

DRYLAND AGRICULTURAL RESEARCH IN INDIA: THRUST IN THE EIGHTIES

**Papers presented at the National Seminar
"A Decade of Dryland Agricultural Research in India
and Thrust in the Eighties"
held in January 18-20, 1982 at Hyderabad**

EDITORS

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and

V. BALA SUBRAMANIAN

1983

ALL INDIA CO-ORDINATED RESEARCH PROJECT FOR
DRYLAND AGRICULTURE

SANTOSHNAGAR, HYDERABAD-500 659

INDIA

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PROGRAMME

NATIONAL SEMINAR ON DRYLAND AGRICULTURE

- Seminar Theme : A Decade of Dryland Agricultural Research in India and Thrust in the Eighties.
- Venue : Central Plant Protection Training Institute, Rajendranagar, Hyderabad.
- Date : 18-20 January, 1982.
- 18 January 1982
- 0900—1000 hr : Registration
- 1000—1130 hr : INAUGURAL SESSION
- Chairman : Dr O.P. Gautam,
Director-General, ICAR.
- Rapporteur : Dr J. Venkateswarlu,
Project Co-ordinator (Research)
- Welcome : Dr N. S. Randhawa,
Deputy Director-General (SAE), ICAR.
- Key-note address : Dr. O P. Gautam,
Director-General, ICAR.
- Inaugural address : Mr C. Venkata Rao,
Honourable Minister for Agriculture, Andhra Pradesh.
- Vote of thanks : Dr R.P. Singh,
Project Director (Dryland)
- 1130—1135 hr : Tea Break

18 January 1982

1145—1330 hr : TECHNICAL SESSION—I
Theme : Cropping Systems for Drylands
Chairman : Dr N.S. Randhawa,
Deputy Director-General (ICAR)
Rapporteur : Dr M. Velayudham
Lead Papers : Dr Mahatim Singh
Dr V. Bala Subramanian
Dr R. Willey, Dr M.S. Reddy and Dr M.R. Rao
Discussion

1330—1500 hr : Lunch Break

1500—1630 hr : TECHNICAL SESSION—II
Theme : Integrated Weed, Pest and Disease Management in
Drylands
Chairman : Dr N. C. Joshi
Rapporteurs : Dr N. K. Sanghi
Dr Meiku Lal
Lead Papers : Dr N.C. Joshi
Dr G. Friesen
Dr K. Lakshminarayana
Discussion

19 January 1982

0930—1100 hr : TECHNICAL SESSION—III
Theme : Integrated Nutrient Supply Systems for Drylands
Chairman : Dr J. S. Kanwar
Rapporteur : Dr K. Vijayalakshmi
Lead Papers : Dr J. Venkateswarlu
Dr Rajat De
Dr Ranjodh Singh
Discussion
1100—1145 hr : Tea Break

1145—1300 hr : TECHNICAL SESSION- IV
 Theme : Runoff Management
 Chairman : Dr B.A. Chaugule
 Rapporteur : Mr C.K.R. Chetty

 Lead Papers : Dr K. Vijayalakshmi
 Dr S. M. Miranda, Dr P. Pathak and Dr. K. L. Srivastava
 Discussion
 1300—1400 hr : Lunch Break
 1400—1530 hr. : TECHNICAL SESSION- V
 Theme : Alternate Land Use Systems for Dryland
 Chairman : Dr K.A. Shankarnarayan
 Rapporteur : Mr R.B. Das
 Lead Papers : Dr K. A. Shankarnarayan
 Dr C.J. Itnal and Dr R. Hampaiah
 Discussion
 1530—1545 hr : Tea Break
 1545—1750 hr : TECHNICAL SESSION—VI
 Theme : Efficient Use of Environment
 Chairman : Dr L.D. Swindale
 Repporteur : Dr V. Bala Subramanian
 Lead Papers : Dr V.V. Dhruva Narayana
 Dr S.M. Virmani
 Discussion
 20 January 1982
 0930—1030 hr : TECHNICAL SESSION—VII
 Theme : Efficient Use of Power in Drylands
 Chairman : Dr G. Friesen
 Rapporteur : Dr C. Sriram
 Lead Papers : Dr D. S. Rajput
 Dr G. E. Thierstein

Discussion	
1030—1045 hr	: Tea Break
1045—1200 hr	: TECHNICAL SESSION—VIII
Theme	: Yield Gap Analysis
Chairman	: Dr R.P. Singh
Rapporteur	: Mr D. L. Vyas
Lead Papers	: Mr B. K. Rastogi Dr R. D. Ghodake and Dr T.S Walker
Discussion	
1200—1315 hr	: TECHNICAL SESSION—IX
Theme	: Field Testing of Dryland Technology
Chairman	: Dr S.K. Sharma
Rapporteur	: Dr S.K. Das
Lead Papers	: Dr B. G. Rajasekhara Dr S. R. Raje
Discussion	
1315—1430 hr	: Lunch Break
1430—1600 hr	: PLENARY SESSION
Chairman	: Dr N. G. Perur
Repporteur	: Dr K. Vijayalakshmi Mr B.K. Rastogi
Presentation	: Sessions' Reports and Chairman's remarks
Vote of thanks	: Dr R.P. Singh
1600—1630 hr	: Tea

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Foreword

The importance of dryland agriculture to total food production in India as well as to the prosperity of dryland farmers needs no emphasis. The ICAR's All India Co-ordinated Research Project for Dryland Agriculture has been conducting adaptive research on various aspects of dryland agriculture through its 23 cooperating centres located at various regions of India. The Project has completed a decade of fruitful research and has come out with simple implementable recommendations on dryland crop production practices.

The end of a ten year period is an appropriate time when the scientists engaged in dryland Agricultural research should critically review the past results and draw-up priorities for the immediate as well as long term future requirements. One of the best ways of achieving this goal is to organise a seminar which brings the scientists concerned together for discussion, exchange of ideas and consensus on decisions. It was done. The National Seminar "A Decade of Dryland Agricultural Research in India and Thrust in the Eighties" was held at Hyderabad from 18-20 January, 1982 with the following objectives :

- i. To take stock of the achievement of the dryland research done during the decade 1971-80
- ii. To identify gaps in dryland knowledge and technology
- iii. To set out dryland agricultural research and development priorities for the eighties.

There were nine technical sessions, which have covered almost all the aspects of dryland agriculture—cropping systems, crop protection, nutrient supply resource management, implements, economics, field testing etc. The seminar was so planned that in each session there were complementary presentations of reviews, and views by the scientists of the All India Co-ordinated Research Project for Dryland Agriculture as well as the scientists with common interest from other research institutions. This approach has resulted in free flow of knowledge from different angles. A uniform format of presentation of articles has not been followed. It may be appreciated that, as the nature of contents vastly differ, the contributor has chosen his own style.

One of the results of this successful seminar is this publication which contains almost all the papers contributed by experts in response to my invitations. It is not merely a documentation. Hopefully the information, data, interpretation, views, suggestions for future etc available in the various articles will also be of value to scientists of other dryland areas of the world.

I wish to express my gratitude to all who have made the seminar a grand success, particularly Mr. C. Venkata Rao, Honourable Minister for Agriculture, Andhra Pradesh, Dr. O.P. Gautam, Director-General, ICAR, Dr N.S. Randhawa, Deputy Director-General (Soils, Agronomy and Engineering), ICAR, chairmen and rapporteurs of all the technical sessions, the contributors and participants. Special thanks are due to Dr N.C. Joshi, Director, Central Plant Protection and Training Institute, Hyderabad for kindly providing the facilities of auditorium for the seminar.

R. P. SINGH
Project Director

Acknowledgements

The editors gratefully acknowledge the help of Mr. V. Annamalai, Mr. D. Gangadhar Rao, Ms Lakshmi Narasu, Ms A. Sambrajamma and Ms Santa Maria Xavier, and the cooperation of the Sapphire Printing Press to bring out this publication.

INAUGURAL SESSION

KEY - NOTE ADDRESS

O. P. GAUTAM

Hon'ble Minister for Agriculture, Mr. Chanamolu Venkata Rao, Distinguished Guests and Fellow Scientists :

I am indeed very pleased to participate in this National Seminar on "A Decade of Dryland Agricultural Research in India and Thrust in the Eighties". It was on May 5, 1979 that I had the opportunity to share my thoughts and benefit from the deliberations of the scientists participating in the Annual Workshop of Dryland Agriculture Project. This Seminar provides good opportunity, therefore, to know the progress made during last three years.

Dryland Agriculture and Food Production

Out of 143 million ha of cultivable land in India 108 million ha is under rainfed agriculture, i.e., drylands constitute about 75 percent of arable land. They contribute about 42 percent of foodgrains, almost all of coarse grains and about 75 percent of pulses and oilseeds. More than 90 percent of sorghum, pearl millet, peanut and pulses are grown in arid and semi-arid areas. About two-thirds of rice and rapeseed-mustard and one-third of wheat are grown in rainfed areas.

To-day, out of about 135 million tons of food produced, about 60 million tons are contributed by drylands. Efforts are being made to bring more area under irrigated agriculture and thus to increase the cropped area; but even when we achieve our target of 113 million ha under irrigation by the year 2000 A. D. we would still have about 45 percent area under rainfed agriculture.

While we shall continue to stress intensive agriculture on irrigated lands, we could not afford to be complacent with our dryland agriculture since its contribution towards total food production would continue to be significant. Intensive irrigated farming is an imperative for survival but improved dryland agriculture is necessary for 'equity'. Also, we can not achieve stability in food production without a stabilised dryland agriculture.

Main Characteristics of Dryland Agriculture

Arid and semi-arid areas are characterised by low crop yields and high yield fluctuations. In these areas the mean annual potential evapotranspiration exceeds the mean annual rainfall which ranges from 350 to 1400 mm. Soils are either black (vertisols) or red (alfisols). Such areas often suffer from periodic

droughts, floods, soil erosion, poor quality drinking water, unemployment, low income and malnutrition. These are areas where poorest of the poor live. Yet these are areas which provide much of our millets, pulses and oilseeds and also the important raw materials like cotton and groundnut.

Doubling the Production on Dryland is a Distinct Possibility

Based on the experimental data of the Dryland Project the average yield of crops in low, medium and high rainfall regions were as follows :

Classification in terms of rainfall (mm)	Approximate area (M ha)	Average crop yields (q/ha)	
		Farmers' fields	Research plots
Low (< 750)	37.65	4.0	10.0
Medium (750-1150)	37.65	8.0	19.0
High (> 1150)	33.70	10.0	30.0
Average		7.3	19.7

It is evident that crop yields on drylands can be increased 2-3 times with the use of improved technology.

