* species is not very much desired in arid zones (Muhammad, 1977).

As regards *Acacia* and miscellaneous species, the genus, *Acacia* has over 20 indigenous and many exotic species from Australia, Israel, Rhodesia, Kenya and Sudan. Out of the 64 *Acacia* species introduced at the Institute arboreta, the most promising ones identified are given below in the order of their performance:

1. *Acacia tortilis,* 2. *A. raddiana,* 3. *A. senegal* (large), 4. *A. planifrons,* 5. *A. ciliata,* 6. *A. aneura,* 7. *A. karroo,* 8. *A. senegal* (small), 9. *A. leucophloia,* 10. *A. saliana,* 11. *A. nilotica,* 12. *A. catechu* and amongst the promising miscellaneous species of indigenous and exotic, the following have been found to have adopted to Indian arid conditions.

Miscellaneous species

Out of 82 miscellaneous exotic and indigenous species introduced, the most promising ones listed below are in the order of their performance:

Exotic species

1. *Prosopis juliflora* (Israel), 2. *Prosopis juliflora* (Chile), 3. *Pittosporum phillyraeoides,* 4. *Brasilettia mollis,* 5. *Colophospermum mopane,* 6. *Adansonia digitata,* 7. *Prosopis alba,* 8. *Zizyphus spinachristi,* 9. *Prosopis juliflora* (Venezuela), 10. *Dichrostachys glomerata.*

Indigenous species

1. *Cassia siamea,* 2. *Dalbergia sissoo,* 3. *Albizzia lebbek,* 4. *Parkinsonia aculeata,* 5. *Aegle marmelos,* 6. *Azadirachta indica,* 7. *Allanthus excelsa,* 8. *Hardwickia binata,* 9. *Tecomella undulata,* 10. *Albizzia amara,* 11. *Prosopis cineraria,* 12. *Albizzia odorotisima,* 13. *Anogeissus rotundifolia.*

Out of the species listed above, *Eucalyptus* species are mainly found suitable for planting along canal banks, roadsides where water table is reasonably high. These are valued for straight poles, fuel wood and less so for oil. None of the *Eucalyptus* species is reported to yield oil which could be commercialised, except *Eucalyptus viridis* of South Australia, which is a medium sized tree with low branching. Leaves of this species have yielded 2.1 per cent oil. It was introduced in Jodhpur in 1962 but it has failed to flower so far. Attempts have been made to raise this species by vegetative propagation but in vain. Similarly, the other promising *Eucalyptus* such as *E. melanophloia, E. sideroxylon, E. populnea, E. bicolor, E. stricklandi* have not flowered so far, not responded to vegetative propagation.

Among *Acacia* species, *Acacia tortilis* has been adjudged the best for arid zone afforestation as this has established its superiority over other species when tried at the following habitats viz., deep sandy soils, sand dune afforestation, rocky refractory sites, sandy loam shallow soils overlying hard calcareous pan beneath, etc. It is the only tree species which has given the maximum mean annual increment at all the sites mentioned above viz., 45.74 cm, 40.32 cm, 30.70 cm, 35.65 cm respectively from trees of twelve year old plantations. The leaves and pods of this species have also been classified as good fodder even though dry fodder yield on an average, per tree has been 4.0 to 6.0 kg and pods, 10-12 kg. The wood is hard and used as fuel with calorific value as high as 7,800 Btu/Lb. Wood, if stored in open yard is liable to be attacked by insects, but if stacked inside sheds, remain without insect attack. Spray with one per cent solution of D.D.T. in oil or one per cent solution of boric acid in water protects the fuel wood from borer attack.

PROPAGATION

Seeds raised in nursery beds or in containers are to be treated with 50 per cent sulphuric acid for 30 to 40 minutes before sowing in order to break the hard seed coat. Such treated seeds germinate from 4th day onwards whereas untreated seeds germinate after 60 days. Germination and plant per cent of treated seeds have been more than 90 and 85 respectively. The young plants have a tendency to develop long tap roots but as the plants grow in age, they send out lateral roots depending on the type.of soil. Recent study made on the root system of 5 year and 10 year old trees revealed that in places of deep sandy soils, the tap roots have not penetrated beyond the *kankar* pan but have sent out lateral roots upto 20 metres away from the main stem and similarly in the case of shallow soils also the lateral roots have gone upto 18 metres away from the main stem. From this observation, it is felt that if this tree species is planted along the field boundary as live hedge or as wind break, care should be taken to dig a deep trench of 0.50 to 0.75 m depth and 0.30 m wide about 1 metre away all along the plants to protect the agricultural crops/fruit crops from root and moisture competition.

Yet another important exotic tree species is *Prosopis juliflora,* which was introduced in India in 1875 and in Rajasthan in 1915. It is fast growing and drought hardy tree species, although susceptible to frost in the early stages. The Institute has conducted provenance studies on *Prosopis juliflora,* namely, from Israel, Peru, Chile, Venezuela, Mexico and Arizona and found that Israel and

Chile varieties have given good performance both in height growth as well as in survival per cent as indicated below:

S. No.	*Provenance*	*M.A.I.*	*Survival percent*
1.	Israel	4.43	66.1
2.	Chile	4.57	61.1
3.	Peru	3.12	50.0
4.	Venezuela	2.61	78.8
5.	Mexico	2.83	75.5
6.	Arizona	2.74	60.5

Apart from their growth attributes, varieties 1 and 2 above have tendency to grow straight (tree form) with clear hole and thus provide facilities for the grasses to grow underneath, whereas the other varieties from Arizona, Peru, Mexico and Venezuela have more of branching and drooping right down to the ground resulting in preventing any vegetation to grow underneath. Fuel yield from Israeli and Chilean varieties has been more than 1 q/tree from 10-year old tree which is much more than those from the other varieties.

Colophospermum mopane and *Dichrostachys glomerata* introduced from S. Rhodesia and Israel, respectively have been found to perform very well with added advantages of their self regenerating capacities, viz., the former by self sown seeds and the latter by root suckers. These species have also fodder value with 12 and 14 per cent crude protein contents respectively and both respond well to annual lopping. Attempts are being made to establish these species to stabilize the shifting sand dunes and their performance seem to be very encouraging.

Planting techniques on indigenous species showed that under rainfed conditions transplanting 6 to 9 month old seedlings have given significantly better performance over direct seeding at site and transplanting in pits of 60×60×60 cm excavated and refilled with weathered soils has given the best performance (Muthana *et al.*, 1976). The time of planting at different periods did not show marked effect on the seedling survival and growth in height of the four indigenous desert tree species viz., *Acacia senegal, Prosopis cineraria, Tecomella undulata* and *Albizzia lebbek* as their establishment depends mainly on the rainfall pattern. Planting trees appears to have improved the available nutrient status of the soils ranging from 203 to 356 kg N/ha and 319 to 633 kg K/ha (Aggarwal *et al.*, 1976).

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II. 6.3

SILVIPASTORAL FARMING FOR AMELIORATION AND INCREASED LAND PRODUCTIVITY OF THE ARID AND SEMI - ARID REGIONS

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INTRODUCTION

Indian arid zone alone cover an area of about 3 lakh sq km, 90 per cent of which is confined in the North West India covering most of the Western Rajasthan, part of Gujarat and small portions of Punjab and Haryana (Krishnan, 1977). Mann *et al.* (1977) pointed out that for twelve western districts of Rajasthan, land is, by and large, unsuitable for crop culture and over 50 per cent of it is accounted for by current fallows, long fallows, culturable wastes and uncultivable barren lands.

Forest area in Indian arid zone is less than 2 per cent as against Indian average of about 22.7 per cent. As per our National Forest Policy we should have atleast 33 per cent of the total area under forests. The firewood situation in the country in general and arid and semi-arid areas in particular is quite alarming. The total consumption of fire wood in India during 1970 was 203 million m^3 of which, only 13 million m^3 was obtained from recorded sources; the requirement is likely to increase to about 300 million m^3 by 1990 (NCA, 1973). One can just imagine the huge area which will be required to meet the fuel wood deficit alone. Deficit and higher cost of fire wood leads to the prevalent wasteful burning of about 60-80 million tons of dried cowdung annually. The plant nutrients and organic matter thus wasted is equivalent to about one third of India's chemical fertilizer use (Eckholm, 1976). Kalla *et al.* (1977) had projected the forage deficit of arid Western Rajasthan alone to the tune of 47 lakh tons even in a favourable year.

Under the increasing demand of forage and fodder for our huge livestocks and fuel wood and small timber for our ever increasing human population there is hardly any alternative but to think in terms of integrated approach of growing fuel cum fodder trees along with forage crops simultaneously on the same land following silvipastoral farming.

MATERIAL AND METHODS

Silvipastoral studies were initiated at the IGFRI, Jhansi, during 1971 with *Acacia tortilis and Leucaena leucocephala* in association with grasses like *Cenchrus ciliaris* and *Cenchrus setigerus.* During 1973, *Albizzia amara* and *Hardwickia binata* in association with *Cenchrus ciliaris* and a mixture of *Chrysopogon fulvus* and *Sehima nervosum* were taken up for studies. In both these experiments tree seedlings (one-year old) were planted at a spacing of 4 m × 4 m and 4 m × 6 m. Immediately after transplanting of tree seedlings grass seeds were sown in lines 45-50 cm apart in between the rows of tree seedlings. During 1976, a series of experiments were also carried out on a typical Bundelkhand wasteland to study the production potential of such wasteland through silvipastoral system. Some of the important results obtained so far are discussed below.

Jhansi experienced total annual rainfall of 1412.5 mm, 743.5 mm, 585.6 mm, 875.2 mm, 875.4 mm and 1065.7 mm during 1971, 1972, 1973, 1974, 1975, and 1976 respectively.

RESULTS AND DISCUSSION

Establishment

After land preparation, about 5 to 11-month old tree seedlings may be planted during monsoon in pits 45^3 cm cross section at a distance of about 5-6 metres from row to row and 2.5 to 6 metres from plant to plant. Tree seeds may be sown in the nursery during February/March or August/September of the previous year depending on the growth of the seedlings. In the trials conducted at the Institute, about five-month old seedlings of small trees/shrubs like *Leucaena leucocephala, Sesbania grandiflora* and *Sesbania aegyptica* were successfully established in association with grasses.

Seedling establishment

Establishment of tree seedlings was not affected by the re-seeding with grasses.

Acacia tortilis exhibited almost cent per cent survival where as *Albizzia amara,* and *Hardwickia binata* showed above 90 per cent survival (Deb Roy and Pathak, 1972, 1974). Gyanchand *et al.* (1973) also reported that percentage seedling establishment remained unaffected by grass seedling and weeding treatments in arid environments.

Growth parameter

In most of the cases growth in height and collar diameter (CD) were recorded but growth in diameter at breast height (DBH) was recorded only during 1976 in case of only one species i.e. *Acacia tortilis.*

Acacia tortilis in association with *Cenchrus ciliaris* gave mean annual increment (m.a.i.) in height growth varying from a minimum of 57 cm in the sixth year (1976) to a maximum of 138 cm during 1973. The mean annual increment (m.a.i.) in collar diameter varied from 1.9 cm in the latter year to 1.38 cm in the former (Deb Roy and Pathak, 1973b, 1976). Studies on the height and collar diameter growth in the sixth year revealed that *Acacia tortilis* in association with *Cenchrus ciliaris* exhibited m.a.i. in height and collar diameter growth of 73 cm and 1.5 cm respectively. But, when it was grown alone without grass association, it exhibited m.a.i. in height and collar diameter growth of 76 cm and 1.5 cm respectively. *Acacia tortilis* grown in association with *Cenchrus setigerus* gave m.a.i. in height and collar diameter growth of 71 cm and 1.3 cm respectively. The m.a.i. in DBH for the above three combinations were 1.6 cm, 1.6 cm and 1.5 cm respectively. Studies on the growth parameter of *Acacia tortilis* revealed that there was hardly any difference in m.a.i. in DBH and collar diameter growth when grown in association with *Cenchrus ciliaris* or without grasses. The m.a.i. in height growth was slightly less compared to no-grass combination. In association with *Cenchrus ciliaris* it exhibited better growth performance compared to *Cenchrus setigerus.* Gyanchand *et al.* (1973) reported increased m.a.i. in height growth under no-grass treatment followed by seeding with *Cenchrus ciliaris, Cenchrus setigerus,* and *Panicum antidotale.* Due to very poor m.a.i. in height growth they concluded that presence of *Dichanthium annulatum* retards the growth of fodder tree species.

Studies on the growth parameter of *Albizzia amara* and *Hardwickia binata* in general revealed that m.a.i. in height growth was higher in the former compared with the latter but m.a.i. in collar diameter growth was higher in the latter compared to the former (Deb Roy and Pathak, 1976). The growth parameter especially the height was much affected by illicit grazing. Inspite of grazing *Albizzia amara* exhibited maximum m.a.i. in height growth of 59.5 cm with no-grass treatment followed by 59.3 cm when grown in association with *Cenchrus ciliaris* followed by 1.06 cm with no-grass treatment. In association with former grass mixture it gave m.a.i. in collar diameter of 0.96 cm. In case of *Hardwickia binata,* maximum m.a.i. in height and collar diameter growth of 49 cm and 1.21 cm respectively was recorded with no-grass association followed by 41.2 cm and 1.09 cm respectively when grown in association with a combination of *Chrysopogon fulvus* and *Sehima nervosum.*

Forage production

Studies on the forage production for the last five years revealed that *Acacia tortilis* in association with *Cenchrus ciliaris* gave a dry forage production varying from 27.2 q/ha during 1973 to 45.6 q/ha during 1975. The total forage production was of the order of 175 q/ha which gives an average annual forage production of 35 q/ha. Forage production in general was higher with *Cenchrus ciliaris* compared with *Cenchrus setigerus*. In association with *Cenchrus setigerus* forage production varied from 23 q/ha during 1973 to 52.1 q/ha during 1975, the yearly average was 29.4 q/ha (Deb Roy and Pathak 1973b, 1975).

Leucaena leucocephala in association with *Cenchrus ciliaris* gave a forage production of 41.5 q, 28.0 q and 46.8 q per hectare during 1972, 1973 and 1974 respectively (Deb Roy and Pathak, 1972, 1973a, 1974). Due to repeated damage by illicit grazing followed by severe termite attack, large number of *Leucaena* plants died during 1974. In association with *Cenchrus setigerus,* forage production for these years were 27.8, 23.5 and 26.8 q/ha respectively. The average annual forage production for the last five years was of the order of 40 q/ha and 31.3 q/ha respectively in association with *Cenchrus ciliaris* and *Cenchrus setigerus.*

Forage production of *Cenchrus ciliaris* was not much affected by the spacing treatments when grown in association with *Acacia tortilis* or with *Leucaena leucocephala. Cenchrus setigerus* in association with *Acacia tortilis* gave higher forage production at a spacing of 4m × 4m compared with 6m × 6m spacing whereas in association with *Leucaena leucocephala* forage production was higher with 4m × 6m spacing compared with 4m × 4m spacing.

The forage production of *Cenchrus ciliaris* and *Cenchrus setigerus* in general was highest during 1975 although highest annual rainfall (1065.7 mm) was during 1976 in Jhansi. Corresponding to the lowest rainfall (585.6 mm), the forage production was also lowest during 1973. In another trial, *Hardwickia binata,* in association with *Cenchrus ciliaris,* gave annual forage production of 37.4 q/ha but in association with a mixture of *Chrysopogon fulvus* and *Sehima nervosum* the forage production was slightly higher (i.e. 42.3 q/ha). The forage production of *Cenchrus ciliaris* was affected by the spacing treatment both in association with *Hardwickia binata* as well as with *Albizzia amara.* But the forage production of a mixture of *Chrysopogon fulvus* and *Sehima nervosum* was not much affected by the spacing treatment. The production of *Cenchrus ciliaris* in general was higher with spacing treatment of 4m × 6m compared with that of 4m × 4m. *Cenchrus ciliaris* in association with *Albizzia amara* gave an average annual forage production of 40 q/ha whereas in association with the same tree species a mixture of *Chrysopogon fulvus* and *Sehima nervosum* gave a slightly higher forage production (i.e. 41.3 q/ha). The forage production in general was highest during 1975 as was observed in earlier cases inspite of the fact that total rainfall during 1975 was much less than in 1976. The low forage production during 1974 may perhaps be due to the initial poor establishment of the grasses.

It has been further observed that with improved management and manipulation of the various silvipastoral components, the production can be increased by another 75-100 per cent. Deb Roy *et al.* (1976) even suggested raising of short rotation cash crop like cowpea and black *tur* in alternate line with the grasses during the first two years of the silvipastoral system for immediate return to the farmers. In the second year of the study, in addition to deriving a dry grass production of 70-80 q/ha cowpea seed at the rate of 1 q/ha was also obtained. Further studies on the various aspects of silvipastoral farming are in progress at the institute.

Tree - grass - legume combinations

A few tree-grass-legume combinations which may be suitable for some of the arid areas are given below:

Trees	Grasses	Legumes
Acacia tortilis	*Cenchrus ciliaris* *Lasiurus sindicus*	*Atylosia scarabaeoides* *Macroptelium atropurpureum*
Prosopis cineraria	*Cenchrus ciliaris* *Panicum turgidum*	*Atylosia scarabaeoides*
Albizzia amara	*Cenchrus ciliaris* *Cenchrus setigerus*	*Macroptelium atropurpureum*
Albizzia lebbek	*Lasiurus sindicus* *Cenchrus ciliaris*	*Atylosia scarabaeoides*
Acacia arabica	*Cenchrus ciliaris* *Cenchrus setigerus*	*Macroptelium atropurpureum* *Clitoria ternatea*
Prosopis juliflora (erect type)	*Cenchrus ciliaris* *Cenchrus setigerus*	*Atylosia scarabaeoides*
Dichrostachys nutans	*Cenchrus ciliaris* *Cenchrus setigerus*	*Macroptelium atropurpureum*
Colophospermum mopanae	*Cenchrus ciliaris* *Cenchrus setigerus*	*Clitorea ternatea*
Tecomella undulata	*Lasiurus sindicus* *Cenchrus ciliaris*	*Atylosia scarabaeoides*
Eucalyptus camaldulensis *Eucalyptus terminalis*	*Cenchrus ciliaris* *Lasiurus sindicus*	*Macroptelium atropurpureum*

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II. 7.3

EFFECT OF SOIL SALINITY LEVELS ON SEED GERMINATION AND GROWTH OF TRANSPLANTED SEEDLINGS OF *BER (ZIZYPHUS ROTUNDIFOLIA)*

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INTRODUCTION

Ber (*jujube*) has natural occurrence in arid and semi-arid regions where soil salinity and low rainfall are common features. Its cultivation is quite scattered and the area under this crop at present is not more than 1000 hectares in Haryana. There is, however, good scope for bringing more area under its cultivation particularly in the arid areas of the state (districts of Hissar, Sirsa, Bhiwani, Mohindergarh and Gurgaon). *Ber* had been almost a neglected fruit until recently when its nutritive value was recognised. *Ber* is deemed to have certainly better chances of sustaining itself even under the adverse soil and moisture conditions. Salinity tolerance of several fruit crops has been studied by various workers at U. S. Salinity Laboratory (Bernstein, 1965) and the literature on the subject has recently been reviewed by Maas and Hoffman (1977) but no information regarding salinity tolerance of *ber* is available in the literature. In view of these facts, it was considered necessary to initiate investigation to study the salinity tolerance of *Zizyphus rotundifolia* species of *ber* which is extensively used as a rootstock. In this paper the results on the effect of soil salinity on seedling emergence and subsequent growth are described.

EXPERIMENTAL

The experiment was conducted in artificially salinized plots (2m×2m×50 cm) at the experimental orchard of the Haryana Agricultural University, Hissar. The plots were excavated by removing 50 cm soil layer and were refilled by putting polythene sheet at the bottom and along the sides to check downward and lateral movement of salts. Salts of NaCl, Na_2SO_4, $CaCl_2$ and $MgCl_2$-$7H_2O$ were applied in such proportions that for various conductivity levels the ratio of Ca+Mg to Na ions was 1:1 (Table 1). Irrigation was given so as to wet the 50 cm soil depth upto field capacity. Plots were then covered with polythene sheet for a week to allow redistribution of salts. Electrical conductivity (of saturation extract) was determined in the beginning as well as during the course of investigation.

Fifty seeds of *ber* (rootstock) were sown in each plot during the last week of May 1976. Observations on seedling emergence and survival were recorded upto 40th and 60th day after sowing, respectively. Then, on July 16, 1976, sixteen seedlings (two-month old) were transplanted in each plot and data on their survival were recorded. Data on height of plants and diameter of stem were also recorded after transplanting. These data were recorded during the following year also.

Table 1. Amount of total salts added for preparing soil of various conductivity levels

Desired salinity (mmhos/cm)	Total salt concentration (me/litre)	Observed E. Ce. (mmhos/cm)
1.5	—	1.80
3.0	34	2.85
6.0	70	5.90
9.0	110	8.80
12.0	154	11.20
15.0	195	14.32

RESULTS AND DISCUSSION

Germination

The results of the present investigation have clearly shown that higher salt concentration had adverse effects on the germination of *ber* seeds (Table 2). In all cases, irrespective of salinity levels, germination was accomplished after 30 days of sowing. The reduction in germination was directly related to the increase in salinity level. Germination was recorded to be the highest in control (84 per cent) followed by T_2 (70 per cent) with a drastic reduction in T_5 (80 per cent). There was no germination in T_6 treatment. Earliest initiation of germination was observed in control after 10 days

Table 2. Germination of *ber* seedlings at different soil salinity levels

Treatment	E. Ce. (mmhos/cm at 25° C)	Days taken for germination after sowing												Percent germination
		10	12	14	16	18	20	22	24	26	28	30	40	
(T$_1$)	1.80	3	7	9	20	25	31	33	36	36	39	42	42	84.00
(T$_2$)	2.85	—	4	9	20	23	27	32	32	33	35	35	35	70.00
(T$_3$)	5.90	—	1	1	1	7	16	17	22	22	24	24	25	50.00
(T$_4$)	8.80	—	—	—	1	5	10	12	16	19	19	20	20	40.00
(T$_5$)	11.20	—	—	—	—	—	1	1	2	3	4	4	4	8.00
(T$_6$)	14.32	—	—	—	—	—	—	—	—	—	—	—	—	0.00

of sowing. A perusal of the data (Table 2) reveals that after 20 days of sowing, germination had initiated in all treatments. But germination percentage, as calculated on the basis of total number of seeds emerged under individual treatment on 30th day, was 74 per cent in T_1 whereas this was only 25 per cent in T_5. The relationship between salinity levels and time taken for 50 per cent germination (Fig. 1) indicates that germination was delayed with increase in salinity levels. This suggests that higher salt concentration not only retarded germination but also delayed it. The germination of seeds has been reported to be affected by soil salinity in two ways; (i) by decreasing the ease with which seeds take up water thereby decreasing the rate of water entry; and (ii) by facilitating the intake of ions in toxic amounts (Unvits, 1946; Ayers and Hayward, 1948). Unvits (1946) found that alfalfa seeds absorbed water at lower rates as osmotic pressure of the substrate increased but that there was an associated increase in accumulation of Cl within the seeds. These physico-chemical effects upon the seed result in a slower rate of emergence of the seeds which germinate and lowered the percentage of germination.

Survival and growth

The data (Table 3) show that when grown at various levels of salinity, the

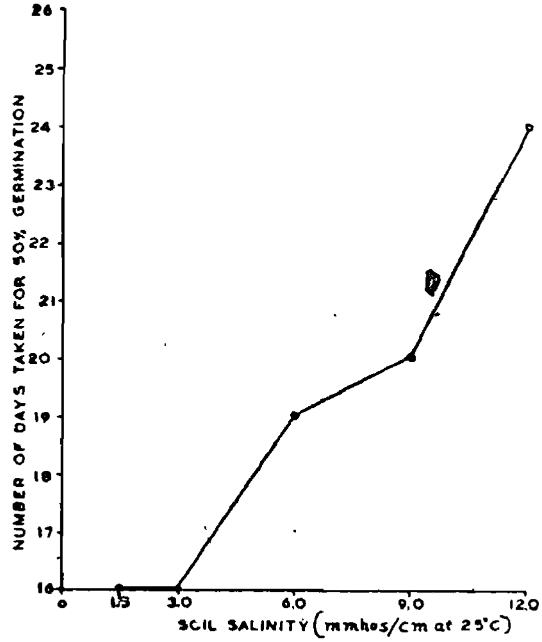

Fig. 1. Soil salinity versus number of days taken for 50 per cent germination of *ber* as calculated from total germination for individual treatment.

Table 3. Effect of salinity levels on the survival of *ber* seedlings

Treatment	Salinity (mmhos/cm)	Survival of seedlings after sixty days of sowing (%)	Survival of transplanted seedlings (after sixty days) (%)		
			1976	Salinity (mmhos/cm)	1977
(T_1)	1.80	95.24	100.00	1.85	100.00
(T_2)	2 85	94.30	81.25	2.80	100.00
(T_3)	5.90	68.00	75.00	6.05	75.00
(T_4)	8.80	55.00	62.50	8.80	75.00
(T_5)	11.20	25.00	56.25	11.88	50.00
(T_6)	14.32	—	—	13.80	50.00

two-month old transplanted seedlings had better survival compared to *in situ* seedlings. The survival of *in situ* seedlings after 60 days of sowing was as high as 95.24 and 94.30 per cent respectively in T_1 and T_2 treatments but in other treatments a progressive decrease with increase in salinity was observed. In T_5 treatment the survival was only 25 per cent. A perusal of data in Table 3 shows that survival of the transplanted seedlings (after 60 days) was comparatively more than that of *in situ* seedlings at all the levels of salinity and the success of transplanting was about 50 per cent even in T_6 where there was no germination.

It was interesting to note that once the *ber* seedlings were well established they maintained equally satisfactory growth (Table 4) even at the highest level of salinity (21.0 mmhos/cm). Height of 6 month old plants ranged from

Table 4. Effect of salinity levels on the growth of transplanted *ber* seedlings (6 months after transplanting)

Treatment	Salinity (mmhos/cm)	Mean height (cm)	Mean diameter (cm)	Percent reduction	
				Height	Diameter
(T_1)	1.85	102.00	1.42	—	—
(T_2)	2.70	99.00	1.35	2.94	4.93
(T_3)	5.80	93.25	1.32	8.57	7.04
(T_4)	8.40	90.05	1.36	11.71	4.22
(T_5)	12.45	90.75	1.27	11.02	10.56
(T_6)	21.00	93.00	1.26	8.82	11.27
C. D. at 5% level.		N. S.	N. S.	N. S.	N. S.

102 cm in T_1 to about 90 cm in T_4. There was no significant effect of salinity on the height of plants. Neither there were any significant differences in stem thickness in various treatments.

The results of the present investigation reveal that tolerance of *ber* seedlings to salinity varies with the stage of growth. Germination was found to be very sensitive and the sensitivity decreased with increase in age of seedlings. The survival of two-month old seedlings was better than that of *in situ* young seedlings. The salinity effect again decreased progressively with the age of plants and after 6 months the plants maintained equally satisfactory growth in all treatments. Similar observations have been reported by Allison (1964) who found that sugar beet can stand salinity levels of only about 4 mmhos/cm in the saturation extract during germination but can easily tolerate three times this level once the seedlings are established. From the present study, it is evident that *ber* plants can withstand high salinity if somehow they manage to escape salinity hazards at germination and the initial stage of growth.

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II. 8.0

RESEARCH AND DEVELOPMENT FOR LIVESTOCK PRODUCTION IN ARID REGION

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Livestock farming occupies an important place in the economy of arid region. Sheep and goat contribute the maximum (68 per cent) to the total livestock population in Rajasthan, whereas, cattle and buffalo contribute the maximum in Gujarat and Haryana. The population of goats as a proportion of the total livestock population is quite sizeable in the arid regions of both Rajasthan and Gujarat. The increase in population of goats both in Rajasthan and Gujarat has been phenomenal inspite of the fact that there have been serious droughts during the last quinquennium. These facts show the better adaptability of goats to such conditions.

PROBLEMS ASSOCIATED WITH LOW PRODUCTIVITY OF LIVESTOCK IN THE REGION

The major reasons for the low productivity of livestock in the arid region are lack of adequate feed resources, provision of health cover and indiscriminate breeding without any effort in affecting genetic improvement. Not only the quality of grazing and supplementary feed available from crop residues is poor but even the total dry matter requirement is not being met. Stock watering facilities are seriously lacking in greater part of the area and in many places the water available is brackish. The lack of grazing resources and stock watering facilities force the livestock breeders to resort to migration to distant places. Some breeders are continuously on the move whereas the others follow definite migratory routes to the seasonal grazing areas and return to their permanent abodes during the monsoon season. Irrespective of the severity of climatic factors, 80 per cent of the livestock migrate from the arid districts e.g. Barmer, Jaisalmer, Pali, Jodhpur and Bikaner. Most of this migration from Rajasthan is to Madhya Pradesh followed by inter-district movement in Gujarat and Haryana. Due to large scale migration, livestock are exposed to hazards of diseases and there are serious marketing problems, because of the latter, the breeders do not show any serious interest in adopting stock improvement measures. Such migratory nature of livestock farming does not further permit any serious development effort through provision of breeding and health cover.

In arid region of Rajasthan, the estimated forage (dry matter availability from the rangeland, top feeds, crop residues etc.) is about 15.43 million tonnes against the total dry matter requirement of 17.46 million tonnes for the existing livestock population. There would be a similar situation in the arid regions of Gujarat and Haryana. About 80 to 90 per cent of the rangeland is in a poor to very poor condition and some of the land under good grass cover is not fully utilised owing to lack of stock watering facilities. This calls for a serious effort for improving feed and fodder and stock watering resources. Forest lands provide grazing to a sizeable percentage of livestock. The grazing pressure on the forest land has been on an increase. The percentage of livestock grazing on forest land in Rajasthan is 7.7, the number of cow unit per 10 hectare of open area being 93. Grazing in forest is not inimical as the proper grazing would rather improve regeneration condition.

RESEARCH AND DEVELOPMENT EFFORTS FOR LIVESTOCK IMPROVEMENT IN THE REGION

1. *Feed and fodder resources*

The development of grazing resources through protection and reseeding of rangelands and development of grass reserves has been recommended as one of the primary objective of social forestry by the National Commission on Agriculture. Grass reserves on a minimum of 200 hectare area, preferably located away from habitation are recommended to be set up. A total of 200,000 hectares would be covered under this programme. The grass in these reserves is to be harvested, baled and stored for 3 years at a time and utilised during scarcity conditions. Sheep and goat are to a large extent maintained on tree loppings and browsing. Tree species like *Prosopis spicigera* does not adversely affect the crop grown in association with it and when fully grown can provide 58 to 72 kg dry leaves per tree from complete lopping (Bhimaya *et al.*, 1964). A hectare of land may provide about 19 quintals of fodder from the tree loppings which is higher than the average forage yield per hectare of 3.39 quintals to 16.30 quintals under different rainfall and soil conditions reported by Ahuja (1977). The natural rangelands/reseeded grasslands may be improved in their nutritive value by introduction of perennial legumes like *Dolichos lablab, Clitoria ternatea, Rhynchosis minima* and number of other annual or perennial legumes suitable for different rainfall and soil conditions. Further improvement in feed resources for livestock can be brought either by inter-cropping grain legumes with perennial grasses or inter-cropping annual/perennial fodder legumes with cereal crops. The results of experiments at CAZRI and CSWRI on the two alternatives have been encouraging. Further, with the irrigation resources being developed through the use of canal or sub-soil water, fodder legumes may be introduced as a rotational crop with cereal or cash crops and such fodder be utilised alongwith the crop residues and natural grazing available. Suitable cereal/cash and fodder crop rotations are available for maximising return per hectare.

There is also a need for incorporation of agro-industrial bye-products, e.g., urea, molasses, beet pulp in livestock feeding system. Feed processing systems for developing complete feed in form of brickets incorporating large percentage (around 80 per cent) of grasses with some grain, urea, molasses and mineral mixture may be developed.

2. *Genetic improvement*

a) *Cattle*: Weighted estimates for heritabilities of and genetic and phenotypic correlations among important production characters in cattle particularly based on the breeds in the region are presented in Table 1. Singh *et al.* (1969) had

Table 1. Heritabilities (diagonal) of, genetic (below diagonal) and phenotypic (above diagonal) correlations among important economic traits of cattle

	First lactation milk yield	Lactation period	Age at first calving	Calving interval
First lactation milk yield	0.195 ± 0.013[a] 0.15 to 0.43[b]	0.54 ± 0.02 0.17 to 0.72	0.121 ± 0.030 −0.07 to 0.18	0.05 ± 0.005 0.05 to 0.31
Lactation period	0.83 ± 0.068 0.34 to 0.85	0.235 ± 0 022 0.10 to 0.86	0.22 ± 0.06 0.17 to 0.22	0.29 ± 0.04 0.22 to 0.46
Age at first calving	0.17 ± 0.08 −0.19 to 0.17	0.34 ± 0.18. —	0.335 ± 0.014 0.14 to 0.66	−0.11 —
Calving interval	−0.79 ± 0.11 −0.79 to 0.19	0.60 ± 0.11 0.60 to 0.99	0.27 —	0.055 ± 0.051 0 to 0.55

Weighted averages were obtained by pooling of estimates where sampling errors were given, this was done by weighting them by inverse of their variance.

[a] = Mean ± S. E. ; [b] = range.

concluded that an index incorporating first lactation milk yield and age at first calving, the latter being given a negative weightage 45 times that of the first lactation milk yield would provide maximum genetic gains in growth, milk yield and reproductive efficiency. Acharya and Lush (1968) have shown a large gain of 1.5 to 2.5 per cent of the first lactation milk yield (10.5 to 16.4 kg) per year through selection for milk and a correlated decrease of 1.48 and 0.23 months in the age at first calving and first calving interval respectively. These gains although large would make the improvement through selection within these breeds rather slow because of the low average production. Acharya (1970) while reviewing the work on crossbreeding of Zebu cattle with exotic dairy cattle breeds had concluded that Hariana combine better with Ayrshire and Holstein Friesian compared to the other indigenous breeds and exotic inheritance of around 50 per cent (1/2 to 5/8ths) would provide the animal with highest milk production and somewhat better reproductive efficiency and better adaptation as reflected from reproduction rate, mortality and length of productive life. The results from Haryana Agricultural University, Hissar (Haryana) involving crossing with Holstein Friesian, Brown Swiss, Red Dane and Jersey indicate reduction in age at first calving in crossbreds by more than 50 per cent (27 *vs* 58 months) and a sizeable improvement in milk yield and lactation length. The lactation in F_1's involving Holstein Friesian, Brown Swiss, Red Dane and Jersey were 3350 kg in 350 days, 2771 kg in 335 days, 3124 kg in 353 days, and 3653 kg in 340 days respectively compared to 730 kg in 280 days of purebred Hariana. The crossbreds had a substantial lower mortality than Hariana's especially when weaned at birth (Lall, 1975).

b) *Buffaloes*: Heritabilities of and phenotypic and genetic correlations among first lactation milk yield, age at first calving and calving interval are presented in Table 2. Since Indian buffaloes especially the two breeds available in

Table 2. Heritabilities (diagonal) of and phenotypic correlation (above diagonal) and genetic correlation (below diagonal) among important economic traits in Murrah buffaloes

Traits	First lactation milk yield	Age at first calving	Calving interval
First lactation milk yield	0.32 ± 0.28[a] — [b]	0.06 ± 0.07 —	0.38 ± 0.07 —
Age at first calving	−0.20 ± 0.07 —	0.77 ± 0.32 0.13 to 0.77	0.17 ± 0.08 —
Calving interval	0.21 ± 0.07 —	0.09 ± 0.08 —	0.34 ± 0.03 —

[a] = Estimates ± S. E.; [b] = range.

the region are among the best in the country, the selection combining the first lactation milk yield, age at first calving and calving interval into an index based on estimates of phenotypic and genetic parameters for these traits would allow the maximum improvement in the milk production and reproductive efficiency.

Both in the case of cattle (purebred and crossbred) and buffaloes, a field progeny testing programme for bulls would have to be initiated, linked with the artificial insemination centres. Young bulls may be selected on the basis of their dams' milk yield in the initial stages and later on the basis of their dams' milk yield and sires' progeny test information. Deep freezing of sufficient quantity of semen of young bulls may eliminate the necessity of keeping them till such time their progeny test informatión becomes available. This will reduce the cost of maintaining large number of bulls.

c) *Sheep*: Weighted averages for heritabilities of and genetic and phenotypic correlations among body weights and among fleece characters are presented in Tables 3 and 4 respectively. Heritabilities of survival from 0 to 14 days of age and 15 to 90 days of age were 0.03 ± 0.24 and 0.26 ± 0.64, respectively (Malik and Acharya, 1972). Acharya (1974) concluded that selection based on six monthly body weight would provide maximum improvement in market weight and the ewe productivity. Similarly, selection based on the first six monthly greasy fleece weight (adjusted for age at shearing to six months) and medullation percentage, would provide improvement in greasy wool production and wool quality. The improvement in carpet wool production and quality would have to be brought through selection within important carpet wool breeds e.g. Marwari and Magra of the region. This would require setting up of large sheep breeding farms of these

Table 3. Heritabilities (diagonal) of and genetic (below diagonal) and phenotypic (above diagonal) correlations among body weights at different ages of sheep

	Weaning weight	Six monthly weight	Yearling weight
Weaning weight	0.21 ± 0.04[a] 0.24 to 0.80[b]	0.69 ± 0.01 0.62 to 0.78	0.46 ± 0.03 0.45 to 0.49
6 monthly weight	0.90 ± 0 03 —	0.38 ± 0.08 —	0.72 ± 0.01 —
Yearling weight	0.77 ± 0.03 0 73 to 0.97	0.97 ± 0.003 0.88 to 0.99	0.42 ± 0.06 0.15 to 0.48

[a] — Mean ± S. E.; [b] — range.