Presently drylands are contributing about 60 million tons of food grains and 12 million tons of oilseeds. The average yields are low but the production potential with the available technology is about 200 million tons. Even if 50 percent of the potential yields are realised, the drylands could contribute about 144 million tons i. e., doubling the present contribution from drylands is a distinct possibility and a realisable goal.

Considering the performance of sorghum and pearl millet during the last 5 to 8 years, it would appear that rainfed agriculture can contribute more than what is projected for the Sixth Plan. The per hectare yields of rainfed cereals (sorghum, pearl millet and finger millet) over the last eight years have already increased by about 50 percent. Even in the case of pulses and oilseeds yields per hectare can be increased by at least 50 percent by using available improved varieties and technology.

Some of the areas which offer clear potential for additional production of pulses and oilseeds are :

S t a t e	Area (M ha)	First crop	Second crop
1. Maharashtra (Vidarbha)	1.0	Sorghum or Greengram	Safflower
2. Madhya Pradesh (Malwa Plateau)	1.5	Sorghum or Maize	Safflower or Chickpea
	0.5	Rice	Chickpea or Safflower
3. Bihar (Plains or Plateau)	0.5	Maize	Pigeonpea or Linseed
	0.5	Rice	Linseed or Chickpea
4. Uttar Pradesh	1.5	Maize or Pearl millet	Rape/Mustard or Chickpea
	1.0	Rice	Chickpea
Total :		6.5	

Organisation and Development of Dryland Agricultural Research

Research in the area of Dryland Agriculture was initiated as early as 1933 in the ICAR sponsored five dryfarming research centres located at Rohtak, Solapur, Bijapur, Raichur and Hagari. This scheme continued for ten years. The recommendations emerging from these centres emphasised *bunding* to conserve soil and water; deep ploughing for improved water intake and storage; use of farm yard manure to supply plant nutrients; and use of low seed rate, wide row spacing, and interculture of crops for efficient use of the limited moisture in the soil. However, the marginal return of 15 to 20 percent over the base yield of 200 to 400 kg/ha did not enthuse the farmers very much to adopt these research results.

The establishment of soil conservation research centres in the mid-fifties was another effort to improve dryland farming under arid and semi-arid conditions. The project aimed to intensify work on land use classification, monitoring of rainfall patterns, runoff collection, fertiliser use etc. The impact of this programme was not also visible until short-duration hybrids/high yielding varie-

ties of sorghum (CSH-1), pearl millet (HB-1) and cotton (PRS) became available for cultivation. These hybrids/varieties grown with improved dry farming methods represented the first major advance in the dry farming agriculture in the mid- sixties

A Decade of Dryland Agricultural Research

The All India Coordinated Research Project for Dryland Agriculture was formally launched in June 1970. It was a multidisciplinary research unit with 23 cooperating centres located in typical agroclimatic zones. I am reminded, at this point, of the late Dr. Ch. Krishnamoorthy who was responsible for organising and initiating the Dryland Agricultural Research Project in its present form and who made valuable contributions towards rationalising our thinking and approach towards dryland agriculture. To-day, we miss him. We remember him with reverence. He would always be remembered for the scientific advance we made in dryland agriculture which was his dream and to which he was totally dedicated.

This project has generated during the last ten years considerable data and information on improved methods of moisture conservation and use; timeliness of preparatory tillage and seeding operations; establishment of adequate crop stands; effective weed control; efficient fertilizer use; new cropping patterns; crop life-saving techniques; and mid-season corrections in crop planning in the drought-prone areas. Adoption of these improved soil, water and crop management practices can reduce fluctuations in production from year to year. Based on climatic and water-balance studies, the growing seasons have been identified for all the 23 regions where dryland research centres are situated. It is now known that with 10 to 20-week cropping season, only a single crop can be taken (100 percent intensity). With a 30 to 50-week period, double cropping (200 percent intensity) is possible where rainfall is in excess of 850 mm and profile moisture storage capacity is in excess of 200 mm. For regions with a 20 to 30-week growing season, cropping intensity can be increased through intercropping in areas where rainfall exceeds 500 mm and profile moisture storage capacity is well above 100 mm.

Crops and Cropping Systems

Different crops and cropping systems have been identified for fuller and more efficient utilisation of rainfall and stored moisture under different soil profile conditions. Optimal plant populations have been determined for recommended high yielding varieties under different farming situations.

With the development of new varieties with shorter duration, wider adaptability and photo-insensitive character, new possibilities of growing *pulses* and *oilseeds* in non-traditional areas are opening up. A number of new intercropping

and double cropping systems with millets, pulses and oilseeds have been evolved under Dryland Agriculture Project for various agroclimatic regions of the country.

It has been extensively demonstrated that almost full yields of the base crop and additional yield of the intercrop could be obtained resulting in Land Equivalent Ratio (LER) upto 1.60. What is needed is to popularise use of seed drills and improved seeding methods of intercropping and double cropping systems under receding moisture situations, optimizing the use of the high cost inputs, such as fertiliser and capitalising on the advantage of a legume component in the system. Similarly, weed control and pest management in these systems warrant fuller attention and studies.

As I mentioned earlier, new possibilities are opening up to grow pulses and oilseeds in non-traditional areas. Examples are the early post-rainy or late rainy season pigeonpea in Bihar, eastern Uttar Pradesh, Malwa plateau and Vidarbha regions; groundnut in Ranchi plateau and Bundelkhand region; castor in the seirozems of north-west India, southern Tamil Nadu and field beans in Deccan region. But new problems may come up as these crops move to new areas, e. g. pigeonpea sown late has the problem of sterility mosaic. There is need, therefore, for a close follow-up. At the same time there is need to introduce and adopt new crops that hold out promise in both traditional and unconventional areas, e. g. we have developed sunflower hybrids and cultivars and an earnest effort has to be made to make the best use of sunflower in our cropping patterns.

Water Harvesting

The source of water for drylands is rainfall and with an average annual rainfall of 1020 mm in India, we get about 370 million hectare meter of precipitation. Of these, 120 million hectare meter are lost through flow into river. Of the remaining, only 43 million hectare meter are available for assured water supply to crops. By minimising evaporation losses and harvesting rain water, more area can have assured water supply for growing successful crops.

Efforts have been made under the Dryland Agriculture Project to harvest rain water in two ways-(i) water harvesting, *in-situ* and (ii) Runoff collection and recycling. Water harvesting *in-situ* was attempted by several land configurations, e. g. broadbed and furrow systems developed by ICRISAT, ridge and furrow on grade etc. The experience of water harvesting indicates that the effect

of land configuration was about 15 percent. We would have to establish beyond doubt that water harvesting *in situ* gives *visible* yield increases.

The progress in adoption of water harvesting methods has been slow. The runoff management techniques need to be refined to suit the dryland farmers. Approaches to suit individual farm situations as also community watersheds need to be worked out, e.g. pond size for different size of holdings or group of holdings. In addition to pond size, more work needs to be done to find feasible methods to prevent seepage losses in light soils and identifying efficient lifting devices. A coordinated interdisciplinary effort involving agronomists and engineers is called for.

Integrated Nutrient Supply System

Fertilisers pay in drylands. But in view of the increasing cost of fertilizers, it is necessary to look to integrated nutrient supply system. Such a system should also suit the *poor* dryland farmers.

The role of legume in cropping systems is receiving attention but the residue management is equally important. Organic matter in the form of cereal and legume plant parts available on our cropped lands in rainfed areas for recycling are huge. Whatever crop residues go as animal feed can again be returned to land as farm yard manure and dung. Organic farming concept has to be promoted and associated practices developed since this can result in the saving of energy upto 40 percent with considerable improvement in soil conservation. The organic farming systems as we know rely upon crop rotations, crop residues, animal manures, legumes, green manure, off-farm organic wastes, mechanical cultivation, mineral bearing rocks, and aspects of biological pest control to maintain soil productivity and tilth, to supply plant nutrients, and to control insects, weeds and other pests.

Studies on finding out more efficient strains of rhizobia and possibilities of utilising other N-fixing microorganisms such as *Azospirillum* and *Azotobacter* associated with rhizosphere of various legume and non-legume crops need to be intensified. Likewise, ways to enhance fertiliser-use efficiency have to be worked out to minimise the use of chemical fertilizers.

Integrated Pest Management

An integrated approach including biological, cultural and chemical methods to control insects, diseases and pests is called for since pest management is crucial to the success of dryland agriculture.

Farm Machinery

Developing suitable simple bullock-drawn farm implements and machinery is even more important under dryland agriculture than under irrigated agriculture because timeliness of operations is most crucial and the time available for carrying out operations is rather limited and beyond control. Results obtained indicate that widening plant rows without reducing plant population does not reduce yields but it saves energy and helps to cover larger areas for a given rainfall event. Further, by adopting off-season tillage the available bullock resources could be efficiently used over time to cover more area for land preparation and weed control.

Some seed-cum-fertilizer drills have been developed, but only a few seem to have gone beyond the precincts of the research farms. Even those that have gone out suffered due to quality control. Our agricultural engineers have an important role to play in this connection.

Optimised Land Use Patterns

In view of our limited land resources for the fast growing population and in view of the current land use patterns, an all-out effort has to be made to (a) contribute towards soil productivity through organic recycling and (b) produce more biomass from marginal degraded lands with appropriate farming systems.

Research has been initiated by the All India Coordinated Research Project for Dryland Agriculture on agro-pastoral and agro-forestry systems but a great deal more need to be done. The work done at the Indian Grassland and Fodder Research Institute, Jhansi and Central Arid Zone Research Institute, Jodhpur should also be taken into consideration while planning these studies. Under dryland agriculture, there is need to promote mixed farming systems with suitable combinations of arable crops, livestock species, and trees and grasses as components. Not enough effort has gone to capitalise on the complementarity of field crops and tree crops. These farming systems are synergistic in terms of nutrients shared and contributed within the system either through biological fixation of nitrogen or siphoning off nutrients from deeper layers to the surface. Tree farming, arid-horticulture and energy plantations could be promising areas for further investigations. In fact for some of the water-logged black soil areas presently growing single crop, rice-cum-fish culture need to be explored. Growing *Leucaena* and *Acacia tortalis* with *Cenchrus ciliaris* as intercrop has been demonstrated as a successful association beyond doubt at Indian Grassland and Fodder Research Institute and Central Arid Zone Research Institute. Similar combinations of crop, tree and shrub species should be worked out for each dry farming region.