(Pooling of estimates where sampling errors were available was done by weighting by inverse of their variances).

Table 4. Heritabilities (diagonal) of and genetic (below diagonal) and phenotypic (above diagonal) correlations among different fleece characteristics of sheep

	Greasy fleece weight	Average fibre diameter	Medullation per cent
Greasy fleece weight	0.11 ± 0.03[a] 0.08 to 0.58[b]	0.399 ± 0 029 0.12 to 0.40	0.031 ± 0.095 0.08 to 0.03
Average fibre diameter	0.18 ± 0.66 —	0.34 ± 0.05 —	0.26 ± 0.03 —
Medullation per cent	0.13 to 0.42	−0.68 to 0.82	0.65 ± 0.07

[a] = Mean ± S. E.; [b] = range.

breeds for producing breeding rams. It will be further desirable to set up co-operative nucleus breeding schemes with the assistance of the State Departments of Animal Husbandry/Sheep and Wool. The performance of Rambouillet× Chokla crosses with different levels of exotic inheritance (1/2, 5/8 and 3/4) and F_1 interbreds (F_2's) are presented in Fig. 1. The major improvement in all the traits is at 50 per cent level and further increase in exotic inheritance results in little further improvement except in fleece quality (average fibre diameter and medullation percentage). There is little heterosis in body weights, fleece weights and fleece quality as evidenced from comparison between the means of F_1 and the contemporary purebreds and the means of F_1 and F_2. Mahalnobis D^2 analysis did not show significant genetic divergence based on the six month weight, first six monthly greasy fleece weight and fleece quality among Rambouillet×Chokla F_1's, F_2's and 5/8ths, 3/4ths because their superior wool quality were genetically divergent from the other three groups (Mani Mohan, 1977). These two clusters viz. F_1's, F_2's and 5/8ths, and 3/4ths have been used as genetic base for interbreeding and further selection to evolve two new strains, one for apparel wool and the other for very fine wool.

Fig. 2 shows the performance of the crosses relative to the contemporary native purebreds for yearling body weight, first six monthly greasy fleece weight and fleece quality. There is sizeable improvement in all the traits in crossbreds over their respective natives.

Karakul sheep for pelt production have recently been introduced and have performed well under hot arid conditions. Some initial crossbreeding work involving extremely coarse carpet wool breed has given promise. It may be possible to take up breeding Karakuls as purebreds, for pelt, wool and meat production or in crosses with some of coarse carpet wool breeds for similar purposes.

d) *Goats*: Heritabilities of and genetic and phenotypic correlations among

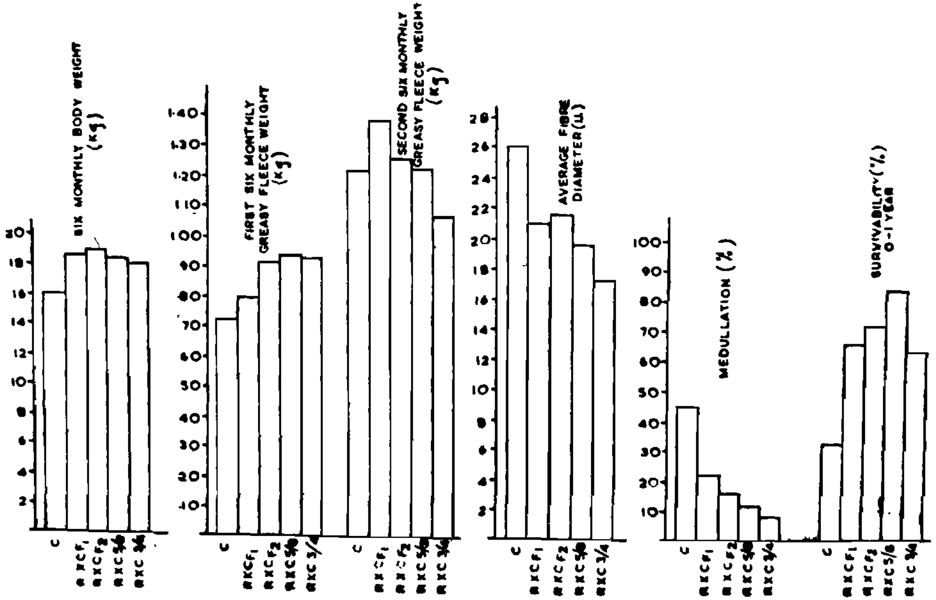

Fig. 1. Least squares averages for important econo.nic traits in Chokla (C) and its grades with Rambouillet (R).

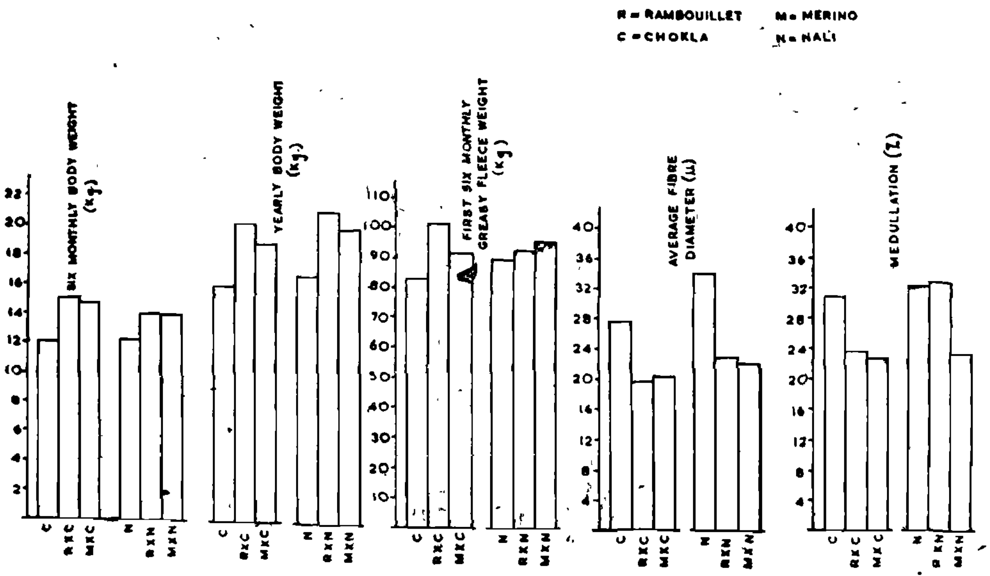

Fig. 2. Averages for important economic characteristics in crosses of Rambouillet and merino indigenous with *Chokla* and *Nali*.

important economic characters in goats are presented in Table 5. Selection within the breeds like Beetal, Jamnapari and Barbari for improving milk production and upgrading of the other breeds with Beetal/Jamnapari can be recommended for improving milk production. Such an upgrading will also help in improving body weights. More quicker improvement in reproductive efficiency and milk production could be brought through crossing indigenous breeds with exotic dairy breeds like Saanen, Alpine Toggenberg, etc.

Table 5. Heritabilities (diagonal) of and genetic (below diagonal) and phenotypic (above diagonal) correlations among important economic traits in goat

	Age at first kidding	Lactation yield	Lactation period	Kidding interval
Age at first kidding	0.54 ± 0.12	0.22 ± 0.03	0.56	−0.11 ± 0.03
Lactation yield	−0.36 ± 0.29	0.25 ± 0.08	0.30	−0.06 ± 0.03
Lactation period	—	—	0.18 ± 0.18	—
Kidding interval	−0.30 ± 0.31	0.05 ± 0.24	—	0.15 ± 0.04

3. *Improvement through appropriate management practices*

Grazing during cooler hours and offering high roughage feed at night would help. Sheep breeds in arid region have good adaptation to water restriction upto 48 hours (Taneja, 1966) and there is little effect on the wool and mutton production when watering is restricted to every third day (More and Sahni, 1974). Digestibility of feed in animals watered every 48 hours was better (Singh *et al.*, 1976; Purohit *et al.*, 1976) as it reduced the rate of passage of feed through digestive system (Purohit *et al.*, 1976). Sheep have been found to tolerate saline water upto 1.0 per cent during summer and 1.2 per cent during monsoon. The salinity beyond 1.2 percent does result in the reduction of water intake (Ram Ratan and Ghosh, 1971).

Earlier shearing can reduce the incidence of canary (yellow) colouration in fleece grown during hot humid season (Singh, 1974). The yellowing of fleece is due to the reaction of alkaline suint with the fleece under hot humid condition. The utilisation of cutaneous evaporative cooling for dissipation of body heat in Indian breeds appears to be the cause of such reaction (Acharya and Singh, 1976). The yellow wool fetches considerably lower price and has serious problems in dyeing. The August-September born lambs have higher survival and better growth than the winter born lambs which is also reflected in their adult performance (Malik *et al.*, 1976). The change in the breeding season from July-August to March-April may be helpful both in improving survival and growth of lambs as well as in utilizing the vegetation available immediately after rains.

The seasonality of breeding in buffaloes could be reduced through provision of protection from solar radiation both to the buffalo bull and the she buffaloes and parading the buffalo bull for detecting the animals in heat during cooler hours.

Although the role of diseases in causing economic losses through mortality and morbidity in different livestock species in the region is not known, it is certain that diseases like haemorrhagic septicaemia in cattle, enterotoxaemia, sheep pox and gastro-intestinal helminthiasis in sheep and enterotoxaemia in goats would be important diseases resulting in serious economic losses and would require prophylactic measures. Such measures against these diseases would need to be instituted.

ORGANISATIONAL INFRASTRUCTURE

It may be ultimately necessary to sedentarize the livestock population in the arid region by development of suitable feed and fodder resources. For organisation of necessary inputs and arranging for marketing of livestock and livestock products, it may be desirable to have primary producers' cooperatives. The experience of the Rajasthan Dairy Development Corporation in this area is quite encouraging. Till such time the sedentarization is possible, it may be necessary to provide input services especially breeding and health cover, and marketing facilities on the migratory routes. This could possibly be done by establishing service centres on the migratory routes which in addition to providing breeding and health cover and marketing facilities, may also provide watering facilities as well as may have reserved fodder available for holding the animals for a few days and providing such fodder under scarcity conditions. These centres may also regulate migration.

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II. 8.8

PROBLEMS AND PROSPECTS IN THE NUTRITION OF ARID ZONE LIVESTOCK

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Although the livestock husbandry contributes greatly to the economy of the arid region, the general productivity of livestock of the region is poor due to indiscriminate breeding and non-availability of proper nutrition. There is not only the shortage of total quantity of feed, but also the quality of the feed available as range forages and crop residues are very poor with respect to their energy, protein and mineral content. Range grasses alone due to their imbalance in the energy-protein ratio, calcium-phosphorus ratio and lack of certain trace minerals, cannot meet the production requirement of different types of livestock. This has resulted in low reproductive rates, high disease incidence and mortality and poor performance.

1. *Feed resources*

About 31 per cent of the total land in low rainfall areas (annual rainfall less than 300 mm) and about 62 per cent of the land in areas having more than 300 mm rainfall are put under cultivation although most of this land is not suitable for cropping. Cereal crops, *Pennisetum typhoides (bajra), Andropogon sorghum . (jowar)* and leguminous crops, *Cyamopsis tetragonoloba (guar), Vigna sinensis* (cowpea) and *Phaseolus aconitifolius (moth)* are grown primarily for grain production for human consumption and only to a limited extent are used as animal feeds. However, the crop residues of these crops are extensively used for feeding livestock, specially to cattle and camels. Cultivated fodders have been introduced as rotational crops to a limited extent in milk-shed areas. Approximately, 15.41 tons of dry fodder is estimated to be available in the arid districts of Rajasthan against an estimated requirement of about 17.5 million tons. Additional energy sources are required to sustain production of animals.

The main grass cover of the region is *Lasiurus-Cenchrus-Dicanthium* type (Dabadghao, 1960), although a total of 12 different types of grass communities have been identified (Satyanarayan, 1964). In addition to the natural grasslands, tree leaves constitute an important source of livestock feed, specially for feeding sheep and goats. The important fodder trees found in the area are *Prosopis cineraria (khejri), Azadirachta indica (neem), Gymnosporea spinosa (kankera), Acacia* species, *Ailanthus excelsa (ardu)*, etc. There are certain bushes like *Zizyphus nummularia (bordi), Calligonum polygonoides (phog), Capparis aphyla (kair)* and *Aerva pseudotomentosa (bui)* which serve as important feed resources for the livestock in the region, specially during the scarcity period. The chemical composition and nutritive value of various livestock feed resources available in the arid zone are compiled by Mathur (1960).

2. *Natural range lands*

About 80 to 90 per cent of the natural range land is under poor to very poor condition and some of the land under climax vegetation cover is not fully utilized due to scarcity of stock watering facilities. Several experiments have been conducted on protected range land at the Central Arid Zone Research Institute, Jodhpur, and at its different Range Management Centres in the arid and semi arid regions of Rajasthan involving performance studies of cattle and sheep. All these works have been reviewed by Mann and Ahuja (1975). These studies have shown that on protected range land of different grass cover, cattle could gain 6 to 11 kg in body weight per month during July-October followed by gradual decline upto middle of December and then sharp decline later. During the monsoon season the animals regained weight lost during summer. It was concluded from these experiments that for optimum production it will be necessary to provide additional feed supplementation during the months of December to June. In case of sheep also the growth was highest in the months of July to October (2-3 kg/ month) followed by gradual decline which reached the minimum (0.6 kg/month) during March-April. Bhatia *et al.* (1973) observed the TDN content of the natural pasture below 50 per cent for most part of the year except from July to September. The crude protein percentage was below 7 per cent during September to

March. During rainy season, protein content was adequate to provide a positive nitrogen balance in adult rams. In general, the calcium content was high and phosphorus content was invariably low with a wide Ca : P ratio. On natural grassland, a carrying capacity of 2.47 sheep per hectare on year long basis was recommended by Das *et al.* (1963). On the natural range land of the semi arid region, Acharya *et al.* (1977) have reported satisfactory performance of sheep and goats at a stocking rate of 3 animals/hectare. Goats have performed much better than the sheep under similar conditions (Tables 1 and 2).

Table 1. Average body weight of sheep and goat on free range grazing on natural range at C.S.W.R.I., Avikanagar

Month	Goat	Sheep
January	27.5* ± 0.91	25.4 ± 0.51
February	27.5 ± 1.22	24.3 ± 0.61
March	28.8 ± 0.86	25.0 ± 0.56
April	30.0 ± 0.99	24.4* ± 0.49
May	30.3 ± 1.04	23.7 ± 0.47
June	30.1 ± 1.13	23.3 ± 0.41
July	30.3 ± 1.06	23.6 ± 0.40
August	28.9 ± 0.77	23.8 ± 0.42
September	30.7* ± 0.82	29.8 ± 0.46
October	30.7* ± 0.63	24.8 ± 0.52
November	32.3 ± 0.82	26.2 ± 0.55

Each figure is mean of 30 animals.
*Mean of 29 animals.

Table 2. Growth of kids and lambs on free range grazing on natural range at C.S.W.R.I., Avikanagar

Species	Sex	Birth weight (kg)	3 months weight (kg)	6 months weight (kg)
Goat	Male	3.27 ± 0.14 (14)	11.11 ± 0.48 (13)	18.86 ± 0.96 (8)
	Female	2.55 ± 0.10 (18)	10.06 ± 0.42 (12)	15.03 ± 0.59 (10)
	Pooled	2.86 ± 0.08 (32)	10.60 ± 0.32 (25)	16.67 ± 0.53 (18)
Sheep	Male	2.53 ± 0.36 (11)	8.42 ± 0.89 (10)	13.0 (2)
	Female	2.38 ± 0.30 (11)	6.63 ± 0.28 (9)	9.48 ± 0.66 (8)
	Pooled	2.45 ± 0.23 (22)	7.57 ± 0.37 (19)	—

Figures in parenthesis indicate number of observations.

3. *Reseeded pastures*

There is a great prospect in reseeding the natural grassland with improved grasses like *Cenchrus ciliaris* (*anjan*), *Cenchrus setigerus, Lasiurus sindicus* (*sewan*), *Dicanthium annulatum* (*karad*) depending upon the rainfall and soil. Reseeding with *Cenchrus* species increases the carrying capacity of the land almost two fold. Acharya *et al.* (1975) obtained satisfactory performance of 40 crossbred ewes, 20 each of superior carpet wool strain (Avikaleen) and fine wool strain (Avikullet), when grazed on reseeded *Cenchrus* pasture at a stocking rate of 5 ewes/hectare under semi arid conditions (Table 3).

The overall body weight ranged from 29 to 36 kg. Six monthly greasy fleece weight, weaning weight of lambs, lambing percentage, adult and lamb survival for the Avikaleen and Avikullet strains averaged 1.14, 1.12 kg; 11.3, 9.9 kg; 75 per cent, 75 per cent; 95 per cent, 90 per cent; 100 per cent and 82 per cent, respectively. The vitamin A levels, total protein, calcium and phosphorus levels (Hajra and Patnayak, 1975) of the ewes on reseeded *Cenchrus* pasture are shown in Table 4.

Serum vitamin A level was found to be satisfactory in September and gradually falling in December and June. The phosphorus content rather showed a seasonal change characterised by an increase in

Table 3. Average body weight of Avikullet (F) and Avikaleen ewes on reseeded *Cenchrus* pasture

Month	Avikullet (F)		Avikaleen	
	Pregnant/ lambed ewes (n = 11)	Dry ewes (n = 9)	Pregnant/ lambed ewes (n = 15)	Dry ewes (n = 5)
February	32.62	29.56	34.97	29.20
March	33.86	30.61	36.61	29.46
April	27.91	29.53	32 00	29.18
May	28.01	30.00	30.87	29.46
June	27.21	29.54	30.25	28.52
	Overall lambs weaned, n = 20.		Overall lambs weaned, n = 20.	
July	—	27.10	—	27.88
August	—	29.53	—	30.02
September	—	29.25	—	28.93
		(Animals bred)		(Animals bred)
October	—	30 61	—	30.23
November	—	33-50	—	32.86
December	—	34.67	—	34.48
January	—	36.1	—	36.8
February	—	35.5	—	37.6
March	—	31.1	—	31.6

Table 4. Serum levels of vitamin A, protein, calcium and phosphorus in new strains of ewes maintained on reseeded *Cenchrus* pasture

Season	Strain	Vitamin A (IU/100 ml)	Total protein (g/100 ml)	Calcium (mg/100 ml)	Phosphorus (mg/100 ml)
Summer	Avikullet	72.0 ± 2.1	7.9 ± 0.1	9.5 ± 0.2	5.8 ± 0.4
(June)	Avikaleen	71.0 ± 2.3	7.6 ± 0.3	8.9 ± 0.5	6.7 ± 0.2
Autumn	Avikullet	120.0 ± 2.1	8.2 ± 0.2	10.0 ± 0.2	6.2 ± 0.4
(Sept.)	Avikaleen	116.2 ± 2.3	8.0 ± 0.2	9.7 ± 0.2	7.2 ± 0.1
Winter	Avikullet	101.8 ± 2.3	8.1 ± 0.2	9.0 ± 0.3	7.4 ± 0.4
(Dec.)	Avikaleen	99.8 ± 2.3	7.8 ± 0.3	8.0 ± 0.6	7.6 ± 0.3

level towards winter. Serum calcium level was found to be highest in September dropping slightly in December. However, the blood levels of these nutrients were not indicative of deficiency when maintained on this pasture. On the other hand, the sheep grazing on natural range in the arid region showed low levels of serum phosphorus. Ghoshal and Dwarkanath (1976) reported plasma carotene and vitamin A levels on desert cattle slightly less than those reported from elsewhere. Sheep showed better vitamin A hardiness than cattle. The mean serum iron values in cattle, sheep and camel in north-western Rajasthan were 213.15 ± 14.0, 141.3 ± 8.26 and 101 ± 4.60 mg/100 ml respectively (Ghoshal *et al.*, 1976). Dwarkanath and Ghoshal (1976) reported evidence of sub-clinical to frank deficiency of blood copper and cobalt in the cattle of Rajasthan and found beneficial effects on supplementation of cobalt at 5 and 10 mg/day/cow in addition to feed cobalt. Sub-normal levels of zinc in the serum of Nali sheep in Bikaner were also observed by the same workers. The trace element status of animals grazed on improved pastures needs to be determined.

Although adult animals show satisfactory performance on *Cenchrus* pasture, pasture alone is not adequate to support satisfactory growth of lambs. Either a legume component should be introduced in the grass pasture or additional supplementation should be provided. A minimum of 10-12 per cent crude protein in the diet is essential to promote growth of lambs. *Cenchrus* pasture alone has the crude protein percentage less than 10 per cent for the most part of the year varying from 10.0 per cent in July to 4.3 per cent in January-February (Bhatia *et al.*, 1973). *Dolichos lablab,* a pasture legume has been introduced successfully in *Cenchrus* pasture with satisfactory results. Weaner lambs averaging 11 kg body weight grazed on *Cenchrus* (C) pasture from August to May attained an average weight of only 16 kg whereas lambs grazing on *Cenchrus-Dolichos* (CD) mixed pasture attained the body weight of 20.5 kg during the same period (Table 5).

The digestibility of nutrients from *Cenchrus* pasture and *Cenchrus-Dolichos*

Table 5. Growth of crossbred weaner lambs on *Cenchrus* (C) pasture and *Cenchrus-Dolichos* (CD) mixed pasture

Month	Body weight (kg)		Daily gain (g)	
	C	CD	C	CD
August	13.2	13.1	—	—
September	14.0	14.1	27	37
October	15.3	15.7	43	53
November	16.0	17.7	23	67
December	16.7	19.8	23	70
January	17.2	20.9	17	37
February	16.4	18.8	– 27	– 70
March	16.3	19.4	– 3	20
April	16.3	21.1	0	57
May	16.1	20.1	– 7	– 33

mixed pasture by the lambs was determined by Bhatia and Patnayak (1976) (Table 6).

Cenchrus pasture had low crude protein digestibility and high crude fibre and ether extract digestibility than the *Cenchrus-Dolichos* mixed pasture during the month of October. The total protein, calcium and phosphorus levels in the serum of lambs grazed on C and CD pasture versus harvested and fed in the stalls are given in Table 7. Grazing animals showed higher levels of these parameters in the blood than the stall-fed animals (Hajra and Patnayak, 1975). *Cenchrus* hay when harvested at seed stage and fed in the stalls serves as a maintenance fodder (Singh, 1974) whereas

Table 6. Digestion coefficient of nutrients (%) and nutrient balance in lambs on *Cenchrus* (C) pasture and *Cenchrus-Dolichos* (CD) mixed pasture

Nutrient	October		February	
	C	CD	C	CD
Dry matter	43.6	50.0	52.6	50.0
Organic matter	53.7	54.0	52.6	50.0
Crude protein	20.1	48.4	70.2	55.8
Ether extract	48.9	26.2	31.5	42.8
Crude fibre	63.9	44.7	64.1	59:3
NFE	58.5	59.1	51.6	49.2
Balance (g/day)				
Nitrogen	– 0.11	0.23	5.58	2.29
Calcium	– 0.46	– 1.45	– 1.18	1.28
Phosphorus	– 0.16	– 0.31	– 0.28	0.15

Table 7. Total protein, calcium and inorganic phosphorus levels in the serum of lambs on *Cenchrus* (C) and *Cenchrus-Dolichos* (CD) mixed pasture

Parameter	Grazing		Stall-fed	
	C	CD	C	CD
Total protein (g/100 ml)	7.36	7 20	5.73	6.53
Calcium (mg/100 ml)	9.10	9.50	8.57	8.92
Inorganic phosphorus (mg/100 ml)	7.68	9.02	6.66	7.42

Cenchrus and *Dolichos* hay harvested at preflowering stage and fed as hay produced 82, 56 and 28 grams per day in crossbred yearling rams on *Dolichos* alone, *Cenchrus* and *Dolichos* mixture (50:50) and *Cenchrus* alone respectively (Chauhan *et al.*, 1974).

In another experiment, 27 lambs were allowed to graze on the mixed pasture of *Dolichos* and *Cenchrus* in strips. The body weight changes of these lambs are presented in Table 8.

Table 8. Growth of Avikaleen and Avikullet (F) weaner lambs on *Cenchrus-Dolichos* strip pasture

	Body weights (kg)				Daily gains (g)			
	Avikaleen		Avikullet		Avikaleen		Avikullet	
Date	M*	F**	M	F	M	F	M	F
17.5.76	10.3	9.4	10.9	10.3	—	—	—	—
14.6.76	13.6	12.3	14.9	13.9	121	104	143	121
12.7.76	19.5	16.9	20.4	18.8	211	164	196	175
16.8.76	22.9	19.4	23.1	21.0	100	74	79	65
13.9.76	25.8	21.6	26.0	23.7	104	79	104	96
27.9.76	27.5	22.6	27.9	25.1	121	71	136	106
17.5.76 to 27.9.76 (133 days)					128	90	128	111

*M – Male. **F – Female.

The average daily gain of male lambs was about 30 % higher (128 g/day) than the female lambs (100 g/day).

It is, therefore, quite possible to obtain satisfactory lamb growth on *Cenchrus-Dolichos* mixed pasture or on *Dolichos* pasture alone. Concentrate supplement to lambs could be reduced substantially if such pasture is available. Table 9 shows the nutrient digestibility in lambs grazing on *Cenchrus-Dolichos* mixed pasture and on *Dolichos* alone as determined by using the double indicator technique (Patnayak et al., 1976).

Table 9. Digestion coefficient of nutrients (%) in lambs grazing on *Cenchrus-Dolichos* strip pasture and *Dolichos* pasture alone

Nutrient	*Cenchrus-Dolichos* strip	*Dolichos* alone	Significance
Crude protein	59.87 ± 2.40	76.27 ± 1.17	**
Ether extract	53.30 ± 2.97	52.50 ± 2.04	NS
Crude fibre	56.16 ± 3.08	51.72 ± 2.24	*
Nitrogen free extract	63.28 ± 2.18	51.61 ± 0.99	**

*<0.05
**<0.01

4. *Top feeds*

Various top feeds serve as main feed resources in the region during the scarcity periods. The most important are *khejri* and *pala* leaves. The protein content of these tree leaves is fairly high (13 to 15 per cent). But the major problem is the low availability of protein from them. Extensive research is needed to utilize these tree leaves in practical feeding and on how to remove the limitations in their nutrient utilization. Feeding experiments of sheep with different kinds of top feeds have shown that *kankera* leaves (Mohan *et al.*, 1977; Faroda and Singh, 1972), *Pala* leaves (Malik and Nath, 1970; Faroda and Singh 1972; Bhatia *et al.*, 1976a) could not maintain the body weights of rams and lambs. The leaves of *Tribulus terrestris* (*gokhru*) and *Indigofera* (*bekaria*) species were quite palatable and the animals could maintain body weights. Green *ardu* leaves could maintain adult body weight (Singh and Patnayak, 1974) and dried *ardu* leaf meal could serve as a good supplement to low quality fodders. Adult animals fed on a mixture of equal proportions of ground wheat straw and *ardu* leaf meal with minerals could maintain body weight.

Khejri leaves when fed as dry leaves or as fresh tree loppings could not maintain the body weight of sheep, but could produce a marginal increase in the weight of goats. Gupta (1967) carried out a detailed work on the *khejri* leaves and reported a very low DCP value, although the leaves contained 14 per cent protein. The leaves contained 14.9 per cent tannic acid and the animals fed *khejri* leaves showed hepatic cirrhosis. By adding ferric chloride in one gram doses to each sheep, the crude protein digestibility was improved by

100 per cent. In another experiment (Bhatia *et al.*, 1976b) *khejri* leaves were incorporated to the extent of 20 per cent by weight in the concentrate supplement for lambs. During 70 days feeding lambs in control group gained better than the experimental group. Protein digestibility was lower (38 per cent) in the experimental lambs than in the control concentrate fed lambs (Table 10).

Table 10. Digestion coefficient (%) of nutrients and nutrient balance in lambs supplemented with concentrate containing *khejri* leaves

Nutrient	Control		Experimental	
	Intake	D. C.	Intake	D. C.
Dry matter	615.6	57.0	583.9	52.3
Organic matter	567.1	60.1	540.7	56.5
Crude protein	66.6	48.0	61.9	38.3
Ether extract	9.9	42.1	11.0	39.0
Crude fibre	145.8	48.0	142.8	46.6
NFE	344.8	66.1	313.0	61.7
Nutrient balance (g/day)				
Nitrogen	10.66	2.87	10.64	3.02
Calcium	2.42	−0.41	3.95	0.32
Phosphorus	1.55	0.15	1.43	−0.01

Pala leaves also contained 14 per cent crude protein, but the digestibility of crude protein was low (Malik and Nath, 1970). *Pala* and *khejri* leaves could provide better performance in terms of wool production than the hay from grasses, viz. *makhra* and *ganthia*. *Pala* and *khejri* leaves could also be incorporated to the extent of 30 per cent by weight in the fattening rations for weaner lambs.

5. *Crop residues*

The crop residues available in the area are also important feed resources for the arid zone livestock, specially cattle. The residues of legume crops like *moong*, *guar* and *moth* are some times fed to sheep. Cereal crop residues are more fibrous, woody and low in protein than the legumes. All the crop residues can be enriched by treatment by urea and molasses and their utilization can be improved by adopting appropriate processing technology by grinding, mixing, pelleting and ensilage with legumes. Supplementation of the crop residues and also low quality fodders with urea-mineral and molasses licks or in the form of drinks would be useful.

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II. 8.13

DAIRY DEVELOPMENT AND SEASONAL VARIATION IN THE QUALITY OF MILK IN THE ARID ZONE OF WESTERN RAJASTHAN

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DAIRY DEVELOPMENT

In the past, due to lack of transportation and proper technology for preservation, marketable surplus milk was confined to the remote villages of the arid zone, where it was converted into products. Only less perishable commodities like *ghee* and *khoa* found their way out from the point of production. These products were not economical to the farmers. In 1961, 59.7 per cent of the total milk produced in the state of Rajasthan was converted into *ghee*.

From April 1973, the Central Government took over the activities of milk procurement and marketing from the Rajasthan Government and a Feeder Balancing Dairy at Jodhpur with a nominal handling capacity of one lakh litres of milk per day became operational on November 1st, 1975.

The project activities were initiated by opening four milk collection and chilling centres at Pali, Pokaran, Balotra and Merta City in the milkshed area of

Jodhpur, Barmer, Pali, Nagaur and Jaisalmer districts.

It has now to its credit the involvement of 19698 farmer producers, who are not only using improved methods of milk production but have also developed individual awareness of partners in progress because as much as Rs. 2,21,79,054 in procurement price was disbursed among these farmers in 1976-77 alone. The Co-operative procurement structure has also steadily grown from 8 in January 1974 to 301 milk producers' societies in 1977. During the year 1976-77, 1,60,12,822 litres of milk was procured from these societies and 464 metric tons of cattle feed was supplied to the farmers. At present this dairy is supplying as much as 50,000 litres of milk per day to the dairy plants of Delhi, to meet the needs of the ever demanding urban population there. It is operating 50 milk booths in Jodhpur City where about 15,000 litres of clean, pasteurised, chilled and laboratory tested milk is sold per day.

In order to ameliorate the economic conditions of the farmers of this zone, the main attention was given on livestock improvement. To improve milk production and quality, a number of programmes was initiated under the major heads of animal breeding, loan schemes, disease control, animal nutrition, artificial insemination, fodder development and introduction of high yielding milch animals.

Rajasthan is the second highest milk producing state in India (Table 1).

Table 1. Milk production and per capita availability in 1976*

State	Human population (m)	Milk production (lakh tons)	Per capita milk consumption (g/day)
J & K	5.17	2.0	106.0
H. P.	3.88	0.7	49.3
Punjab	15.18	23.0	415.0
Haryana	11.65	14.3	336.2
Rajasthan	28.86	26.4	250.5
U. P.	98.94	56.2	155.5
Gujarat	29.90	22.0	215.0
Maharashtra	56.46	12.0	58.2
M. P.	46.65	18.7	109.8
Bihar	63.11	17.6	76.3
West Bengal	49.62	10.0	55.3
Orissa	24.57	2.2	24.5
Karnataka	32.82	10.0	83.4
A. P.	48.72	19.7	109.5
Tamil Nadu	46.14	11.0	65.2
Kerala	23.91	4.4	50.3
Assam, Meghalaya, Nagaland	18.10	3.3	49.3
Manipur	1.19	0.1	16.1
Tripura	1.75	0.4	62.5
Union Territories	9.70	1.0	28.2
Total	616.32	254.7	113.2 (Av.)

*Based on Nagarcenkar (1977).

Fig. 1 reveals that procurement was maximum in the month of January and minimum in the month of August. There was a constant fall from April to June and a uniform increase from October to December. The sudden fall in the month of August was due to heavy rains. Due to flush season in the Jaisalmer district, procurement has gone up in the month of July as compared to September, October and November.

The dairy industry of today is playing a significant role in saving the producers from exploitation by the middlemen and the consumers from adulterated products. Rigid quality control measures were introduced from the collection points onwards. The emphasis on quality brought a remarkable change in the consumers at large. *Ghee* has become available to the consumers under the special seal of Agmark. Other products like butter and skimmed milk powder (S.M.P.) will appear in the market very soon.

Several other plans for consolidation, expansion and diversification have been identified and are moving fast towards quick and time bound implementation. The dairy industry is expanding at a tremendous rate. In view of the fact that more and more farmers are realising the importance of better feeding of the animals for better production, better prices are

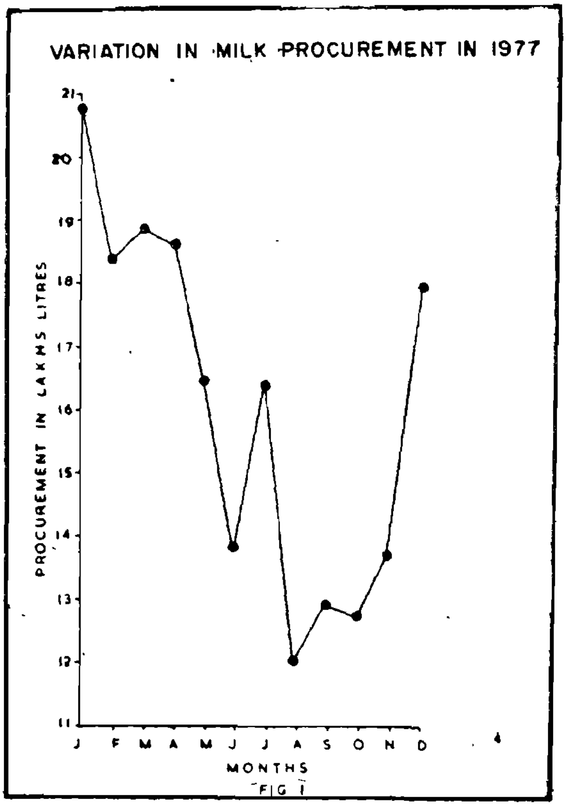

FIG 1

realised from the animals' output and more farmers are shifting from subsistence to the commercial production, expansion in the dairy industry is expected to continue for a long time to come.

INFLUENCE OF SEASON ON THE QUALITY OF MILK

There is a wide-spread demand to revise and lower the solids not fat (S.N.F.) content of cow and buffalo milk stipulated in the Prevention of Food Adulteration (PFA) Rules. In view of the importance of this aspect, an investigation to assess the influence of season on the composition of milk was undertaken.

MATERIAL AND METHODS

Samples of mixed milk were received for analysis from the Milk Collection and Chilling Centres viz., Pali, Pokaran, Balotra, and Merta City situated in the different districts of the Western Rajasthan. Fat was determined by Gerber method and S.N.F. by the Richmond formula based on specific gravity and also by gravimetric method. In all, 527 samples were received. Of these, 162 represented *summer production*, 170 *monsoon* production and 195 winter production.

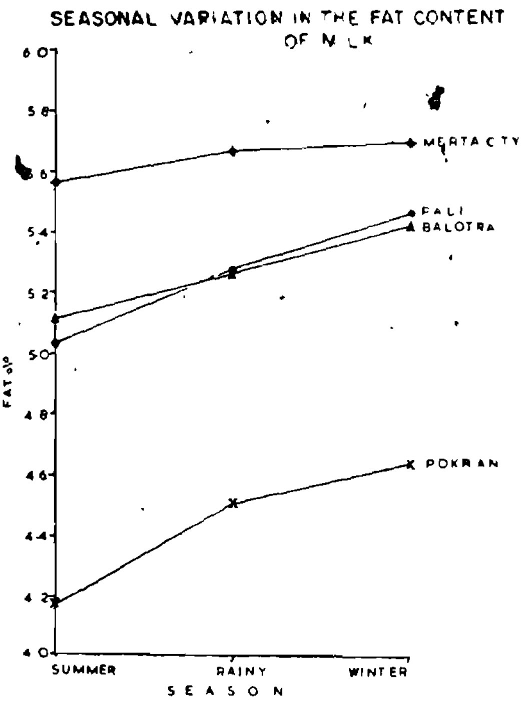

FIG 2

RESULTS AND DISCUSSION

1. *Fat content*

It will be seen from Fig. 2 that the fat content of mixed milk varied considerably during the different seasons of the year and it is generally low during summer months. The results showed that there is a marked rise in the fat content during the winter season. The average fat contents during summer and winter (Table 2) range from 5.03 to 5.45, 4.17 to 4.63, 5.11 to 5.41, 5.56 to 5.68 of the mixed milk samples received from Pali, Pokaran, Balotra and Merta City respectively. Fat percentage in the milk of Merta City is higher than the other areas. The fat percentage in the milk received from Pokaran has been observed to be the lowest. The average fat content of Pokaran milk was 4.17, 4.50 and 4.63 per cent in the summer, rainy and winter season respectively.

Ghosh and Anantakrishnan (1963) have reported that the fat percentage of milk is generally low in summer and increase during winter months. Many investigators have found that the fat percentage is influenced by atmospheric temperature. Ragsdale and Brody (1922) have found that every 10°F fall in environmental temperature increased the fat content of the milk by 0.2 per cent. In the present study, it was found that the fat percentage tended to decline during summer months and gradually increased through the monsoon season. This difference is probably due to temperature variation and feed quality. Hence, the combined effect of environmental temperature, humidity and feed, which

Table 2. Average quality of mixed milk with seasonal variation

Name of the chilling centre	Total number of samples	Character (%)	Summer season	Rainy season (July & Aug.)	Winter season	Approx. cow milk (%)	Approx. buffalo milk (%)
Pali	162	Fat	5.03	5.27	5.45	60	40
		S.N.F	8.00	8.14	8 38		
			(37)	(37)	(88)		
Pokaran	133	Fat	4.17	4.50	4.63	95	5
		S.N.F	8.09	8.26	8.13		
			(49)	(60)	(24)		
Balotra	168	Fat	5.11	5.26	5.41	60	40
		S.N F	8.27	8.44	8.56		
			(60)	(55)	(53)		
Merta City	64	Fat	5.56	5.66	5 68	60	40
		S.N.F	8.21	8.35	8.40		
			(16)	(18)	(30)		

Number of samples analysed in different seasons have been given in the brackets.

influences the local conditions, seems to be the cause for the variation in the milk fat content during different seasons.

2. *Solids-not-fat content*

From Fig. 3 it is clear that the S.N.F. content of mixed milk varies considerably during the different seasons and it is low during the summer months. The results showed that there is a marked rise in the S.N.F. content during the winter season except for the milk samples of Pokaran. The highest S.N.F. content of milk received from Pokaran was found during the rainy season and no marked change was observed in the values for summer and winter seasons. In Jaisalmer district, during the rainy season *sewan* grass which is very rich in protein content becomes available to the animals. During the rainy season the increase in S.N.F. content of milk from Pokaran may be due to this unique grass. The average S.N.F. content during summer and winter (Table 2) ranges from 8.00 to 8.38, 8.27 to 8.56, 8.21 to 8.40 of the mixed milk samples received from Pali, Balotra and Merta City respectively. The results showed that S.N.F. content in the milk of Balotra is higher than that for other areas.

Many workers have reported lower S.N.F. in milk during June to September. Some workers have found higher S.N.F. towards the end of the year and during winter. The present findings of low S.N.F. values in summer and high values in winter are in agreement with those of previous workers.

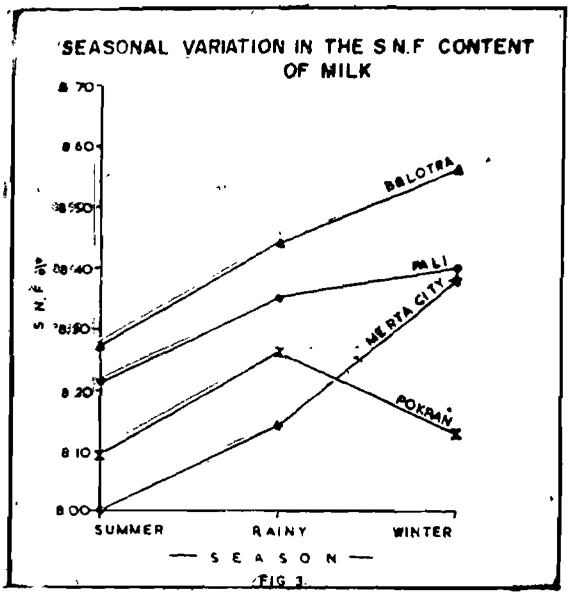

FIG 3

CONCLUSION

An investigation was carried out to study the seasonal effect on the fat and S.N.F. contents of mixed milk in Western Rajasthan. It was found that the fat and S.N.F. contents tended to decline during summer and gradually increased through the monsoon season. These contents were maximum in the winter season. It has been concluded that the combined effect of environmental temperature, humidity and feed seems to be the cause for the variation in the milk fat and S.N.F. contents.

The S.N.F. contents stipulated in PFA Rules viz. 8.50 per cent and 9.00 per cent for cow and buffalo milk respectively are rather high for this zone. There is need for lowering the S.N.F. standard, because under Section 7 of the PFA Act, no person shall himself, or by any person on his behalf, manufacture for sale, store, sale or distribute adulterated or misbranded food. Thus a dairy which procures substandard milk is liable to be penalised.

In fact, payment of low price does not make the dairy organisation immune to the provision of Section 7 of the PFA Act. Hence the village societies, milk unions and dairies of this zone are procuring milk under a constant threat of prosecution. As far as fat content is concerned the minimum standards stipulated in the PFA Rules for cow milk (3.5 per cent) and buffalo milk (5.0 per cent) are quite liberal. It will be better if the standards of quality may be modified on seasonal basis as there are wide variations in the fat and S.N.F. contents from season to season.

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II. 8.14

ANIMALS FOR DRY AREAS

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Deserts will be with us for thousands of years to come and they may become more extensive before they become cooler. To deal with this reality short-term tactical approaches to the vegetation and its interaction with animals are needed, as well as long-term strategies for obtaining the optimum use of these very large tracts of land and the water supplies which determine their usefulness.

Tactics with animals

The major use that can be made of arid vegetation, is in converting it to meat, milk, fibre, skins or transport using herbivores.

1) *The rate of stocking*

Animal density should be adjusted for optimum use of vegetation, but excess stocking produces changes in the albedo of the land, and thus of world thermodynamics. The primary tactic accordingly, is that of restraint in numbers to a level where vegetation remains in steady state. In the Negev and Nubia, along the Sahel and in the Rift Valley, over-grazing has been severe in the past

6-8 years. Much of this has come, unfortunately, from the obsessive need to maintain livestock as social status symbols; as elements of wealth which are there largely for trade, rather than for consumption. Control of stocking rate, accordingly, requires a series of sociological adjustments in which other forms of status symbol and wealth are achieved. Animal numbers should be based on as much knowledge as possible on the recovery potentials of desert ecosystems.

2) *Control of vegetation*

During the time of the domestication of animals in the last 12,000 years, burning has been practiced to remove dry grasses and to encourage green growth. In the northwest of Australia—200 mm rainfall country—the sheep carrying capacity of *Triodia* (spinifex) was reduced within 50 years to ineffective levels, largely by a mixture of over-stocking and burning before seeds had formed and dropped ready to provide replacement after the burn had gone through. This human desertification was very clearly derived from inadequate knowledge of the biology of the plants in the region. It has taken more than 20 years to get at least partial recovery from these inapposite processes (Suijdendorp, 1969). Prevention of seeding by burning or overgrazing for 5 to 8 years can be sufficient to destroy a plant association in desert conditions.

3) *Water resources*

As long as domestic animals have been associated with man and the desert, the oasis has been a centre of survival. The distance animals can move from the water source (the piosphere of Lange, 1969) determines the zone of pasture utilization. The more watering points, the more evenly pasture can be exploited. When sheep move towards water, they follow each other and generate divaricating tracks which are free of vegetation, and become subject to wind and water erosion. This habit of sheep has destructive qualities. Goats on the other hand, do not follow each other but tend to weave in small groups and therefore, are rather less destructive. Camels do not make specific tracks to the water sources. Cattle on the other hand, tend to stay around water during hot weather, and thus eat out vegetation (Yeates and Schmidt, 1974). They move out to graze at night. Goats have similar behaviour. The distance different species can move from water varies with the temperature and the wetness of forage. In dry areas with temperatures over 40°C each day, a camel can move over 100 km from water and return for drinking. And goats can move 10 km but for sheep 5 km is nearer the maximum. *Bos indicus* cattle can walk out more than 10 km. *Bos taurus* rarely moves more than 4 km from water in the circumstances, though some individuals travel further, e.g. 7 km (Alexander and Williams, 1973; Yeates and Schmidt, 1974).

The tactics of water distribution determine patterns of pasture use when the hot season imposes the need to drink to meet evaporative cooling. The rate-function of water use is thus a determinant of the extent of grazing. The highest rates of water turnover (Table 1) are in buffalo and *Bos taurus*, lower in *Bos* *indicus* and horses, lower still in sheep and goats and least in camels (Macfarlane *et al.*, 1971; Macfarlane and Howard, 1972).

4) *Water spreading*

On the desert fringe concentration of water onto productive flats can give crops or reserves of fodder such as lucerne. Various catchments have been used, and for small areas of rolling country, they can be effective.

5) *Migration and transhumance*

Increasingly, with settlements forming to accommodate the exponential increment in human population, the possibilities of maintaining the old nomadic routes

Table 1. Water turnover of grazing ruminants measured by TOH dilution

Animals	Body solids (% body weight)	Body weight (kg)	Water turnover		Environmental conditions
			1/24 h	ml/kg$^{0.82}$/24 h	
Genera					
Camel (4)	28.0	520	32	192	desert
Boran cattle (4)	23.0	197	27	347	summer
Goats (4)	31.0	40	3.8	185	
Ogaden sheep (4)	32.5	31	3.3	197	
Species					
Buffalo (4)	21.4	330	70.7	524	wet
Bos taurus (4)	26.1	322	54.1	484	tropics
Banteng (4)	22.7	355	47.0	427	summer
Bos indicus (3)	38.6	531	65.5	361	
Breeds					
Guernsey (2)	38.5	517	46.2	273	Kenya highlands
Ayreshire × zebu (2)	29.3	246	32.8	362	equator
Boran (2)	32.0	425	37.2	261	(twin pairs)
Merino (6)	22.0	26	3.9	260	dry
Merino × Dorset (6)	29.0	32	3.9	230	summer
Merino (6)	38.5	76	8.4	245	saltbush
Leicester (6)	30.8	67	11.8	377	

Groups of ruminants grazing together differ in mean water turnover at generic, specific, breed (and individual) levels. Body solids relate to the degree of fatness of the animals.

of migration are being reduced. The movement of flocks and herds from one used area of vegetation to another which has received a downfall of rain, is traditional in all the desert ecosystems. More people, however, mean increasing need for livestock both as food sources and as wealth and thus the grazing pressure and reduced migration potential interact and lead to less production. The tactic of movement for feeding herds is soundly based. In modern terms, however, it often means motorised transport to move animals long distances, to a region on which rain has fallen. This neo-nomadism is expensive in energy and can only work economically when prices for meat are high.

6) *Settlement of nomads*

Bedouin, Masai and other African tribal groups that have practised nomadic herdsmanship over millenia, are slowly taking to settlements. This means that the young people will tend to go to paid jobs in industry or farming while the herds are looked after by only a small proportion of the original group. Since there is still a possibility of feeding people on grain if they work to pay for it, these settlements are an effective way of coping with a way of life which has been less than adequate during droughts. It requires considerable social adjustment, particularly for the older people and several generations are likely to lapse before an economic parity is reached with more urban people. Arid ecosystems will increasingly present problems of social readjustment, rather than of plants and animals.

7) *Diversification*

The traditional use of animals in dry country has been to produce meat, fibre, milk and hides. These are still major products and economically they are likely to continue since the use of tillable land for grain and vegetable production must increase to meet world populations and the vegetation of the arid zone is available for ruminant conversion.

Different sorts of animals, however, may be able to contribute to the uses of the ecosystem. Diversification of flocks by breeding goats for mohair or cashmere, rather than for meat or for milk production can help the economy. Similarly, cattle designed for desert areas can be productive during the good seasons. Breeds of sheep producing both wool and meat have been introduced. Merino-Awassi crosses in Israel provides not only flesh, but also fibre with cash from both. On the other hand, the cross of the Ogaden sheep with Dorsets provided a more acceptable meat animal—the Dorper–for growth in 100 mm precipitation zones of Africa.

Other sorts of diversification are those of the introduction of more craft and other light industries. Certainly in much of the arid nomadic country the use of wool spun and turned into carpets has been an admirable cash crop and its encouragement is well worthwhile. In this increasing mobile world, during the drought in Australia, many of the cattle stations turned to looking after tourists as a source of income when all their livestock had perished or been moved out. Similarly, tourism is likely to penetrate into the less hospitable parts of the world as more people seek unfamiliar scenes and more dramatic environments. Tourism in the Australian desert is now a major industry.

Strategies

The long-term approach to the arid ecosystems requires planning on information gathered with good quantitation over long and ecologically significant periods of time. The Central Arid Zone Research Institute is properly involved with this, and the prediction of the outcomes of any policies adopted will be improved, as information is accumulated and reused.

It would seem that the 6 Es, viz. Exponentials, Ecology, Energy, Ecophysiology, Efficiency and Economics would form part of the language of survival over the next hundred years.

1) *Exponentials*

It is not easy to think exponentially, yet all the major processes affecting the human condition are moving exponentially. The compound interest of population growth gives a doubling time of 35 years for the world. The growth of domestic animal populations has kept pace so that there are now 4 milliards of people matched by 4 milliards of domestic animals. All of these consume foodstuff, water and other materials and man at least does this exponentially. The consumption of energy is compounding to double every 17 years, or less. Even more formidably the use of water for domestic, and particularly for industrial processes is doubling every 10 years. For desert areas, this water exponent holds more hazards than for other areas. The exponential increment in information is encouraging, however, and as it compounds with a doubling time of 7 years, it should be of value in helping work out cause and effect, or in giving reasonable prognoses, but the information has to be sorted, coordinated and acted upon, if that exponential increment is not to be meaningless.

The overall strategy of exponential thinking is essential and yet it is rarely present in governmental arrangements. With relatively short budgets of 1 to 3 years and with short lives of government, thinking tends to be segmental with little regard to the compounding process.

2) *Ecological measurements*

The measurement of the flow of energy and chemical constituents through plants to herbivores, to primary and secondary carnivores, and then the recycling of this energy has become political and sometimes almost religious. But whatever way it is regarded, ecological process go on and man is now one of the most influencial components of all ecosystems. Where ecosystems such as the arid areas can be very rapidly modified by human carelessness, extinction of species can occur quite rapidly. There is good evidence that the rate of animal and bird extinction over the past 2000 years has followed a similar exponential to the growth of population. The sequence of cause and effect needs to be looked at closely with each change in animal husbandry or management. India has a long history of irrigation leading to salination of soils, for instance. The outcome of interactions of changes in any one part of a system, require a form of insight that is not automatic, nor is it one which develops easily out of individual attempts at survival or profit. Group responsibility for ecosystems is essential.

3) *Energy*

The daily consumption by 4 milliards of humans is something in the order of 5×10^8 tonnes of water and about 6×10^7 tonnes for domestic animals. The dry matter of human food amounts daily to about 3×10^6 tonnes and domestic animals take about 14×10^6 tonnes dry matter each day. If these formidable quantities are not looked at as daily requirements but are seen in exponential perspective, the system looks almost uncontrollable. But with skills and insight there still is a possibility of both conceptual and actual control being achieved. There is a direct proportion between the gross national product of countries and their energy (and protein) consumption.

4) *Ecophysiology and ecotypes*

Most of the basic functions of plants and animals now extant, came to their present form in the Pliocene through evolutionary processes. There was surprisingly good adaptation to and survival in the successive ice ages of the Pleistocene (Kurten, 1971). Ecotypes achieved a reasonably good fit to niches, as natural selection acted on chromosomal and DNA sequence types of mutation. So the camel evolved both functionally and structurally in the dry environments in the southwest of North America during the Pliocene and then moved to the deserts of Asia and Africa 3 million years ago. Cattle on the other hand, seem to have evolved in South Asian tropics. They are water-dependent and suited to wet habitats. Sheep and goats evolved in the Caucasian mountains and fall between cattle and camels in their dependence upon water.

There is a very great deal, not only of protein polymorphism in animals and plants, but also polyfunctionalism. The diversity of function to be found even in pure breeds of mammals is wide. Some sheep will survive without water, in a hot environment for twice as long as others, although they are of the same breed, let alone species (Macfarlane *et al.*, 1961). Some sheep will die when drinking 1.2 per cent NaCl, but others with 1.8 per cent. These physiological sub-groups within a breed are of importance in meeting difficult environments. Camels in this hierarchy tolerate 5 per cent salt in drinking water, some goats up to 2 per cent, Merino sheep 1.3 per cent and cattle about 1 per cent of salt (Macfarlane, 1971).

Animals that live in a given ecosystem, fall into two main classes. The first comprises those which evolved with functions and structures well-matched to the environmental extremes. These are the water buffalo, cattle and pigs for warm wet environments; and camels, wombats, or gerbils and the marsupial rat, *Dasycercus* for desert habitats. But there is a second group of opportunistic animals that use the arid areas when food and water is available and then either migrate or die off when the droughts come. Cattle brought into the arid ecosystem are in this category, so are horses and man.

Without behavioural, endocrine, and enzymatic adaptational processes, they are not likely to live through the thermal, nutritional or water stresses of the desert.

So there is a hierarchy of functions ranging from the swamp and tropical forest types of animals through the mesic and sclerophyll forests to the grasslands and finally to the hot deserts (Macfarlane *et al.,* 1971; Macfarlane and Howard, 1972; Macfarlane, 1976). The rate at which water moves through swamp animals is (when adjusted for the effects of size) two or three times greater than that rate in the desert forms. Water acts as a stream flowing continuously through animals and plants, carrying with it carbon compounds, nitrogen, phosphorus and oxygen, from which energy may be built into chemical storages or broken down for work functions. So there is a close relationship between the rate at which energy is used and water is consumed, although about 10 mols of water pass through animals for every mol of carbon or oxygen. When animals have high rates of water use, this corresponds with the high rates of energy use. Similarly, there is a correspondence in the rate of building and breaking proteins (Macfarlane, 1976). There are thus, three linked rate functions, suiting animals to arid, mesic or wet ecosystems. It is likely that a genetic programming of the rate of protein turnover underlies the rate at which energy is used and this in turn determines the rate at which water is washed through the animal body (Macfarlane and Howard, 1974; Macfarlane, 1976; Young *et al.,* 1975). These three linked functions are also proportional to the rates of transpiration, that is, the rate of diffusion of water from the respiratory tract and the skin, as well as to the rate of uptake of fluids from the gut.

There are reciprocal functions also. The lower the rate of water, energy and protein turnover, the greater is the power of renal concentration, the greater the sensitivity to vasopressin action and the more are faeces reduced in water content. Carnivores do not reach the highest rates of urine concentration, since urates and urea need to be excreted in water. The highest urine concentrations occur in the seed-eating Australian mice (*Notomys* and *Pseudomys*) which evolved in the desert (MacMillen and Lee, 1970) and have very low water use rates.

When the introduction of or design of different animals for arid ecosystems is contemplated, it is necessary to consider the genetic and evolutionary setting of rate functions of the animals. The nearer the rate of use of water, energy and protein may be to the supplies of those materials in the desert, the more likely the animal is to survive. On the other hand, if large turnovers of product are required, then high turnover rate animals can be contemplated but their survival is likely to be short in any time of deprivation, either of food or water. Cattle, for instance, in the central desert of Australia with daily temperatures of 40°C, die without water in 4 days while camels in the same environment live satisfactorily for more than 15 days without water. High metabolic rate animals on short rations consume fat at a higher rate than low rate animals such as the camel or the wombat. The camel carries, when well fed, some 6 months supply of energy on its back, while cattle are unlikely to have more than 2 or 3 months supply, if they run out of food. Within any species or breed, there is a degree of polyfunctionalism, which may allow considerable selection of the most viable and productive animals for the arid environment (Macfarlane, 1964, 1968).

5) *Efficiencies*

There are many concepts of efficiency. The efficiency with which the energy of food is turned into the energetic content of milk or meat, is one way of regarding this problem. Or the efficiency of protein digestion and deposition may be considered. In the grazing ecosystem of the arid fringes of the desert in Australia, sheep have an efficiency of 0.7 per cent in the conversion of dry grass to wool. With cattle, the efficiency of the herd comes out at 0.2–0.3 per cent if the wastages of calves that die, as well as the necessity of maintaining bulls and breeding cows is put into the total food consumption equation. If use is made of animals even at this level of efficiency a reasonable yield of protein is possible. But if more animals are kept for greater status and for increased populations wanting to have wealth in the form of cattle, then the only way greater numbers can be carried is by increasing the energy efficiency of the animals.

There is evidence (Macfarlane *et al.*, 1966; Macfarlane and Howard, 1970) that sheep on arid pastures, can be selected for greater production of wool but in 10 generations this amounted to 0.5 kg/year. It was clear, however, that amongst the majority of sheep more growth of wool demanded more water and more food. There were, however, some sheep which grew relatively large amounts of wool with lower than average amounts of water input. These animals are not easy to detect in a flock and yet their competence in dealing with the environment merits attention. They could be selected and bred as low maintenance, high production animals. The same approach has been used at the Belmont Cattle Breeding Station of CSIRO in Queensland, where crosses of *Bos indicus* with *Bos taurus* have produced low consumption, good production types of animals (Siefert and Kennedy, 1972).

There are, however, other sorts of efficiency, which need consideration. One is the expenditure of money for monetary return. This economic efficiency is often associated with considerable bioenergetic waste. It is possible to make money from wasteful processes, and this is a characteristic of the lot-feeding systems of cattle rearing, where large amounts of machinery, fuel, grain and irrigation water may be used to produce a profit: but at high cost of resources.

Of more importance is the ecological efficiency of animals in particular environments. It is not very efficient to keep goats in an improved pasture complex, when goats are more suited to browsing on arid shrubs. It is not efficient to have the short-term gain from burning spinifex before seeds form in order to get green sprouting, if there is no regeneration of the plant. It is not efficient in the long run to irrigate arid lands which contain salt, if salination within a few years produces a salt desert of the land treated.

6) *Economics*

It is only recently that economists have turned any attention to the economic cost of ecological responsibility and to control in terms of an approach to equilibrium. There is a cost in both manpower and energy to provide ecological protection. To grow trees providing shade for animals in dry country is expensive on water. In Israel, eucalypts have been brought from Australia, to grow in the arid wilderness, partly because they provide shade, partly because they relieve the barren landscape. It is an ecological cost which the people are willing to accept. To maintain species of animals which are not economically exploited, may mean that there is less vegetation for the domestic stock. Yet in the approach to equilibrium between man, physical and chemical resources, and the biological world, these types of compromise are essential. The economic costs of ecological responsibility need conscious appraisal.

MODELS AND THE DESIGN OF ANIMALS FOR ECOSYSTEMS

There are some mammals which can be looked on as models for life and survival in the desert. Small eutherian animals like gerbils, and *Dipodomys* economise on water and energy use, and escape into holes. Similarly, amongst the marsupials, *Dasyuroides* (120 g) and the hairynosed wombat *Lasiorhinus* (30 kg) are both excellent desert animals, both are fossorial, escaping the heat of the sun, and both have very low rates of metabolism, water use and protein synthesis. They can survive without drinking. There is however, little chance that human cultivation of fossorial animals as meat sources will really come about.

Camels evolved in America with physiological traits which even after 3 million years fit them admirably for arid conditions. The soft elastic feet with skin 1 cm thick are good to travel on sandy substrates. The camel's nose has a sphincteric nostril which cuts out sand and flies for 9/10ths of the time. It has a low metabolic rate around 220-250 KJ/kg$^{0.75}$/day. Its rate of water use is similarly low at less than half that of the highest rate of ungulates, such as reindeer and *Bos taurus* (Macfarlane *et al.*, 1963; Schmidt-Nielsen, 1964; Siebert and Macfarlane, 1971, 1975). It can recycle urea and probably has very low rates of protein synthesis.

The renal concentrating power of the camel kidney is not unusually high (Siebert and Macfarlane, 1971; Maloiy, 1972) being about 3,100 mosmol/1. Since its use of water is low, the normal kidney output is not more than 2 or 3 1 a day. During dehydration, when drinking is not available the camel lessens urine flow by a reduction in glomerular filtration down to one fifth the normal level. This of course, results in the accumulation of Na (up to 205 meq/1) and of urea (up to 100 meq/1) in the extracellular fluid. The camel tolerates these high rates of extracellular Na without difficulty. At the same time this system results in the maintenance of blood K below 8 or 9 meq/1 presumably by the action of vasopressin. The camel is upto 10 times more sensitive to vasopressin than are cattle. And vasopressin (Macfarlane *et al.*, 1967) increases the output of K from the kidnev. This in turn decreases the water flow, so at the cost of a small loss of water, blood K is kept below a level at which there may be undue excitation of the heart muscle or nerve by depolarisation.

The overall effect of the dehydration of the camel is then to leave it with good stores of extracellular water. Plasma volume is maintained in part by the synthesis of more albumin to retain water through onchotic pressure, while gut fluids are used as a water resource to sustian circulation. In the extracellular fluid, Na is retained not excreted, so that in a 700 kg camel, something in the order of 1800 meq of Na would be available for dilution, after drinking, to the normal 140 meq/1. Even more urea is stored by the reduction in glomerular filtration. Urea in both cell and extracellular water can amount to over 2 kg of available urea. When the camel drinks 80-100 1, after two weeks without water, this fluid is not immediately absorbed. Instead water and electrolytes are withdrawn from the plasma to produce a more nearly isotonic fluid in the gut. During the course of a whole day after a drink, the urine flow and the output of Na and K may be reduced to one fifth of the level found during the period prior to drinking (Macfarlane, 1968). After absorption, both Na and urea concentrations fall and the extracellular fluid is replenished without further Na ingestion. At the same time urea moves through the saliva into the rumen to supply nitrogen to rumen organisms for the synthesis of new portein.

The heat tolerance of the camel (Schmidt-Nielsen, 1964) and its salt tolerance (drinking water of 5 per cent concentration, Maloiy, 1972) are both valuable assets for survival in desert environments. Salt tolerance may arise from high activities of NaK ATPase in cells. Certainly the red blood cell has 5 times the amount of this enzyme for extruding Na that is present in sheep (Macfarlane, 1976). Behaviourally also the camel is able to cope with a very wide range of coarse, salty and poorly nutrient vegetations.

In addition to the ecophysiological bases of low rates of water, energy and protein turnover, it has some further specialisations for desert life. These include opportunistic breeding when some two months of good food intake has been available. After 11 months gestation it is likely that similar food supplies could be there to feed the lactating mother. Lactation proceeds for 18 months to 2 years and this gives a solid protein and energy supply to the calf, allowing it to adjust to desert conditions. And finally the camel has the built-in behaviour of eating more than is required for immediate needs when there is food available. This excess foodstuff is converted to fat which occupies the hump. Up to 200 kg may be deposited as fat. Not only could this keep the camel alive without other food for about 6 months, but also it is positioned so that it gives some insulation against the sun, while other parts of the belly and flank of the camel which are only lightly covered with hair and can act as heat convectors or conductors. If the fat were evenly distributed over the body as in whales, there would be much less adequate cooling.

The camel as a model of a desert animal has evolved with many of the most apposite functions for arid areas. In designing animals for these regions the camel model can give a lead to what functions should be sought in other species.

In the design of cattle for hot dry environments, the CSIRO Station at Belmont, Queensland has produced 2 models which seem to be effective. These are the Belmont Red, a cross between Afrikander *B. indicus* cattle (50 per cent) and Hereford and Shorthorn breeds (25 per cent each); and the Australian Milking Zebu. This is derived from *Bos indicus* crossed to Shorthorn and Friesian cattle. Both these types of synthesised animal have been selected for productivity and a short shiny coat to reflect the high levels of solar radiation, temperature tolerance, tick tolerance and behaviour which allows them to accept domestication, but at the same time to go on feeding even though the temperatures are high and the food dry (Lampkin and Kennedy, 1965). They have high efficiencies of digestion of cellulose and protein, as well as high rates of growth. In the Milking Zebu up to 4,000 l/lactation have been obtained in dry country. Fertility has been maintained, although this is not true of all crosses that have been made (Seebeck, 1973). By rigorous selection associated with metabolic measurements at each stage, effective animals have been produced for the hot dry and hot wet environments. These animals have lower metabolic rates and lower water turnover by 5 to 15 per cent than the *Bos taurus* breeds which have in the past been used in sub-tropics (Vercoe and O'Kelly, 1972).

Although cattle have their use in the semi-arid areas, they are still high in metabolic rate, water turnover and protein consumption, relative to sheep, so that even the best are likely to die quickly as droughts intervene. For arid areas with precipitations between 200 and 400 mm a year, sheep and goats are intrinsically better able to withstand the fluctuations of both food and water supply. They are also easier to handle. Some sheep have been designed for specific purposes, the Corriedale sheep was put together in New Zealand a hundred years ago from the Merino and Lincoln breeds to produce a hardy animal which would yield both wool and meat. In the course of a century of selection it has improved, but it is still not quite a stable breed. The possibility of making tropical forms of Corriedale has been explored in Israel. There the crosses between Merinos and Awassis have potential both for medium fine wool and for meat production. India is clearly thinking along these lines and specifications for the physiological and biochemical characteristics of sheep for the arid pasture lands have to some extent been drawn up. Breeds with low water and energy turnover should be the first considered for Rajasthan (Merino and Dorset amongst European sheep). The information on African and Asian breeds in these respects is still scarce. There may be some very useful animals for this purpose. In addition there seems to be good sense in having a dual-purpose sheep which produces usable wool in good quality, as well as meat. For the wool Merinos are the obvious answer, and for meat, the Dorset has low water turnover, reasonable heat tolerance and greater production of fat than the Merino, which is essentially a lean animal (Table 1). The Merinos are not the same in all sub-breeds. German and Russian Merinos have higher fecundity and more meatiness than the Australian Merino which has been bred usually for growing wool. Pepin Merinos of Australia are not very good mothers nor is their milk output much beyond 1.5 1 a day at peak and they rarely produce twins. Twins in the desert are biologically hazardous, since in only some years is it likely that two lambs will survive on the milk available. But selection for milk production on desert grasses is worthwhile (Yates *et al.,* 1971).

The rate of water turnover measured by heavy water on tritiated water or the rate of weight loss with temperatures daily reaching 40°C when a sheep is without water are both good indices of desert hardiness. If a sheep is exposed to sun with temperatures around 40°C and it loses weight at less than 4 per cent/day over 8 to 10 days, it is a good desert type. The Merino can concentrate urine up to 3.8 osmol/1 when deprived of water. Good urine concentrating powers and the ability to extract water from faeces down to 50 per cent water are also indices of desert competence. It is useful to have animals which breed through the year. This is true of most tropical breeds and some strains of Merino have little spring depression of breeds. The Dorset is an all-year-round breeder also.

A potentially useful combination which could be tried is that of a Meidob or Kababish sheep of Nubia which have excellent walking prowess, good reproductivity and survive in very arid conditions. If these were crossed with Merinos, a desert-hardy sheep could be produced and possibly some Dorset in the cross would add to the meat component of such an animal. This would resemble the Belmont Red cattle. Such a complex might well produce 2 to 3 kg of 25 μm wool, as well as a meat carcass during many of the desert seasons, and yield 150 lambs per 100 ewes.

Goats have the advantage of being browsing animals, but they have a very broad diversity of ecophysiological rates. Saanen or Toggenburg types have quite high metabolic rates and water turnovers well into the range of sheep. Goats of Somalia and the Middle East requires less water usually than sheep and have somewhat lower metabolic rates, while the Sinai goat, a small black animal, is 20 per cent less demanding on water (Shkolnik *et al.,* 1972). It is clear that the goat has a better survival potential on salt country or in scrub lands than sheep, since it has a greater tolerance to salt (upto 1.8 per cent NaCl in drinking water) and it accepts a wider range of foodstuffs. Goats also produce more milk and more offspring in arid conditions than sheep.

There are two special aspects of goats which offer possibilities when diversification is needed. These are the Angora, which is increasingly popular, and the Cashmere goat. South Africa has produced both meat goats and Angora goats of high productivity for semi-arid areas. As a measure of the Angora fashion the present price for an Angora buck in Australia is $ US 9,000. As the amount of mohair production increases both stud and hair prices will fall but for some years yet there will be good markets for mohair. There is probably a longer term market for cashmere, which is a labour intensive fibre and is suitable to nomadic and village production. Goats have good arid zone potential and they are not as destructive as they have been accused of being (Kolars, 1966).

In any breeding programme to design new and productive animals, it seems that two basic types should be considered. One is a milk-meat goat with desert competence and a low metabolic rate, low water turnover base, to which could be added some Saanen or boer goat for extra milk and meat production. The second type might be desert-based selections of Angora and Cashmere breeds, able to produce some meat but also producing their specific forms of pelage.

It is likely that the relative demand for meat or mohair or cashmere from arid areas will increase rather than decrease. All these are to some extent luxury products, but with the continuing relative opulence of all societies (in spite of notable areas of poverty) there is likely to be continuing demand for protein fibres. The rates of expansion of the terylene industry is beginning to slow down after 20 years of doubling each 3 years. The agreeable qualities and textures of wool, mohair and cashmere still surpass the synthetic products and arid country can produce all of them. As a secondary consequence, also, village or nomad industries of spun and woven products or carpets can be maintained with minimal sociological change, in the modern world.

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II. 9.2

DESIGN AND DEVELOPMENT OF A FRUIT AND VEGETABLE SOLAR AGRICULTURAL DRYER

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INTRODUCTION

In India, only 0.5 per cent of the 32 million tonnes of fruits and vegetables produced every year is processed and preserved by the industries and about 25 per cent of the total production gets spoiled before it reaches the consumer. This is contrary to the trend in advanced countries where horticultural production is closely linked to the processing industry. Our post-harvest technology is very deficient, naturally contributing to the kind of colossal waste as pointed out above. To minimise such losses, a forced convection type of solar dryer suitable for dehydration of cash crops was designed, fabricated and tested.

Design and development of the dryer

In fruits and vegetables, flavour is one of the important factors which is sensitive to such drying conditions as contamination by dirt, exposure to rain, over-heating, extended drying, growth of fungus and bacteria, a suitable forced convection type fruit and vegetable dryer has been designed, fabricated and tested at CAZRI, Jodhpur, for drying fruits and vegetables e.g., chillies, *ber*, onion, date palm, etc.

The dryer was designed for drying about 100 kg of chillies and 150 kg of *ber*, date palm, onion, etc.

The total heat required for dehydrating 100 kg of chillies from 75 per cent moisture content (w.b.) to 8 per cent (w.b.) moisture content at about 40° to 50°C is calculated as follows:

Original weight of wet chillies = 100 kg.

Final weight of dried chillies = original

$$\frac{\text{weight} \times 100\text{—initial moisture (\%)}}{100\text{—final moisture (\%)}}$$

$$= \frac{100\ (100 - 75)}{100 - 8} = 27.17 \text{ kg}$$

Weight lost = 100 − 27.17 = 72.83 kg.

If drying is done at 40°C, then heat required to dry 100 kg of chillies = 72.83×560 = 40784.8 kcals.

The latent heat of vaporization will vary somewhat with the temperature at which evaporation occur, but at the temperatures used in the drying of fruits and vegetables an average of about 560 cals may be taken for the purpose of calculation of air requirements etc. This amount is required regardless of whether the product from which the water is evaporated undergoes boiling. The mere fact that heat is conducted to the product by air and that evaporation of the moisture from the product occurs without boiling, does not alter the amount of heat required for evaporation.

The total solar radiation on inclined plane on an average at Jodhpur is 625 cal/cm^2/day or 6250 kcal/m^2/day.

If we suppose the efficiency of our air heater to be 50 per cent i.e., 50 per cent of the total solar radiation is being utilised in heating the air, then utilised solar energy will be 3125 kcal/m^2/day, and the area of the collector required for getting sufficient heat to dry the material will be 13.05 sq m.