International and Inter-Institutional Collaboration

Realising the importance of strengthening the dryland agricultural research, we made every possible effort to attract international assistance. In this case, we had the collaboration with CIDA with assistance from the Canadian Government from the very beginning and we were greatly benefited from it. Likewise, Government of India invited the CGIAR to establish ICRISAT in India. I must say that our working relationship with ICRISAT has been most rewarding. In future, we shall have to zealously guard against possible duplication between national and international research effort. We certainly look to the international scientific community for more basic and mission-oriented research to overcome some of the more difficult problems and develop new methodologies to accelerate the pace of scientific advance. As in the case of CIDA, INDO-UK collaboration in Dry Farming has been equally fruitful at Indore. We deeply appreciate the assistance received through these agencies. Equally important is the collaboration between national institutes-ICAR'S own Institutes and Agricultural Universities. We have established an extensive network. We must use it even more effectively.

Transfer of Technology

We have millions of small farm holdings and problems of dryland agriculture are particularly location-specific. In order to develop technology for drylands and transferring it to the user, it is very necessary to involve the farmer himself in the extension process. He should be considered as a participant in this exercise and not just a user. This then calls for identifying the location specific requirements and priorities and need-based technologies. It was to meet this need that ICAR had associated "PILOT PROJECT" with each Dry Farming Research Centre under this Project. Later, to meet the need for skill training Krishi Vigyan Kendra specifically for Dry Farming was established. The Pilot Project or Operational Research Projects are expected to identify the constraints on the adoption of recommended technologies as well as to adapt the technologies to specific locations and farm families. Past experience indicate that the process of constraint analysis needs to be greatly refined.

That the improved dryland practices pay is amply established. But the technology is not getting transferred to the farmers. There seem to be unique features of technology adoption. Weather being unpredictable, risks are higher and the element of *management* is crucial in dryland agriculture. Speed and timeliness of operations determine success or failure. Keeping in view the problems encountered in moisture conservation, water harvesting, plant protection, and adoption of farm machines, group action would seem to be crucial. Along with technologies, cooperative effort would have to be organised. Some

of the unconventional approaches would have to be adopted for extending loans and subsidies to dryland farmers. Instead of cash subsidies, 'service subsidies' may have to be thought of. The whole management approach will have to be linked to each watershed. Risk factor will have to be neutralised by providing insurance or minimum yield guarantee against crop failures. On the one hand research programmes and strategies will have to be developed to conserve our natural resources-soil and water-and on the other, they will have to be tailored to human benefits employment potential, income generation and nutrition.

Dry farming is a challenge for the eighties. This is an opportunity to fulfil our pledge for the poorest of the poor. I have no doubt, fellow Scientists, that your efforts and contributions will help the Nation to fulfil this pledge. I wish your deliberations all success.

INAUGURAL ADDRESS

C. VENKATA RAO

Dr. O.P. Gautam, Director-General, Indian Council of Agricultural Research, Honourable Guests, Distinguished Scientists, Ladies and Gentlemen :

It gives me great pleasure to be here with you today to inaugurate the National Seminar on Dryland Agriculture and also learn what the Indian Council of Agricultural Research is doing to improve the lot of the dryland farmer

I am heartened to hear Dr. Gautam's key-note address which has shown the excellent potential of increasing food production from drylands as well. I am particularly happy when he brought out the immense scope of increasing production of the much needed pulses and oilseeds through increasing the crop intensity in the high rainfall areas. Similarly, his advice for the researchers to acquaint themselves with the real-farm situations while developing need-based technology is most timely. I note with urgency the unconventional steps he sought the Government to take to improve crop production in the drylands.

I, coming from a farming family, always feel that the drylands and wet lands are two eyes to the farmer. Both systems of farming are equally important to bring about increase and stability in crop production.

Drylands in Andhra Pradesh

In Andhra Pradesh, we have 11.3 million ha under plough, of which 69 per cent are rainfed. Even with full exploitation of the water resources, about 52 percent land would still remain rainfed by 2000 A. D. Thus, we will have to increase and stabilise crop production in these drylands, if we have to meet the needs of the growing millions. In the years to come transport would be a bigger constraint and hence it would be necessary to produce the food and fodder requirements of a given region in that region itself.

Hyderabad- A Veritable Centre of Agricultural Research

At this juncture, I like to offer my sincere appreciation to Dr. O.P. Gautam in particular, and Government of India and the Indian Council of Agricultural Research in general, for the generosity and interest shown by them in establishing several agricultural institution in Hyderabad. Among them are :

1. All India Coordinated Sorghum Improvement Project and the Regional Research Station of IARI

2. All India Coordinated Rice Improvement Project.
3. Directorate of Oilseeds Research
4. National Academy of Agricultural Research Management
5. All India Coordinated Research Project for Dryland Agriculture
6. All India Coordinated Soil Test Crop Response Project
7. National Institute of Rural Development
8. Directorate of Oilseeds Development
9. Zonal Rice Development Directorate
10. Regional Station for Forage Production and Demonstration
11. International Crops Research Institute for Semi-Arid Tropics (ICRISAT)

Besides these pivotal institutions, the State Agricultural University is participating in as many as 40 Coordinated Projects in different disciplines. We have NARP programme at the following centres:

1. Tirupathi, Chittoor
2. Lam, Guntur
3. Palem, Mahaboobnagar
4. Jagitial, Karimnagar
5. Nandyal, Kurnool

At Rajahmundry, we have the Central Tobacco Research Institute of the Indian Council of Agricultural Research.

I hope all these efforts of ICAR, Government of India and International bodies jointly with our State counterparts would lead to quantum jumps in all spheres of development at farm level.

Further, I am tempted to request the chief of ICAR to always consider this state with such an excellent infrastructure facilities as a 'take-off' ground for any new venture in agriculture research and education. To improve working efficiency we have divided our state into 6 zones and appointed Zonal Senior Directors of Agriculture who would be responsible for the agricultural production programmes in totality for the respective zones. Similarly, may I suggest to you, Dr. Gautam, to consider creation of Zonal Deputy Directors-General of ICAR of which one can be located in Hyderabad for the Southern Zone.

Productivity of Dryland Crops in the State

As per the Bureau of Economics and Statistics, the dryland crop yields over the last 25 years have been as follows:

Crops	Productivity (q/ha)	
	1956-1957	1980-1981
Sorghum	4.4	6.3
Pearl millet	4.9	6.5
Maize	5.6	12.6
Finger millet	9.7	9.7
Groundnut	9.1	6.6
Sesamum	2.2	1.5
Castor	1.9	1.0

In other words, there is some increase in yield of coarse cereals, except finger millet. In the case of oilseeds there has been a decline in the productivity over the last 25 years. With pulses the picture is encouraging, the total production being 2,77,000 tons in 1956-57 and 4,15,000 tons in 1980-81. This is largely because of the concerted effort to grow short duration pulses like greengram and blackgram in rice fallows.

Production Problems

Coarse cereals: In the recent past, striga on sorghum has become a serious menace in certain areas of the state, more so with the high yielding varieties/hybrids. Grain deterioration is yet another problem with these varieties.

Pulses: Yellow mosaic virus on greengram, sterility mosaic and pod borer on pigeonpea have assumed serious dimensions.

Oilseeds: We thought of solving the problems of groundnut production by increasing area under irrigation. So we started taking winter groundnut. But bud necrosis has become a serious menace. In castor, semilooper control through biological means was attempted in our state with some success. The declining yield of oilseeds with their associated problems make me feel very uneasy. All-out efforts to avoid the pest menace and finding out new venues to grow this much needed commodity should be of utmost considera-

tion for the State. Dr. Gautam talked of sunflower. I also desire that we should reexamine the place of this crop, particularly because of its short duration and high quality oil.

Place of Seed

The other day, I was speaking at the Seed Seminar where it was pointed out that the public sector undertakings should go all out to produce more and more of certified seed of oilseeds. Seed is the catalyst in the whole programme of crop production and the declining yield trends in oilseeds might be halted and even made to move up if good seeds are made available.

Here again, I thank the ICAR for providing us with the Seed Technology Research Unit in the Agricultural University, which I hope will help in proper technology for storage of seed of oilseed crops.

Rainwater Management for Boosting Yields

The main source of water for drylands is the rain water. I am told that the Dryland Project and ICRIASAT are carrying out experiments for storing rain water in ponds and recycling it for the needy dryland crops. Dr. Gautam pointed out that the cost of such a programme should be borne by the Government. I think this needs a quick examination and I believe it is a potential programme for bringing stability in drylands. I also feel conjunctive use of groundwater should become the concern of the dryland scientists.

In our state gully plugging and construction of checkdams for improving ground-water re-charge is being attempted. Such an approach might be particularly useful in areas grown with groundnut.

Governmental Action to Improve Crop Production in Drylands

Thanks to the excellent cooperation between the State Department of Agriculture, A. P. Agricultural University and ICAR organisations situated in Hyderabad, a big effort with moderate success has been made to improve the lot of dryland farmers in this state. Among other things it includes, :

- i. Supply of improved seed on seed exchange basis
- ii. Minimum Yield Guarantee Programme
- iii. Crop-insurance scheme

Besides what is normally available for the farmers as subsidy under IRDP, our government has allowed seed exchange on barter basis i. e., improved seed being supplied against local varieties to the farmers. This was done for crops like sorghum, pearl millet, maize and castor.

Under the Minimum Yield Guarantee Programme, the farmers were trained in improved crop production technology and were inspired to obtain higher yields by adopting the new cropping practices. This has been a grand success over the last two years. It is being implemented at the rate of 60-80 hectares per sub-assistant on important crops over the State. This programme has shown to the farmer the increased potential in drylands.

Crop insurance scheme is implemented on an experimental basis in a few blocks covering rice, sorghum and groundnut and we look forward for the results.

Need for Training

As Dr. Gautam said, the dryland farmer has to be trained to take timely judgement as the crop grows from seed to seed. And for this, intensive coaching through 'learning-while-doing' must be attempted. I hope the T and V system proposed for the State will provide this base. If need be, I would like to ask my Director of Agriculture to examine the scope for exclusive staff for this purpose and look to ICAR and APAU for providing the need-based training to the trainers.