Drying is essentially a heat and mass transfer phenomenon. It involves heating of the product, vaporization of water from liquid state on the surface as well as within the product, travel of vapours or liquid from within the grain to outside by diffusion or capillary action, mixing the vapour with the drying air and removal by carrying away the moist air. So drying of different products cannot be compared as such unless experimental details are available. Drying details of vegetables as reported by Girdharilal *et al.* (1960) are given in Table 1.

It is to be noted that drying depends on the size of the vegetable pieces, small pieces dry more rapidly than large ones, because the volume is smaller in proportion to the surface and because the moisture within the piece has shorter distance to travel in order to reach the surface (Table 2).

Table 1. Drying details of vegetables

Vegetable	Drying temperature (°C)	Time required for drying (hr)	Drying ratio
Cabbage	50-60	12-14	18:1
Carrot	70-75	14-16	18:1
Cauliflower	60	10-12	35:1
Onion	50-60	14-16	10:1
Potato	60	7-8	7:1
Tomato	50-56	9-10	27:1

Table 2. Drying details of different fruits

Fruit	Drying temperature (°C)	*Time required* for drying (hr)	*Total yield* (%)
Grapes	60-70	20-30	21-27
Banana	55	18-20	14-20
Ber	50-60	18	30-40
Date palm	50-60	15-20	30-40

However the drying depends on the mass flow rate of the air also. The rate of evaporation can be given by the emperical formula (Hall, 1970):

$$\frac{dM}{dt} = (a + bv)\,\Delta p$$

where,

a is a constant representing evaporation in still air,

b is a constant representing evaporation in moving air,

v is velocity of drying air, m/min,

Δp is the difference in vapour pressure in product and in air.

Keeping this in view we designed our solar dryer for drying approximately 100 kg of chillies in one day.

This dryer consists of an electric blower connected to six solar air heaters with a total area of 13.4 sq m which are connected in series and then joined to a vertical drying chamber having nine drying shelves equally spaced. Each solar air heater is a rectangular galvanized iron tank (160 cm×140 cm×5 cm) placed in a mild steel box. The G.I. tank is insulated at the base as well as at sides with 5 cm of fibre glass insulation. The top surface of the tank is painted black with black board paint which absorbs the incoming solar radiation. The top is covered with a glass cover of 3 mm thickness. To increase the heat transfer rate from the absorber plate to the air which is blown in between the top and rear plate, 12 kg of iron filling (workshop waste), are filled inside the rectangular tank. The inlet and the outlet of the air are made diagonally opposite so that air may come in contact of maximum surface area of the absorbing plate. The air gap which is stagnant between the cover and the absorber plate minimises convection losses from the air heater.

These solar air heaters are connected in series and inclined at 23° from horizontal and oriented due south to collect maximum solar rediation during the whole year at Jodhpur.

The drying chamber is essentially a box of galvanized iron sheet 154 × 90 × 90 cm in which, nine 82 × 80 cm trays made of G. I. wire mesh can be stacked on supports at equal distance of 10 cm. Agricultural product, which is to be dried, can be kept over these trays. The outlet of the air heater is connected to the inlet of drying chamber which has a funnel shaped opening so that incoming air may diffuse in all the directions. The outlet for air is made at the top of the drying chamber.

Different calculations carried out for this dryer for drying different agricultural products reveals that fruits and vegetables can be dried in one to two days depending on the moisture content of the material (Table 3).

Collector efficiency

The collector efficiency of the heater is defined as the ratio of useful heat collected to the solar radiation intensity incident on it. Mathematically it can be given by the following relation:

$$\eta = \frac{G\ C_p\ (t_2' - t_1)}{AH}$$

where,

G is the mass flow rate of air through absorber, (kg/m^2/hr),
C_p is specific heat of air (kcal/gm°C),
t_1 is temperature (°C) of air at the inlet of air heater,
t_2 is temperature (°C) of air at the outlet of air heater,
A is total area of the collector absorbing solar radiations (m^2),
H is solar insolation on collector (kcal/m^2/hr).

Table 3. Drying of agricultural products

Agricultural product which is dried	Initial weight (kg)	Initial moisture content(%)	Final moisture content (%)	Time for drying (hr)
Chillies	100	75	8	9-10
Onion	150	90	5	17-20
Ber	150	75	10	16-17
Datepalm	150	65	10	15-16

Mass flow rate of air is one of the important aspects of the dryer. Increase in the air flow rates results in lower outlet temperatures of the air and also lowers the temperature in the air heater. This reduces the heat losses from the heater and thus increases the heat collection efficiency of the air heater. However, if we go on increasing mass flow rate of air, the temperature rise is quite less than required and simultaneously it increases the fan running cost. Thus mass flow rate of the air as well as the outlet temperature of air are changed according to the requirement.

Experiments show that harnessing solar energy for drying fruits and vegetables provides not only a good keeping quality material but simultaneously offers a substitute for non-replenishable fossil fuels which are used for the same purpose otherwise. Experiment also shows that the quality of the dried fruits and vegetables is as good as dried by other conventional methods.

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II. 9.3

BALANITES ROXBURGHII AS A SOURCE OF DIOSGENIN

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INTRODUCTION

One of the most significant advances in medicine, in recent years, has been the wide spread use of steroid hormones as drugs for a variety of disorders. Drugs such as progresterone and cortisone and their derivatives are extensively used for the control of a variety of diseases. A more recent development is the use of non-steroid derivatives such as norethisterone as oral contraceptives. The steroid sapogenins, diosgenin and yamogenin are the most important raw materials for the production of these pharmaceutical steroids (Hardman and Safowara, 1972). Earlier, Dioscorea species have been the chief source of supply of diosgenin for steroid industry. This source is however very much depleted due to large scale and indiscriminate tapping over the years. According to an estimate*, the total requirement of diosgenin in the country is of the order of 200 tonnes per annum

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*Information kindly made available by Dr. J. S. Patwardhan, Incharge Drugs, DGTD, New Delhi.

whereas the actual production is only 30 tonnes per annum. It has, therefore, become imperative to find out alternative source of diosgenin. *Balanites* species have been recommended in a UNESCO Report (Chopra *et al.,* 1960) on "Medicinal plants of the arid zones" as a source of diosgenin. Diosgenin has been isolated from the leaves, (Dawidar and Fayaz, 1969), fruit pericarp (Dhekne and Bhide, 1951) and kernel (Varshney and Shamsuddin, 1962) of *B. roxburghii,* growing wild in India. Recently diosgenin has been isolated in 2.2 per cent yield from the dry roots (less than 0.5 cm thickness) of *Balanites roxburghii* by Puri (1976). This has prompted us to carry out the chemical investigation of the roots and fruits of *B. roxburghii,* collected from different habitats of Western Rajasthan, for diosgenin content and the results obtained have been described in this work.

MATERIAL AND METHODS

Solvent extraction method was used to isolate sapogenin from roots and fruits of *Balanites roxburghii* (*hingot*) collected from different distribution zones of Western Rajasthan. Melting points were determined on Gallenkamp apparatus and are uncorrected.

I. *Isolation of sapogenin from roots*

Roots of *hingot* (0.5 cm thick) were dried and ground with the help of willey mill: The coarsely ground powder was then defatted with light petroleum (40-60°C) for 3 days. The powder was then dried and extracted with alcohol. The extract was distilled to remove alcohol and the residue refluxed with 2N HCl for 2 hours. It was then cooled, filtered, washed successively with water, 10 per cent ammonia solution and again with water. The residue was dried in oven at 80°C for 4 hours and then exhausted with light petroleum (40-60°C) in a Soxhlet apparatus. On concentration to a small volume and keeping overnight, crystalline commercially acceptable sapogenin separated out.

II. *Isolation of sapogenin from fruitwall and seeds*

(a) *Isolation of sapogenin from fruitwall*

Fruit samples, collected from Jodhpur, after the removal of epicarp were soaked in water for 3 days. The mixture was then mechanically agitated with an electrical stirrer to remove the softened mesocarp. The nuts were separated, washed and dried. The washings were added to the fruitwall, pulp filtered through a cloth and then brought to 2N acidity by adding sufficient HCl before it was refluxed for 2 hours. The mixture was washed in the usual manner and the dried solid was extracted with light petroleum (40-60°C) in a Soxhlet. On concentration, sapogenin in the yield of 1.5 per cent was obtained.

(b) *Isolation of sapogenin from seeds*

The seeds obtained after removal of the hard endocarp, was crushed and extracted with light petroleum (40-60°C) to remove oil (40.3 per cent of oil on dry weight basis). The defatted seeds were extracted with alcohol, the extract concentrated to dryness and the residue refluxed with 2N HCl for 2 hours. It was washed in the usual manner and the dried solid was then exhausted with petroleum ether in a Soxhlet. Upon concentration, sapogenin in the yield of 0.58 per cent was obtained.

RESULTS AND DISCUSSION

The major sapogenin, isolated from the root and fruits has been found to be a mixture of diosgenin and its 25B epimer yamogenin. No effort has however been made to separate them as the mixture as such can be used as a raw material,for steroid hormones. A preliminary defatting of the root samples with petroleum ether (60-80°C) removed the unwanted material which interfered with the final isolation of sapogenin.

The steroidal sapogenin melted between 194-198°C whereas the melting point reported for diosgenin in literature (D.O.C., 1965) is 204-207°C. This shows a difference of 10°C in melting point which is in agreement with the findings of Marker *et al.* (1947) who found that a mixture of diosgenin with yamogenin melted at 10°C lower. As much as 20°C difference in melting point has also been reported by the same workers for hecogenin and this has been attributed to the possibility that plant sapogenins could exist in polymorphic forms. The sapogenins give characteristic IR absorptions at 867, 900, 917, 985, 1050, 2900 cm^{-1} in which the absorbance at 900 cm^{-1} was stronger than at 917 cm^{-1} unlike yamogenin indicating the predominance of diosgenin.

Table 1. Areas giving high sapogenin content in roots

Location		Sapogenin content		
		Total* (%)	Proportion (%)	
			25α	25β
Jalore				
	Jalore	1.47	87	13
Pali				
	Pali	0.81	87	13
	Dhola	1.23	86	14
	Bisalpur	1.04	85	15
Jodhpur				
	Borunda	0.95	87	13
	Bilara	0.83	86	14
	Jodhpur	0.82	87	13
	Kailana	1.34	87	13
Barmer				
	Balotra	1.38	86	14
	Samdari	0.94	86	14

*On dry weight basis.

The present study shows (Table 1) that root samples, collected from Jodhpur, Pali, Jalore and part of Barmer district, give uniformly high yield of sapogenin (0.81-1.47 per cent). However, sapogenin content is uniformly low (0.44-0.75 per cent) in root samples collected from Churu and Bikaner districts (Table 2).

Chemical analysis of fruitwall was given up because of low sapogenin content. Our observation of seasonal variation in sapogenin content in root samples has however led us to reinvestigate the sapogenin content in the fruitwall. Thus, fruits, collected in the month of December, have fairly high sapogenin (1.5 per cent) in the fruitwall as compared to 0.8 per cent reported earlier by Shah *et al.* (1976). Sapogenin content in seed is, however, lower (0.584 per cent) as compared to fruitwall.

Table 2. Area giving low sapogenin content in roots

Location		Sapogenin content		
		Total* (%)	Proportion (%)	
			25α	25β
Bikaner				
	Bikaner	0.44	87	13
Churu				
	Ketsar	0.75	86	14
	Ratangarh	0.63	86	14

*On dry weight basis.

Analysis of root samples, collected from Kailana, Borunda and Jodhpur in the months of August and December, show variation in sapogenin content (Table 3). It has been observed that the yield of sapogenin is high in the month of December. This suggests that there is a seasonal variation in sapogenin content which, however, needs further investigaton.

Table 3. Seasonal variation in sapogenin content

Location	Sapogenin content (%)	
	August	December
Jodhpur	0.52	0.82
Borunda	0.82	0.95
Kailana	0.88	1.34

In a study conducted by Tropical Products Institute, London (1961), it has been estimated that the cost of production of diosgenin, based on 1 per cent yield, from the seeds of *Balanites aegyptiaca* would be less compared with diosgenin obtained from Dioscorea species. This does not take into account the fact that diosgenin is also present in the fruitwall. Also, the seed oil which is edible would increase overall value of the fruit as reported by Chopra *et al.* (1960). With 1.4 per cent, 1.5 per cent and 0.58 per cent of sapogenin present in the root, fruitwall and seed respectively, *Balanites roxburghii* could provide industry with a new source of diosgenin for steroid hormone production.

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II. 9.5

SOME INVESTIGATIONS ON *GUAR* GERM PROTEIN

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Guar, Cyamopsis tetragonoloba, a leguminous herb is used as a food for both humans and animals. *Guar* plant grows best in semi-arid areas and moderate salinity. It is drought tolerant, performing well in areas having 400-900 mm annual rainfall.

Guar germ, which is obtained as a by-product during the extraction of gum from *guar* seed, is known to contain 50-55 per cent protein, and is now being used as fodder for animals. However, the nutritive value of the germ protein is very much reduced due to the presence of some toxic constituents such as trypsin inhibitor, toxic phenolic compounds and unpleasing flavour.

This paper presents data on amino acid composition of *guar* germ, effect of heating on trypsin inhibiting activity in *guar* germ and methods by which toxic phenolic compounds and unpleasing flavour can be removed from *guar* germ.

Removal of unpleasing flavour, toxic phenolic compounds and pigments

Guar germ was cleaned and powdered in a flour mill. The powder was then subjected to solvent extraction by petroleum ether in a Soxhlet apparatus for three hours to ensure *guar* germ defatted. A 0.5 per cent of the dry weight of the original sample was found to be lost during ether extraction. It was then subjected to methanol extraction in the same apparatus until it became free from toxic phenolic compounds, as checked by negative ferric chloride test. A 5 per cent loss in the sample weight occurred during methanol extraction. During these two extractions pigments were also found to be removed simultaneously from the powdered sample. Subsequently, the germ flour was dried in an oven at 60-70°C. The procedure was repeated till the dry germ flour gave constant weight. It was then stored in an air tight bottle and marked as sample A and was used for further study.

Amino acid analysis of guar germ and husk

Amino acid analysis of germ (Sample A) of *guar* seed was carried out by automatic amino acid analysis* (Table 1).

(i) Determination of protein concentration

During fractionation of the proteins for isolation of trypsin inhibitor, the protein concentrations were determined by observing the absorbance of the test solution after proper dilution (usually 1:10 dilution) at 280 nm, using a Beckman DU2 Spectrophotometer. Lima bean trypsin inhibitor was selected as a protein standard, because it is a trypsin inhibitor isolated from legume and the experimental material was expected to be similar to it in amino acid composition.

(ii) *Determination of trypsin activity*

Reagents

Trypsin solution—10 μg/ml in tris-buffer.

Substrate solution - 45 mg per 100 ml was prepared in tris-buffer (30 mM) by the method described earlier.

Acetic acid - 30 per cent v/v in water.

To 5 ml of substrate, 0.9 ml water was added and the mixture was maintained at 37°C in a water bath for 5 minutes. At zero time 0.1 ml of the enzyme solution was added and the reaction allowed to run for 10 minutes. Addition of 1.0 ml of 30 per cent acetic acid terminated the reaction and the quantity of p-nitroaniline liberated was estimated spectrophotometrically at 410 nm using Calvin method against a blank determination carried out under identical conditions without using the enzyme.

The inhibition of tryptic hydrolysis of N^{α} - benzoylarginine-p-nitroaniline (BAPA) was measured by change in absorbance at 410 nm. Tryptic hydrolysis of this substrate produces the chromophore p-nitroaniline, the concentration of which can be measured by observing the absorbance at 410 nm.

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*Amino acid analysis was carried out at N. R. C., Ottawa, Canada.

Table 1. Amino acid composition of *guar* germ

Amino acid	Amino acid (g) per 100 g germ	Amino acid (g moles) per 10^5 g germ	Amino acid (g) per g N
Aspartic acid	5.55	41.73	0.60
Threonine	1.57	13.20	0.17
Serine	2.50	23.84	0.27
Glutamic acid	12.06	82.06	1.32
Proline	1.83	15.97	0.20
Glycine	2.65	35.39	0.29
Alanine	1.97	22.19	0.21
Valine	1.94	16.56	0.21
Isoleucine	1.67	12.75	0.18
Leucine	3.16	24.15	0.34
Tyrosine	1.93	10.67	0 21
Phenylalanine	2.07	12.54	0.22
Histidine	1.37	8.87	0.15
Lysine	2.34	16.08	0.25
Arginine	7.37	42.34	0.80
Methionine <	Histidine		
Cystine <	Histidine		
Cysteine <	Histidine		

Procedure for extracting trypsin inhibiting activity from guar germ

Trypsin inhibiting activity of the material under investigation was extracted by the procedure mentioned by Kassel (1971). The substrate (BAPA) (5 ml) and 0.5 ml of water were pipetted out into a series of test tubes maintained at 25°C in a water bath. In a second series of test tubes were introduced 1 ml of trypsin plus 1 ml of buffer or 1 ml of inhibitor for the standard and unknown, respectively. These were allowed to incubate for 10 minutes. Timing with a stop watch, 0.5 ml of the enzyme (or enzyme and inhibitor) was withdrawn from the second series of test tubes and transferred to the substrate solution. The resulting solution was stirred to ensure thorough mixing. Exactly ten minutes later, 1 ml of 30 per cent acetic acid solution was added to each of 1st series of test tubes to arrest the reaction. The absorbance of the solution was recorded at 410 nm with a Beckman DU2 Spectrophotometer against a blank without enzyme or inhibitor. The absorbance of the unknown was subtracted from that of the known, i.e., standard trypsin.

Screening of guar germ for quantitative determination of trypsin inhibiting activity

The crude enzyme extracts of the *guar* germ was subjected to quantitative assay by the procedure already described. The protein concentration in the extract was determined by recording the absorbance of the test solution after 1:10 dilution, at 280 nm using Beckman DU2 Spectrophotometer (Table 2).

Table 2. Trypsin inhibiting activity of *guar* germ

Way of expression	Trypsin inhibiting activity
units/ml	32
units/g	820
units/mg protein	2.5

Effect of heating on trypsin inhibiting activity of guar germ protein

Known quantities of the sample A were taken in distilled water and adjusted to neutral and slightly alkaline pH by adding sodium carbonate. The solution was subjected to heating at 100°C for different intervals of time. Baking experiments were carried out with powdered sample A and the activity was measured by the procedure described earlier (Table 3).

Table 3. Effect of heat on inhibiting activity

Treatment given	Loss in activity (per cent of the original activity)
Heating in water bath at 100° C for 15 min.	89
Baking the powder of Sample A for 15 min.	65
Autoclaving in pressure cooker at 15 psi for 15 min.	
i) Acidic pH	95
((ii) Neutral pH	95
(iii) Alkaline pH	97

DISCUSSION

Studies on non-essential amino acids of *guar* germ (Table 1) indicate that glutamic acid is present in very high concentration. Preliminary investigations have shown that it is economically feasible to isolate glutamic acid from the germ protein hydrolysate by fractional crystallisation. In addition, aspartic acid, glycine and serine content in *guar* germ is fairly high, even rest of the amino acids are present in good concentrations.

Trypsin inhibitors (Liener, 1969) had been reported to be present in a number of legumes and cereals, a toxic factor which is known to be rich in sulphur containing amino acids. The widespread distribution of trypsin inhibitors in legumes, provides the most likely explanation for the observation that heating increases the *in vitro* and *in vivo* digestibility of many leguminous proteins, thus enhancing their nutritive value. Soybean protein has been thoroughly studied for in this respect. It has been found that the extent to which the inhibitor is destroyed is a function of temperature, duration of heating, moisture conditions, particle size, etc. It has been observed that more than 95 per cent trypsin inhibitor activity in soybean is destroyed within 15 minutes regardless of moisture content. Soybean, according to an earlier report, can be almost freed of trypsin inhibiting activity if treated with 1 per cent calcium hydroxide at 80°C for 1 hour.

In order to study effect of heating and baking on trypsin inhibiting activity of *guar* germ, sample A was heated to different temperatures. Eighty-nine per cent inhibiting activity was destroyed when it was subjected to heating in water bath at 100°C for 15 minutes Ninety-five per cent trypsin inhibiting activity was lost when sample A was subjected to heating in a pressure cooker at 15 psi for 15 minutes in either acidic or neutral pH range. Maximum loss in activity (97 per cent) was observed when pH was maintained in alkaline range, other conditions remaining the same. It is assumed that protein gets hydrolysed comparatively easily in alkaline pH range resulting in maximum loss. Baking experiment showed lesser deactivation (65 per cent) probably due to larger particle size of the *guar* germ.

Guar germ is very poor in sulphur containing amino acid (Table 1), e.g., methionine. Still it contains high amounts of arginine, lysine and threonine which can serve as useful supplements in diets lacking in these amino acids. Lysine deficiency in cereal proteins, which forms a large part of protein source in vegetarian diet, may be compensated by *guar* germ protein if this is adequately supplemented with methionine.

In conclusion it may be said that *guar* germ protein after proper processing can prove to be a cheap and useful source of protein for making texturised protein foods.

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IV. 0.1

SOCIAL RESEARCH IN ARID ZONE - ITS RETROSPECT AND PROSPECT

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INTRODUCTION

It may seem trite to repeat that one of the basic problems of the Indian arid zone is that of human ecology. Man has been and continues to be the most important agent of biotic interference in the fragile ecosystems of the Indian arid zone. Over-exploitation of water, plant and land resources has disturbed the delicate ecological balance. The society inhabiting the region is structured on the basis of kinship, and is by and large value-oriented rather than oriented by commercial or other objective aims. The economic problems also have a human dimension, most of them being embedded in the social structure of the population. Rcognizing this, investigations have been conducted to assess the nature and type of available human resources with a view to suggest ways and means for their optimum utilization.

The chief methods applied have been socio-economic surveys as a part of the integrated natural resources, surveys and a few small-scale community studies.

SALIENT FINDINGS

Socio-demographic factors

The Rajasthan arid zone has an average density of 48 persons per sq km and is the most thickly populated of all other arid areas of the world. The growth rate (1901-1971) of population in the arid zone of Rajasthan has been higher (186 per cent) than that of Rajasthan State (150 per cent) and of the country as a whole (132 per cent). The present broad-based age pyramid and civil conditions of the population exhibit expansive future growth potentials. Socio-anthropological studies in one of the communities—Bishnois—revealed that the major factor responsible for this phenomenal growth is the prevalence of high fertility norms originally developed under the high mortality culture of the arid zone to assure the survival of family, lineage and society. The positive sanctions encouraging fertility far outweigh the negative ones. The intensive labour requirements of a traditional agriculture marked by instability and periodic failure and the consequent felt need for more children add to the values which pre-dispose towards larger families. Family Planning programmes have yet to make any inroads due mainly to an inherent weakness in terms of neglect of the cultural variables which are mainly responsible for creating chains of resistance. In-depth anthropological case studies of the customs and norms related to fertility among different castes and communities would provide basic information and sources of support for population control.

Raising the age of marriage, strict enforcement of laws regarding the performance of death ceremonies at which child marriages are organized and the creation of employment opportunities for women as well as giving women preference with regard to certain types of employment and developing an intensive education programme are some of the measures which need attention.

Patterns of living

The population is handicapped by living in villages scattered over long distances and in dispersed dwellings situated in their fields. Communication between the hamlets and farms is difficult. The web of social relationships is confined within the cluster of *dhanis* (dispersed dwellings). There is much smaller use of community facilities, and the network of services such as education and health care normally do not reach the *dhanis*. Intensive survey and research on concerted basis to bring about improvements in human settlements which are compatible with socio-cultural values and which make better use of local materials to make the traditional dwellings more comfortable is an immediate necessity.

Nomads and nomadism

A sizeable proportion of the population still leads a nomadic or semi-nomadic life, although the traditional relationship of mutual dependence between them and the sedentary population has largely broken down and the economy of the nomads has suffered a heavy decline. Each type of nomad is associated with some kind of livestock which make indiscriminate use of the meagre water and grazing resources and destroy local soil conservation measures. The nomads of the present day thus form a menace to the whole society, and their sedentarization is inescapable. The question that haunts the ecologists and sociologists today is how to absorb these people within the framework of modern living and make them useful members of society by exploiting their natural aptitudes. Pioneering sociological studies undertaken among artisan (*Gadoliya Lohars*), trading (*Banjaras*) and cattle-breeder nomads have provided leads proposals for their sedentarization based on the kinship structure, socio-economic concepts and cultural values. Linked with the studies among the nomads, studies for the establishment of regional agro-industries to arrest nomadism assume great significance.

Social structure

The majority of the populations remain illiterate traditionalists with strong factional divisions. Village society enjoins upon each caste the performance of certain functions which are interdependent and complementary. This social institution has, however, restricted social and occupational mobility and has fostered values concerning cultivation and animal husbandry, some of which are definitely economically untenable. All the castes are living hierarchically ordered, and caste distinctions in commensal as well as with regard to other behavioural aspects often act as a drag on development.

The traditional large joint households are disintegrating into smaller nuclear households, and this is posing a paradox just when increasing longevity is generating the need for the care of the aged in the joint family, other forces are conspiring against it. There being little prospect of state security measures for old age, the parents like to have additional sons so that they can fall back upon at least one during their old age. This transformation of the household has further resulted in increasing fragmentation of land holdings, uneconomic with the duplication of assets and excessive pressure of livestock on land.

Livelihood sources

Inspite of the low and erratic rainfall, cultivation is the mainstay of over three-quarter of the work force. The system of agriculture followed is expressive of the limitations imposed by aridity. The availability of economically viable units of cultivable lands, the proper mix of agricultural inputs, and above all adequate water are only a dream for the farmers of the arid zone of Rajasthan. Prior to the abolition of feudal land system, most of the lands were under the system of tenure known as 'Jagiri'. Now almost all the land is held directly from the state on payment of land tax. The average size of land holding in the arid Rajasthan works out at 9.9 ha, which is almost double the average size of holding in the state of Rajasthan. The man-land ratio, is fast declining. The total land available per household was 18 ha in 1951, but only 15 ha and 12 ha was available in 1961 and 1971 respectively and only 8 ha is likely to be available by the turn of the century. Similarly, the total cultivable land available per household declined from 14 ha in 1951 to 10 ha in 1971, and only 6 ha is likely to be available in 2001.

Subsistence farming predominates which tends to make the farmer security-oriented. In a case study on the differential adoption of recommended practices it was found that membership participation and technical knowledge scores accounted for a greater amount of the variation than did those for land holding, irrigated land holding, or material possessions. The study thus suggested that it will be useful to encourage as much participation and involvement in various activities as possible and to explore the ways and means to provide a fuller knowledge of the improved package of agricultural practices and the advantages of the innovations, as these two factors predispose the farmers to a quicker adoption of innovations.

Animal husbandry is the next important sector after agriculture. Like the growing human populations the livestock population has increased from 10 millions in 1951 to 16 millions in 1972. The desert areas possess some of the best breeds of cattle, sheep, goats, camels, etc. The pressure of livestock on the grazing lands, however, is acute and there is a recurrent shortfall of forage. Production from livestock is consequently low. A study of the composition of livestock reveals not only the preponderance of goats and sheep in the total livestock population, but also an increase in the relative goat population during the famine years. The importance of the goat, however, lies not merely in the returns that this hardy animal gives to the owner but also in its role in the raising of sheep.

Another major occupation followed by the rural workers is that of household industries. Trade, mining and other services form the chief occupation of only a small percentage of earners. It is thus evident that with the increase in the number of earners (due mainly to the increasing population) the diversification in adopting occupations other than cultivation has not occurred in the region because of non-availability of alternative avenues of employment.

Vegetation-human-relationship

Due to increase in population, not only has more land been brought under the plough, thereby reducing the number of trees and shrubs, but also the increasing demand for wood has led to an unwise over-exploitation of vegetal resources. Most of the villagers in rural areas procure firewood free from their own fields or from unoccupied lands. Digging *phog* (*Calligonum polygonoides*) is a regular occupation and provides employment for a large number of people and the use of their camels when not otherwise occupied. The digging of the roots loosens the soil and accelerates wind erosion. The majority of the rural population is now facing an acute shortage of wood fuel. Unless alternative sources for meeting fuel needs are developed the process is likely to continue to add to desertification processes in the area.

Cooperative societies have been functioning in some villages but these have so far been unable to replace the money-lender. One of the chief reasons for this is that these societies do not provide loans for socio-religious needs of the community. Also, the foresight of the people for advantages of controlled credit and their punctual repayment is lacking.

Prospect

The foregoing account is indicative of the value of the sociological studies so far undertaken. More precisely, the undertaking of the following studies is advocated.

(a) Social values, norms and customs as related to fertility among different castes and communities.

(b) Anthropogeographical studies pertaining to human settlements.

(c) Rural social institutions, social customs, rituals and beliefs inhibitng socio-economic development, and means of harnessing local institutions for securing community participation.

(d) Socio-economic constraints in the adoption of improved technology and the identification of traditional incentives and social mechanisms for acceleration of adoption of innovations.

(e) Special studies pertaining to the weaker sections of society, including the scheduled castes, scheduled tribes, backward classes and nomads. Researches for establishment of "agro-industrial complex" for arresting nomadism also assume significance.

(f) Environmental perception studies including the measurement of social indicators of desertification, the strategies adopted by local inhabitants, and the steps taken by official agencies to reduce or modify the consequences of desertification.

Last but not least the most important factor that warrants attention is to devise ways and means for strengthening cooperation between the research and development agencies.

IV. 0.2

THE OPERATING MECHANISM OF DESERTIFICATION AND CHOICE OF INTERVENTIONS

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INTRODUCTION

Notwithstanding the unsettled controversy over march of the Rajasthan desert, the fact of accentuation of desertic conditions within the arid zone of Western Rajasthan has been largely accepted. Accentuation of desertic conditions due to unscientific use of land resources is indicated by the following:

Growth of waste lands caused by loss of top soils or submersion of fertile lands under shifting sand dunes (Ghose *et al.,* 1968); conversion of fertile lands into patches of saline waste lands in the low lying areas near seasonal streams (Anon., 1964); drying of dug wells or increased salinity of well waters (Anon., 1967); replacement of superior perennial species by inferior or annual (including non-edible) species in the grasslands (Prakash and Ahuja, 1964); reduced productivity of crops due to their extension to submarginal lands; increased extent of out migration of humans and animals to overcome the seasonal hunger gap and finally increasing frugality of habitants of arid lands due to increased impact of droughts and weakening of the farmers' adjustment mechanism against drought.

The country's concern about the above problems and consequent corrective measures have led to the adoption of measures ranging from establishment of CAZRI for generating technological solutions to the desertification problem to initiation of area specific development schemes like Drought Prone Area Programme (DPAP) or Desert Development Programme. However, neither technological options nor highly subsidized area focussed development schemes can help much unless the operating mechanism of desertification is properly understood. For understanding the latter, it is essential to have an idea of the traditional system of farming in the arid zone and the changes it has been undergoing particularly in the recent decades.

THE TRADITIONAL SYSTEM OF MIXED FARMING

As indicated by the scientists as well as the traditional wisdom of the desert farmer, the bulk of natural resource base of the arid region is most suited to pasture based livestock farming and only a few pockets are good for sustained cropping (Jodha and Vyas, 1969). The consequence was evolution of system of mixed farming–including crop and animal husbandry—which matched the potential and limitations of the natural resource base. Mainly pasture based livestock rearing ensured stability of earnings (through seasonal migration) against spatial variability of weather, the efficient utilization of lands unsuited to crop farming, and benefit of complementarity between crop and livestock farming. The selective crop farming, even on submarginal lands was attempted to take advantage of occasional good rain years. The misuse of land (i.e., ploughing of lands best suited to natural grasses) was rectified partly by a practice of crop and long fallow (bush fallow) rotation.

The relative importance of crop and livestock components of mixed farming did differ among different rainfall zones of the arid region itself. A micro-level situation of mixed farming is illustrated by Table 1. Livestock accounts for a substantially larger share of the total asset value as well as gross farm income in drier areas like Jaisalmer. Its importance declines as rainfall situation improves. Similar pattern has been observed at macro-level when district-level aggregate data are examined (Jodha, 1977). Furthermore, as will be indicated later, the traditional system initially had a number of institutional arrangements which prevented over exploitation of resources through mixed farming.

The changes in the system

However, as revealed by micro-level data the situation is fast changing. Because of factors to be discussed later, pastorals are undertaking crop farming besides livestock rearing. For completely different reasons more and more of traditional cultivators are incorporating sheep raising and dairying as their subsidiary occupation. Studies carried out during 1964-65, in seven villages revealed that out of the total households following mixed farming, 48 per cent did not do cultivation prior to 1952-54, the peak period of land reforms (Table 2). Similarly, 28 per cent of them did not have sheep/goat raising as one of their occupations. Of course, siuation differs from district to district. Thus, the extent of mixed farming is on the increase. The consequence is progressive extension of ploughing on submarginal lands only suited to natural grass, overstocking of fast-shrinking grazing space.

At the aggregate level for the arid

Table 1. Details of enterprise combinations on farms practicing mixed farming in three areas of arid region of Rajasthan (1964-65) (Animal units are calculated on the basis of : 1 cattle/camel = 1 animal unit; 1 sheep/goat = 0.15 animal unit)

District	Annual average rainfall (mm)	Sample households (mixed farming) (No.)	Per-household details of land and livestock					
			Land (ha)	Animal units (No.)	Relative share (total)			
					Asset value		Gross farm income	
					Land (%)	Live-stock (%)	Crop (%)	Livestock (%)
Jaisalmer	179	43	32	40	18	82	26	74
Jodhpur	340	48	23	18	63	37	71	29
Nagaur	310	50	18	17	61	39	63	37

Table 2. Details indicating changes in the occupation pattern of households following mixed farming during 1964-65 in seven villages

District	Total households	Per cent households which did not have the following occupation prior to 1954		
		Cultivation	Sheep/goat rearing	Dairying
Jaisalmer	172	78	9	7
Jodhpur	188	34	32	19
Nagaur	264	38	36	12
Total	624	48	28	13

regions as a whole the above changes are reflected through the following:

For the arid region as a whole, net area put under crops which was 6.6 million hectares in 1951 had increased by 49.5 per cent by 1961. This was the peak period of land-reforms implementations (Jodha, 1966). During the next decade, the area under crops further increased by 13 per cent (Mann and Kalla, 1977). There has been a corresponding decline in the land-use categories described as cultivable waste and barren lands, which are nothing but grazing lands (excluding the very limited designated permanent pastures). The net situation is that in the arid region where only 21 per cent of lands scattered in different parts is suitable for sustained cropping (Jodha and Vyas, 1969), nearly 49 per cent of the area is used for cropping. This figure would rise further if cropped area is viewed in the context of total geographical area excluding areas not available for agricultural use.

Livestock numbered 4,697,000 expressed in animal units in 1951. This had increased by 45 per cent by 1961. They had further increased by 5 per cent during the next 5 years. Correspondingly, the density of livestock per 100 hectares of grazing space (including permanent pastures, cultivable waste, current and bush fallows, barren and uncultivable lands) disregarding its forage potential, has increased from 36 animal units in 1951 to 62 and 67 animal units in 1961 and 1965 respectively (Jodha and Vyas, 1969). The effective density is much more as the animal pressure is concentrated only around watering places which have been turned into barren grassless patches.

THE OPERATIONAL MECHANISM OF DESERTIFICATION

The changes mentioned above are in fact the outcome of the forces operating at and influencing the farm level decisions. The diagnosis of these forces alone can impart the understanding of how the desertification process operates and how it can be controlled. This is attempted using micro-level illustrations.

At micro-level the two forces which induce the farmers to over exploit the land resources base are (i) increased pressure of subsistence requirement. and (ii) apparently enhanced profitability of exploitations of arid lands. The subsistence oriented farmers (including grazier) over exploit the land in their attempt to compensate for the declining per acre productivity by means of expanding production effort on larger units of area both by way of cropping on submarginal lands and reducing periodic fallowing of lands. In the case of livestock rearing too the same approach is followed where number gets priority over quality. The basic reason for the above situation is the rise in the pressure on land following interventions which accentuate and maintain the pressure disregarding the carrying capacity of the resource base. The profit oriented farmers on the other hand contribute to the desertification process through over exploitation of the land resources because, again following certain interventions of institutional nature, the cost of land use has substantially declined and profitability of desert products, particularly animal products has increased by many folds.

Elaboration of these points calls for an understanding of back wash effects of the well intended interventions or institutional and other changes in the arid region. These changes are (i) reduced isolation and increased market integration of arid areas with other areas and (ii) the government's land reforms policies which have completely disregarded the limitations of the land resource base in the region. These two factors have been positively associated with development elsewhere, but in the arid zone their indirect impact has proved more *damaging.*

Effects of improved market infrastructure on arid lands

The first factor which initiated change in the traditional system of farming was reduced physical and marketwise isolation of the arid areas. This had two major implications. (i) It ensured quick relief supplies to arid areas during droughts, and reduced drought distress. Human deaths due to famine became a thing of past. Animal casualties during scarcity years were much fewer. The role of droughts as levellers of pressure on land disappeared. However, relief and resource transfers – being temporary devices for crisis periods – always resulted in subsequently increased pressure on land after every drought. Every intervention in terms of relief, though well intended, by another logic, sowed the seeds for the next crisis with higher severity because it protected the increased pressure on resource base without strengthening the resource base itself. Improved means of communication also helped in betterment of health and medical facilities, which also contributed to population growth as in other areas. (ii) The second implication was increased marketability of and facility to market products of arid areas. Its final impact is reflected in higher prices for farm products (Table 3). This favoured particularly the livestock products and pulses in which arid areas have comparative cost advantages. This imparted market orientation to the farming system and made the farmers profit-minded. This also expanded the market catchment of the products, unlike the system of normally localized demand under subsistence farming. Increased demand and strong profit motives to satisfy it, unaccompanied by simultaneous improvement in production base, could only result in over-exploitation of the resource base.

Impact of land reforms

In Rajasthan State land reforms, particularly abolition of the feudal form of land ownership and village administration, distribution of ownership rights to tenants and landless people and fixation of land revenue rates, etc. were largely completed during 1952-54. Its consequences, relevant to our discussion, included the following:

(i) In the first place land reforms helped the distribution of sub-marginal lands for crop farming and resource exploitative consequences associated with it. As mentioned earlier during the peak period of land distribution the area under crops increased from 6.6 million hectares in 1951 to around 10 million hectares in 1961.

Table 3. Details indicating private cost (taxes, etc.) of land use during the periods before and after land reforms in some villages of the arid region of Rajasthan

(All values as 1976-77 prices)

Particulars	Situation during Pre-land reforms period (1950-51)	Post land reforms period (1964-65)
(A) *Better crop land (chahi)*		
Pearl millet yield (kg/ha) (1964-65)	520	520
No. of times cropped in 5 years	4	5
Land revenue (rent) (Rs/ha)	83	6
(B) *Sub-marginal land (barani)*		
Pearl millet yield (kg/ha) (1964-65)	200	200
No. of times cropped in 5 years	2	3
Land revenue (rent) (Rs/ha)	16	1.5
(C) *Pearl millet av. cost of production (Rs/ha)*	—	285
(D) *Grazing land (gochar)*		
Grazing tax (Rs/animal)	1.25	—
Other livestock related levies/penalties (Rs/household)	23	—
Value of contribution to protection/maintenance of pasture/tank etc. (Rs/household)	18	—
(E) *Animal product prices etc.*		
Wool price (Rs/q)	90	480
Ghee (Rs/kg)	5	18
Milk (Rs/litre)	—	0.60

(ii) Equally important effect of land reforms was drastic reduction in the cost of land use – both for cropping and grazing. For instance according to the tenurial arrangements under feudal system, a farmer had to pay between 25 to 75 per cent of his crop as rent in kind to the *Jagirdar* (feudal landlords), rent alone accounted for a substantial share of cost of cultivation.

The *Jagirdar* also imposed animal grazing tax (*ghas-mari*) and periodic free gifts (*laag*) especially from the owners of bigger flocks of sheep and goat. He imposed severe penalties on graziers for violation of regulations designed for controlled grazing and water use from *Tobas* (tanks), as this formed important source of revenue for him.

With the abolition of feudal arrangements most of the exploitative features of the tenurial system disappeared. Huge rents got substituted by paltry sums of permanently fixed land revenues. Penalties and taxes on indiscriminate animal grazing also disappeared, and despite legal provisions they could not be reimposed by the village *Panchayats* which inherited the functions of village administration. This led to complete disappearance of some items of private cost in terms of contribution of labour etc., towards protection/maintenance of grazing lands, shelter-belts (*matt*), water tanks (*Tobas*) etc.

The final consequence is drastic reduction in the cost of land use for both cropping and grazing (Table 3). Accordingly, on better crop land a farmer paid around Rs 83 per hectare as kind rate (expressed in 1976-77 prices) prior to land reforms. After land reforms he paid only Rs 6 per hectare. On the sub-marginal lands, the corresponding amounts are Rs 16 and Rs 1.5 per hectare. The livestock related expenditure of land use (excluding grazing fee) was Rs 47 per household prior to land reforms, which became zero after the land reforms. Grazing fee also came down to zero from Rs 1.25 per animal earlier. The wool and milk prices on the other hand increased by many folds during the same period, largely due to widened market and better means of transport. Table 3 describes the situation in a cluster of villages in Nagaur district but with minor differences it could apply to other areas too.

To sum up, the reduced physical and marketwise isolation of arid areas and welfare-oriented egalitarian institutional (land-reforms) changes induced a process which accentuated the rate of exploitation of an already deficient and fast-depleting resource base. At micro-level the operating mechanism is as follows:

1. The bulk of people have to manage their subsistence out of a per capita reduced natural resource base of progressively declining productivity. Attempt is made to compensate for lower per unit productivity by spreading production effort on larger units. This is done both by extending ploughing to submarginal lands and reducing the practice of periodic resting of the land, particularly through long fallows.

2. In the case of livestock, they seek security against risk in terms of larger flocks and herds, rather than better quality of animals, as this practice seems to increase the chances of survival of at least some animals during scarcity periods.

3. The role of compulsion to over-exploit resources, mentioned above, is complemented by incentive to over-exploit. The incentive is offered by reduced private cost of resource use in terms of taxation, rents, or contributions through informal institutional arrangements for resource protection. The lower cost compared with improved mrketability and profitability of animal products, further strengthens the tendency to over exploit the resources.

REMEDIAL MEASURES

The reversal of resource exploitation process should start with neutralizing the factors listed above. This calls for a suitable mixture of technological and economic measures to deal with the specific situations.

Control of subsistence related over-exploitation

Broadly speaking, the need for over exploitation of resources for maintaining subsistence can be removed by: (i) defusing the pressure on land; (ii) increasing pressure-absorption capacity of the land.

The former can take place either through permanent population transfers to other areas or through promotion of non-agricultural vocations. However, the scope for spatial migration hardly exists in an over populated country like India. In view of the non-congenial environment for loose-foot industries in the region, the scope for occupational migration within the region, is fairly restricted, unless agriculture prospers and sustains stable agro-based industries. Thus, in the near future, unless agriculture itself develops the pressure defusing options are almost non-existent.

Regarding the pressure absorption capacity of the land the provision of irrigation is the key requirement. However, notwithstanding the ambitious Rajasthan Canal Project, which on completion will irrigate 1.3 million hectares, the bulk of the arid zone will have to depend on low and uncertain rains.

Technological options

This leads one to search for technological options which can work under low and uncertain rainfall situation to ensure higher production from smaller areas. The CAZRI has evolved various devices to increase and stabilize the productivity of grazing lands and crop lands. If this objective is achieved, the compulsion for over-exploitation of resources will weaken. Measures include stabilization of sand dunes, regeneration of range lands through reseeding, ridges and contour trenching, etc., creation of shelter-belts, micro-wind breaks, and a number of additional moisture-conservation measures, various agronomic practices, use of high yielding and drought resistant crop varieties, etc.

However, the technological options generated by scientists for low rainfall areas are faced with two constraints.

(i) *Complementarity of seed-centred and resource centred technologies*

In view of the adverse environmental conditions, particularly low and unstable moisture, the seed-centred technologies cannot yield to their full potential in arid conditions unless soil-moisture conservation devices are adopted simultaneously. This applies to both crop lands and pastures. The adoption of total package involving both types of technologies add to the costs which the farmer with very narrow time horizon and limited resources cannot associate with returns he gets from them. This makes the cost factor a major deterrent to adoption of new technology in arid areas. This calls for generation of low cost technology and also provides justification for subsidies for resource development under schemes like DPAP.

(ii) *Individual vs. group centred technology*

As mentioned earlier, most of the resource conservation measures ranging from sand dune stabilization and contour bunding to controlled and regulated grazing, cover more than a farm or even a village depending upon their catchment. Thus to a greater extent the resource conservation and management technologies for arid areas are group centred. Hence, their adoption is hard to come especially in view of farmers' and graziers' present approach of over exploiting common resource for private gains. Hence a need for some institutional arrangements to ensure collective action on the part of the beneficiaries of new technology. However, such group action is difficult unless the technology is profitable to private individuals to begin with.

It may be noted that increased resource productivity cannot permanently keep the pressure on land lower than its carrying capacity. Higher the productivity greater will be the temptation to over-exploit it unless necessary fiscal devices such as progressive taxation on land use are adopted to ensure resource use within the limits.

Control of profit-related over-exploitation

Reduced cost of land use and increased profitability of products, as mentioned earlier have greatly accentuated the resource exploitation. Regulation of resource use through fiscal measures is a well established part of state policy. However, this has never been tried in the case of arid lands in Rajasthan. As indicated by Table 3, land revenue is the only tax paid by the land user now. This tax is rather an ownership tax and it is in no way related to the rate of exploitation of the resource capacity. Moreover, for use of public lands (for grazing) there is no tax at all.

Though there is no justification for raising land tax to the old level of feudal rents as even the irrigated farms are not taxed that heavily at present, yet there is a clear case for taxation linked to the extent of land use for cropping and grazing.

For operational convenience the progressive taxes could be based on the number of grazing animals, or income from land use as these are broad indicators of the extent to which one benefits from exploitation of the resources. Tax rebate may be given to those who adopt conservation measures. To neutralize the non-egalitarian implication of taxing, users of arid lands who are already poorer' than farmers in irrigated areas, arrangements may be made to reinvest the revenue from these taxes for the development of arid lands themselves.

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IV. 0.3

SOCIO - ECONOMIC CONSEQUENCES OF DROUGHT IN AN ARID TRACT - A CASE STUDY

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INTRODUCTION

Droughts in arid regions cause large scale socio-economic distress causing deviation of the normal pattern of behaviour. Various earlier (Famine Commission Reports, 1880, 1901; Erskine, 1909) and recent studies (Swaminathan, 1972; Singh, 1975; Jodha, 1975; Mann *et al.*, 1977) have been undertaken on droughts in arid and semi-arid regions from various angles. All these studies are mostly centred around the definition of drought, its effects, causes, prediction, relief measures and policies.

The present study was taken up in the context of the local stresses, social structure and economic effects in Shergarh *Tehsil*–a true representative of an arid area of district Jodhpur in Western Rajasthan. The study attempts to analyse the nature and extent of the area, villages and population affected; social changes including social and economic values; disturbances in agrarian sector – land use changes, area sown, crops grown, predominant subsistence oriented cropping pattern, decline in productivity and crop produce losses and changes in livestock. The nature of the years was determined on the basis of rainfall; extent of area, villages and population affected; and area harvested (expressed as *Zamana* in terms of percentage maturity of *kharif* crops).

FINDINGS

Drought and population affected

Rainfall data for the past 78 years (1899-1976) revealed that out of 78 years, 8 years (approximately one in ten years) were surplus years witnessing cent per cent *Zamana;* 43 mild drought years with hardly 50 per cent *Zamana,* 19 drought years with 25 per cent *Zamana* and 8 disastrous years with zero crop maturity. Droughts stimulated migration; people accompanied by their flocks and herds emigrated to Gujarat and Malva.

Human and livestock mortality varying from one-third to one-half occurred during the famines of 1812-13, 1868-69, 1877-78, 1991-92, 1899-1900, 1939-40, etc. The magnitude and intensity of drought revealed a quite distressing situation during the last decade of 1964-65 to 1975-76. On an average, annually over 40 per cent of the area, villages and population were directly affected by droughts. The decade witnessed two disastrous years of 1968-69 and 1969-70 and two severe drought years of 1972-73 and 1974-75 affecting the whole of *Tehsil,* spread over an area of 3812 sq km, inhabiting 1.35 lakhs population in 92 villages. The years 1964-65, 1967-68, 1971-72 and 1973-74 were mild drought years; 1965-66, 1966-67 average years; 1970-71 and 1975-76 good years.

During drought years, cent per cent area, villages and population were affected, a moderately drought year affected 26 per cent of the total population occupying 28 per cent of the villages in 18 per cent of the total area and a surplus year of good *Zamana* had also affected about 10 per cent of the total area, villages and population (Table 1).

Table 1. Comparison of mean annual area, villages and population affected during drought, moderately deficit and surplus years (1964-65 to 1975-76)

Nature of year	Mean annual parameters affected			
	Rainfall (mm)	Area affected (sq km)	Villages affected (No.)	Population affected
Drought year	71.05	3,812	92	1,35,654
Moderately drought year	181.44	718	26	35,572
Surplus year	318.50	396	11	17,418
Mean	190.33	1,642	43	63,214
Per cent of total	—	43	47	46

Drought and social changes

Recurring droughts and famines brought changes in the nature and extent of the socio-economic values and attitudes. Increased sense of cooperation was observed during migration of human for livelihood; livestock for grazing, night camping, security and defence of livestock and for construction of roads, *tankas, nadis* and relief centres.

The rigid caste and communal distinctions which normally become stratified in normal year broke down under the pressure of drought (Table 2).

Due to frequent droughts, life cycle ceremonies, religious and agro-pastoral (sowing, harvesting, shearing) and festivals received decreasing importance and attachment towards land decreased. Per household mean annual area sold decreased from 8.69 ha in good year to 8.60 ha in drought year and its value from Rs 326.55 per ha to Rs 298.55 per ha during the respective periods. Agriculturists having completely dependent upon lands were more adversely affected than non-agriculturists who had diversified economic base also. *Jajmani* and *Aat* system (traditional mode of payment

Table 2. Comparison of changes in socio-economic values and their importance in drought and good year

Values	Drought year		Good year	
	Change*	Importance**	Change	Importance
Social values				
i) Caste rigidity	2	2	1	1
ii) Education	2	2	1	1
iii) Social solidarity	1	1	2	2
iv) Social participation	2	3	1	2
v) Symbiotic relationship	2	2	1	1
vi) Socio-religious ceremonies	2	2	1	1
vii) Traditional occupational rigidity	2	1	1	1
Economic values				
i) Attachment towards land	2	2	1	1
ii) Attachment towards livestock	1	1	2	2
iii) Occupational diversification	1	1	3	3
iv) Traditional stocking of assets	1	1	1	1
v) Relief measures	1	1	2	3

*Change in values	*Codes*	**Importance	*Codes*
Increase	(1)	More important	(1)
Decrease	(2)	Less important	(2)
No change	(3)	Not important	(3)

in kind or cash in lieu of services rendered) decreased affecting adversely the economy of the servicing and occupational castes.

DISTURBANCES IN AGRARIAN SECTOR

Land use changes

Impact on land use was analysed during the drought, moderately deficit and surplus years (Table 3).

Table 3. Comparative mean annual land use characteristics in drought, moderate drought and surplus year

Land use category	Mean annual area in 000' ha (per cent of total)		
	Drought year	Moderate drought year	Surplus year
Culturable fallow	155 (40.7)	97 (25.5)	113 (29.6)
Net area sown	181 (47.5)	239 (62.8)	224 (58.7)
Unirrigated cultivated	180 (47.4)	239 (62.8)	223 (58·4)
Degenerated	192 (50.5)	135 (35.4)	150 (39.3)
Per capita cultivated land (ha)	1.34	1.77	1.66
Per household net area sown (ha)	7.94	10.50	9.81
Per capita cultivable fallow land (ha)	1.14	0.71	0.83

Droughts lead to increase in area under culturable fallow and degenerated lands. Increase in fallow lands reduced net area sown from 58.71 per cent (surplus year) to 47.53 per cent (drought year).

Area Sown

As an impact of drought on dry land agriculture, changes occurred in the nature and extent of the area sown, damaged, matured and crops grown (Table 4).

Significant relationship exists between the nature of the year and area sown. On an average annual unirrigated area sown decreased from 224 thousands ha (66.6 per cent of the total cultivable area) in a surplus year to 181 thousand ha (53.7 per cent of the total cultivable area) in drought year. Moderately deficit and surplus year revealed no significant difference in the extent of area sown.

Positive correlation was found between the intensity of drought and extent of area damaged. On an average, annual

Table 4. Comparison of total and per household mean annual area sown, damaged and matured during drought, moderately deficit and surplus year

Category	Mean annual area (000'ha)			Mean annual area (ha) per household		
	Drought year	Moderately drought year	Surplus year	Drought year	Moderately drought year	Surplus year
i) Area sown	181	237	224	7.9	10.4	9.8
ii) Area damaged	181	77	—	7.9	3.4	—
iii) Area matured	—	159	224	—	7.0	9.8
iv) % of ii) to i)	100.0	32.6	—	100.0	32.7	—
v) % of iii) to i)	—	67.3	100.0	—	67.3	100.0

area damaged under crops increased from 77 thousand ha (32.6 per cent of the total area sown) in moderately deficit year to 181 thousand ha (100 per cent of the total area sown) in a drought year.

On an average, annual area matured under crops increased from nil in drought year to 159 thousand ha (67.3 per cent of the total area sown) in moderately deficit year to 224 thousand ha (100 per cent of the total area sown) in surplus year.

Crops grown

As an impact of drought, almost all the rainfed crops were vulnerable to adverse effect as cent per cent of the area sown was damaged during drought year. During moderate drought year, 40.34 per cent of the total area sown under *bajra* was damaged followed by *moth* (38.36 per cent), sesamum (34.49 per cent), *moong* (30.0 per cent) and *jowar* (8.62 per cent). Irrigated crops like wheat, gram, *sarson* were not damaged during moderate drought years. Irrespective of the nature of the year, cultivation mainly for cereals has expanded very fast in the tract where the crop maturity is extremely uncertain and the yields very low, due to the population increase.

Decline in productivity and production losses

Mean annual yield of various crops decreased during drought year as compared to moderately deficit and surplus year (Table 5).

The mean annual yield of *kharif* crops decreased ranging from 90 per cent to 100 per cent in a drought year and 30-66 per cent in moderately deficit year as compared to a surplus or good year. Considering moderately deficit year as an average year in the region more than half of the crop yield is reduced annually as compared to a good year.

Table 5. Mean annual yield (kg/ha) of *kharif* crops

Crops	Drought year (1)	Moderately deficit year (2)	Surplus year (3)	per cent decrease (3-1)	per cent decrease (3-2)
Bajra	21	175	412	95	57
Jowar	7	66	194	96	66
Moth	25	200	289	91	31
Til	—	106	261	100	59
Moong	—	50	100	100	50
Fodder	70	605	1515	95	60

On an average, a household during a drought year suffered a loss of 130 kg of food grains amounting to Rs 133/- constituting more han half of pulse crop (*moth*, 58.72 kg). In moderately drought year the loss increased to about 620 kg of food grains, amounting to Rs 600/- including *bajra* (393.47 kg), *jowar* (negligible), *moth* (229.68 kg), *moong* (negligible) and *til* (1.00 kg). Fodder crops (*chari bajra, chari jowar,* and *chari guar*) during moderately deficit year, matured fully and there were no losses on account of it. Drought affected the fodder crops badly.

Effect on livestock (Table 6)

Scarcity of water and fodder sources as an impact of drought lead to livestock hazards which include over and irrational utilization of water and grazing resources, damage to culturable lands, migration and mortality. In the past, emigration effect of famine on livestock revealed that in 1868-69, 9/10ths of cattle died in migration; in 1891-92 and 1896-97, $\frac{1}{5}$ of cattle died and in 1899-1900, $\frac{3}{4}$ths cattle died. In the famines of 1902-03, 1918-19 and 1919-20 quite a number of human deaths occurred during and after the famines. During 1939-40 famine, mortality of cattle, buffaloes, sheep and goats was 50 per cent, 24 per cent, 41 per cent and 17 per cent respectively.

Villages grazing resources like *Orans, Nari Ka Agor,* fallow lands and harvested fields were affected adversely by traditional conventional grazing methods. Droughts lead to exhaustion of their previous fodder stocks; force borrowing or purchasing of fodder; disposal of personal assets—land, livestock, ornaments and finally migration.

On an average, about 90 per cent of the total livestock @ 89 sq km and a household having 15 livestock units @ 2.7/capita is affected during the drought period. Mean livestock decreased from 380 thousands in 1961 to 305 thousands in 1966 giving a net decrease of 19.7

Table 6. Livestock affected in drought year in Shergarh Tehsil

Year	Total (000')	Number of livestock affected per unit			
		Sq km	Village	Household	Capita
1968-69	305	80	3318	13	2.7
1969-70	297	78	3223	13	2.6
1972-73	379	99	4123	17	2.8
1974-75	379	99	4123	17	2.8
Total	1360	356	14787	60	10.9
Mean	340	89	3697	15	2.7

per cent and in 1972 the number further increased to 379 thousands. Significant decrease occurred in the cattle (49.8 per cent), buffaloes (61.9 per cent) and sheep (4.4 per cent) while there was an increase in goats (34.8 per cent) and camels (38.5 per cent) in the tract during 1961 to 1972. Thus, drought affected cattle adversely decreasing its composition from 23.3 per cent to 11.7 per cent and goats favourably increasing its composition from 37.9 per cent to 57.2 per cent of the total livestock in the area during the period of 1961-72.

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WELFARE AND WANDERERS - THE ORGANISATION OF SOCIAL SERVICES FOR PASTORALISTS

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INTRODUCTION

Pastoral areas[1] and pastoralists occur in countries of very different economic and political structures, with corresponding differences in the organisation of their pastoral sectors. Yet inspite of differences in national, economic and political structure, in climate and in topography, there are remarkable similarities in the way in which the provision of social services is organised in pastoral areas in different parts of the world. It is unlikely that these similarities are purely fortuitous. Rather they show that the nature of pastoral areas, and of pastoral forms of landuse, presents special problems and requirements for the provisions of social

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[1] Areas of natural vegetation in arid and semi-arid regions which are used for livestock production on an extensive basis. "Pastoralists" are those who spend most of their time and derive the greater part of their livelihood from extensive livestock production; and the term includes nomads, semi-nomads, transhumants and sedentary livestock keepers.

services which can override other considerations.

Those concerned with the ecological management of pastoral areas and those with a responsibility to provide social services have often worked quite independently of each other. There are, however, important interrelationships. Some of the technical and managerial innovations that can improve the productivity of rangelands require a more educated and healthy population. A more healthy population, however, will have a higher rate of natural growth than is found currently among many pastoral populations. To cope with this growth, and, even in its absence, to raise per caput incomes within the pastoral sector, emigration from pastoral into non-pastoral occupations is needed. If these emigrants are not to occupy the most miserable and vulnerable positions in their national societies they need to have received an education that will fit them for something higher. At the same time parents in pastoral societies may be reluctant to send their children to school unless the education provided also has some relevance to life within pastoral society.

NATURE AND CONTENT OF PRIMARY HEALTH AND EDUCATION SERVICES

Health, in the context of this paper refers to only what is called "primary health care", about which there has been considerable debate in recent years, especially in respect of what should be provided in the rural areas of developing countries. It follows the recommendations of the recent joint study by UNICEF and WHO which proposed that primary health care should include: sufficient immunisation; assistance to mothers during pregnancy and at delivery; post-natal and child care; advice, where acceptable, on family planning; adequate safe and accessible water supplies; sanitation and vector control; education in health and nutrition; diagnosis and treatment of simple diseases; first aid and emergency treatment; facilities for referral to higher grade or more specialist facilities. This list errs on the side of over-inclusiveness and clearly priorities will have to be set that reflect local circumstances.

There has been some speculation on whether the health problems of pastoralists, and especially of nomadic pastoralists are different from those of neighbouring cultivators. Lack of adequate health services to either set of communities, and hence lack of data, prevent firm conclusions. It is believed that nomads may suffer relatively more from anthrax, brucellosis, rabies, hydatic cysts, tuberculosis and other bronchopulmonary diseases, some gastro-intestinal infections, wounds and injuries, and, possibly, venereal diseases. They appear to suffer relatively less from cardio-vascular and mental disease, epidemics and pandemics (e.g., malaria, typhus, smallpox). Except at times of acute or extended drought they seem to be less subject to malnutrition, and especially to protein-deficiency. They appear, however, to play an important role in the re-importation of diseases such as malaria and smallpox into regions previously cleared of these diseases.

Many people believe that in future education should be much more concerned with preparing people for the environment in which the majority of them will actually live, and less with the academic preparation of that very small proportion who will eventually follow occupations for which academic achievement is desirable. Others believe that such occupation-oriented education ill conceals discrimination against rural people and a desire to keep them in their proper place both physically and metaphorically.

Many of the factors and difficulties that influence the appropriate way of providing ("delivering") primary health care also influence the appropriate way of providing primary education. There are also, however, major differences in the nature of the administrative requirements of the two services. The differences between the two services do not, however, appear to vary very significantly in relation to whether the community served is pastoral or not.

The delivery of primary health care and education services can be organised, as well shall see in more detail later in the paper, in a number of different and alternative ways. Schools may be day or boarding, single - or multi-teacher, static or mobile. The same, by and large, applies to clinics. We need some criteria for judging the appropriateness of the organisational form selected. This paper is not the place for considering the more fundamental objectives of health and education policy. It will be assumed that these are known and agreed, and that we are concerned only with the efficiency of our progress towards meeting them. In terms of organisational efficiency we need to consider:

a) *Cost-effectiveness* (Maximum cover for a given cost to the supplier of the service, or least expenditure for a given degree of cover).

b) *The extent of cover* (e.g., per cent of all children attending primary school).

c) *The equity of cover* (Do the poor get equal access, e.g., to midwives, as the rich?).

d) *The quality of the service* (Do the children at school learn to read? Do the sick recover? Is infant mortality reduced?).

e) *Convenience for the clientele* (minimising the cost to them, in terms of money, time, and other resources, and the disruption of their lives, of using the services).

f) *Administrative viability* (Will the programme go from strength to strength? Or will it, when the initial impetus is exhausted, tend to fade away due to demoralised staff, inadequate political support, and excessive budgetary and administrative demands?).

These criteria are not quite independent of each other. Clearly there are close links between cost-effectiveness, quality of service and administrative viability. The links between them are sometimes such that not only *may* the criteria conflict but that they have an inherent *probability* of doing so. It will be easiest to minimise the unit-cost of schooling or health care if static schools and clinics are located only in areas of dense population where classes are always full and dressers work at least eight hours a day. The consequence of emphasising the importance of cost-effectiveness will be that members of small, isolated, or dispersed communities will not have access to the services unless they happen to be rich and can board their children or wives with relatives or at hostels in the towns where facilities are located. One can usually improve the cost-effectiveness for the supplier of a service by shifting the burden on to someone else, thereby decreasing, for example, convenience to the clientele; but at the same time this shift may also improve administrative viability. Mobile units, or ones in isolated areas, can be established but they are difficult to supervise or supply. The consequence will be that drugs and exercise books run out and the standard of teaching and treatment decline. There is a constant need to trade off achievement in terms of one criterion against that of another.

It would be intellectually neat if a single criterion of administrative efficiency could be designed which would incorporate these other criteria and give an unequivocal answer to the question as to whether a particular method of organising delivery of health or education is more efficient than another one. Such an all-embracing criterion would be analogous to the quasi-algebraic formulae for cost-benefit analysis recommended by appraisal economists, that can evaluate all the effects (in the light of a multiplicity of objectives) of a proposed project in terms of a single criterion (net social benefit) expressed in monetary value. However, such all-embracing criteria can obscure more than they enlighten, and it may be preferable not to combine the different criteria in a single one but to present the result of the different criteria separately but simultaneously in a "decision matrix". Such a decision matrix, in our case, might look as shown below (The values shown are ILLUSTRATIVE *only*).

While the eventual choice of organisational form remains "subjective" in the sense that one has to decide, for example, whether "excellence" in terms of one criterion is more or less valuable than excellence in terms of another, such decision matrices, which can be as complex as one wants to make them, do enable considered choices to be made rather than purely intuitive selections that simply ignore all criteria, or decisions which are based *solely* on one criterion to the exclusion of the rest. They have the advantage over single all-inclusive criteria that they are a good deal easier to

Organisation form	Criterion of efficiency					
	Cost-effectiveness	Extent of cover	Equity of cover	Quality of service	Convenience to clientele	Admin. viability
Static day school	Excellent	Fair	Fair	Good	Poor	Excellent
Static boarding school	Poor	Poor	Poor	Excellent	Fair	Fair
Mobile day school	Good	Excellent	Good	Fair	Excellent	Poor

comprehend, and they therefore widen the circle of people able to take part in making decisions without first having to undergo special training.

Special problems in providing social services in pastoral areas

The provision of health and education in rural areas in developing countries is almost always more difficult than in urban. In comparison to the generality of rural areas, pastoral ones suffer disadvantages to an even further degree. The density of the human population within them is generally low and communications, due to this low density and to unfavourable topography and climate, are undeveloped. The pastoral population in these areas tends to move from place to place in a more or less unpredictable way; and, to the extent that it is grouped in clusters or communities at all, it tends to be composed of groups that are smaller in size than are needed to support (in the sense of providing the clientele of) the lowest, field-level, units of the social services (e.g., primary day schools and out-patient clinics) at minimum cost when these follow conventional lines. Moreover, the composition of such human groups as there are tends to be unstable over time. The consequences are that when *static* services are provided attendance at the facilities tends to be low, and less than full use is made of buildings and staff, with corresponding high overhead costs per head of population served. Where *mobile* services are provided the transport costs involved are high both when expressed per kilometre travelled and, more particularly, per person served. With both static and more especially with mobile facilities, supervision and supply of necessities (staff-salaries, drugs, books) tend to be expensive and difficult.

Superimposed on these more physical problems are more psychological ones. In pastoral areas life is frequently hazardous, both for ordinary pastoralists and for others such as employees of the social services and tradesmen, due to banditry, inter-tribal raiding, wildlife and thirst. These real hazards are further magnified in the imaginations of those staff of the social services who have been posted in from other areas. Often a cultural and linguistic gap exists between, on the one hand, technicians, administrators and professionals who man and direct the social services and, on the other, the lowest levels of staff and the population served. As a consequence trained and qualified staff are usually particularly reluctant to serve in pastoral areas both because of their own feelings of isolation and insecurity, and because their wives and families may refuse to accompany them there. Special, and therefore costly, allowances and facilities may be necessary to attract and retain staff; but inspite of these extras their morale tends to be low and turnover high. Even inspectors and supervisors avoid visiting pastoral areas. Where staff are recruited from within the ranks of pastoral society they may not respond to the normal techniques of staff-management applied by their supervisors. Where staff are outsiders they may be indifferent to the community's criticism of their work. All these factors tend to lower the quality of performance by staff at their jobs.

The hazards of pastoral life result in irregular attendance by pastoralists at schools and clinics. The cultural and linguistic gap may also, at any rate initially, depress demand for services. Teacher and parent, medical dresser and patient may have no common language for communication; and the private style of life and behaviour of the staff may disgust and alarm the potential clients and their families. The content of both health and education services may have, and, yet more effectively, may appear to have, little relevance for pastoral life.

Responses to the problems of providing social services

Some of the particular problems of pastoral areas will remain permanent and inevitable features, while others, such as linguistic and cultural barriers, may fade with the passing of time. In many countries very little effort has been made to provide any health and education services to pastoralists; and where an effort has been made, the most common response by the suppliers of social services (governments, charitable organisations, individuals) to the special problems of pastoral areas has been to ignore them, and to treat pastoral areas as though they are the same as other rural areas. This has thrown the burden of responding to the special problems on to the pastoralists themselves, only some of whom have been able to surmount them, while the majority have, in effect, been denied access. As a consequence, rates of literacy and vaccination coverage have been generally far lower among pastoralists in developing countries than among other parts of their rural population who themselves fare less well than their urban compatriots.

Where the education and medical services have tried to tackle the special problems of the pastoral areas they have tended to do so in five main ways:

a) By resettling pastoral communities in relatively high-density settlements of a size large enough to support conventional field-level social service units.

b) By providing social services of a kind that are conventional in all respects except their greater mobility (e.g. flying doctors, landroverborne dispensaries, travelling catechists).

c) By providing residential facilities; e.g. boarding houses at schools or overnight accommodation at clinics, which are otherwise of a conventional kind.

d) By providing special transport services to the clientele so that they can visit the social service facilities, or by locating these facilities on existing public transport routes.

e) By recruiting staff for the social services from the community concerned, even if they are not as well qualified or trained as could be obtained from other sources, in order to have more contented staff and ones with a better rapport with the community.

Only in rather few cases have the providers tried to adapt the nature of the services provided, as opposed to the way in which they are provided, to the special circumstances of pastoral areas.

Population density, mobility, and experience with pastoral education

Clearly there will be underlying factors that tend to favour or inhibit particular organisational responses. For example, the more developed a pastoral area is in terms of road communications, and the wealthier the pastoralists, the more likely it is that the clientele can be brought in to visit static social service facilities. Conversely the poorer the people, and the less developed the public transport facilities, the more necessary it will be to take the services out to the people. One factor that is likely to be critically important, and which tends to be overlooked in general discussions of settling nomads, is that of population density; and one needs to distinguish between the problems arising from the low *density* of the human population and that arising from its *mobility*. Where soils, aridity, or other factors require that the method of exploiting the environment should be by the grazing of domestic livestock on natural vegetation, then the low density of human population that is consequent on the low productivity of this form of land-use can provide a constraint on the provision and use of conventional social services that is quite independent of additional problems caused by mobility (nomadism).

We can now consider the effect that *mobility* (i.e. transhumant or nomadic pastoralism) will have on the constraints set out in the previous section of the paper. One way for the education system to cope with mobility is for the school to be stationary but to provide boarding facilities for the children of mobile pastoralists. Boarding schools for the children of pastoralists, even at primary level, have been, or are being, successfully used in Mongolia, USSR, Niger, and Kenya, just as examples. But this solution may not always be viable; for example, because children's labour is required daily at certain times for milking or herding tasks; because parents do not believe that formal education contains enough practical training for future pastoralists and wish themselves to be able to give additional daily instruction; and because of cultural or religious inhibitions against sending children, and especially girls, away from home. But if a boarding education is acceptable on other grounds it may still be ruled out on grounds of cost. Boarding education both in pastoral areas in Kenya and at private schools in Britain tends to be at least twice as expensive as day education. The same appears to be the case at boarding schools for shepherds' children in arid areas of the USSR. Education at boarding school in Tanzania also cost about twice the amount per child as did education at the same grade in day school. The annual boarding fee at primary school charged in Kenya Maasailand per child is (early 1970s) about 15 per cent of the average Kenyan agricultural family income (including subsistence); and the local government subsidises this with an amount equivalent to about a further 40 per cent of the same income. If, on average, about one in every two families has one eligible child (i.e. of appropriate age), this would indicate that if all eligible children went to boarding school it would cost about 25 per cent of the total income of the community concerned; and this only for the boarding element of the cost of the first 4 years of primary education. Even if high "boarding fees" are not charged, boarding schools may well tend to attract the sons mainly of the influential and wealthy; and a decision to change from emphasis on boarding education toward day education in pastoral areas in Sudan in the 1920s was associated in time with a broadening of the social base of recruitment into schools.

Another way to cope with pastoral mobility is to provide an education which is conventional in other respects, but in which the school itself (staff, children, materials like books, blackboards, desks) and structure (e.g. tent, caravan) is mobile, moving from one watering point or grazing area to another in consonance with movements of the pastoral herd or community. Children then attend daily at the schools returning to their own families at night. Such mobility can, in fact, help to overcome the problem of low human population density which occurs with sedentarised pastoralism previously mentioned. For if the maximum *year-round* capacity is, say, 12 livestock units per km^2 (8 ha per LU), for shorter periods *within* the year it can be much higher provided that the livestock then move to another area. If, for example, shortage of water points in the dry season requires that herds congregate around the same water point for up to 4 months at a stretch, then if the *year-round* carrying capacity is 12 livestock units/km, for this *shorter period* it would be, say, 36 allowing a greater density of the human population and hence an enhanced ability to support a primary day school. Such *mobile* day schools can therefore, be economically viable in less productive environments than can static ones, provided the extra costs associated with mobility (transport of tents, hardship allowances for teachers) can be kept down. Some such system of mobile schools operates at present in the Fars Province of Iran and in pastoral areas of mainland China. But not much detail is known about them. In Sudan, however, in the 1920s it was found possible to locate a conventional static day school at a trible dry-season watering point which the concentration of people and stock there kept fully utilised during the long dry season. Being a monomodal rainfall region with a comparatively short wet season it did not matter that the student-body departed with the herds at the onset of the rains. A general problem with all mobile schools, and with static ones in isolated pastoral environments, is to provide a reliable supply of food to the teacher and his family.

A difficulty, however, with mobile schools is that typically in pastoral societies a pastoral "movement group", defined here as one which moves from one area to another at roughly the same time, is considerably smaller in size than the size of community (c. 330 households) necessary to support a conventional 4-year, 4-class primary school. How much smaller varies from one pastoral context to another. In south west Asia (Turkey, Iran, Afghanistan) there appears to be considerable synchronisation of mass movement from summer to winter grazing areas, probably enough synchronization to allow the period of migration to be treated as "School holidays" and the period each end as "term-time". In much of pastoral Africa, however, movement is both less synchronised and less definite in its direction and terminal points, and the "movement groups" are, I suspect, smaller. But whatever the size of the movement group and however constant its *total* size may remain, membership in terms of individual households tends not to stay constant over time; and these may join, leave, and rejoin at quite frequent intervals. This obviously presents problems in terms of continuity of a child's education.