Being a farmer, I appreciate very much the concern of the Director-General in asking you all to take the farmer as a participant in the programme of development of the technology.

Epilogue

To sum up, I like to remind you, ladies and gentlemen, that the dryland farmer is by and large a poor farmer and crop production is beset with considerable risk. So most efficient agricultural systems built on the locally available resources should be the endeavour of all of you. I strongly feel that you must provide alternative strategies to meet the different economic situations as well as weather aberrations.

I am glad to inaugurate this National Seminar on Dryland Agriculture and look forward to your very useful recommendations for adoption by both researchers and extension workers to improve the economic condition of the dryland farmers.

CROPPING SYSTEMS FOR DRYLANDS

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CROPPING SYSTEMS FOR DRYLANDS

MAHATIM SINGH

Indian agriculture is predominantly rainfed agriculture. Approximately 75 percent of the cultivated land is rainfed and covers regions receiving a mean annual rainfall of 400 to 1125 mm in two to five months. About 45 percent of the nation's food is produced on dryland and any serious fluctuations in it is bound to affect the nation's food supply.

The success of crop production in rainfed areas depends mostly on monsoon rains. Poor yields and uncertainty in producing even such yields are twin problems of rainfed areas. The major cause of such problems has been the erratic and undependable nature of the rainfall during the monsoon months. Erratic monsoon coupled with inadequate rain water management techniques and traditional agronomic practices further reduces the chances of improving production in such areas. The research results obtained through All India Co-ordinated Research Project for Dryland Agriculture in the past 10 years have clearly revealed that there still exists an untapped yield reservoir in rainfed areas which can be exploited by adopting suitable resource and agronomic management. The extent of such a reservoir in the states of Uttar Pradesh, Madhya Pradesh, Bihar and Orissa is indicated in Table 1.

Traditional Cropping Pattern

Most Cropping patterns followed in the rainfed areas of the country are based on the traditional systems of subsistence farming where every farmer tries to produce everything he needs; however, most of the larger farmers do produce for the market. The evolution of cropping system is determined mainly by the physical characteristics of land, climate, availability of labour and capital and need of the house-hold for food and fodder. Until recently, crop production was based on the utilisation of the inherent fertility of the soil without use of modern inputs such as fertilisers, pesticides etc.

The varieties grown in dryland are of long duration which invariably suffer from moisture stress after the stoppage of monsoon rains. Natural selection operated in favour of survival rather than productivity. They hardly respond to inputs and high level management. Hence these traditional cropping systems are characterised by low and unstable yield.

Table 1: Untapped yield reservoir in rainfed areas

Regions	Crop	Average grain yield (q/ha)	
		Farmer's field	Research station
Uttar Pradesh			
Varanasi	Upland Rice	8.6	25.0
	Pearl millet	7.4	14.0
	Black gram	3.8	11.7
	Barley	7.7	25.1
	Chickpea	6.2	27.7
	Mustard	5.1	13.6
Bihar			
Ranchi	Upland Rice	8.0	25.4
Madhya Pradesh			
Indor	Sorghum	10.0	25.4
	Safflower	New Crop	26.3
Rewa	Upland Rice	25.0	35.0
	Wheat	7.0	14.2
Orissa			
Bhubaneswar	Upland Rice	11.0	32.5

Cropping systems differ according to climate and soil types. In regions of low rainfall (400 mm), short growing season (2 to 2½ months) and shallow soil as in Western Rajasthan, parts of Haryana and Kutch, grass is the principal crop. In addition to grasses, short duration pulses or agro-forestry based system might hold promise in such areas. With increasing rainfall and growing season, the cereals like pearl millet, sorghum, maize or upland rice take the place. Areas having 400-750 mm annual rainfall, monocropping with traditional long duration crops is common. Even areas having an annual rainfall above 750 mm and a soil storage capacity of 150 to 200 mm of available moisture, farmers have been growing either rainy season crop or a post-rainy season crop on residual soil moisture after following during the rainy season. The traditional practice leads to poor yield per unit area in drylands.

Crops and Varieties

Selecting suitable crops and varieties will not only help increase production of a single crop but also will help increase cropping intensity. Many criteria have been set out for selecting a crop variety to meet the requirement of drylands; however, the capacity to produce a fairly good yield under limited soil moisture conditions is the most desirable one. The crop for rainfed areas should be of short duration, drought tolerant and high yielding. The performance of traditional and improved varieties are given in Table 2. Simply by

Table 2 : Performance of local and improved varieties in Varanasi

Crop	Varieties	Grain yield (q/ha)					Mean
		1971-72	72-73	73-74	74-75	75-76	
Rice	Local (Nagina 22)	—	—	26.0	23.3	16.6	21.9
	Improved (Cauvery)	—	—	28.3	30.3	20.8	26.5
Maize	Local (Jaunpuri)	11.9	19.0	5.1	39.2	—	18.8
	Improved (Ganga Safed .2)	—	35.1	11.8	28.0	—	25.0
Pearlmillet	Local	3.2	9.7	4.9	14.1	—	8.0
	Improved (HYB-3)	—	6.0	14.5	18.8	—	13.0
Blackgram	Local (Black)	9.2	6.9	5.6	—	—	7.2
	Improved (T9)	11.4	9.3	6.3	—	—	9.0
Sesamum	Local	4.5	2.6	—	—	—	3.6
	Improved (T 13)	6.4	6.0	8.5	—	—	7.0
Mustard	Local	—	15.4	5.5	17.6	15.2	13.4
	Improved (Varuna)	—	22.5	7.4	16.4	19.9	16.6
Linseed	Local	6.8	15.0	14.6	—	—	12.1
	Improved (T 7397)	6.4	19.9	16.7	—	—	14.3
Safflower	Local	—	—	—	16.4	16.3	16.3
	Improved (N62-8)	—	—	—	19.9	20.5	20.2

replacing the traditional varieties by improved ones, yields can be increased in dryland areas of Varanasi region.

Crops are also selected according to soil depth. Millets do much better than sorghum on light and shallow soils. Roots of crops like castor or pigeon-pea are able to penetrate compact sub-soils better than sorghum or millets. Greater yield advantage would accrue from cropping in the rainy season in Indore, Sholapur and other regions with heavier soils. This may call for a provision of field drainage in black soils receiving high rainfall.

Crop substitution is yet another aspect which can help improve the yield potential from drylands. Basically what is attempted is to introduce more efficient crops for a given situation in place of traditional ones. Typical examples are : safflower in place of cotton and wheat in the Deccan and replacement of wheat by barley or mustard or chickpea on the Indo-Gangetic alluvium from west to east. Rainfed wheat should be preferred in low lying areas and in areas receiving 8 to 10 cm of rains during the winter season.

The farmers of dryland areas attach great importance to food crops. Rarely would they agree to buy food from the market. This should be recognized in introducing a new crop. In the present context in India, grain legumes and oilseeds are the chosen crops to replace inefficient cereals. Decisions should be taken on the basis of marketability and the value of the new crops. Legumes and oilseeds improve the economic status of the farmers and also serve the nation's need. Any crop substitution must be followed by an efficient transport system to move the produce from areas of efficient production to areas of consumption.

Cropping Intensity

With the available dryland technology like rain water management, choice of crops and other agronomical practices, a greater portion of drylands can be put under intensive cropping system. Depending upon the rainfall, soil depth and management aspects, the system may vary from one region to another region. This could be achieved through mixed or intercropping and sequential (double) cropping.

Mixed or Intercropping :

Planning of cropping system should be done on yearly and on entire catchment basis. The type of planning will certainly lead to a proper balance between food, fibre and fodder. When the rainfall is between 500 to 700 mm with a distinct period of moisture surplus, intercropping system should be developed for improving crop production. Even in higher rainfall areas (750 to

Table 3 : Important intercropping systems in rainfed areas

Region	Crops	Grain yield (q/ha)		
		Main crop	Inter crop	Total production
Uttar Pradesh				
Varanasi	Pearl millet alone	13.8	-	13.8
	Pearl millet + Black gram	10.4	4.7	15.1
Agra	Mustard alone	14.6	-	14.6
	Mustard + Chickpea	12.8	4.7	17.5
Jhansi	Sorghum alone	18.1	-	18.1
	Sorghum + Pigeonpea	14.1	5.1	19.2
Dehradun	Maize alone	28.0	-	28.0
	Maize + Soybean	22.8	10.8	33.6
Madhya Pradesh				
Indore	Maize alone	28.5	-	28.5
	Maize + Soybean	24.0	6.2	30.2
Rewa	Sorghum alone	40.1	-	40.1
	Sorghum + Pigeonpea	34.0	9.0	43.0
Bihar				
Ranchi	Chickpea alone	4.9	-	4.9
	Chickpea + Mustard	2.2	8.7	10.9
Orissa				
Bhubaneswar	Maize alone	13.2	-	13.2
	Maize + Pigeonpea (3:1)	8.9	5.4	14.3

1100 mm) intercropping facilitates growing either cereal-legume or legume-legume system of different maturity patterns. In high rainfall areas, intercropping has also been helpful in quick drainage (ridge-furrow system of intercropp-

ing). The most important point in its favour is the minimization of risk of crop failure in drylands. Mixing seeds of two or even more crops (a normal practice with farmers) and broadcasting the mixture hinders post sowing operations. In fact, more and more thinking should now be devoted to intercropping in space. Here the choice of varieties within the crops become important. By and large the future intercropping systems in drylands of India should be cereal-legumes; the objectives are to: 1. minimise fertiliser use, 2. minimise pest and disease incidence on legumes, 3. produce balanced foods, 4. provide legume fodder for cattle and 5. take advantage of extended growing season. Some of the examples of intercropping at different centres of dryland research are presented in Table 3.

Sequential Cropping :

In areas having more than 750 mm annual rainfall with a soil storage capacity of 150 mm or more of available moisture, sequence cropping is possible. Here, the objective should be to maximise the returns from the system rather than from the individual crops. While developing such system, consideration should be given for soil fertility management, growing season, integrated insect-pest management, and above all much needed food which might help nation's food reserve, particularly pulses and oilseeds. Some examples of sequential cropping are given in Table 4.