Where movement groups are too small to provide a full intake to a school organised on conventional lines, an alternative system is one in which a single teacher instructs smaller classes (say up to 25 children each) of mixed ages and following different syllabuses. Stationary schools of this kind are found in isolated farming communities in some developed countries. In Mauritania such itinerant single-teacher schools for children of nomads, with an average, teacher-pupil ratio of 1 to 20, were started by the French Colonial Authorities; and a similar scheme existed in Sudan fifty years ago. For that size of class pastoral movement groups of only 40-50 households may be sufficient to provide an adequate supply of eligible children. However, the already serious problem of obtaining qualified teachers who are happy to teach in stationary and conventional primary schools in isolated pastoral areas, and which would probably be more serious still in mobile *multi*-teacher schools, could prove over-whelming in the case of *single* teacher *mobile* schools. The cultural gap between teacher and community may be too wide and the consequent sense of isolation of the teacher too deep. In both the Mauritanian and Sudanese examples referred to, the selected teachers tended to be close relatives of tribal leaders. This may have alleviated their feeling of cultural isolation, but it also increased the difficulty of effective professional supervision of their work.

A further variation of the "single-teacher" school is the mobile or static "temporary school" which is attached to a community for a limited number of years. During this period it educates a "reservoir" of children drawn from a very wide range of ages. When this "reservior" is exhausted (i.e. the only additional children coming forward for education each year represent the births six years previously) then the school moves on to another community, returning to the first one when the reservoir has filled up again with several years' recruitment. This method also was used in the Sudan, but is clearly going to provide a level of education from which transfer into higher levels will be difficult for many of the children involved since they will be old relative to their academic achievements. Nevertheless such a system may be preferable to one where no education at all is provided; which may be the real alternative.

In both Sudan and in former British Somaliland attempts were made by the education authorities to make use of existing Koranic schools in nomadic tribal societies as a foundation on to which to graft, through retraining of the teacher in subjects such as mathematics and hygiene, a more secular and conventional school curriculum and system. The Somali experiment was reported in the 1950s to have been a moderate success, and these schools still continue, but the Sudanese one was abandoned after a few years, as much because of the opposition of other more conventionally trained school teachers as because of any objective assesment of its merits. In any case, problems of morale and of supervision are likely to loom large in isolated mobile single-teacher schools in pastoral areas. For class sizes under 25 costs per pupil are unlikely to be much lower in mobile day schools than in static boarding schools with class sizes of 35-40. However such mobile schools in sparsely-populated nomadic areas can probably spread education more widely, more equitably, and with less inconvenience and disruption to family life than can either static day or boarding schools. But this is only *probably* so since, as far as I am aware, no serious study has been carried out that would test these very tentative ideas.

Experiences with the delivery of primary health care to pastoralists

As we have seen, experiments in delivering primary education to pastoralists have tended to concentrate on the *form* a delivery, (e.g. mobile versus static schools) rather than on its content, which has tended to remain the same and this is in line with the rather homogeneous nature and demands of primary education. In contrast delivery of primary health care has experimented not only with the forms but also with different contents for different forms and again this reflects the heterogeneous nature and demands of primary health care.

The tendency in the delivery of primary health care, which is not really significantly different in the case of pastoralists from that of other neighbouring scattered rural communities, has been to develop a battery of different and largely parallel but related elements to deliver different parts of the package of primary health programmes. In some pastoral regions some form of mobile service is the only form of primary health care. In the early days after the 1917 revolution in the USSR, so-called "red caravans", which comprised medical and teaching staff as well as other economic services, travelled round visiting the nomads camps in Kazakhstan. In Sudan a camel-mounted medical dresser, equipped with some medical drugs, was employed to follow the migrations of a nomadic tribe. But in many pastoral regions the basic infrastructure still takes the form of a number of static clinics, which are often poorly attended because of the low density of human population in these areas, and therefore the small number of potential clients who live, or are to be found at any one time, within a distance that makes the facility really accessible to them.

A number of attempts have been made to supplement static facilities with mobile, motor-vehicle-borne, clinics or vaccination campaigns. In some cases even airborne facilities are provided. In general such motorised facilities tend to be expensive, with a unit cost some eight to ten times as high as the delivery of comparable health services to non-pastoral people or through static services. However, mobile vaccination campaigns can be effective, but it takes time for pastoralists to acquire confidence in them; and the programme must be adapted to fit in with the pastoralists' seasonal migrations or so as to reach them when they are congregated at dry-season watering places. Although the costs are relatively high it may be the only way in which pastoralists can be immunised. Similarly *specialised* treatment or diagnostic services (e.g. chest screening) can also be effectively delivered in this way, albeit at high costs.

Mobile motorised clinics to provide routine diagnostic and treatment services have also been tried. There is a tendency, connected with their high overall unit cost, for such services to peter out when the initial funds and vehicle have been expended. But a further, and more serious, problem is that, unless they are backed up by some facility for evacuating patients who require continuing or repeated treatment to where they can get it elsewhere, or unless such mobile services are not really "front-line" but supervisory to and supportive of field-level units with a more permanent presence, then the contact between service and client that they appear to make possible may in fact be an unfruitful one.

In a number of countries programmes have been started, usually on a pilot or experimental basis, in which people of quite low educational qualifications are selected from within a pastoral society, given a brief training in health care, and then equipped and appointed to provide primary health care to their own communitties. Such people, popularly often called "barefoot doctors" but referred to in this paper as FLHWs (Front Line Health Workers), have been given a variety of functions. In Somalia their task was simple first aid and hygiene and to act as a first link to refer more serious cases to clinics and hospitals. In northern Kenya their main function appears to be educational, to improve hygiene, but one of the consequences has been a much higher attendance by pastoralists at other health facilities. In Fars Province of Iran the FLHWs selected had received 6 years of primary education which was then followed by one year of health training; and each FLHW serves a community of between 500 and 1,500 people. A rough rule of thumb appears to be that up to 20 per cent of patients seen by an FLHW need to be referred to higher level health workers or facilities; but the FLHWs themselves are substantially involved in curative care for major childhood diseases, delivery of babies, first aid, and dentistry. While exact comparisons are difficult (and it is not clear from the report concerned exactly how nomadic or dependent on pastoralism the communities concerned are) nevertheless such calculations of unit costs as can be made do *not* show a higher level of costs per person in more pastoral than in less pastoral communities.

IV. 0.8

PROBLEMS OF DEVELOPMENT AND TECHNOLOGY TRANSFER IN THE WORLD'S DRYLANDS

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INTRODUCTION

A recent review of obstacles to the development of arid and semi-arid lands (UNESCO, 1977) refers to the extensive research carried out into arid zone problems in the 1950's and 1960's.

Programmes of reclamation and development based on the assumption that continuing research and technological development on present lines must inevitably improve the lot of the inhabitants of the world's drylands and the status of their land systems will probably fail as in the past. Any effective plan of action to combat desertification and establish stable livelihood systems in the drylands must first identify those obstacles that have operated in the past against the successful transfer of technology and design its measures to avoid or overcome them. The obstacles, whether environmental, socio-economic or politico-legal in character, will doubtless differ from place to place, and recognition of the human and physical variety of the drylands is also essential in planning.

Recognition of environmental constraints

Accounts of arid lands problems are commonly prefaced with the statement that the drylands occupy one third of the earth's land surface but support less than one seventh of its population. The drylands are now generally recognized as areas of declining productivity, deteriorating human conditions and settlement retreat, where environmental degradation calls for urgent remedial action.

The major environmental limitations of the drylands, the low and uncertain rainfall, are not likely to be eased by technological developments in the near future. Stimulation of local rainfall through cloud-seeding for which promising results were claimed a decade ago (Gabriel, 1967), has not so far proved to be generally significant in the drylands, and the global scale of the atmospheric circulations that determine zonal aridity indicate that other interventions such as man-made lakes will not diminish regional deficits in precipitation.

Irrigation promises a direct remedy for rainfall deficiencies and mobilises the important compensating climatic advantages of long sunshine hours and high temperatures enjoyed by the drylands. The resulting enhanced productivity makes it profitable to invest in overcoming other natural handicaps such as infertile or poorly-structured soils.

In very large parts of the world's drylands however irrigation will always be limited by shortage of water, by unsuitable terrain and soils, or by lack of capital and the absence of the requisite social, technological and administrative supports. In Western Rajasthan for example, completion of the Rajasthan Canal Project will still leave 89 per cent of the cultivated area fully dependent on rainfall (Mann *et al.,* 1977). It is improbable that the rapid extension of irrigation over the past 25 years will be maintained, and a modest 1 per cent growth has been predicted for the future (Eckholm, 1976). Conversely, irrigation has brought its own problems of desertification, through the waterlogging and salinization of soils, and more than half the 95 million ha now irrigated in developing countries is in urgent need of remedial action on this account.

Over most of the world's drylands therefore, technology development and transfer will operate against the same background of climatic and related limitations and uncertainty as in the past.

Human constraints on development and the transfer of technology

Impoverishment of the human condition associated with diminishing productivity in desert lands urgently affects 50 million of the world's poorest people in the poorest countries; that these people generally occupy the most poorly endowed areas of greatest drought hazard; and that most of them are disadvantaged socially and politically as well as economically, either because of their geographical remoteness from centres of political and economic influence, or for cultural or ethnic reasons. These disadvantages, in addition to lack of local resources, hinder any flexible or multi-optional response to their problems. They now commonly far outweigh any compensating ecological advantages that their traditional livelihoods may once have conferred.

Desertification in its severest forms is the general problem of the developing countries aggravated by aridity and associated hazards. Its impact has been much less catastrophic in technologically advanced and industrialised countries, and somewhat less in those other countries which control rich oil or other mineral resources. Desertification shares the feature common to problems of the developing nations, that the gap between the material status of those affected and that of the better-off communities continues to widen, as does that between the actualities of land use and living standards in the societies affected and those which research and technology development have indicated as attainable.

Principles to guide development and technology transfer

Recognition of the human and physical environmental limitations to development and reclamation of the drylands is a necessary first step in formulating principles that should guide the design of programmes to combat desertification and to establish stable and more productive livelihood systems. Some of these are suggested below, in a sequence that gives first place to the human problems.

Acceptability of the programme to the community affected

The best measure of the desirability of a proposed technological change is the willingness of the local population to adopt it, and community participation has been stressed as a key factor in the United Nations Plan of Action to Combat Desertification. This will depend on many factors, some of which arise from the nature of the proposed measures, whilst others, perhaps more important, arise from the relationship between those measures and the community involved.

Relevance to local perception of the problem

The proposed changes should address problems as they are seen to be important by the local community, and show them to be capable of solution. For example Fonaroff (1963) attributed the failure of soil conservation on Navajo tribal lands in the United States to the fact that the Navajo did not recognise soil erosion as a problem, nor would they in any case have considered it as one that it was possible to solve.

The large-scale social engineering which accompanied the introduction of irrigation and the reform of nomadic pastoral systems in southern USSR, as recorded in the Case Studies presented to the United Nations Conference (Babaev and Nechaeva, 1976), depended for its success on government ownership of land, control of population movements, and the integration of administrative and technical services under the political control of a centralised socialist state. In different social and political settings the smaller community or the individual land owner will be the target of reform, and programmes must be designed to offer incentives for participation at appropriate levels. A wide range of measures is involved, including compensation for immediate loss of income, subsidies or loans to sustain the land-user during the period of establishment of the new productive system, assistance with re-settlement, encouragement and training in the adoption of new techniques or alternative livelihoods, and above all the demonstration of ultimate advantage through trial projects that are seen to be relevant, practicable and profitable for the land manager.

Migration

The drylands have traditionally been areas of out-migration, whether seasonal or permanent, in response to economic pressure at home and to the attraction of employment opportunities in towns and mining settlements within and outside the arid zones. Remittance home of earnings of migrants has become a fundamental part of the economy of many traditional dryland communities. Out-migration has accelerated in recent decades, forming part of an associated growth of cities, where the opportunity of wage-labour for different types of work often appeals across cultural barriers which oppose employment in non-traditional forms of agriculture. Often the source areas have become devitalized through extensive loss of their young labour force, and systems of herding, terrace agriculture and irrigation have commonly broken down, adding to local impoverishment.

Measures to guide and facilitate migration and urban re-settlement are of central importance under these conditions, and it has been proposed that they should receive priority over programmes of population control in most areas (Kates *et al.*, 1977). Priorities in resettlement programmes include housing and welfare services, financial assistance, and above all provision of employment. Where possible, resettlement should maintain the cultural integrity of migrant groups, and housing design should also serve to mitigate the social shock of migration. Education and technical training are also important, because lack of relevant skills is a main obstacle to the employment of the migrant. Community participation is essential if programmes of resettlement are to be reinforced by the maintenance of social identity.

The growth of dryland cities, whilst relieving pressure on surrounding arid lands, creates its own environment problems, for towns can be major instruments of desertification, through their extension into agricultural lands, through competition for scarce resources such as water and fuel, and through the increased traffic on their perimeters. They pose special problems of waste-and sewage-disposal and of atmospheric and soil pollution under the prevailing conditions of climate and drainage. The environmental impact of such towns calls for special attention in development programmes, including measures to control movement in the urban perimeters through the provision of paved roads and fences, and strict protection of vegetation in the surrounds.

Local resettlement

Within the drylands there is an increasing tendency for formerly dispersed rural populations to concentrate in nucleated settlements, and for the smallest hamlets to decay with the growth and extension of the range of larger service centres. In many areas this is linked with the sedentarization or part-sedentarization of formerly nomadic populations. This development provides its own problems of resettlement, and these in turn are closely linked with that of providing services to populations that are still largely relatively remote and dispersed.

The need for a network of dryland settlements is closely linked with the provision of alternative livelihoods for the dryland communities, to increase incomes and at the same time relieve pressure on the land. Many developing countries are giving priority to the establishment of small rural industrial plants as well as craft-based workshops, as under the Rural Industries Projects programme within the Development Plans of the Government of India (Hogg, 1976).

Since the local land-use options will remain limited by environmental and socio-economic constraints, most initial developments will consist of modifications of existing land-use systems, of an evolutionary rather than a revolutionary type, and in such cases those technological innovations which are most readily adaptable to established usages will be most likely to succeed. This suggests some guiding principles.

Maintenane of ecologically desirable features in traditional land use

The introduction of market outlets into a subsistence farming economy may assist by bringing incentives for increased efficiency and improvement in the quality of product, by absorbing occasional surpluses, and by providing cash reserves against bad seasons or for investment, but the change should be accompanied by safeguards against the neglect of food production for local consumption, the breakdown of systems of communal support, and the weakening of the position of the less competitive members in the local society. Otherwise the result will be the addition of a new vulnerability—subjection to uncontrolled market forces—to pre-existing natural hazards. Similarly, where a network of perennial watering points increases the seasonal range of pasturing, there is a need for corresponding controls to avoid excessive concentrations of livestock and to assist with de-stocking in dry spells. Improvement in the quality of livestock and in its reproductive performance, with higher yields of milk, meat and fibre, should be allied with measures to limit grazing pressure. The reconciliation of technological innovation with the maintenance of environmentally sound traditional practices remains a major challenge to technology transfer.

Establishing environmental limitations to existing land use

Determinations of carrying capacities of rangelands as set by the productivity, phenological requirements and response to grazing of pasture plants under various seasonal conditions constitutes another form of environmental assessment. Such studies will provide strategic information to land-use planners, but recommendations for withdrawal of land from existing uses can be applied to land users only as part of integrated schemes of development which provide alternative resources.

ENVIRONMENTAL COMPATIBILITY OF TECHNOLOGY TRANSFERS

Environmental assessments of proposed technological changes

Many past problems are attributable to the fact that innovations are commonly brought in from higher-rainfall areas on the evidence of successful operation under conditions of lower environmental hazard. Among agricultural innovations of this type is the introduction of heavy tractor-drawn tillage equipment on the friable unprotected soils of dryland fields, a common cause of accelerated soil erosion. The risks are particularly great in industrial and mining developments and in the associated growth of towns in arid settings. Scarcity of water for the removal of domestic and industrial wastes, the slow recovery of desert vegetation on disturbed ground and the resulting dust nuisance, and the high risk of atmospheric pollution through enhanced photochemical activity and the prevalent atmospheric inversions exemplify the environmental problems that can arise.

Determination of the environmental range of technological innovations

It is important to ascertain the climatic limits within which a technological innovation can result in increased productivity. The Case Study presented to the Desertification Conference by Israel illustrated the value of experimentation of this kind in the Negev (Schechter, 1977). For example it was determined that under existing conditions of rain-fed cereal cropping the addition of nitrogenous fertilizers is unprofitable where annual rainfall is below 200 mm, and that the substitution of rotational or continuous cropping for crop-fallow systems is impracticable with less than about 300 mm rainfall. Other tests have shown no benefit in cereal yields from deep cultivation of the land before sowing compared with superficial preparation, and only slight advantage over no preliminary land treatment. It has also been confirmed that native range pastures perform as well as planted forage plants, and that the application of fertilizer on rangelands is not warranted except in important local areas of run-on.

An integrated approach to livelihood systems

Problems arise through the introduction of technological changes in one part only of livelihood systems, whereas its successful implementation requires supporting changes throughout the structure of land management. For example the introduction of heavy mechanical tillage in the absence of conservational practices such as strip cultivation or contour banks has commonly resulted in accelerated erosion of fields in rain-fed farming areas of the drylands. Similarly, the establishment of irrigation without adequate drainage, water control, technical training of farmers etc. has led to widespread waterlogging and salinization of soils. Kates *et al.* (1977) refer to 'an endemic lag in the process of technology transfer, whereby only the central functions in the new technology are transferred, without the necessary complements'.

The reason is that the adoption of a technological innovation, particularly of a mechanical kind, may be relatively easy, and indeed attractive through its promise of labour saving or increased returns, whereas the conservational land management needed to support it usually involves a fundamental change in traditional practices, and comes up against socio-economic and cultural or even legal constraints. The problem is illustrated by the difficulty of introducing deferred or rotational grazing or the limitation of stock numbers to support the introduction of watering points where pastures are used communally by family-owned flocks, or of establishing and managing woodlots of introduced tree species where unrestricted cutting of scarce wood fuel has long been a major daily preoccupation or of removing marginal croplands from tillage where fragmentation of holdings hinders consolidation. Changes in traditional land management are unlikely to be acceptable if seen to be imposed from without, and will not occur until community participation is secured through the changes being perceived as parts of an integrated system of development, preferably with the assistance of demonstration projects.

PRIORITIES IN RESEARCH AND TECHNOLOGY DEVELOPMENT AND TRANSFER

Obstacles to development programmes

The obstacles to be overcome in development and technology transfer will differ in kind at various stages in the planning and implementation of programmes, and this must be allowed for in the strategy and design of the proposed developments.

The first obstacle is that posed by the politicians and civil servants who determine the allocation of resources in the country concerned. In the communities most affected by desertification, initiatives for technological change are certainly beyond the means of the individual land user and commonly beyond that of the community or region itself, and support from national governments is needed. In many new nation states the drylands remain politically disadvantaged, and it will be an important task of the United Nations, through its Plan of Action to Combat Desertification, to influence national governments through its influence over international aid programmes.

The second test is that of securing community participation, and success here will depend on the perceived relevance of the objectives to the social values of the community and on the feasibility of adoption of the proposed technological innovations for land users and householders, as *determined by their cheapness, simplicity* and ease of maintenance, and their appropriateness to the proposed use. Training and extension services, demonstration projects, and the recruitment of community leaders are vital at this stage. Most importantly, the project must integrate technological and cultural changes and include provisions for improvement in health, education and social welfare.

The overriding middle-term criterion is that of economic viability. The initial stage should include a pilot project based on the land and human resources found by inventory survey to be characteristic of the region, and this, like all subsequent stages, should be tested by cost-benefit analysis. Particular care is needed in transferring the experience of a pilot project to the livelihood system at large. The programme should include repeated monitoring of progress in economic and social terms, and the possibility of periodic review of objectives and methods. As already indicated, due consideration must be given to limitations imposed by the physical environment and by available human resources, and these caution against over-ambitious programmes. Nevertheless the investment called for will generally fall beyond the regional resources, and in many developing dryland countries will exceed the national capacity. Foreign aid requirements of the Sahelian countries alone have been estimated at $9 billion for the period 1975-2000 (Kamrany, 1977).

Ecological considerations, although probably dominant in the long term, are not likely to prevail among the considerations that determine priorities between programmes. They may in fact appear to be at odds with the criteria of human welfare. Many of the case studies presented to the Desertification Conference have stressed that land improvement schemes to combat desertification should first concentrate on those less degraded areas that show the best prospects for restoration and rapid and profitable recovery, whereas humanitarian considerations must generally accord priority to the most depressed and most vulnerable populations. It is not suggested that sound ecological principles are irreconcilable with social considerations; nevertheless, where human needs and environmental considerations are in immediate conflict, the former must predominate and some environmental deterioration must be accepted.

This sequence of priorities recommends a two-pronged approach to development. Planning strategy should proceed from the top downwards in that it involves recognition at national and international levels of the special needs of the drylands; on the other hand, the successful implementation of development plans and the adoption of technological innovations will be dependent on action from the bottom upwards, because they involve the creation of incentives and capabilities at the level of the community and of the individual land user.

Priorities in research

A current review of trends in research and in the application of science and technology in the arid zones indicates the following stages of applied research into zonal problems over the last few decades:

- a dominance of fundamental research in such fields as meteorology, hydrology and plant physiology, exemplified by publications in the UNESCO *Arid Zone Series* between the late 1950's and the mid-1960's;
- a development of concern with the ecological impact of land use in the drylands, particularly in relation to the natural vegetation, as evidenced in the Man and the Biosphere Programme of UNESCO from the early 1970's;
- a growing current interest in the stability and productivity of land-use systems, as recorded in technical reviews of problems of reclamation and development in the drylands, notably in the drought-stricken Sahel (UNESCO, 1975).

This constitutes a logical trend, with increasing focus on the problems of human existence in the drylands, but the gap between research and its implementation in livelihood systems has nevertheless continued to widen. The United Nations task force referred to at the outset stressed the need for applied research in the social sciences in order to close the gap, a need which received less than its due emphasis under the Plan of Action to Combat Desertification affirmed at the United Nations Conference. Among many topics which present themselves in this field, two appear to be particularly relevant.

Identification of indicators of social condition

The priority accorded to human considerations in the choice and design of reclamation or development programmes in dryland regions raises the need for social indicators which might give early warning of deterioration in human conditions and also serve as a basis or monitoring the effectiveness of combative measures. The Science Associations' Nairobi Seminar on Desertification, held in conjunction with the United Nations Conference, confirmed this need but disclosed a present lack of agreement on the choice of social indicators and on how to use them in conjunction with physical and biological indicators of desertification.

Linking science and technology with the land user

This important area of overlap of the discipline of the social scientist and the technologist embraces several topics calling for investigation. At the technological margin is the question of strengthening local (i.e., national) science and technology, accorded high priority in the United Nations Plan of Action, as a means of supporting national programmes and as a first link in the chain of adaptation of general scientific and technological principles to specific regional problems. In the field of technical education is the need to train managers at intermediate levels, which the Nairobi Seminar suggested has also been overlooked in the United Nations Plan of Action. Moving closer to the dryland community, there is the need for applied research into means of harnessing indigenous knowledge and traditional skills into reformed livelihood systems, desirable not only in anticipation of their environmental appropriateness, but also as encouraging local participation in an evolutionary process of technological exchange. Finally, and most important, is the need for research into local perspectives of the desert environment and its potential, and of the resulting social constraints on technological innovation within the context of the total livelihood system.

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V. 0.2

THE FUTURE OF ARID ENVIRONMENTS

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INTRODUCTION

The rise of technology has changed the face of the earth. It has led to enormous increases in the possession of material goods and to the squandering of the world's resources at an unprecedented rate. Those natural resources on which we depend are energy, minerals, soil, water, air, plants and animals; but we tend to assess them in an absurdly materialistic way. We regard land that is unproductive in economic terms as being 'wasteland', forgetting that, in its natural state, it may be beautiful, scientifically interesting, or merely the home of native plants and wild animals. There is, therefore, a dichotomy of views among the leaders of the Western world. There are moves among them to exploit the resources of the desert, and counter-moves by environmentalists to prevent the development of the wilderness — neither of which would appear very realistic to the inhabitants of developing nations.

Man and desert have long been intimately related. The desert has seen the genesis of Christianity and the birth of the Moslem religion. It has witnessed savage warfare throughout the ages: it has brought out the worst, and the best of human nature. In his speech before the Battle of the Pyramids in 1798, Napoleon Bonaparte said: 'Soldiers, consider that from the summit of these pyramids, forty centuries look down upon you'. He was not without a due sense of history. The ecologist must also be aware of history, and of evolution, as well as of animals and plants, soil and weather, day and night, summer and winter. For the desert everywhere is expanding at an alarming rate as a result of man's misuse of the environment—through overgrazing by domestic stock, the felling of trees for fuel and bad agricultural practices (Cloudsley-Thompson, 1977a).

It is easy to see that desert encroachment might be checked and degraded lands rehabilitated, but this could take place only if there were strong determination and political stability, since the measures which would have to be adopted would greatly interfere with the daily lives of the people concerned. They include population control, transfer to other areas or activities, enforced emigration and education, as well as control over the use of land and water. Few existing governments would dare tackle such inflammatory issues (Cloudsley-Thompson, 1977b; Rapp *et al.*, 1976).

If it were possible to overcome the political and sociological problems of the arid zones, how could they best be managed? This is the subject of the following paragraphs.

THE DESERT AND ITS RATIONAL EXPLOITATION

Complex problems seldom respond to simple solutions. From an ecological viewpoint, the best prospects for the arid regions of the globe lie in multiple land use — a view that has been expressed on many occasions — for the central problem is to find and maintain a balance between human needs and the sustainable productivity of the land. Throughout history, man has consistently reduced the productive capability of arid lands through over-exploitation. Yet, by multiple land use, considerably greater returns might have been achieved without damage to the environment. Rational exploitation of the desert must therefore be based not on single, large-scale projects, but on a multiplicity of smaller schemes, each one complimenting the others (Cloudsley-Thompson, 1977a).

Nomadism

Pastoralism is clearly a major cause of desert expansion and cannot, therefore, be advocated as a form of land use in desert regions except under strict control and supervision. Nomadism, as practised in the Sahara, the deserts of the Middle East, and in Central Asia, on the other hand, is a remarkably efficient adaptation to the vagaries of the desert climate. There is nothing random about the migrations of the nomads in the Sahel savanna belt of Africa, for instance. The dry season finds them as far southward as they can go without entering the region of the tsetse fly. Here their cattle graze the stubble remaining from the crops of the sedentary farmers and, at the same time, manure the fields. In return, the nomads receive millet (*dura*) from the farmers. With the first rains, however, the grass springs up and the herds then move northward in search of fresh fodder. The migration continues until the northern edge of the Sahelian rain belt is reached, and then the return to the south begins anew, the cattle grazing the grass that grew up behind them on their northward journey (Wade, 1974). The traditional migration routes and the amount of time a herd may spend at any particular well are governed by rules worked out by the tribal chiefs. In this way, overgrazing and conflict are avoided.

Although the nomadic mode of life is probably the only one that will ever produce protein from arid desert regions, governmental policies towards nomadism are usually unimaginative and unenlightened, and appear to be directed chiefly towards the settlement of the nomads. It would be better for all concerned if the nomads were encouraged and their way of life modernised. The hardships they endure could be ameliorated by a flying doctor service, mobile markets, and practical educational facilities. Grazing might be further controlled, or even improved, while news of distant rainfall could be transmitted by radio. In this way the desert cores would continue to contribute usefully to the economy of man.

Game ranching

The indigenous fauna of any region is naturally better adapted and more productive than any exotic, domesticated species. For this reason, game ranching is frequently advocated as a form of land use in the wilderness regions of the world. In the case of the Asian saiga antelope, for example, it has been spectacularly successful — but there have been few other attempts at game ranching in the arid regions of the world. The problems of this type of land use, again, are basically administrative. The great mobility of game animals, which prevents them from over-grazing, makes them difficult to control or to protect from poachers. Large scale game ranching in the desert might well repay the initial capital investment, but it would also require a strong, mobile corps of game wardens equipped with efficient ground transport and aircraft (Cloudsley-Thompson, 1977a).

Dryland farming

Until recently, land in the Sahelian zone of Africa had been left fallow for 15-20 years before recropping. The people had developed a great variety of their staple crops, millet and sorghum, each adapted to different growing seasons and situations—and the land was not overexploited. With the introduction of cash crops, such as cotton and groundnut to earn foreign exchange, marginal areas were brought into use to provide food for the increasing population and these ecologically fragile regions could not take the strain of intensive agriculture. Fertility declined, slowly at first, and then in a vicious spiral.

Productivity could, however, be improved by scientific land management, and the harmful effects of drought lessened by selecting crops whose requirements of water are compatible with the normal precipitation in the area. Soil fertility can be raised and crops adapted to growing seasons by plant breeding methods.

Irrigation schemes

Irrigation schemes are an effective form of land use where water is obtainable in quantity from regions beyond the desert's fringe, and many crops can be taken annually when supplies are unlimited. On the other hand, in regions where ground water is a fossil resource that is not being recharged, as in Libya, Texas and Baja California, its exploitation can only be temporarily beneficial and, in the long run, may cause irreparable harm. In such cases, the utmost economy should be employed — for example, by the use of hydroponics. Moreover, large irrigation schemes often engender problems of salinization. In 1954, over 24 per cent of the Indus irrigation system was affected by waterlogging and about 34 per cent suffered from salinity. Despite several costly projects that were intended to reverse this trend, the rate at which productive land is harmed by salinization has continued to rise. Only 10 years after the initiation of the Jordan valley irrigation scheme, salt and waterlogging were affecting 12 per cent of the project areas. In China, the fertility of at least one fifth of irrigated areas is declining because of salinity; in Patagonia and Argentina the figure is as high as 25 per cent. Similar problems have arisen in Brazil, Haiti, Iraq, Syria, Mexico and elsewhere.

In many desert regions, the water that emerges from springs and artesian wells, or is pumped from boreholes is often highly mineralised. Whereas animals and man can tolerate sodium chloride, they cannot live on water with a high content of sodium or magnesium sulphate, while plants are killed by chlorates, sodium carbonate and bicarbonate in solution. Although desalination is still too expensive for the production of water for agricultural purposes, it clearly has a future, especially in arid regions that are endowed with oil and natural gas. Many desert cities, of course, already depend upon distilled sea-water.

At the present time, the greatest disadvantages of irrigation schemes in tropical and sub-tropical deserts lie in the debilitating human diseases they engender. Of these, bilharzia and malaria are undoubtedly the most important. At the same time, irrigation schemes may provide permanent breeding places for locusts and other agricultural pests: they should, therefore, only be initiated under careful entomological and medical supervision.

Land reclamation

Soil erosion can be checked in a number of ways, including mechanical and chemical control of trees and bushes so that grass grows in their place, furrowing and contouring the soil to slow the rate of run-off from disturbed and overgrazed areas, and the construction of dams in large and active gulleys. If the grasslands thus produced were managed scientifically, by regulated grazing and the maintenance of a nutritious combination of grass and legumes, they would be capable of supporting a wealth of cattle and sheep, the quality of which could also be greatly improved by selective breeding.

Desert expansion can be reversed by the enlargement of existing oases and, where water is available, by the creation of new ones. Oases are important, not only because they are highly productive, but because, to some extent, they combat the world-wide tendency for deserts to expand (Cloudsley-Thompson, 1974).

In areas where the rainfall exceeds 150 mm per year, sand dunes can support permanent vegetation provided that the surface of the soil has been stabilised. This may be achieved by spraying the dunes with a mixture of oil and synthetic rubber before planting, seedlings of *Acacia* and *Eucalyptus*. When these have become established, their roots exploit the moisture stored below the surface of the sand from one wet season to the next. As the trees grow they provide a natural windbreak, and dead foliage then becomes incorporated into the soil, increasing its cohesiveness.

Mineral resources, industry and tourism

The most obvious assets of the world's arid regions are the deposits of oil and minerals that lie under the ground. The latter include borax beneath the Mojave desert, silver in Mexico and Mongolia, copper in Nevada and Chile, gold in Australia, diamonds in southern Africa, iron ore in Mauretania, and uranium in Utah, New Mexico and at the foot of the Air in Niger. Apart from oil and natural gas, the desert possesses an inexhaustible supply of solar energy. This can be harnessed for domestic and research purposes and may, one day, provide unlimited power for industrial development. It seems unlikely, however, that solar energy can make a major contribution to the world energy supplies within the next two decades at least. It must therefore be thought of in terms of an asset that is not immediately available for exploitation. In contrast, the potentials of plant breeding may become apparent—in the production of crops that can tolerate drought or salinity—very much sooner.

Since industrial economy uses very much less water per head of population than does agriculture or stock rearing, it is quite the most efficient form of land use in arid regions. For this reason, the standard of living of desert dwellers could be raised more advantageously by industrialisation and the expansion of tourism than by over-exploitation of limited water resources. But it may take many years for the inhabitants of underdeveloped countries to acquire the necessary technological skills–and innumerable sociological problems would be created for them. It is, therefore, important that education services should be improved and expanded, with all possible speed (Cloudsley-Thompson, 1977b). Other problems also remain. These include the disposal of sewage and industrial wastes, which demands vast quantities of water unless expensive chemical conversion plants are installed (Walton, 1969). But such technological difficulties are unlikely to delay the development of the desert where this is desired.

PROSPECTS

The fear that misuse of the land may engender the incidence of drought is long standing. If the soil surface is denuded of vegetation, its albedo will increase, resulting in a further decrease in rainfall. Although this may not necessarily lead to permanent desiccation, the albedo feedback will certainly intensify and prolong existing droughts (Hare, 1977). Increased grazing in good years inevitably leads to an increase in the herds until their numbers exceed the carrying capacity of the land. Increased cultivation, at the same time, enlarges the area of exposed soil that has to survive each dry season. The pressure on trees and woody plants from grazing, and collecting timber for fuel, also increases. Shade is reduced and regeneration prevented. Ensuing drought results in deflation of the soil, death of the livestock from starvation and then, when the rains return, they cause sheet erosion and gullying.

This is the state of affairs today, and the situation that has been deteriorating with increased rapidity during the last century or more. Fortunately politicians and some members of the general public have at last become aware of the dangers. Even so, it will inevitably be many years before the tide turns. We can, however, see the ways in which this can be made to occur. Chiefly, it will be by multiple land use so that no individual parameter of the environment receives more exploitation than it can be reasonably expected to withstand. Whether in the form of oil revenue subsidies or bank loans, the poorer desert countries of the world must receive massive injections of foreign exchange, as well as technological and scientific assistance, if they are to prevent further expansion of the desert—which would be to the ultimate detriment of the entire world.

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DRY FARMING RESEARCH - ITS RELEVANCE AND PROSPECTS FOR ARID ZONE AGRICULTURE

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The problems of crop production in the Indian arid zone are well documented (Mann and Singh, 1977). It is recognized that an acute ecological imbalance of the components of productivity is primarily responsible for limiting the consistency of remunerative crop production in the arid regions. Harsh and unfavourable climatic conditions, wind erosion, poor soils with poor moisture retention capacity are some of the important problems for poor yields.

The need for strengthening dry farming research, having relevance to arid zone agriculture, becomes obvious when it is realized that about 90 per cent of the cultivated area of this region will continue to be rainfed for many years to come. For ameliorating and rejuvenating the economy of this region, the crop yields per unit area have to be upgraded and crop production on drylands stabilized at a reasonable level. Ecological and economic considerations make dry farming research more a matter of obligation than choice.

It is proposed to deal with the topic under reference in three broad heads viz., malady-remedy analysis, research achievements and highlights, gaps in knowledge and future lines of research. Although some useful dry farming research work has already been accomplished, but maladies afflicting crop production being numerous, lot more concerted research efforts are needed to arrive at tangible results.

I. Malady-remedy analysis: Lack of moisture and restricted period of moisture availability is the primary malady afflicting remunerative crop production on drylands of this region. This malady is further aggravated by lack of natural vegetation as a result of uncontrolled grazing, and felling of trees and shrubs for fuel, leading to a large-scale soil and nutrient loss caused by wind erosion. The pressure of population has led to the extension of cultivation to marginal and sub-marginal lands. Low and unstable crop yields are therefore end products of the eco-system.

The approach outlined below has been adopted on the premise that it will mitigate the maladies and ameliorate the imbalances in the eco-system.