Table 4 : Production and income from single and double crop systems

Region	Crop sequence (grain yield in q/ha)			Income (Rs./ha)
	Rainy		Post-rainy	
Dehradun	Fallow	—	Chickpea 16.8	1304
	Maize	45.1	Chickpea 15.4	2766
Ludhiana	Fallow	—	Wheat 27.6	3036
	Maize	31.9	Wheat 20.9	4660
Indore	Fallow	—	Wheat 21.8	3762
	Soyabean	29.0	Wheat 19.4	7971
Solapur	Fallow	—	Chickpea 14.9	3503
	Sorghum	37.2	Chickpea 8.4	7311
Bijapur	Fallow	—	Safflower 12.4	2724
	Greengram	7.6	Safflower 12.9	4100
Akola	Fallow	—	Safflower 10.0	2512
	Greengram	6.1	Safflower 13.5	4595

In addition to what has been discussed so far, adoption of timely sowing and suitable methods of sowing, contingent planning for weather aberrations, fertiliser use and adequate insect-pest management are essential pre-requisites for making cropping systems a successful enterprise. The collection of runoff water and its recycling adds a new dimension to the flexibility of cropping system.

Low Monetary Input

For higher yields, maintenance of optimum plant population per unit area is important. Plant population depends, besides the seed rate, on the time and method of sowing which are low monetary inputs. Experimental evidences indicate that early sowings are better than late ones (Table 5).

Table 5: Effect of dates of sowing on grain yield (q/ha)

Date of Sowing	Jhansi	Bhubaneswar		
	Sorghum	Pigeonpea	Castor	Fingermillet
July 1	21.4	8.1	6.4	14.1
July 16	11.2	8.9	3.7	12.9
August 1	—	7.9	2.7	8.9
August 16	—	0.5	0.8	6.6

In general, rainy season crops should be planted with the first soaking rains. Crops can thus make use of early season rain and major portion of their cycle is completed before rains cease. This also facilitates timely sowing of successive winter crops. To accomplish this, field should be ready before the monsoon starts. In this context concept of year-round tillage/summer tillage would be useful.

During winter season, pulses and particularly oilseeds have more flexibility with regard to dates of sowing as compared to cereals.

Cropping Systems for Aberrant Weather

Because of the unpredictable weather, one must be prepared for making adjustments for an aberrant weather which, by and large, comprises the following: (a) delayed onset of monsoon. (b) long gaps in rainfall, and (c) early stoppage of rains.

Cropping systems suitable for the three kinds of aberrations have already been developed by different centres. The strategy involves choice of alternate crops, ratooning and thinning, use of urea spray for rapid regeneration, emergency nurseries in case of upland rice and providing life saving irrigation to moisture-stressed crops. Experience at many of the centres suggests, that in case of delayed onset, cereals should be replaced by suitable pulses or oilseeds: for example, greengram/blackgram/sesamum in the place of upland rice in Varanasi.

Cropping Systems and Fertiliser Use

Cropping system should be so designed that it economises the fertiliser use. This fact is particularly relevant today when there is a global scarcity of fertilisers. The system for minimum fertiliser use involves : 1. improving the efficiency of fertiliser use by split application in relation to crop needs and available moisture (Table 6) and 2. developing suitable cropping systems. In fact, in a cereal-cereal rotation in addition to higher consumption of fertilisers, fertility

Table 6 : Crop yields in relation to split application of nitrogen

Region	Crop	Application method	Grain yield (q/ha)
Dehradun	Maize	All at planting	34.7
		Three splits	38.1
Ranchi	Upland Rice	All at planting	24.8
		Three splits	33.9
Rewa	Upland Rice	All at planting	27.0
		Three splits	41.0
Agra	Pearl millet	All at planting	8.5
		Two splits	13.3

Three splits usually means $\frac{1}{3}$ at sowing, $\frac{1}{3}$ at tillering and $\frac{1}{3}$ at heading.

balance of the soil is also affected. Hence, systems should be developed in which phosphates are applied to legumes and nitrogen to cereals and these crops may be grown alternatively. It is well known fact that legumes are benefitted by phosphate application, and cereal responds to nitrogen. Example of nitrogen

economy in a cereal and pulse-based cropping sequence is given in Table 7. An area of research in this context will be utilisation of crop residue either directly in the soil or through the animal. Also, integrated nutrient supply needs more attention in planning a cropping system in a particular region.

Table 7: Nitrogen management in a cereal and legume based cropping sequence in Varanasi

Nitrogen levels (Kg./ha)	Grain yield of mustard (q/ha)		Nitrogen levels (Kg./ha)	Grain yield of barley (q/ha)	
	After blackgram	After maize		After black gram	After maize
0	5.93	5.14	0	16.01	12.06
20	8.76	6.89	30	26.63	21.87
40	10.20	8.85	60	28.75	23.90
60	9.62	9.50	90	33.34	27.65

Conclusions

The traditional cropping system of drylands are characterised by low risk and low yield. It must be recognised that low risk will continue to be the guiding principle in developing cropping systems in view of the socio-economic conditions of the dryland farmers. The problem would be then how to combine low risk with high yield. Following approaches may help in solving this problem :

1. Developing cropping systems to meet the aberrant weather.
2. Combining low monetary inputs with high level management: selection of crops and varieties, choice of sowing dates, sowing methods, maintaining adequate plant stand, and weeding.
3. Supplementing the natural resources with monetary inputs such as fertiliser and life saving irrigation. It has already been realised by the dryland farmers that without adequate use of fertiliser, they cannot obtain full benefit of natural resources.

4. Alteration in the choice of crops in the cropping systems. At many stations, cropping sequence in which pulses or oilseeds are grown have given more net return than cereal-cereal rotation. This point needs more attention because of the fact that nation has to import bulk of pulses and oilseeds from other countries.

PULSES AND OILSEEDS IN RAINFED CROPPING SYSTEMS

V. BALA SUBRAMANIAN

The current annual grain production of pulse crops and oilseed crops amounts to about 12 and 10 million tons, respectively. Substantial increase in chickpea production has occurred due to increase in yield per unit area but the increase in production of pigeonpea and other pulses did not match the increase in area; obviously there has been decline in the productivity of these pulses, most likely due to environmental rather than genetic reasons. There has been improvement in the productivity of all the major oilseed crops. Groundnut and rapeseed/mustard contribute about 85 percent of the total oilseeds production in the country. In the past three decades, the area under these two crops increased by about 70 percent but the present increase in production of rapeseed/mustard is far higher than that of groundnut. More significant is the fact that the castor production was up by 20 per cent despite a reduction of 20 per cent in area.

Increase in production is a fact but the current national average grain yields of pulses and oilseeds per unit area are very low (Table 1). Since the chemical compositions of pulse, oilseed and cereal grains vary in respect of proportions of carbohydrates, protein, and lipids, the amount of photosynthate, required for unit dry matter is different. Moreover, the durations of crops also vary. Therefore, grain yield comparisons have been made on the basis of amount of glucose required for the grain dry matter yields harvested and for a uniform crop duration of 100 days. The grain glucose yields of castor and mustard are on par with rainfed sorghum and that of groundnut is even higher. The low level of basic biological productivity is evident in the case of pulses, and sesamum safflower and linseed.

In 1970s, pulses and oilseeds received as much attention as did cereals in the research programmes of the 23 centres of the Dryland Project. As a result, improved agronomic practices for pulse crops and oilseed crops for a particular region have been developed for maximising grain yields. Cropping systems with pulses and oilseeds as components to increase the grain production have also been identified and recommended.



Table 1 : Comparison of grain yields and glucose yields in pulses, oilseeds and sorghum

Crops	Average crop duration (days)	Current national average grain yield (t/ha)	Corresponding national average grain glucose yield* (t/ha)
Pulses			
Chickpea	160	0.74	0.65
Pigeonpea	150	0.72	0.63
Cowpea	80	0.35	0.58
Oilseeds			
Groundnut (Kernels)	110	0.60	1.19
Castor	140	0.53	0.96
Rapeseed/mustard	130	0.53	0.92
Sesamum	85	0.22	0.60
Safflower	140	0.30	0.46
Linseed	125	0.25	0.42
Cereal			
Sorghum	120	0.80	0.94

* Computation as described by Penning de Vries (1975) based on chemical composition of grains and for a uniform crop duration of 100 days.

Evaluation for superior genotypes

Crop evaluation experiments for identifying superior genotypes of pulse and oilseeds reveal the current level of grain yields in the research farms under rainfed condition. At present, chickpea yield level is the highest amongst the

pulse crops (Table 2). The average grain yield of chickpea is about 2.6 t/ha, while that of pigeonpea is only 1.6 t/ha. The short duration pulses yield only about 1.0 t/ha.

Table-2 : Average grain yields of pulse crops under rainfed conditions in research farms

Crops	Average grain yield* (t/ha)	Centres
Chickpea	2.6	Dehradun, Hissar, Varanasi
Pigeonpea	1.6	Akola, Bangalore, Hyderabad, Indore, Solapur, Udaipur
Cluster beans	1.1	Agra, Akola, Hissar, Jodhpur, Kovilpatti, Udaipur
Cowpea	1.1	Bangalore, Hissar, Hyderabad, Indore, Kovilpatti, Jodhpur.
Greengram	1.1	Akola, Bhubaneswar, Hissar, Jodhpur, Rajkot, Varanasi
Blackgram	1.0	Akola, Bhubaneswar, Hissar, Ludhiana, Rewa, Varanasi
Dolichos	0.8	Bellary, Bijapur, Hyderabad, Kovilpatti, Solapur
Horsegram	0.8	Anantapur, Bangalore, Bhubaneswar, Hyderabad, Ranchi, Solapur

* Pooled averages of grain yields of top genotypes in the crop evaluation experiments for many seasons during 1971-80 at the research farms of the centres.

Amongst the oilseed crops, soyabean yield level is the highest (Table 3), but its area is restricted to a small region. The grain yields of the two quantitatively important oilseeds, rapeseed/mustard and groundnut, are 1.7 and 1.5 t/ha respectively. The yield levels of sesamum and linseed are very poor, averaging about 0.5 t/ha only, although these crops are ranked as major oilseeds of the country.

Table 3 : Average grain yields of oilseed crops under rainfed conditions in research farms

Crops	Average grain yield* (t/ha)	Centres
Soyabean	2.0	Bangalore, Indore
Rapeseed/mustard	1.7	Hissar, Jammu, Ludhiana, Udaipur, Varanasi
Groundnut	1.5	Akola, Anantapur, Bangalore, Rajkot, Rewa
Safflower	1.4	Akola, Bellary, Bijapur, Indore, Kovilpatti, Solapur
Castor	1.1	Anand, Hyderabad, Kovilpatti
Sesamum	0.5	Dehradun, Solapur, Varanasi
Linseed	0.5	Indore, Ranchi, Rewa

* Pooled averages of grain yields of top genotypes in the crop evaluation experiments for many seasons during 1971-80 at the research farms of the centres.

In comparison to pulses and oilseeds, the average yield levels of cereals are far higher (Table 4). However, the yield levels of the "low rainfall area crops"

Table 4 : Average grain yields of cereals under rainfed conditions in research farms

Crops	Average grain yields* (t/ha)	Centres
Upland rice	3.4	Bhubaneswar, Dehradun, Jammu, Ranchi, Rewa, Varanasi
Maize	3.3	Bangalore, Bhubaneswar, Indore, Dehradun, Kovilpatti, Ludhiana, Ranchi
Wheat	3.0	Dehradun, Jammu, Ludhiana, Varanasi
Rainy season Sorghum	3.1	Akola, Hyderabad, Jhansi, Udaipur
Post-rainy season Sorghum	2.7	Bellary, Bijapur, Solapur
Pearlmillet	2.3	Agra, Bijapur, Hissar, Jodhpur, Rajkot, Solapur
Foxtail millet	1.4	Anantapur, Hyderabad, Kovilpatti, Solapur

* Pooled averages of grain yields of top genotypes in the crop evaluation experiments for many seasons during 1971-80 at the research farms of the centres,

such as pearl millet and foxtail millet are lower than those of "high rainfall area crops" like rice and maize.

Sequence Cropping

Various centres have identified very productive sequence cropping systems in which a pulse (Table 5) or an oilseed (Table 6) is a component.

Table 5: Recommended rainfed sequence cropping systems with pulse crops

First crop	Succeeding crop	Centres
Cereal	Pulse	
Rice	Chickpea	Dehradun, Rewa, Varanasi
Rice	Lentil	Rewa
Maize	Chickpea	Dehradun
Maize	Horsegram	Bhubaneswar (Upland)
Sorghum	Chickpea	Rewa
Pearl millet	Chickpea	Varanasi
Pulse	Cereal	
Cowpea	Maize	Bhubaneswar (Upland)
Cowpea	Sorghum	Bhubaneswar (Upland)
Pulse	Pulse	
Cowpea	Chickpea	Jhansi
Blackgram	Chickpea	Jhansi, Rewa
Pulse	Oilseed	
Cowpea	Safflower	Jhansi
Greengram	Safflower	Akola, Udaipur
Blackgram	Safflower	Jhansi

Depending upon regions, a pulse crop or an oilseed crop is grown either in the rainy season or in the post-rainy winter (or cool) season. As the duration of the rainy season crop is an important consideration in double cropped areas, only short duration pulse crops such as cowpea, greengram, and blackgram find a place as the first crop in sequence cropping areas.

Table 6 : Recommended rainfed sequence cropping systems with oilseed crops

First crop	Succeeding crop	Centres
Cereal	Oilseed	
Rice	Linseed	Ranchi
Maize	Mustard	Jammu, Ludhiana (in sandy loam-clay loam)
Maize	Linseed	Ranchi
Fodder sorghum	Mustard	Jhansi, Udaipur
Sorghum	Safflower	Akola, Jhansi
Oilseed	Cereal	
Groundnut	Barley	Ranchi
Soyabean	Wheat	Dehradun
Soyabean	Barley	Dehradun
Oilseed	Oilseed	
Soyabean	Mustard	Jhansi
Soyabean	Safflower	Indore, Jhansi
Oilseed	Pulse	
Soyabean	Chickpea	Indore
Sesamum	Chickpea	Varanasi

Sequence cropping systems in which pulses and oilseeds only are components i. e., without a cereal component have also been developed in many centres. A pulse-pulse crop combination of cowpea or blackgram followed by chickpea has been recommended for Jhansi and Rewa regions. Similarly, an oilseed crop followed by another oilseed crop in sequence cropping (soyabean followed by mustard or safflower) has been found productive in Indore and Jhansi regions. These recommended cropping systems, if practised, would certainly contribute towards increasing the production of pulses and oilseeds.

Intercropping

Intercropping systems, optimised in such temporal and spatial aspects as compatibility, duration differences, population density and geometry of crops etc provide possibilities of increasing the production of pulses and oilseeds in

many regions, where rainfall distribution is such that two crops can be simultaneously grown in the same piece of land. The dryland research centres have experimented on numerous combinations of cereals, pulses, and oilseeds and have found certain combinations of crops as more productive. The recommended intercropping systems with a pulse or an oilseed crop are given in Tables 7 and 8.

Table 7 : Intercropping systems with pulse crops

Systems	Land Equivalent Ratio	Centres
Cereal + Pulse (longer duration)		
Maize + pigeonpea	1.35-1.95	Ranchi, Udaipur
Finger millet + pigeonpea	1.45	Bhubaneswar
Sorghum + pigeonpea	1.48-1.96	Akola, Bijapur, Hyderabad, Jhansi, Kovilpatti, Rewa
Pearl millet + pigeonpea	1.65-1.93	Agra, Akola, Anand, Bijapur, Rajkot, Solapur
Setaria + pigeonpea	1.31-1.43	Bijapur, Solapur
Cereal + Pulse (shorter duration)		
Maize + greengram	1.46-1.49	Hyderabad, Jammu
Maize + blackgram	1.38	Bhubaneswar, Udaipur
Sorghum + cluster bean	1.48	Hyderabad
Sorghum + cowpea	1.60	Kovilpatti
Sorghum + greengram	1.46	Akola
Sorghum + blackgram	1.20	Udaipur
Pearl millet + cluster bean	1.84	Solapur
Pulse + Pulse		
Pigeonpea + blackgram	1.81	Varanasi

Table 8 : Intercropping systems with oilseed crops

Systems	Land Equivalent Ratio	Centres
Cereal + Oilseed		
Maize + Soyabean	1.52	Dehradun
Sorghum + soyabean	1.58	Indore, Udaipur
Oilseed + Oilseed		
Groundnut + soyabean	1.49	Akola
Oilseed + Pulse		
Groundnut + pigeonpea	1.36-1.76	Anantapur, Bangalore, Bijapur, Rajkot
Oilseed + Tuber		
Castor + colocacia	1.80	Bhubaneswar
Fibre-cum-oilseed + Pulse		
Cotton + cowpea	—	Kovilpatti
Cotton + blackgram	—	Kovilpatti

Besides many cereal and pulse, cereal and oilseeds combinations, a pulse and pulse (pigeonpea + blackgram) intercropping in Varanasi and an oilseed and oilseed (groundnut + soyabean) in Akola are interesting examples. The oilseed and pulse (groundnut + pigeonpea) intercropping system is well known to the farmers long before scientists have experimented on this combination for maximising the productivity. On an average, Land Equivalent Ratios (LER) around 1.50 seem to be possible with the recommended intercropping systems. The castor + colocacia in Bhubaneswar and cotton + cowpea or blackgram in Kovilpatti indicate the scope of further increasing the production of pulses and oilseeds through various other kinds of intercropping systems.

On the basis of a decade of research experience, two general conclusions have been brought out from the numerous experiments on intercropping by the various centres : 1. By and large, intercropping is successful in a good or above normal rainy season only. 2. The LER of intercropping systems in

post-rainy season is not high. By implication it means that, if the production of pigeonpea, the second most important crop amongst the pulse crops and the major rainy season pulse usually grown as intercrop, were to improve and stabilise at higher levels, sole cropping of it should also receive emphasis. Similarly, sole cropping of post-rainy pulses and oilseeds should be encouraged.

Substitute Crops

The efficient crop for a region need not necessarily be the traditional crop of the area. The dryland research centres have conducted experiments to identify the more productive crops for the respective regions. Wheat is the traditional post-rainy winter crop in Agra, Bijapur, Indore and Udaipur regions. Experiments, however, reveal that wheat should be substituted by mustard in Agra region and by safflower in the other three regions, as the grain yields of the oilseeds are twice that of wheat (Table 9).

Table 9: Oilseed crop as substitute crop

Centres	Traditional crop	Grain yield (t/ha)	Substitute oilseed crop	Grain yield (t/ha)
Agra	Wheat	1.0	Mustard	2.0
Bijapur	Wheat	0.9	Safflower	1.8
Indore	Wheat	1.1	Safflower	2.4
Udaipur	Wheat	1.6	Safflower	2.0

Yield Stability

Besides high crop yields, stability of yields over seasons at high levels is also a very important consideration in rainfed crop production. The grain yields of chickpea provide such a stability in Varanasi region (Table 10). Grain yields of wheat and chickpea were compared for four seasons from 1973-74 to 1976-77. Chickpea gave consistently high yields of 2.5 to 3.0 t/ha, while wheat yields were relatively less for two out of four seasons.

Table 10 : Stability of grain yields in Varanasi

Year	Grain yield (t/ha)	
	Wheat	Chickpea
1973-74	2.7	2.6
1974-75	1.9	2.5
1975-76	1.7	2.6
1976-77	3.0	3.0
Mean \pm S. D.	2.3+0.62	2.7+0.22

Catch Crops

Short duration pulse crops fit in very well as catch crops in otherwise single crop regions in years when onset of season is earlier than usual. For example, in Bangalore if rainfall exceeds 50 mm in May and soil moisture saturation is upto a depth of 30 cm, land could be sown with cowpea. It comes up for harvest in the first fortnight of August and the land gets ready for sowing of finger millet, the traditional crop.

If rainy season is extended, there is a possibility of taking a second crop of horse gram in Hyderabad region after harvest of the first crop of sorghum.

Insurance Crops

Short duration pulse crops, and the oilseed crops like sunflower serve as insurance crops against vagaries of the rainy season to prevent total crop failure in a season. Horse gram could be sown as late as August, or even in early September in Anantapur, and cluster bean is recommended for delayed sowings in August in Hissar.