The amelioration of arid regions, falling in the rainfall range of 300 mm and below can be best achieved by large-scale afforestation with suitable species of trees and by developing a grass cover by growing adapted species of grasses. Crop production in such regions should be discouraged. Animal husbandry backed up by rangeland management and forestry should be the mainstay in these regions. In the transition belts, with an annual precipitation ranging from 300-400 mm, an integration of crop husbandry and animal husbandry should go together for stabilized production (Singh and Prasad, 1976). In areas receiving 400 mm of rainfall and above, the technology for dryland crop production should be adopted for improving and stabilizing crop yields. In order to make crop production a remunerative enterprise in these areas, the following approach (Mann and Singh, 1977), should be adopted.

(a) Selection of crops and varieties having growth patterns matching the rainfall pattern and possessing higher moisture-use efficiency.

(b) Selection of suitable crops and varieties for conditions of delayed onset of the monsoon and other weather aberrations.

(c) The adjustment of sowing time so as to ensure that the periods of flowering and grain-filling coincide with the periods of adequate moisture availability.

(d) Tillage practices conducive to good seed-bed preparation without much loss of soil, moisture and nutrients. Techniques ensuring a proper placement of seed and fertilizers in the moist zone, leading to optimum crop stands.

(e) A judicious fertilizer use commensurate with the status of soil, nutrient needs of crops, plant population and available soil moisture.

(f) The adoption of appropriate water-harvesting techniques so as to ensure higher amounts of moisture for longer periods.

(g) The conservation of moisture through the use of partial or complete sub-surface moisture barriers and organic mulches to cut down losses owing to deep percolation and evaporation respectively.

(h) A timely control of weeds and the adoption of effective plant-protection measures.

(i) The harvesting of crops of appropriate cropping systems so as to impart stability in years of sub-normal rainfall and to increase production in years of normal and above-normal rainfall.

II. Research achievements and highlights: Important achievements resulting from the research work carried out by a multi-disciplinary team of scientists at the CAZRI since 1971 are listed below:

(1) Varietal evaluation studies have led to the identification of varieties and hybrids of pearl millet, green gram, Sesamum, cluster bean, dew gram, castor and sunflower, which are not only early in maturity but possess high yield potential and higher moisture use efficiency.

(2) In the event of delayed onset of monsoon, crops like green gram, castor, cluster bean and sunflower, have been found to be suitable. Oilseed crops like mustard and safflower have been found to be promising for planting on stored/conserved soil moisture.

(3) Studies on cropping systems for drylands have revealed that:

(i) *Cenchrus ciliaris,* cluster bean and castor bean, together with the inter-cropping systems involving grasses as one of the component crops have been found to impart stability to production on drylands:

(ii) In years of good rainfall (>500 mm) with an extended rainy season, double cropping is a distinct possibility on drylands. Double cropping systems consisting of pearl millet in the rainy season followed by mustard in the winter season or *moong* bean in the rainy season and mustard or safflower in the winter season have been found to be one of the most remunerative and promising cropping systems.

(iii) For stabilizing and maximizing yield of pearl millet, transplanting of 21-25-day old seedlings late in the season, has been found to result in 22 to 36 per cent higher grain yield over the direct seeded pearl millet.

(4) Fertilizer use, particularly that of nitrogen has been found to be advantageous for dryland crops. Yield increase of the order of 45-250 per cent were obtained in case of crops like pearl millet, fodder and forage grasses.

(5) Phosphorus application to green gram has been found to carry considerable residual value to pearl

millet grown in green gram-pearl millet rotation.. Furthermore, it has been found that a saving in N to the extent of 20 kg/ha can be obtained by growing pearl millet in rotation with green gram instead of continuous cropping of pearl millet on the same field year after year.

(6) In the case of aberrant weather, particularly when sowing of the crop is followed by a long drought, application of a surface mulch may delay the surface drying and promote seedling emergence and stand establishment. Pearl millet husk—a waste material, when applied @ 4-6 t/ha as 80 to100 per cent cover soon after sowing, has shown promise for use as surface mulch.

(7) Use of bentonite clay, as subsurface moisture barrier for reducing the deep percolation of moisture to the *murrum* sub-strata, has been found promising. A technique comprising partial (localized) incorporation of bentonite in pits and trenches and run-off concentration has been developed for successful production of vegetable crops like *tinda* on drylands.

(8) Among the various *in situ* water harvesting techniques, inter-row water harvesting has been found quite suitable for crops like pearl millet.

(9) Inter-cropping of cluster bean and green gram in *Cenchrus ciliaris* has been found remunerative in good and average rainfall years, respectively, and is promising with regard to productivity per unit area, time and water use. Inter-cropping of cowpea and green gram in sunflower has proved to hold promise in average and good rainfall years both with regard to productivity and moisture use efficiency. The yield of grain legumes in the range of 5 to 8 q/ha, therefore, comes as a bonus. Leguminous inter-crops in the sunflower cropping system can also supplement the N reserves of the soil to the tune of 30 kg/ha.

(10) Inter-cropping of pearl millet in double or triple rows of green gram has been found advantageous. Paired row planting system under intercropping or otherwise has proved advantageous particularly in low rainfall years.

(11) Seed soaking and seeding of castor at 10-15 cm depth, ensured faster and higher seedling emergence, respectively.

(12) Sweep cultivation has proved to be a good tillage practice for these soils. This restricts weed growth and allows better intake of moisture in soil. Packing attachment with seeding devices have been found to give better seedling emergence.

(13) Of the various chemical herbicides tried, pre-planting incorporation of Treflan or pre-emergence application of Lasso, Amiben or Basalin

or one hand weeding 20 days after sowing have been found to be more effective for controlling weeds in green gram on drylands.

III. Gaps in knowledge and future lines of work: Research efforts made so far have led to some useful results, but there is lot more to be done. Some of the more important future lines of work are indicated below:

(1) Research work carried out so far has been rather fragmentary. There is need to adopt a water-shed based management approach so that appropriate soil and moisture conservation measures, water harvesting and run-off recycling procedures, and judicious crop planning, could be dovetailed for optimum utilization of the scarce water resources.

(2) Farming systems, involving appropriate allocation of land and water resources to pasture management, crop production and farm forestry, need to be evolved with a view to guaranteeing the normal living standard for the farming community. A multi-disciplinary approach should be brought to bear to solve the tangle.

(3) Cropping systems which can impart stability to crop production on drylands during sub-normal rainfall years and maximise production in normal and above normal rainfall years, should be evolved for small, medium and large farmers of the arid zone.

(4) A water harvesting system appropriate to varying land characteristics and rainfall patterns obtainable in different micro-agro-climatic regions of the arid zone should be perfected so that crop failures are altogether averted. Crop life saving research including run-off recycling procedures should form an integral part of any water harvesting research. A relationship between the catchment and farm pond size should be established.

(5) Precise information on the relationship between plant population and fertilizer use for a given quantum of water available in the soil profile is wanting for most of the dryland crops. Studies under controlled environmental conditions alone will yield precise results.

(6) Grain legumes have either not responded or have given poor response to phosphate application. Reasons for lack of response should be carefully looked into and studies on phosphate fertilization and inoculation of legumes should be intensified.

(7) Basic information on moisture retention and its rate of release in respect of major land forms and soil series is lacking. Moisture movement characteristics operating under different agronomical practices should be investigated by Soil Physicists in collaboration with Agronomists.

(8) Soil crusting is a very serious problem of this area. Some lukewarm efforts have been made to solve the problem and it is not surprising therefore that the problem still remains unresolved. More serious and concerted efforts are therefore needed to have a dig at the problem.

(9) Weed control aspects in grasses and field crops have altogether been neglected in our research programmes. Of late, some preliminary studies have been initiated on weed control in green gram and cluster bean, but the research efforts put in so far are far from satisfactory. An intensification of research efforts in this direction is urgently called for.

(10) Micro-climatic studies in relation to cropping systems and crop management practices evolved for the arid zone should be taken up so as to utilize the available abundant solar energy and scarce water resources to the best advantage for optimising productivity per unit area, time and moisture.

(11) Crop research, both with regard to genetic improvement and formulation of agronomic practices, in respect of cluster bean and dew gram (*moth* bean)—the two principal grain legumes of this region, was so far relegated to the background. Unfortunately, these two crops did not catch the imagination of the workers engaged in the All India Coordinated Research Project on the Improvement of Pulses. It is time that the I.C.A.R. establishes a National Centre on *Guar* and *Moth* Research.

(12) Animal husbandry is the mainstay of the economy of this region. Application of range-management research has remained confined to the boundaries of the range-management areas. Cultivated fodder crops have not received the attention they deserve. Before the grasses become popular with the farming community of this area, it is necessary to concentrate efforts on the formulation of suitable agronomic practices for each of the fodder crops cultivated in the area. 'Cheepta' cultivation system has yet to be made more productive and remunerative.

(13) Arid zone crops like *zeera* (cumin), *dhania* (coriander), *isabgol* (*Plantago sativa*), *saunf* (fennel), *pyaz* (onion), etc. with immense production potential, but giving low yields at present, hold every passer-by by the skirt and say groaningly 'we are being neglected'. Some one has to listen to their bemoanings. The time is now ripe for a zonal centre of research on spices to be established at this Institute.

(14) Chillies is the important cash crop of the irrigated areas of this region. Rajasthan stands fifth in area and production of chillies in the country. Lot of valuable water resources

are being wasted on the growing of this crop. Studies on efficient water management in conjunction with balanced fertilizer use have to be initiated, along with other aspects of agronomical research, so as to boost up the productivity of this crop per unit of water. Any saving in water could be fruitfully utilized for extending the area under equally remunerative but less water demanding crops like brassicas. Intensification of research efforts on evolving suitable cropping patterns for limited moisture supply conditions, is therefore logical and relevant.

(15) Agricultural Engineers engaged in the All India Coordinated Research Project on Dryland Agriculture have made limited efforts to improve the efficiency of the implements already available with our poor dryland farmers. Research efforts are therefore to be directed towards improvement of local implements and fabrication of suitable implements with feasibility and acceptability potential.

(16) Suitable studies on organic recycling should be designed with a view to tapping the untapped reservoir of organic resources in crop stubbles and farm wastes. An integrated nutrient supply system, involving the use of farm yard manure, fertilizers and nitrogen fixation through legumes, should form the basis of efficient crop production on drylands.

CONCLUDING REMARKS

The problems relating to crop production on drylands are immense and challenging. A correct approach to the varied problems will pave the way to remunerative and viable crop production technology. Piecemeal research efforts have not led us anywhere. An integrated systems approach will pay rich dividends. There are some creditable research accomplishments but lot more still remains to be done. Strengthening of dry farming research, having relevance to arid zone agriculture, is the need of the hour.

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V. 0.11

SOME NEW DIRECTIONS IN ARID ZONE RESEARCH

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INTRODUCTION

Recent conferences on problems of desertification have emphasized the need for immediate action to prevent the continued irretrievable loss of large areas of formally productive lands. It is clear that there is a large body of technology already at hand that could be applied to alleviate the present acute situation. Among the major barriers to the implementation of existing technology are social, political and cultural factors as well as a very real lack of investment capital.

It is also clear that there are large gaps in our understanding of many desert phenomena, and the choice of alternative technologies suitable to arid and semi-arid regions is severely limited or often non-existent. Without detracting from the necessity for immediate remedial activities, there is a dire need for more intensive research for improvement of existing technologies and the development of new ones. Any program for containment or rehabilitation of arid areas will require at least a generation to gain momentum and to achieve visible impact. Research should accompany every development project, be considered as an integral part of each action program, and receive a specified percentage of the total budget. This paper discusses a few of those research areas which have only recently been entered by the author's research institute.

Selection and management of "multiple use" woody species

The accelerated large-scale destruction of the indigenous vegetation which has occurred in arid and semi-arid zones during the past generation has led to rapid expansion of desert areas and to the impoverishment or annihilation of the life-sustaining ecosystems of these regions. This problem has received wide publicity in the wake of the recent Sahelian tragedy, and a series of international seminars have been held, culminating in the large "Symposium on Desertification" organized by U.N.E.P. last year. The causes of desertification processes have been minutely analyzed and a "plan of action" adopted to combat this phenomenon (UN Report 1977).

Among the large number of projects and programs suggested, emphasis has been placed on revegetation of endangered areas, largely with woody species. Trees and shrubs have been successfully utilized to stabilize dunes by binding the soil and reducing wind velocities near the ground (Niknam and Ahranjani, 1975; Prego *et al.*, 1971). Once established, such areas can be a source of much-needed fuel and in higher rainfall areas a source of building material. With good management, grazing is possible between the rows and on the pods, young shoots and leaves of the trees or bushes. Certain trees could provide valuable industrial materials such as waxes, gums and edible oils. Wherever suitable, a "multiple use" approach should be considered in the selection of species for revegetation.

The "multiple use" approach has the added advantage of providing an economic basis for local inhabitants, which can possibly obviate the need for many of the ecologically disruptive economic activities presently practiced by desert people in order to sustain themselves. If desertification is to be combatted, alternate sources of income will have to be provided, as well as better management techniques. Trees and bushes properly selected and managed can constitute a major source of such alternative activities and at the same time act as a barrier to the expansion of the deserts. For example, successful experiments have been carried out in several countries utilizing various species of *Atriplex* for raising sheep and cattle. Yields of over 12 tons per hectare with a 15 per cent protein content have been obtained in a 200 mm winter rainfall area (Forti, 1970). Jojoba bushes or trees such as *Acacia senegal* are good examples of species that could provide valuable industrial material while binding sands or providing wind breaks. Various species of *Eucalyptus, Acacia, Prosopis,* Indian *Neem,* etc. have a multiplicity of uses. The selection and management of "multiple use" species for arid zone rehabilitation constitutes a field of research which deserves wide international support.

Vegetative propagation of woody species

Plans for combatting desertification call for large scale reforestation programs. While some of these plans are on a colossal scale and possibly of doubtful efficacy, there is a strong consensus that revegetation will play an important and even critical role in achieving a measure of ecological stability in the endangered areas. Reforestation projects are expensive and decades will lapse before ecologically significant areas have been planted. It is to be hoped that, with proper management these rehabilitated lands will maintain their yields over several decades before requiring replacement. Considering the long time scales and the large expenses involved, great importance should be attributed to the selection of species to be used and to the propagation of the most suitable and productive individuals within that species.

Unfortunately, almost none of our indigenous arid and semi-arid zone woody species have undergone a process of selection or breeding. They are mostly wild types with a wide spectrum of genetic characteristics. If we grow seedlings from seed of the best individual within the species, genetic recombination again results in a whole spectrum of characteristics and productivity hardly better than the usual species performance. The difference in productivity between the best individual of a species compared to the average, grown under the same conditions, can be tremendous. For example, jojoba bushes growing under identical conditions have highly varied individual yields. The best individual has a yield of 5 times the average and many fold that of the poorest individuals (Forti, 1976). Selection and genetic improvement needed to obtain a pure strain which will give the highest yields under the particular environmental conditions will require decades to achieve significant results. The economic feasibility of commercial jojoba plantations now being developed in Mexico, Israel and the U.S.A. will finally be dependent on success in obtaining high yields of the valuable liquid wax produced by these plants. A stand of trees or bushes often produces one outstanding individual of far greater productivity, even though it has no environmental advantage over its neighbours. Such individuals, chosen with great care, should be the basis for vegetative propagation of seedlings to be used for revegetating a particular region with similar edaphic and climatic conditions. Methods of vegetative propagation are the only available means of preparing such high-yielding seedlings within a reasonable time scale.

There are several methods commonly used for vegetative propagation, such as the rooting of cuttings and the use of grafting techniques. Cuttings of woody species are often difficult to root and usually the superior individual tree or bush does not provide sufficient plant material for large-scale seedling production. The use of plant hormones has greatly increased the percentage of rooting, but more research is still needed on the subject. There also remains the problem of "hardening" of the rooted cutting, a process also in great need of improvement. To provide a larger and continuous source of superior genetic material the first rooted cuttings must be set out in a special nursery and grown under especially favourable conditions so as to provide further cuttings for commercial seedling production. This is a long and tedious process, but probably the cheapest of all the methods discussed. An alternative method is to graft the cuttings onto root stocks instead of rooting them. This method, however, is more expensive and requires skilled manpower. The problem of shortage of genetic material is a limiting factor here as well, but where good root stocks already exist in the field, this method may find suitable application.

The relatively new process of tissue culture propagation holds out great promise for the rapid mass production of genetically superior seedlings. This technique requires only a minutely small amount of plant material. By one approach this material is grown as a callus under laboratory conditions on a special growth medium which promotes cell division and inhibits differentiation. The callus is then divided into individual test tubes and, by hormonal treatments, the cells are forced to differentiate to form roots and shoots. A miniature seedling in a test tube is obtained, which is then "hardened" under controlled greenhouse conditions. There are many variations on this procedure depending upon the plant species and the preference of the laboratory. Tissue culture propagation is used successfully for herbaceous species but little work has been done to adapt this technology to the woody perennial species considered for desert rehabilitation. A well organized research and development program aimed at utilizing tissue culture for woody species is urgently needed.

The advantage of tissue culture propagation is that from a single twig of a selected tree or bush, an unlimited number of seedlings with the identical genetic constitution of the mother plant can be produced. The method will not be cheap and skilled central propagation centres will have to be established to produce the seedlings. Many problems remain to be overcome, such as the danger of spontaneous mutations. However, once trees or shrubs are planted they should be productive for decades, thus repaying the high outlay and helping to elevate the standard of living of the local inhabitants.

Energy from salt

It is not generally known that there exists a large potential energy difference between a concentrated brine and a dilute solution such as saline water or sea water. This energy potential is proportional to the absolute temperature of the solutions and to the logarithm of their concentration ratios. A well known manifestation of this potential is the difference in osmotic pressure which can force water through a semi-permeable membrane against considerable back-pressure. The osmotic pressure difference between sea water and river water, for example, is equivalent to a waterfall about 230 metres high. The osmotic pressure of Dead Sea water, which has a concentration of over 300,000 ppm, would be equivalent to a drop of over 5000 metres. Unfortunately this energy is not easily extracted, and research has only recently been undertaken to find efficient methods for realizing this potential (Loeb, 1975).

There are other manifestations of the energy of concentration differences. For example, the vapor pressure over a concentrated salt solution is lower than that over a dilute solution. Hence, in a suitable device vapor will naturally flow from the dilute solution to the concentrated solution and could turn a turbine along the way. Such an apparatus can be "multistaged" so as to yield higher pressure differences. Estimates show that the cost of electricity generated in this fashion from a concentrated brine together with sea water could be reasonable.

A third manifestation of this energy difference involves placing an ion exchange membrane between a concentrated and a dilute solution. The membrane will allow only positive or only negative ions to cross, depending upon the type of membrane used. An electric voltage is developed between the two solutions, and with appropriate apparatus we can use the concentrated and dilute solutions to generate an electric current. Such a device is called a dialytic battery and several prototypes have been constructed (Forgacs, 1977).

It is not within the scope of this paper to describe the various devices proposed to exploit this energy source. Suffice it to mention that these methods are the reverse of water desalination technologies and utilize the same or similar equipment (Norman, 1974). This is fortunate since water desalination techniques are fairly well developed and provide a good starting point for development of such energy generating devices.

Arid and semi-arid areas are rich in salt resources (Smith, 1977) (of all types, and not only common table salt). These deposits are found both as surface outcroppings and in the form of saline lakes of various concentrations. The Dead Sea and the Great Salt Lake are well known examples of the latter, and numerous other salt lakes can be found throughout the arid and semi-arid zones. Over 30,000 kilometres of desert's border on oceans which are a virtually inexhaustible supply of salt. The end brines or bitterns left over from table salt production from sea water would be an excellent source of concentrated brine for these processes. Enormous underground salt domes and underground deposits of various sorts exist as well as underground concentrated brines.

Evaporation pans could be used in arid areas for the production of concentrated brines from sea water and from salt lakes. Once produced, these brines could be recirculated to the evaporation pans and reconcentrated so that little or no extra salt will be needed. This could be a good way of storing solar energy. It has been estimated that a square kilometre of evaporation pans in arid areas could yield sufficient brines for 3 to 5 MW of electrical power (Rappaport, 1977).

Two huge projects are being studied for conveying sea water inland and obtaining hydro-electricity by dropping the water through turbines into large inland areas of sub-sea level elevations. One of these projects relates to the Qattarah Depression of Egypt and the other to the Dead Sea. In the former case the sea water after producing hydro-electricity can be further concentrated in evaporation pans easily constructed in the Qattarah Depression. The unconcentrated sea water would serve as the dilute solution and a considerable additional amount of electricity could be generated from the concentrated brine. The Dead Sea could supply a sufficiently concentrated solution (without need for evaporation pans) which coupled with the incoming Mediterranean Sea water (the dilute solution) could provide energy further to that already obtained by the hydraulic drop. In both cases such a system could more than double the energy obtained from each unit of water conveyed from the Mediterranean Sea to the inland depressions, thereby increasing the economic viability of these projects.

Aside from these possible largescale projects, some of these devices could be produced of a sufficiently small size to provide electric power to small cities, villages and communities. These processes have the advantage of providing energy day and night, winter and summer. It is much simpler to store a concentrated brine than to store solar energy in the form of heat. As previously mentioned, adaptation of already existing desalination technology could provide a good starting point. Research on these systems has been started in Israel, Japan and the U. S. A. but only on a small scale. In the light of the acute energy problems of the arid and semi-arid zones and the attendant ecological havoc caused by wood gathering, no feasible energy alternative should be overlooked.

Solar greenhouses

Many aspects of greenhouse horticulture could have special relevance for arid and semi-arid regions. The high yields obtained per unit of water used in comparison to conventional horticulture may allow many areas with scarce or expensive water resources to supply fresh vegetables to local populations. Interesting experiments in the use of greenhouses with totally controlled internal environments have been made in Tucson (U. S. A.), Puente Penasco (Mexico), Abu Dhabi, Iran and Saudi Arabia. This concept, largely pioneered by the University of Arizona, has been aimed at obtaining hermetically sealed systems in which the irrigation water can be conserved by recycling.

We have set ourselves a more modest goal, at least for the first stage of greenhouse development (Pasternak and Rappaport, 1976). In Israel greenhouse vegetables and flowers are cultivated for export to Europe during the winter season. The mild winters and high solar radiation give Israeli products an economic advantage over European greenhouses. However, there is a rapid loss of heat at night due to radiation from the greenhouse to the clear desert skies, necessitating the use of a fuel consuming heating system. Durin a large part of the day the greenhouses have to be opened and ventilated due to the increase in temperature caused by the high solar radiation. We sought a way of absorbing heat from the greenhouse during the day, storing it and then using the stored heat during the night. This was accomplished by allowing a thin film of water to run down the greenhouse roof between the plastic sheets. The water absorbs about 10-15 per cent of the sunlight and is then passed through a network of thin tubes buried about 40 cm underground. Heat is transferred from the warm water in the tubes to the moist soil where it is stored. The water is then pumped up again to the roof where it is again heated by the solar radiation. In this manner the greenhouse is cooled in the daytime and the heat stored in the soil. At night the same cycle continues but this time heat is taken from the soil and brought to the roof of the greenhouse, thus protecting the plants from the usual radiative heat loss. It is hoped that use of such a system will greatly reduce or entirely eliminate the need for fuel.

The cooling of the greenhouse during the hot part of the day may bring an additional bonus, by decreasing the ventilation, thus greatly reducing water requirements. In addition it may make possible fertilization with CO_2 on a practical and economically feasible basis. There are many arid areas with climatic conditions similar to Israel which could use such techniques for their own consumption or for export to colder climates.

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V. 0.12

DEVELOPMENT AND PROTECTION OF NATURAL RESOURCES OF DESERTS AND SEMIDESERTS

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In the recent decades there occurred in a number of arid regions a disturbance of the ecological balance in the environment resulting from an increased influence upon nature and a rapid growth of the development of natural resources, both in rural economy and in industry. In consequence, there expanded the desertification of landscapes.

We designate as *desertification* the combination of geographical and anthropogenous processes resulting in the destruction of ecosystems of the arid and semiarid regions, the degradation of their natural resources, this causing a diminution of the natural-economic potential of these territories.

These processes can promote considerable spatial expansion of desert conditions or can be confined to comparatively small areas.

Desertification is connected, as a rule, with unreasonable utilization of the natural resources of arid regions (unreasonable methods of conducting rural economy, clear-cutting of forests, overgrazing, urbanization, construction of roads, etc.), but can also result from many consecutive years of droughts.

There can be distinguished four types of the contacts of man with the nature of deserts and semideserts:

1) utilization of natural resources without disturbing the ecosystems: moderate grazing, hunting, collection of useful plants, etc.;

2) optimization of physico-geographical processes for increasing the biological productivity of ecosystems: irrigation improvement of pastures, selection of domestic animals and plants, etc.;

3) gradual destruction of ecosystems by inadequate introduction of rural economy into deserts: unreasonable grazing, overloading of pastures with animals, secondary salination of soils by improper irrigation, breaking-up of overgrown sands and sandy soils;

4) rapid destruction of ecosystems by industrial development of natural resources followed by the appearance of industrial landscapes: construction of highways and railways, oil and gas pipelines, settlements, industrial enterprises, etc.

When the degree and rate of anthropogenous influence upon arid territories exceed the aptness of landscapes to restore themselves, there begins the desertification of these territories.

In discussing the forms and degree of ecological changes of the arid ecosystems, we can distinguish two principal reasons for their partial or complete destruction.

1. Dynamics of the ecosystems influenced by the natural course of processes occurring in nature under progressive desiccation of the desert territory. It is determined by slow climatic variations of different periodicity - 11, 22, 100 and more years or by catastrophic situations –droughts, floods, etc. The results of such natural stresses are overcome without the interference by man, in the course of slow restoration of the destroyed ecosystems or the development of new ones. Slow changes of environmental conditions lead in their turn to gradual adaptation of the plant and animal world to new conditions.

2. Anthropogenous influence upon ecosystems can have a positive effect when man improves the environment for the optimization of its utilization, or a negative one when the environment is destroyed, and in the place of natural landscapes there appear anthropogenous ones with low biological productivity.

The character of ecosystem destruction varies considerably, depending upon the type of human influence upon the environment. Under natural stresses the change in ecosystems usually extends over vast territories (e.g. after droughts). Under anthropogenous influence the ecosystems are destroyed mainly locally and usually do not extend over such large territories.

Different types of anthropogenous landscapes and areas grew up in the course of the development of natural resources of the arid regions. They can be classified as follows.

1. Anthropogenous landscapes of the agrarian type, resulting from the utilization of territories for rural economy: oases with irrigated fields and rural-type settlements; secondary solonchaks; large areas of impoverished pastures; massifs of

shifting sands; small settlements in deserts around animal-raising farms, around wells.

2. Anthropogenous landscapes of the industrial type, resulting from mining of economic minerals, industrial and transport construction: settlements ranging from large cities to small railway stations; industrial enterprises - plants, factories, mines, open-pit mining of economic minerals, etc.; railways and highways, airdromes, oil, gas, and water pipelines; gas collectors and pump stations; massifs of shifting sands resulting from the operation of modern mechanization facilities.

The total area of the anthropogenous landscapes in the arid regions of the USSR is comparatively small. Thus, oases with irrigated agriculture occupy only about 3 per cent of the total territory of deserts. The general tendency is characterized however by the increase of desertification.

The forms and degree of the anthropogenous change of natural ecosystems in the USSR are varied.

The principal ones are the following:

a) degradation of range vegetation in the result of overgrazing;

b) deflation of light sandy soils utilized for unirrigated agriculture, this often leading to an increased intensity of dust storms and the destruction of the fertile soil layer;

c) deflation of overgrown sands under the influence of different factors: breaking up of compact sands by removing shrubs for fuel, accompanied by stubbing up of roots; earthwork; construction of roads, pipelines, large irrigation canals, industrial enterprises, settlements, etc.

In the result of the destruction of vegetation and loosening the surface soils and sands are blown off by winds and accumulate into shifting aeolian forms-sand fields, barkhans, barkhan chains, etc.

Thus in the course of time the old basic desert and semidesert landscapes, with their relatively well developed vegetation cover which keeps together the surface sands and soils, change into landscapes of shifting barkhan sands.

The process of natural overgrowth of shifting sands and restoration of broken-up ecosystems is very slow in the arid regions, but it can be speeded up by replanting.

In the nearest future the influence of man on the nature of the arid regions of the USSR will grow incessantly. It can be seen from the plans for the development of people's economy of the republics of Middle Asia and Kazakhstan in the 10th five-year plan. Obviously these plans should be materialized with rigorous adherence to the demands of reasonable utilization and restoration of natural resources.

Study of the processes of the interaction of man with his environment, and of the methods of development of natural resources of nature, permits to see that the character and degree of the destruction of natural ecosystems are varied. They can be divided into two categories: temporary and permanent.

Into the category of the temporary destructions of ecosystems can be included earthwork for the construction of irrigation canals, trenches for different pipelines and underground cables, construction of railways and highways, supports for electric transmission lines, boring towers, etc. In the course of such construction there sometimes are formed large areas of the massifs of displaced sands. Upon completion of these types of work, the displaced sands can be fairly quickly replanted and will be held together by vegetation.

Into the category of permanent negative effect on the ecosystems of arid regions should be included industrial enterprises, settlements, towns, animal-husbandry farms, gas collectors outside of irrigated oases, dirt roads, etc.

The landscapes around such objects usually experience constant destruction of their ecosystems, sometimes irrevocable. Settlements in sandy deserts can serve as an example of such unreasonable influence of man on his environment. The settlements are always surrounded by massifs of shifting sands.

One of the important tasks that face scientists is the determination of the limits of loads upon ecosystems of the arid regions, permissible under different methods of the utilization of the region's natural resources. Knowing these estimations, we can take care that the load upon natural environment is more moderate and most efficient. Such norms of maximum loads should be recorded and enforced by law.

There appeared in the geographic literature of recent years a new term— optimization of landscapes, — meaning such influence of man on landscapes which can result in maximum productivity. This aim should be borne in mind in working out methods for the development of the natural resources of deserts and semideserts.

The following measures can be outlined for the distant future of the development and protection of the deserts and semideserts of the USSR.

The first place will belong to irrigated agriculture. Its production will have to ensure the supply of raw materials for industry and of foodstuffs for the rapidly increasing population. For this purpose improved methods of irrigation will be used: underground, drip-type, overhead irrigation, etc. Secondary salination of soils will be prevented by the universal use of closed and vertical drainage. Large massifs of sandy soils will be used for agriculture with the aid of overhead irrigation.

These measures will result in the appearance of new large agricultural oases in the deserts and semideserts of Middle Asia and Western Kazakhstan. Their area will be however fairly small - about 10 per cent of the total territory of the arid zone.

Other desert and semidesert territories will still be used for animal husbandry. But the forms of this economy will change. Industrial animal-raising, with its greater productivity, will be used along with pasturing. In the arid regions rich in economic minerals, extraction and mining (oil, gas, non-ferrous and rare metals, gold, etc.) will rapidly develop along with the industry for their partial beneficiation.

The rate of urbanization of the arid regions will also grow. New towns and settlements will appear, the population of old ones will increase.

In connection with the increase of the population of the arid regions of the USSR, their recreational role will also grow. Tourists will be attracted by the peculiar beauty of deserts, varied flora and fauna and, of course, by the pristine silence. Interest will also increase for the utilization of hot and dry climate for medical purposes.

All these branches of people's economy in the arid regions of Middle Asia and Southern Kazakhstan should develop harmoniously without interfering with the other branches of economy.

If we do not ensure the carrying-out of the necessary measures for the protection of the environment, we shall be up against a progressing process of desertification.

The general forecast of the dynamics of ecosystems of the arid regions under unreasonable use of their resources is this: in sandy deserts and semideserts well reinforced with vegetation there will appear in place of valuable pastures extensive massifs of shifting barkhan sands. Oases, settlements, industrial enterprises and transport lines will be increasingly sand-bound.

Deflation of soil and its erosional washing-off is the result of overgrazing in the loess deserts of the piedmontane plains beyond the irrigated regions will increase. This will lead to considerable breaking up of the relief and will make impossible the development of territories for irrigated agriculture. Moreover, the biological productivity of ranges will fall sharply. The irrigated areas of northern loamy deserts of Southern Kazakhstan will also lose their productivity in the result of overgrazing, when valuable forage plants will be replaced by poorly palatable ones.

Forecast analyses of the dynamics of ecosystems are one of the forms of analysis of landscape dynamics in the arid regions under the influence of man. They are made out both in the form of schemes and of forecast maps. The latter may be special and integrated. Some authors call them ecological maps. Examples of these are the wind-erosion maps for the deserts of Turkmenia or forecast maps compiled by the Institute of Geography of the Academy of Sciences of the USSR for the zone of influence of the Karakum canal.

Maps of the anthropogenous changes in the arid regions of the USSR, both general and regional ones, would be undoubtedly interesting. They should show irrigated and non-irrigated lands, massifs of shifting sands, different degrees of degradation of pastures, etc.

Long-term forecasting of physico-geographical processes in places of considerable influence of man upon nature should become especially important. Making such forecasts is a very complicated business, since a large number of factors and processes is to be taken into account. Forecasting can be accomplished only by using integrated physico-geographical investigations with the aid of mathematical and physical methods, including the modelling of natural processes.

The following measures are necessary for harmonious development of different branches of people's economy in the arid regions:

1) readjustment of the methods of agrarian and industrial production, to ensure the fullest possible development of natural resources, the maximum productivity of labour and the preservation of the environment;

2) carrying-out of measures for renewed cultivation of the destroyed ecosystems, for introducing them into the economic turnover, in particular the

introduction of advanced technique into irrigated agriculture for the prevention of secondary salination and bogging-up of irrigated lands, for reforestation and stopping the shifting of sands, etc.;

3) determination of the size of maximum loads on the ecosystems of the arid regions for different methods of the utilization of natural resources, for the preservation of maximum productivity;

4) preparation of short-term and long-term forecasts for the protection of the environment while utilizing natural resources;

5) extensive propaganda of the tasks of protection of the environment and engaging the population in the struggle with desertification;

6) explaining to all population the ecological and economic practice of reasonable utilization of natural resources of the arid territories (land, water, animal and plant resources, economic minerals, etc.);

7) analysis and assessment of natural and human resources in the developed territories from the standpoint of their reasonable utilization (optimum versions of a project) and prevention of the processes of desertification.

VI. 0.1

ROLE OF THE WORLD SCIENTIFIC COMMUNITY IN IMPLEMENTING THE PLAN OF ACTION TO COMBAT DESERTIFICATION

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The United Nations Conference on Desertification, which was held at Nairobi, Kenya, from 29 August to 9 September 1977, has adopted the Plan of Action to Combat Desertification. The decisions and recommendations of the Conference, including the Plan of Action to Combat Desertification, were subsequently approved by the thirty-second session of the United Nations General Assembly as a worldwide programme of concrete anti-desertification measures to be fully implemented by the year 2000.

A number of general considerations in respect to the problem of desertification were agreed by the Conference. The main considerations are:

a. that the main cause of desertification is the interaction of man with a fragile environment of the drylands; man is the main factor of desertification and its victim; the inappropriate land-use practices, in degree or in kind, are the immediate causes of desertification in the marginal areas;

b. that the problem of desertification is global and that countries not directly affected suffer indirect effects;

c. that the problem is serious, especially so in an era when food production must be dramatically increased to provide adequate nourishment to growing populations;

d. that, in view of the world's food requirements, and because desertification could be a self accelerating process, certain aspects of the problem require urgent action;

e. that man now possesses sufficient knowledge and technical means to begin actions against desertification without delay; however, that should not be considered as implying a rejection of the value of carefully directed research, whose findings could facilitate the struggle against desertification and speed the achievements of the goals of the Plan of Action; it meant. rather, that no country had to wait for further research before initiating action.

The immediate goal of the Plan of Action to Combat Desertification is to prevent and to arrest the advance of desertification and, where possible, to reclaim desertified land for productive use. The ultimate objective is to sustain and promote, within ecological limits, the productivity of arid, semi-arid, subhumid and other areas vulnerable to desertification in order to improve the quality of life of their inhabitants.

The Plan of Action presents a set of recommendations for initiating and sustaining a co-operative effort on the scale required to combat desertification. This co-operative effort should reinforce and integrate national, regional and global international actions against desertification that are currently going on both inside and outside the United Nations family. The seven-year period 1978-1984 has been chosen for the implementation of the immediate actions required and as an indication of the time at which a first general assessment of progress could be made.

A central theme of the Plan of Action is the immediate adaptation and application of the existing knowledge, particularly in the implementation of urgent corrective measures against desertification, in educating the people and the affected communities to an awareness of the problem, and instituting training programmes in collaboration with the current programmes of existing organization in this area. Improved land use, calling for assessment, planning and sound management on the basis of the application of known ecological principles to areas subject to desertification, is a key to success in combating this menace.

The Plan of Action is to be carried out as an effective, comprehensive and coordinated action programme against desertification, including the building up of local and national scientific, technological and administrative facilities in the areas concerned; all recommended measures are to be primarily directed toward the well-being and development of the peoples affected or vulnerable to desertification; and the efforts should be consistent with, and form part of, wider programmes for development and social progress.

The Plan of Action covers areas where desertification is occurring now and other which are vulnerable to future desertification, including arid, semi-arid and subhumid areas.

Although the central theme of the Plan of Action is the immediate adaptation and application of existing knowledge, additional research, both fundamental and adaptive, is required to clarify a number of major problems for the solution of which the requisite scientific knowledge is not yet available; this research should be consistent with strengthening the scientific and technological capacity of the affected areas and should draw on the local experience, knowledge and expertise.

At this point, it would be most appropriate to state that the success of the Conference, as far as the preparations of the background scientific material were concerned, was to a largest degree attributed to the wide participation of the world scientific community. It was the full cooperation of the scientists from all over the world, whether advisory consultants or the scientific institutions, which carried out a vast body of studies. I would also like to mention, in particular, the very valuable contribution from the Central Arid Zone Research Institute of Jodhpur and from its director, Professor Mann, who participated in many preparatory meetings, as well as in the Conference itself. There is no doubt that the successful implementation of the recommendations of the Plan of Action will fully depend on the wide participation of the world scientific community from all branches of natural and social sciences.

If we would look now through the whole set of the recommendations of the Plan of Action, we shall easily see that each and every one of them calls for one research activity or the other, or for assembling and evaluating the existing knowledge in order to translate it into practical technological recommendations for the actions required. Despite the large number of anti-desertification technologies that have been developed during the long history of arid lands development and rehabilitation throughout the world, we still do not always know how to effectively get them into operation in those areas where they are so desperately needed, particularly taking into account various, economic, social and cultural constraints existing in different regions. Local strategies for the development and management of arid lands and anti-desertification measures should be developed urgently by the local and national scientific institutions as the global approach in this area provides only a general framework of the campaign.

One particular recommendation of the Plan of Action, Recommendation 18, calls for appropriate action to be taken, at national and regional levels, to utilize and strengthen national capabilities in science and technology, with particular attention to planning and management for rational utilization of resources, as part of the campaign against desertification, as well as to establish conditions which will lead to a more adequate international flow of technology to the developing countries. In implementing this recommendation, the role of national and international inter-governmental and non-governmental scientific research institutions and individual scientists will be of utmost importance as they are expected to advise the authorities concerned on the administrative and other arrangements required.

To implement the above recommendation, as specified in the Plan of Action, action would be required to:

a. Establish, co-ordinate or strengthen national scientific institutions concerned with the problem of desertification so that they may assist in the transfer and modification of technology and in the dissemination of information on current progress in science and technology related to combating desertification;
b. Give due attention to the modification of technologies to suit local conditions, taking into account social, cultural and economic factors, and ensuring a proper combination of local and imported technology;
c. Provide advisory or extension services and training on the application of new or modified technologies, bearing in mind their impact on national technologies;
d. Provide existing scientific and technological centres, including the universities and agricultural institutes, with the staff, equipment, material and funds necessary for their operation;
e. Establish or reinforce with the help of international organizations, machinery for monitoring desertification and the human condition;
f. Promote the development of programmes to revive traditional techniques for combating desertification, complementing them with existing innovations, and encourage the exchange of these techniques among countries.

As far as the additional research is concerned, the co-ordinated and comprehensive research programmes should be directed to filling up the gaps in the existing knowledge in order to provide an effective assistance for the implementation of the recommendations of the Plan of Action. Some of the gaps in knowledge will undoubtedly be filled up in the course of application of existing knowledge, but there are gaps that require a long-term national and international research effort. A global, comprehensive, co-ordinated research programme, embracing existing national, regional and international research centres and institute, including the universities, for the rapid and economical acquisition of new knowledge regarding the problems of desertification should be established.

Such research programme should cover a wide range of pertinent items, including both natural and social sciences. In the first instance, it could include *inter alia* the following topics on which available knowledge is still not adequate:

ASSESSMENT AND MONITORING OF DESERTIFICATION

1. Parameters, indexes and criteria of desertification for the purposes of:

— assessment of the problem in a particular area,
— preparation of desertification maps,
— sustained monitoring of desertification,
— assessment of the effectiveness of the corrective measures undertaken:

a. selection of critical indicators of desertification in different natural conditions;
b. relative indicative value of various indicators in different natural conditions;

c. relative indicative value of physical and social indicators of desertification;
d. indicators of short-term and long-term changes in the environment;
e. indicators of long-term trends in the environment;
f. value of remote-sensing techniques in assessment and monitoring of desertification;
g. relative value and complementarity of remote sensing, airphoto surveys and ground surveys and sets of the critical indicators for each of the approaches;
h. interpretation of various materials (space imagery, air-photographs, ground survey maps for the purposes of assessment and monitoring of different natural conditions in terms of measurable parameters.

2. Standardization of survey and monitoring facilities and methods:

a. determination of scales of survey for different purposes (general assessment, planning, project designing, etc., in rangelands, irrigated lands, etc.) and at different levels (farm, township, district, province, state, country, region);
b. criteria for selection of the most appropriate method of survey and monitoring depending on physical, economic and social/political considerations;
c. standard techniques for multipurpose and thematic surveys of various kinds.

3. Methodology of data collecting, storing, processing and evaluating:

a. standardization of data charts and codings;
b. use of existing services for specific data collections;
c. use of computers for data storing and processing;
d. computerized programmes for data evaluating;
e. insurance schemes for sustained flow of data;
f. automatic systems for desertification monitoring.

CORRECTIVE ANTI-DESERTIFICATION MEASURES

1. Methodology of land-use planning at various levels of management: farm, holding, village track, township, district, province, state, country:

a. relationship of a land-use plan with general programme of socio-economic development;
b. potential land-use capabilities of land in different natural conditions;
c. physical, social, economic and cultural parameters determining types of land-use;
d. relationships between land-use plans of different scales and levels;
e. upwards versus downwards approaches in the land-use planning: where to start from? from the farm or from the country?

2. Methodology of land-use survey at various levels:

a. standard data required for each scale of the survey: physical, economic, social, cultural, political;
b. topographical or other cartographic bases for different scales of surveys;
c. standard techniques for different scales of surveys.

3. Methodology and procedure for implementing a comprehensive land-use

plan at various levels, including legislation:

- a. social, economic, political, cultural and legislative constraints to land-use planning and ways to overcome them;
- b. role of local communities, governmental services, political establishments in implementing land-use plans.

4. Measures to ensure efficient public participation in anti-desertification programmes:

- a. role of public education and extension services;
- b. role of farmers unions, youth and women movements, children associations, clubs and other public social establishments;
- c. role of mass media;
- d. role of government services, scientific institutions.

5. Effects of combination of industrialization and urbanization with the development of agriculture on the ecology of arid areas.

6. Effective schemes of integrated water management.

7. Effective methods of water use, re-use and conservation.

8. Control of water-borne diseases.

9. Methods of water recycling and water pollution control.

10. Use of brackish water for different purposes, including irrigation:

- a. use of drainage water for irrigation;
- b. crop adaptation for brackish water;
- c. conditions of drainage and crop rotation under the use of brackish water.

11. Weather modification, evaporation reduction and increase of water condensation.

12. Regulating of soil moisture:

- a. methods of moisture conservation in soils;
- b. methods of moisture condensation in soils;
- c. efficient use of available soil moisture.

13. Regeneration of degraded rangelands.

14. Improved grazing strategies and range management.

15. Improved systems of rainfed agriculture:

- a. Zonal systems of agriculture;
- b. Systems of agriculture depending on soil cover;
- c. Crop adaptation patterns;
- d. Crop rotations under different conditions;
- e. Appropriate technologies in different agricultural systems.

16. Efficient methods of irrigation and protection of soils against degradation:

- a. Water/salt balances in soils and ground waters;
- b. Methods of prognosing water/salt soil regimes;
- c. Methods of soil protecting against salinization;
- d. Methods of soil protecting against alkalization;
- e. Methods of maintaining soil physical status;
- f. Methods of maintaining soil nutrients status.

17. Methods of revegetation of degraded lands.

18. Effects of the social, economic, cultural and political factors on the processes of desertification and on the measures to combat them.

19. Effective and economical use of energy sources and introduction of unconventional sources of energy.

The above list of the topics for the fundamental and adaptive research is far from completeness, of course. It gives just an idea of the scope and the magnitude of the research programme needed, of the variety of questions to be studied in depth. It is certain that no existing scientific institution in the world would be able to undertake such a wide research programme alone. Thus, the co-operation between different institutions and distribution of responsibilities among them could only solve the problem. It is necessary to avoid duplication of research activities in order to economize on scarce resources available and to speed up the findings. At the same time, an integrated multi-disciplinary approach in the studies of the problems involved should be promoted.

To prepare a global, comprehensive, co-ordinated research programme for the rapid and economical acquisition of new knowledge regarding the problems of desertification is not an easy task. It would be necessary to identify the areas and gaps for the most urgently needed research, to concentrate efforts in these areas and to divide various items among institutions concerned in a co-ordinated manner. Several international scientific unions and other organizations could be engaged in such an exercise. Particularly, the United Nations University, the Scientific Committee on the Problems of Environment, UNESCO and other relevant bodies could be approached. National scientific institutions, organizations and unions should play a very important role in this international endeavour, because only through them the goal could be achieved. The geographical scope of such a programme should not be overlooked, because each geographical region has its own unique peculiarities and its own unique scientific experience.

In conclusion, it would be proper to say that through international co-operation and co-ordination, including periodical scientific symposia, seminars, workshops and conferences, the knowledge required for combating desertification would be acquired much more rapidly and economically than if each country would do on its own. In this respect, the exchange of scientific information and dissemination of information would be of major importance. Regular exchange of information within the global network of the scientific institutions concerned should be established and properly maintained. This would require *inter alia* a very efficient work of various scientific unions, documentation centres, national and international information systems and data banks.

There is no doubt that the international scientific community will contribute greatly to the implementation of the Plan of Action to Combat Desertification. The follow-up and co-ordination of the implementation of the Plan of Action at the international level was vested by the United Nations General Assembly with the United Nations Environment Programme and the United Nations Inter-Agency Working Group on Desertification. These United Nations organs are going to draw heavily on the international scientific community in order to be able to accomplish their tasks. The reverse is also true: the international scientific community may fully rely on the help of these bodies in the research efforts directed to the common goal.

VI. 0.3

REMOTE SENSING FOR MONITORING RESOURCES FOR DEVELOPMENT AND CONSERVATION OF DESERT AND SEMI-DESERT AREAS

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Less than half the world's drier zones are unproductive deserts for climatic reasons. Rather, land once usable for grazing and agriculture is deteriorating because of the influence of man and livestock, resulting in what is commonly called desertification. It is a process leading to reduced biological productivity and the consequent reduction in plant biomass, in the reduced carrying capacity of the land for livestock and in reduced crop yields and human well-being.

Whether a climatic change or an ecological change brought about by man is responsible for the desertification process, suggestion that there is a change in rainfall might indeed be correct. However, the drop in available moisture has unquestionably been at least partially brought about by mismanagement of the land. The deterioration of resources in critical arid areas is brought about by overgrazing, erosion, salinity and alkalinity, high water tables, cutting of woodlands on mountain slopes, and others.

Concern for environmental problems such as desertification appears to be increasing throughout the world. For example, the United Nations recently sponsored regional feasibility studies on three continents to determine the need for and the interest in halting the spread of desertification as well as reclaiming those areas affected by desertification. Also, an international meeting was held in Nairobi, Kenya in September 1977 at which all facets of desertification were discussed. An awareness of desertification has been established, but implementation of a programme will require financing, further development and refinement of technology, and extensive training.

An assessment of the resources and desertification indicators of the affected areas along with the monitoring of changes, whether they be improvements or further deterioration can best be made using remote sensing procedures, and indeed may be the only way where large areas are involved. Also, remote sensing may be the only practical means of eliminating the often high percentage of the area that is nonfragile and therefore of no concern and of defining the areas of critical concern that justify monitoring and documentation expense.

JUSTIFICATION FOR MONITORING THE PROCESS OF DESERTIFICATION

In areas involving desertification, the major emphasis in collecting earth resources data should be to provide a basis for resource development. The discussion of resource survey criteria should begin with a consideration of the development level of affected areas and the capacity of the country to finance data acquisition activities and to utilize these results. The intensity and timing of a survey are certainly affected by such factors as intensity of development and size of the area affected, availability of resource data and aerial photography from previous surveys, extent of development or remedial programme planned and others.

Following are justifications for a monitoring programme.

THE NEED FOR SURVEYS

The desertification process can be halted and reclamation procedures initiated only if there is a physical assessment of the processes involved, an estimate of the magnitude of the problem, and the specific problem areas located along with areas of potential for reclamation.

ACCELERATED SURVEYS

Progress is being made in many countries in a methodical, conventional manner toward completing natural resource surveys; however, completion of these surveys is generally programmed over a period of many years. A practical method of acquiring resource data is to place priorities on areas where development is most probable. Resource information can then be classified according to high, medium, or low development potential with greatest attention given to the areas of highest potential.

AERIAL PHOTO COVERAGE

Aerial photo coverage of parts of most developing countries is not available. In particular, recent coverage in colour which is important for resource surveys is generally not available. Of more significance, however, is the fact that low altitude coverage, even if available, would be unmanageable because of the large scale and great quantity of photos required to cover a large area. Also, the photography would not provide the spatial and temporal advantages inherent in spacecraft imagery. Aerial photos may be necessary however for coverage of limited-sized calibration sites or for multistage studies.

ADVANTAGES OF LANDSAT

As an aid in recognizing resource boundaries and in classifying resources Landsat imagery has distinct advantages such as the synoptic view, the near-orthographic scenes, the repetitive coverage, and the multispectral coverage. Also, digital data are available.

COSTS OF MONITORING

Monitoring of arid or semi-arid areas must be done at a very low cost to be feasible. Landsat technology has reduced costs in such a way that it permits the accomplishment of tasks that were previously not feasible in a reasonable time frame.

In connection with the Mexico National Water Plan, as an example, a potential land use study was performed on 45 million hectares at a rate of 4 million hectares per month at a cost of 0.33 cents/hectare.

INTEGRATION OF EXISTING SURVEYS

Existing data related to geology, topography, soils, natural vegetation, present land use, and climate should be utilized but are usually not in compatible formats. A resource integration and monitoring programme provides the methodology for taking resource data at various scales and degrees of accuracy, and placing it on a reliable base map for easy reference and use.

MONITORING FOR TRANSIENT TYPE DATA

Qualitative or quantitative data concerning phenomena such as soil moisture, changing vegetative patterns, detection of periodic or permanent changes, and other phenomena require a relatively cheap method of periodic surveillance. Repetitive data can be obtained rather quickly from satellites now in orbit (every 12 or 6 days for Landsat I and II) with fairly good resolution for broad reconnaissance purposes.

National Oceanographic and Atmospheric Administration (NOAA) imagery, at less resolution than Landsat, covers the entire world twice daily. The temperature measuring capability of the NOAA satellites can be useful for monitoring soil moisture which is important for rehabilitation measures in critical areas.

MONITORING OF FEATURES AND CONDITIONS RELATED TO DESERTIFICATION

The objectives of a monitoring programme for desertification are to assess existing ecological and resource conditions, to detect physical indicators of desertification, and to observe changes representative of improvement or further deterioration of natural resources.

Certain diagnostic indicators of desertification can be useful as early warning methods for planning disaster relief. Some of these indicators can be observed on Landsat imagery, some on NOAA Synchronous Meteorological Satellite (SMS) imagery, and others might be routinely monitored on the ground by unattended data platforms which can then transmit the data twice each day via satellite to receiving stations.

Some of these early warning indicators are:

1. Rainfall trends
2. Higher than normal temperatures
3. Extension of grazing patterns in vicinity of water holes
4. Numbers of dust storms
5. Receding water levels in wells
6. Changes in sediment load in streams, lakes and reservoirs
7. Extension of cultivated areas into unsuitable drylands
8. Destruction of vegetation for fuel and construction
9. Occurrence of surface soil crusts
10. Change in soil organic matter.

The above physical indicators would normally be considered along with social and economic indicators.

Recognition of various resources and their quality or condition at various times is the essence of a monitoring and rehabilitation programme. Can these features be monitored using primarily space imagery? The answer is a qualified yes — depending on the particular parameter and considering that a study of desertification must be conducted initially on a reconnaissance level. A knowledge of certain features described in this section are essential to a desertification study. The objectives of studying each feature as well as the detection feasibility of each are discussed in the following section.

Features discussed are: (1) natural vegetation, (2) soils, (3) land use, (4) soil erosion, (5) high water tables and salinity, (6) ground-water, (7) soil moisture, and (8) energy balance.

NATURAL VEGETATION

Objectives: Map and monitor current vegetative cover and changes that may occur.

Inventory rangeland productivity and utilization including ecological condition, successional direction of change, grazing intensity, vulnerability to damage, evidence of mismanagement, and seasonal changes.

Assess potential productivity.

Suggest areas for rehabilitation or improvement.

Methods: Landsat imagery as colour composites and band 5 alone, at a scale of 1:250,000 or smaller shows general distribution and conditions of vegetation. Desert vegetation must be observed on Landsat imagery at a time most favourable to plant growth to exert a significant influence on the spectral signature. Imagery from different seasons can provide additional information. Multistage imagery can provide a progressively more detailed analysis of vegetation. Medium altitude aerial photographs (scale about 1:30,000) for sample areas allows verification of Landsat interpretations and provides further information on the vegetation type within relatively homogeneous areas shown on Landsat. Large scale aerial photographs can be used for specific range type identification. Finally ground samples must be taken to determine vegetative species in plant communities as well as forage production and forage potential.

Where vegetation density is low, interpretation and analysis of imagery may be difficult or impossible. Where vegetation is more dense, it is generally the most prominent feature of the imagery and provides useful indirect information on soils and hydrology. The best soil indicators are those plants that have shallow root systems (Vinogradov, 1971). Shrubs are a more reliable and widely used basis for soils interpretation than are grassy or semi-shrubby plants. Plants with deep root systems are ecologically rather impartial to the various soils.

SOILS

Objectives: Map soil associations.

Map potential land use and soil limitations.

Identify rangeland vegetation and crops suitable for each soil type.

Methods: Landsat colour composite and band 5 alone, at a scale of 1:500,000 or 1:125,000 is utilized for wet and dry seasons. Preliminary soil association maps can be prepared from FAO and other general soil studies using Landsat imagery as a base. Final corrected soil maps can be prepared by synthesizing background material with observations and data obtained in the field. Final descriptions of each mapping unit and complete soil properties and soil interpretation tables are prepared. Finally interpretive maps are prepared showing rangeland potential, agricultural potential, erosion hazard, etc.

Soil landscapes which are interpreted from Landsat imagery are classified and shown on soil association maps. Soil landscapes exhibit a characteristic surface geometry, kind and density of vegetation, and hydrology (Westin and Frazee, 1976). Landsat imagery shows patterns from which inferences must be drawn by qualified soil scientists based on at least limited field studies and sampling.

LAND USE

Objectives: To survey present land use in the critical areas of desertification.

To provide basic information for determining potential land use.

Methods: Using all available maps, air photos, and other data concerning current land use, preliminary maps at a suggested scale of 1:500,000 or 1:250,000 are prepared, preferably using the land use classification system of Anderson *et al.* (1976). Landsat imagery at the same scale as the preliminary map can then be used to update the map and fill in areas of previously unknown land use. Levels I and II and in some cases Level III land use can be distinguished on the imagery. The updated map can be verified in selected key areas by low altitude flights or ground surveys. Wherever possible imagery for different seasons of the year should be utilized — dry season imagery for soils and wet season imagery for vegetation.

SOIL EROSION

Objectives: Map and monitor extent and severity of erosion.

Identify areas vulnerable to erosion.

Identify areas for erosion control projects.

Methods: On Landsat imagery erosion is temporarily apparent as changes in soil type and colour, in appearance of sand and gravel and bare rock, in accentuated dendritic drainage patterns and others. Information needs include a measure of accelerated erosion and of the concentration of gullies and rills. Information regarding the location of blowouts, wind deposits and alluvial deposits is also required.

As in the case of soil maps, preliminary maps are prepared, checked by low altitude aircraft flights and by field work and revised to give final maps. The erosion and erosion vulnerability maps can be used with other ecological and socio-economic information to identify areas where erosion control measures would yield greatest benefits.

HIGH WATER TABLES AND SALINITY

Objectives: Determine cause and extent of high water tables.

Identify areas affected by salinity.

Identify waterlogged and salt-affected areas which can be rehabilitated with leaching and salt tolerant grasses and forage crops.

Methods: Since water tables and salinity are not visible except in extreme situations, analysis is generally indirect through effects on vegetation. Since the conditions are often seasonal or only seasonally visible, the timing of the imagery may be critical. Research in the United States has shown correlations between crop reflectance and depth to water table and concentration of salinity; however local research will be necessary to determine local correlations. Reflectance in the near infrared has been shown by Myers *et al.* (1966) to be effective in estimating the severity and extent of salt-affected areas in cotton fields.

GROUND WATER

Objectives: Detect and map shallow aquifers and detect indicators of deep aquifers.

Methods: For very shallow aquifers the techniques described above for high water tables are applicable. Shallow sand

and gravel aquifers can often be identified on the basis of the features that produced the aquifers. These include geologic structures, landforms, old meander loops, scars and others. Keys to detection of deeper aquifers include the occurrence of fracture traces and lineaments on imagery. Discharge areas are indicated by flowing streams during periods of low flow, by lineament locations in topographically low areas, by the continually healthy growth of vegetation during droughts, and by water use.

SOIL MOISTURE

Objectives: Map and monitor rainfall patterns.

Estimate moisture in bare soil to a depth of at least 5 cm.

Estimate soil moisture available in root zones based on indirect indicators

Methods; Visible, thermal infrared and microwave techniques each has application for sensing soil moisture parameters. Moist soil is darker than dry soil, thus reflectance patterns may be utilized for estimating surface moisture. Thermal infrared imagery obtained at night on bare soils provides temperature patterns that are interpretable in relation to moisture to a depth of 5 to 10 cm. Also, thermal infrared sensing of vegetation canopies which nearly or totally cover the soil can be used to relate vegetation temperature to soil moisture status. The thermal sensors aboard NOAA satellites can provide data for moisture detection. Data from the very-high-resolution radiometer (VHRR) are used. Microwave data, although not yet routinely available, will provide estimates of soil moisture under adverse weather conditions.

ENERGY BALANCE

Objectives: Measure parameters for climatic modeling.

Methods: The balance between incoming and outgoing radiation is the most important factor that determines local microclimates and regional climates, but the mechanisms are not clearly understood. Since many of the processes of desertification result in increased albedo due to a decrease in vegetation cover or loss of topsoil, a change in microclimate results.

The elements for computing albedo can be obtained from spacecraft if supplemental measurements of incoming radiation are made. Thermal emittance is presently being gathered over broad areas by NOAA satellites.

Ground truth instrumentation for energy balance and microclimate studies might include air temperature, net radiation, soil temperature, soil moisture, evaporation and others. Data collection platforms may be located in remote areas and have capability for transmitting most of the above information to satellites and back to ground receiving stations on a daily basis.

INFORMATION DATA BASE

An effective programme for monitoring the advance and/or control of desertification requires large amounts of resource data. Management of these data without the use of automated techniques would be unrealistic timewise. A computerized cellular information data base system is therefore implemented to aid in the storage, retrieval, collation, interpretation and tabulation of these resource data.

Data which are input to the data base system may originate from a variety of spatially-oriented sources and scales. Both already existing thematic maps and those interpreted from remote sensing imagery can serve as input. The basic question which must be resolved prior to the input of data concerns the cell size which will be used. Factors such as the complexity of the input maps and the limitations of the sensor resolution need to be considered when the cell size is determined.

Computer-plotted resource maps were generated in connection with an earlier desertification feasibility study for an area around Jodhpur, India. The Landsat image and the resource overlays were divided into 4 km^2 cells by computer drawn grids and oriented to latitude and longitude. For each resource map the dominant characteristic of each element was entered into the computer. Output which results from this basic data base operation consists of a plotter map and frequency and areal tabulations. Additional interpretations may be made from each input resource map with the same output products. For example, once the basic soils and topographic data have been entered into the data base system, an interpretation for erosion hazard can be made and the output tabulated and plotted on this basis.

An additional feature of the information data base is the theme overlay capability which is extremely valuable when the interaction among various types of resource data and soil limitations are analyzed. Any combination of resource data sets which are spatially registered and have the same cell size may be combined. Output products are again plots and tabulations. An example of this data base feature is the overlaying of soils, and vegetation data for the purpose of establishing pasture potential and the types of vegetation a certain soil type will support. Charateristics of high and low potential are based on inputs such as soil capability, erosion, rainfall, stock water availability, salinity hazard and others.

Changes in resources over long periods of time are important for recognizing the trends of further deterioration or improvement in desertification processes. The data base information system described here lends itself to updating resource data from any source including temporal Landsat imagery, other ground surveys, and aerial photographs.

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PLENARY SESSION

RECOMMENDATIONS OF THE SYMPOSIUM

I. The Symposium commends the Central Arid Zone Research Institute (CAZRI) and its predecessor organisations for its achievements in 25 years of research into problems of maintaining and developing the natural resources of the Indian arid zone. In view of this contribution, and the high priority of such work in the Indian and other arid regions with large human populations, it is recommended that:

(a) additional support, facilities and collaboration be provided by the relevant national and international agencies to enable it to continue and to extend its research and development studies;

(b) its expertise and scientific competence be fully utilized by recognising it as a Regional Arid Lands Institution as envisaged under the 'United Nations Plan of Action to Combat Desertification';

(c) an association of arid zone research and development institutions within the Asian and African countries sharing common problems of aridity and desertification be constituted, for the exchange of experience and knowledge and conduct of training programmes, whereby CAZRI may contribute to and gain from the experience of neighbouring regions.

Monitoring Desertification

II. The Symposium commends the Transnational Projects within the 'United Nations Plan of Action to combat Desertification', particularly the "Project to Monitor Desertification Processes and Related Natural Resources in Arid and Semi-Arid Areas of Southwest Asia", and stresses the need for prompt action by the governments concerned.

III. The Symposium endorses the recommendations of the Science Associations' Seminar, held in Nairobi on 21-25 August 1977, concerning the great importance of identifying physical, biological and social indicators of desertification and of developing methods of testing and applying them in selected areas, and suggests that attention also be given to economic indicators. It accordingly recommends that:

(a) in view of its experience in relevant fields, CAZRI, Jodhpur, be supported at national and international levels in establishing indicators of desertification and methods of applying them, particularly the social and economic indicators;

(b) western Rajasthan be one of the selected areas for testing the validity of such indicators and CAZRI be afforded the facilities and support to monitor desertification in this region.

Social and Economic Factors and Traditional Knowledge

IV. Recognising that the main objective of research and development in the arid lands is improved living standards for their human populations, and that pressure of population on basic resources is an important factor in arid-lands problems, the Symposium recommends that:

(a) the determination of priorities in research and development be more closely guided by, and linked with, studies of the demographic, social and economic factors;

(b) in the areas of adaptive research, demonstration, pilot projects and extension, greater attention be given to the social and economic circumstances of the communities affected, and to the socio-economic impacts of technological changes that have been introduced;

(c) development of educational facilities appropriate to arid regions and especially to nomadic people.

V. The Symposium recommends that research in the following fields be supported, to facilitate the application of knowledge and technology, both traditional and modern:

(a) local perceptions of environmental and socio-economic problems, including desertification and drought risk, of priorities for development, and of constraints to the improvement of living conditions;

(b) social attitudes, values and preferences in respect of crops and livestock and of systems of land use;

(c) the identification of incentives and social mechanisms which may assist the acceptance of new technologies by communities which, as yet, have little commercial orientation;

(d) means of harnessing local leadership to secure community participation in developmental programmes;

(e) social and economic obstacles to the formation of credit and the establishment of cooperative societies ;

(f) appropriate information systems and other means of extension including provision of local language material;

(g) local and national land tenure systems.

VI. The Symposium recommends that studies be carried out:

(a) on the possible extent of externalising social costs of the adoption of new technologies in arid regions;

(b) on the choice of fiscal and monetary instruments to circumvent the problems of economic imbalance within arid regions;

(c) on the administrative logistics of implementation of policies of reclamation and development of the arid lands.

VII. Programmes of development for the arid lands should respect and benefit from traditional knowledge of the local environment and its resources. The Symposium recommends that programmes of research and development take full account of the following among others:

(a) traditional uses of local plants as sources of food, medicinal drugs, fibres, oils, gum, etc. with a view to their potential agro-industrial uses;

(b) the bases of selection and adaptation of indigenous crop and pasture plants and breeds of livestock;

(c) traditional systems of crop and animal husbandry in relation to the local environment;

(d) traditional social systems of risk-sharing, and strategies for coping with periodic drought;

(e) traditional uses of constructional materials and traditional designs of housing, settlements, etc.

Development of Scarce Water Resources

VIII. Noting the constraints to arid-lands development set by scarce water resources,the Symposium recommends that, where supplies are limited:

(a) priority be given to the provision of good community drinking-water supplies, and to the management of water resources on a community basis;

(b) assessments of local groundwater resources and of the groundwater balance be carried out, to facilitate their rational and conservational development;

(c) measures be undertaken to improve recharge to local acquifers where feasible;

(d) suitable water purification processes be applied to provide potable water for rural and urban populations.

IX. In areas of rainfed farming where supplemental irrigation is limited by scarce water supplies, the Symposium recommends that emphasis be given to, among others:

(a) the development of alternative contingent cropping plans for different patterns of rainfall distribution;

(b) investigations of practices to enhance the utilization of stored soil water by crops;

(c) the refinement of water harvesting techniques and watershed management, and the design and treatment of storage reservoirs and water-transport systems to minimise losses through seepage and evaporation;

(d) systems of reduced tillage combined with chemical weed control;

(e) the breeding and selection of water-efficient plants;

(f) the effects of mulches and anti-transpirants of plant-water relations and crop yields.

X In areas of irrigation farming, the Symposium recommends that additional emphasis be given to:

(a) evaluation of check-basin, furrow, sub-surface, sprinkler, drip and foliar mist irrigation in relation to soil character, rise of water table, and related factors;

(b) determination of the time-sequence of water use and the water-extraction patterns in relation to crop yield under different management practices;

(c) development of cropping patterns and practices in relation to water supplies and other inputs;

(d) more efficient means of storing, conveying and applying irrigation water;

(e) agro-climatological studies to determine the water needs of crops, and plant-physiological studies to ascertain critical periods of water need as a guide to irrigation schedules.

XI. The Symposium recommends that, where saline water is used for drinking and irrigation, emphasis be given to:

(a) reviewing existing standards of water-quality for irrigation, with a view to formulating more realistic standards;

(b) further studies on the effect of irrigation with saline water on soil and crop yield and quality, and on the development of models for predicting the build-up of salinity in the soil;

(c) further development of salt-resistant plants;

(d) development of appropriate management practices using saline and sodic water for irrigation;

(e) development of technologies for the reclamation of salt-affected lands using natural precipitation and saline or sodic ground water;

(f) determining salt-tolerance limits in livestock and humans and effects of saline water on animal metabolism and production.

Silvipastoral Systems

XII. Recognising the importance of improved livesotck husbandry as an ecologically appropriate and stable form of land use over much of the drier parts of the arid zones, the Symposium recommends that:

(a) applicable (adaptive) research be continued into systems of rangeland management, particularly the productivity, persistence and nutritional requirements of native and introduced grasses and legumes, and the use of fodder trees and shrubs in silvipastoral systems, with increased emphasis on economic evaluation on the basis of animal production, including secondary animal products;

(b) additional emphasis on studies of animal-plant relations in support of livestock production in arid zones;

(c) re-assessment of the role of the goat in arid land use, including its ecological impacts and its management in relation to pasture types, and its complementary functions in systems of livestock husbandry based primarily on other animals, such as sheep;

(d) livestock-breeding programmes should include selection for, in addition to production, such qualities as heat tolerance and efficient conversion of low nutritive fodder. Superior exotic breeds used for crossbreeding should have gene frequencies of blood biochemical traits similar to indigenous breeds.

XIII. The Symposium recognises the need for an increased cover of trees and shrubs in arid lands, to protect the ground surface, stabilise food and fodder production and provide fuel wood. Accordingly, it recommends that trees and shrubs be planted on a large scale, particularly on land classes unsuitable for cropping, through a planned programme of social forestry involving local communities, through the following measures:

(a) *inducement to farmers to plant* trees on fields and around farmhouses, where appropriate;

(b) intensified research in the fields of fodder and fruit trees, indigenous and exotic, suited to arid environments, with special emphasis on fodder trees, their adaptability, productivity and genetic improvement, and their integration into improved systems of land management. As far as possible, multi-purpose leguminous species should be preferred;

(c) adaptive research into the establishment and management of woodlots, with particular emphasis on the identification of the most suitable and productive species and on the integration of managed woodlots within general schemes of afforestation, shelter belts, sand stabilisation, and soil and water conservation;

(d) pilot and demonstration projects should be extended, and governments should be urged to reserve lands of the appropriate capability classes for the establishment of village woodlots.

Crop and Livestock Protection

XIV. The Symposium notes the critical importance of preventing losses of food crops and livestock in arid lands, and recommends that technologies for the pre- and post-harvest protection of food crops and animal products be developed as an integrated management technology and applied at national levels. It commends the formulation of the "National Programme for Rodent Pest Management" *in India as an example of the schemes* of research, training and extension required.

Increased Productivity

XV. Noting the high levels of human and livestock pressure on land resources in many arid regions, the Symposium recommends that:

(a) endeavours be increased into research to improve soil fertility, soil-physical conditions and crop production, patricularly in the context of the availability of nutrients and water to crop plants and the role of legumes, including tree legumes, in cropping systems, with supporting studies of desirable soil microbiota;

(b) increased attention be given to improving the quality of plant and animal production, through genetic improvement.

Conservational Measures

XVI. The Symposium recommends that the principles and methods of revegetating denuded areas, stabilising sand dunes, preventing soil erosion and conserving soil and water should be further developed where necessary in the arid zones, but that increasing emphasis should now be placed on economic analyses of such measures, and on their integration into conservational land-use systems consistent with land capability and other regional characteristics.

Alternative Energy Sources

XVII. To meet the energy requirements of arid-land populations for cooking and heating, and to reduce the pressure on the vegetation as an energy source. It is recommended that existing endeavours towards the development of inexpensive and socially acceptable devices for harnessing solar, wind, biological and other alternative energy sources be supported on an increased scale.

Wildlife and Desert Reserves

XVIII. Realizing the extreme paucity of biological information on wildlife species in the arid lands, and the need to take immediate action to manage their numbers, the Symposium recommends:

- (a) the establishment of desert national parks, nature reserves and wildlife sanctuaries on a priority basis, including the proposed Indian Desert National Park;
- (b) studies of desert wildlife by desert research institutions;
- (c) studies into the role of wildlife in desert rangelands, and into the economic potential of the wildlife resource.

Introduction of Technology

XIX. Noting the possible harmful consequences of introducing new technologies as single items, without reference to the total system of resource management, the Symposium recommends that development of the arid lands should take the form of integrated programmes in which technology packages are supported by appropriate conservational forms of resource management, together with the necessary social and financial services and other infrastructures..

Resource Inventories

XX. The Symposium notes that little use has so far been made of integrated regional inventories of natural and human resources of the arid lands. It stresses the value of such inventories as a means of identifying problems for applied research and as a basis for planning research programmes. It recommends that such surveys should be carried out in the framework of approved development schemes and in direct collaboration with the responsible development agencies, or in the context of specific problem-oriented research projects in conjunction with the research scientists involved. Particular attention should be given to the need for survey teams to monitor the progress of development programmes, including periodic resurveys as required, with a view to modifying original development proposals in the light of experience. Where appropriate, remote sensing techniques could be applied for rapid inventory.

Measures to Counter Risk in Arid Land Use

XXI. In view of the urgent need for diversified livelihood sources in those arid lands in which the pressure of population of land resources is heavy, it is recommended that alternative sources be identified and developed in order to improve and stabilise living conditions, for example industries based on minerals and agriculture, cottage and small-scale industries based on local handicrafts, and tourism.

XXII. Recognizing that drought-risk insurance and drought relief are not alternatives to the development of more stable livestock systems in arid regions, the Symposium recommends that these measures be included in schemes for regional development, including:

(a) research into the efficient and economic preservation of excess forage produced in years of high rainfall, and the development of systems of storage and distribution;

(b) the establishment of reserve food depots at central points, and the provision of adequate means of food distribution, such as transport and communications;

(c) the establishment of seed stores, nurseries and livestock pools to facilitate recovery after drought;

(d) the establishment of appropriate schemes of drought-risk insurance and arrangements for relief loans, where appropriate in kind.

Commitment to Development

XXIII. Recognizing that in many arid regions scientific knowledge and technology are already adequate for the commencement of development programmes, but generally remain unapplied, and that the gap between research and development continues to widen, the Symposium stresses on decision-makers at all levels the need for efficient commitment to the development of the arid regions, whereby existing knowledge can be mobilised for the benefit of their populations.

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