Need for Higher Productivity

From the Dryland Project's research experience in 1970s, it is evident that the average grain yield levels of pulses and oilseeds per unit area need to be raised in the research farm itself. Except for chickpea, the average yields are less than 2.0 t/ha for all the major pulse and oilseed crops. The grain yield realisation, i.e. ratio of current average grain yield at the national level to that at the dryland research farms for the pulse crops and oilseed crops, is presented in Table 11. In case of pulse crops, the grain yield realization is about 30 percent

Table 11 : Productivity realisation in pulse and oilseed crops

Crop	Productivity realisation* (%)
Pulse crops	
Pigeonpea	45
Cowpea	31
Chickpea	29
Oilseed crops	
Groundnut	58
Castor	47
Linseed	43
Sesamum	39
Rapeseed/mustard	31
Safflower	21

* Ratio of national average grain yield per unit area to the average grain yield in dryland research farms

for chickpea and cowpea, and 45 percent for pigeonpea. For oilseed crops, the value ranges from about 20 percent for safflower to about 60 percent for groundnut. These data do not merely reflect the 'gap' between the research farm potential in dryland and the realised yield: the more revealing fact is that the potential itself is low for crops like sesamum and linseed and, therefore, the percentage realisation is inflated. More research emphasis is required for raising the yield plateau of these two oilseed crops. In general, the realisation from the post-rainy winter crops (chickpea, rapeseed-mustard, and safflower) is lower than that from the rainy season crops (pigeonpea, groundnut and castor). Progressively increasing water stress during post-rainy season could be one of the reasons.

Basic Research Approaches for Improving Yields

Yield components : Plant productivity at harvest is the net result of complex processes during growth and development as influenced by environment. In order to increase grain yield levels at the research farms the yield components should be considered. The two ultimate yield components are grain number and grain weight. These components are determined sequentially during the growth and development of crop. The grain number potential is determined

before anthesis but the realisation of the potential occurs at anthesis. The other component grain weight, is determined from anthesis until physiological maturity. Therefore, the grain yield realisation is influenced by genotype x environment interaction until harvest. Between the two yield components, grain weight is relatively more stable. Hence, grain number per unit area is the major determinant of grain yield of crops. Correlation between grain yield per unit area and grain number have been found highly significant. In Table 12, grain per unit area required for target yields of important pulse and oilseed crops are given. Grain number per unit area is the product of number of seeds per pod and number of pods per unit area. It is influenced by the number of flowers produced and proportion of flowers actually set as pods. The pod setting percentage is very low in pulses and oilseeds ranging from 10 to 30 percent, due to flower and pod abscission and seed abortion (Ojehomon 1968; Sinha, 1977). The number of seeds per pod is also a stable character like grain weight. So, pod number per unit area actually determines the number of seeds under field conditions.

Table 12: Yield components for target grain yields of pulse and oilseed crops

Crop	Target grain yield (t/ha)	Yield components	
		Average 1000 grain weight (g)	No. of grains per m ²
Pulse			
Chickpea	3.0	150	2,000
Pigeonpea	2.5	120	2,100
Cowpea	2.0	110	1,800
Green gram	2.0	45	4,450
Black gram	2.0	40	5,000
Oilseed			
Groundnut	3.0	250	1,200
Rapeseed/ mustard	3.0	4	75,000
Safflower	2.5	60	4,150
Castor	2.0	220	900
Sesamum	1.0	3	33,300
Linseed	1.0	5	20,000

Increasing pod set and reducing seed abortion should increase grain yields in pulses and oilseeds. Besides plant factors environmental factors (water, temperature, light intensity and nutrition) influence the grain number. For example, low light intensity and water stress promote flower and pod abscission. Investigations on plant and environmental factors on flower production and abscission, pod set, seed abortion and final grain number per unit area will lead to improvement in grain yield through agronomic management and breeding.

Determinate types: Intense competition for photosynthates between emerging leaves and growing flowers and developing grains, is a likely reason for poor sink capacity in indeterminate crops in general. In legumes, there is further competition for photosynthates from nodules. In cereals, the percentage seed set is very high. The determinate growth habit of cereals is the major difference in their growth and development from that of pulses and oilseeds. Owing to their indeterminate growth habit, reproductive and grain filling stages overlap each other. When flowering commences and pods grow, there is also simultaneous production of new leaves and floral differentiation in the same plant. The growing pods, young expanding leaves, and developing flowers are all powerful sinks competing with each other at the same time for photosynthates from the same source, i.e., fully expanded leaves. In legumes, the vegetative part is a stronger sink than developing grains during flowering and early grain filling stage (Hanway and Weber, 1971)

The yield plateau of the determinate cereals is higher amongst the grain crops. Therefore, if the pulse and oilseed crops were to have determinate pattern of growth like cereals, higher yield potential could be expected. The so called advantage of producing some yield at least in indeterminate crops, if water stress occurs during reproductive phase, can be expected only in crops cultivated during rainy season. With determinate cultivars and by tailoring the duration of the pulse and oilseed crops to agro-climatically determined cropping duration, it could be possible to reduce the risk of water stress effects.

Assimilate allocation during vegetative phase : Grain filling stage is not the sole determinant of grain yields. Crop canopy development, dry matter production before anthesis, and floral differentiation and growth of floral initiation are all important in determining the grain yield potential. More allocation of assimilates for production of new photosynthetic tissues should maximise dry matter production during vegetative phase. A rapid expansion phenophase, the time from planting to full ground cover, has been identified as a physiological basis for increased yield potential in groundnut (McCloud 1980). Understanding

of the factors influencing allocation of assimilates to various plant parts during vegetative phase should provide useful information for improving plant productivity.

Remobilisation during grain growth : Current photosynthesis after anthesis provides the major proportion of photosynthates for grain growth. However, remobilisation of stored photosynthates particularly from stem, assimilated before flowering, is also known to contribute towards grain filling. The proportion of remobilisation of stored photosynthates to grain increases if current photosynthesis is affected by environmental stress like drought during grain filling phase. This compensatory mechanism at an appreciable level in cultivars is likely to produce normal grain yields, within limits of environmental stress, thus ensuring stability in rainfed situations.

Besides photosynthates, nutrients like nitrogen, phosphorus etc, also are mobilised from stem and leaves into grains. As certain percentage of genetically determined chemical compositions of grain dry matter is a biochemical requirement, any further increase in yield potential would be determined by flow of both photosynthates and nutrients to the grains. As Evans (1975) noted, grain number, size, filling duration, and potential growth rate are important aspects of sink strength determining mobilisation. Therefore, increase in potential remobilisation of photosynthates and nutrients during grain filling is important for raising the yield plateau.

Photosynthesis and N fixation relationship : Increase in grain yields of legumes, which includes the oilseed crops (groundnut and soyabean), would depend on improvement in the supply of photosynthates from leaves to nodules and reduced N from nodules to vegetative parts until flowering and subsequently to grains. Both duration and rate of N fixation need to be increased. For most legumes, N fixation rate has been shown in general to be high during vegetative phase and then to decline progressively during the reproductive phase when the demand for N by developing grains increases. In chickpea, there was no net gain of C¹⁴ photosynthates in nodules after flowering (Shantakumari *et al.*, 1975). Factors, which increase photosynthesis, increase N fixation and those, which decrease photosynthesis, decrease N fixation (Minchin *et al.*, 1981). These findings indicate that N fixation even during vegetative phase may be rate limited by lack of adequate supply of photosynthates to nodules. Therefore, relationships during ontogeny amongst N fixation, photosynthesis, growth and yield should be elucidated. In rainfed situations effects of water stress and soil temperature interaction in rainy and post-rainy seasons on nodulation and N fixation needs investigation for increasing the efficiency of symbiosis.

Experiments with N fertiliser given as 'booster' dose of 10-20 kg/ha to legumes have produced inconsistent results. It is obvious that environmental conditions in which fertiliser N is to be given for better growth needs to be defined not only for efficient use of fertiliser N but also for taking advantage of Nature's gift of non-polluting symbiotic N fixation in legumes.

Conclusions

The average grain yields of crops at the research farms under rainfed conditions vary from 1.4 to 3.4 t/ha for cereals, from 0.8 to 2.6 t/ha for pulses, and from 0.6 to 2.0 t/ha for oilseeds. Based on the results of numerous experiments of the Dryland Project in 1970's, the increase in production of pulses and oilseeds are to be achieved through productive sequence and intercropping systems in which pulse and oilseed crops are components. Mustard and safflower are better substitute crops for wheat in certain regions. Chickpea gives more stable grain yield than wheat in some regions. Short duration pulse crops offer possibilities as catch crops in otherwise single crop regions, in case of early onset of rains. Crops like horsegram and sunflower are insurance crops to prevent total crop failure in the event of very delayed onset of rains in a region.

The following basic research approaches are considered as useful for grain yield improvement in pulses and oilseeds. 1. The influence of plant and environmental factors on flower production, abscission, podset, fruit abortion and final grain number per unit area. 2. Developing determinate cultivars of pulses and oilseeds with appropriate duration to match the cropping season of a region. 3. Assimilate allocation during vegetative phase. 4. Remobilisation of photosynthates and nutrients during grain filling, and 5. Interaction of symbiotic N fixation, photosynthesis, growth, and yield under rainfed environment.

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INTEGRATED WEED,
PEST AND DISEASE
MANAGEMENT
IN DRYLANDS

RECENT ADVANCES IN PEST MANAGEMENT

N. C. JOSHI

India is losing yearly vast amount of agricultural produce due to ravage of pests (i.e. weeds, diseases, insects and rodents at 33 percent, 20 percent, 16 percent and 6 percent respectively), the average loss being to the tune of 18 percent.

With the introduction of new high yielding varieties and hybrids grown in irrigated areas under high fertility conditions, the pest problems have increased. For instance, in TN-1 and IR-8 the bacterial leaf-blight (BLB) and Tungro virus have appeared in severe form. Similarly ergot and downy mildew in hybrid pearl millet are posing serious problems. Some new problems pertaining to weeds, i.e. wild oats (*Avena fatua*) and *Phalaris minor* and in non-crop areas congress grass (*Parthenium hysterophorus*) are becoming problems of all India importance. There is an awareness and enthusiasm among farmers for taking plant protection measure.

Chemical Control

From 1950 onwards considerable progress has been made on chemical control in India. The cost benefit ratio is high in case of seed treatment, ranging from 10 to 45 because of low cost of seed treatment, whereas in the case of post sowing treatment the ratio ranges from 2.3 to 9.5. Our country is producing about 31,600 tons of 43 different pesticides. Besides, about 1,400 tons are imported. Average use of pesticide is about 200g against 1000g in Japan. For keeping quality of pesticides, the Indian Standards Institute has published 45 standards for technical grade and 55 formulated products. All these standards have been accepted under Insecticides Act 1968, which aims at regulating the production, transport, storage, sale and use of pesticides. Indiscriminate use of pesticides results in problems like residue, resistance in insects, air, water and soil pollution and depletion of natural enemies of injurious species.

In view of the above mentioned hazards due to indiscriminate use of pesticides, the present strategy is towards integrated pest management. This advocates the minimal use of pesticides that too should only be used at a certain level (i.e. economic threshold); it should not be used at all, if injury (i.e. threshold of tolerance) does not justify the treatment.

Biological Control

It is another method which needs to be explored. There are about 110 pests in more than 60 countries that have been controlled totally or partially by use of parasites, predators and pathogens. The advantage of their use is economy.

The organism like *Bacillus thuringiensis* is now utilised for biological control. The commercial preparation in the form of dusts/sprays are available in some countries. The other micro-organisms like viruses, fungi and nematodes are also being used as microbial control agents.

Use of Varieties

The use of resistant or tolerant varieties of crops aims at pest disease avoidance rather than their control. The production of insect pest resistant varieties is a cooperative effort among Entomologists, Pathologists and Plant Breeders. In USA, it has been found that by adopting this method, the benefit-cost ratio have been estimated to be 300:1.

Cultural Control

Burning of crop residues, deep ploughing, early sowing, early harvesting, manuring and managing water and trap cropping help in minimising the pest problem. In many locations, short duration varieties have proved useful since they mature before pests become serious. Some notable progress has been achieved in crops like cotton, sugarcane, paddy, sorghum etc but sustained efforts in other economic crops are necessary to manage pest population.

Use of Light Traps

In reducing the intensity of insect population light traps may also play a role. Many types of light traps are now available.

Irradiation

In insects, egg stage is highly radio-sensitive and requires much smaller dose to cause irradiation injury as compared to larval, pupal or adult stages. The stored grains when irradiated are protected from pests and quality is maintained for considerable time.

Chemosterilization

Chemosterilants are chemicals when applied orally, sprayed, or injected into insects would deprive them of their ability to reproduce. These chemicals cause sterility by preventing the development of sperms or ova. Apholate and Metape are commonly used as sterilants in India.

Use of Sex Attractants

Insect pheromones are defined as chemical substances which are secreted out by insects and perceived by other insects of the same species in which they trigger a specific reaction. In insect control, these compounds are used as attractants and therefore termed as sex attractants or sex lurers. Sex pheromones of 40 insect species have been identified so far. Now-a-days commercial quantities of synthetic sex attractants are readily available for economic insect control.

Use of Antifeedants

These compounds prevent insects from feeding on treated foliage without killing or even repelling them. These compounds can be regarded as inhibitors of gustatory reflexes or as feeding deterrents. Examples of antifeedants are pyrethrum, neem seed (Azadirachtin), triphenyl hydroxide, cycocel, copper stearate etc.

Conclusion

The programme of pest control should be chalked out in such a way as to keep the insect population below economic tolerance levels by adopting use of resistant varieties, biological control methods, use of antifeedants, chemosterilants, irradiation techniques and minimal use of pesticides. For achieving success in integrated pest management, the need for efficient pest surveillance service and quick forecasting of pest and disease attack have become essential so that pest population can be brought down immediately before any significant damage is done.

INTEGRATED WEED MANAGEMENT FOR DRYLAND

G. H. FRIESEN

Integrated weed management may be defined as the optimum combination of all available methods or techniques required to reduce the weed problem to a manageable level in various cropping systems. The different techniques or methods of weed control in such systems include :

1. Preventive methods
2. Mechanical methods
3. Cultural and cropping methods
4. Biological methods
5. Chemical methods

The use of the most effective and efficient combination of the above methods has been the basis of sound weed control recommendations for the past three or four decades. Thus, nothing has really changed except the 'name' from 'effective and efficient weed control practices' to 'integrated weed management systems'. This new terminology has recently attracted the attention of many agricultural administrators, resulting in increased funding for weed control research in some countries. The change, therefore, has been to enhance the credibility of weed scientists.

Weed Problems in India

Estimates of the crop losses caused by weeds in India range from 10 to 27 percent of field crop production. Using the lowest figure of 10 per cent, the total loss is more than 10 million tons of food grains annually. The tragedy of the weed problem in countries like India has been appropriately described by Mr. Mirdha, Chairman, National Commission on Agriculture in 1973 as follows: "About one-half of the men and women are in the fields, stooped, moving slowly, and silently weeding. In their hands there is always a crude iron hoe. These people, without identity, symbolize the great mass of humanity that spends a life time in weeding. There are unborn millions still to come who are already doomed to the same fate".

Weeds compete directly with crop plants for soil moisture, nutrients, sunlight and other growth factors. Some weeds exude toxic substances from roots, foliage, and decaying plant residues which reduce crop growth (allelopathic

influences). Weed interference in crop production is the largest single factor affecting crop yields. Other weeds affect the health of domesticated animals and of man himself; they harbour insect and disease problems and reduce the value of farm produce.

At Jhansi Centre, it was found that on the average, weeds extracted twice as much N, 25 percent more K, and twice as much Ca as crop plants. At Bangalore, it was found that 27 Kg N, 3.2 kg P and 7.6 kg K could be saved by weed control in finger millet. The effect of integrated weed management systems involving various tillage practices and simazine on nutrient uptake in maize was studied at Dehradun. It was found that the most efficient combination of tillage and herbicides reduced the fertiliser requirements in a maize crop by 25-30 kg/ha N, 10-12 kg/ha P and 10-15 kg/ha K. It is an important consideration in a country where manufactured fertilisers are expensive and often in short supply.

Let us now look at the various weed control methods and contribution each can make to an integrated weed management system.

Preventive Methods

This method attempts to prevent the spread of weed seeds by man, animals, birds, wind, water etc. It involves such practices as sowing of clean seed (free from weed seeds); controlling weeds on bunds, levees, headlands, fence row, irrigation or ditch banks etc.; removing weed seeds from farm machinery before transporting them from one field or farm to another; preventing soil erosion; spreading only well rotten farm yard manure; controlling the movement of livestock etc. Even international trade, which moves millions of tons of grain and agricultural produce across countries and continents, becomes a potential source of spreading new species of weeds to the importing countries. Preventive methods must, therefore, be the first step in developing sound weed management systems.

Mechanical Methods

This method of controlling weeds has been practised since the beginning of agriculture. It involves physically uprooting or cutting the weeds by hand pulling, hand hoeing, or with mechanical devices of many types drawn by animals or tractors. The type of machine selected depends on the weed species, land use or cropping program, need for soil conservation practices, soil type and season of the year. Machines or tools are designed to remove weeds between and within crop rows, before sowing, after harvest and during the fallow period. Recent innovative methods of weed destruction include selective flaming (burning) and the use of high voltage electrical shocks.

Mechanical methods of weed control are simple and require little ingenuity or management skills. Often they are also time consuming, expensive in terms of energy use and equipment costs, and can lead to increased soil erosion. Other disadvantages are the nonavailability of labour at peak periods of cropping season and the difficulty of entering fields when soils are wet and sticky. There is frequent need to reduce or supplement this method with other methods

Cultural and Cropping Methods

These methods aim at employing agronomic practices that will enhance the growth of the crop and place the interfering weeds at disadvantages. Cultural practices such as proper fertiliser placement, selective irrigation, early sowing, optimum plant populations, uniform seeding depth etc, will encourage improved crop growth at the expense of weeds. Improved drainage will reduce weeds which prefer wet soil conditions and flooding will benefit water tolerant crops at the expense of weeds.

It is well known that grass-type weeds are frequently dominant in grass-type crops and broadleaved weeds in broadleaved crops. Alternating such crops (crop rotations) can frequently bring about a gradual reduction of both types of weeds. Rapidly growing high shade producing crops (smother crops) can suppress weed growth. Early maturing crops are harvested before competing weeds produce viable seeds, thus reducing the weed problem in succeeding years. Perennial crops, because of their rapid growth in early spring or following onset of rainy periods, seriously suppress and sometimes almost eliminate annual weeds.

Any cultural or cropping practice that tilts the balance in favour of crops at the expense of weeds should be common practice in any cropping system. These methods also enhance the degree of weed control from supplemental mechanical or chemical control practices.

Biological Methods

The use of insects, plant diseases and animals as agents for weed destruction has attracted considerable attention in recent years. The almost complete eradication of *Opuntia* spp (prickly pear) by *Cactoblastis cactorum* in Australia and *Hypericum perforatum* (Klamath weed) by *Chrysolina hyperici* in the western USA has prompted the search for insects that may control other serious weed species. At last count active research is underway to find predators specific for at least 30 serious weed species.

The use of phytopathogens as weed control agents has also received considerable attention in recent years. Some progress has been achieved in the control of northern Janovitch weed in rice and the control of *Xanthium strumarium* with *Helminthosporium tuitici repentis*. Active research is underway to find pathogens that will control *Parthenium hesterophorus* and *Eupatorium adorum* in India.

Recorded history also lists sheep, hogs, geese and deer having, at one time or another, been used for selectively controlling weeds in some crops. As far as is known, such higher animals are no longer used deliberately for weed control.

Chemical Methods

Selective weed control with herbicides became popular in the late 1940's. Today, there are about 120 herbicidal compounds registered for use somewhere in the world, but only a few of these are commercially available in India. Thus chemical weed control in India is not widely practised except in plantation crops, in wheat and, to some extent, rice. This, of course, could change, as labour becomes more expensive or unavailable during peak periods, and as more herbicides become registered in India. In the future, herbicides may become an important component of weed management systems even in India. A suitable hand operated or bullock drawn sprayer is still to be developed. In the opinion of this writer, chemical weed control in the major dryland crops will have to become an important part of weed management systems before the next major yield plateau can be reached.

Integrating the Various Control Methods.

All of the above methods have a place in an overall weed control package and to use the most effective and efficient combination of these methods is the objective of all sound and long term weed control programmes. One control method is seldom adequate by itself.

Weed management systems in all crops should start with preventive methods (clean seed, sanitation in noncropped areas etc). This must be followed by appropriate cropping and cultural practices that give the crop a competitive advantage (rotations, fertiliser placement, seeding methods etc). Mechanical methods may vary from crop to crop and region to region and must take into consideration pre-seeding, post harvest, interrow and intrarow weed removal by efficient and effective tillage or hand weeding methods. Herbicides also have an important part to play in this package, especially for hard-to-kill weeds (eg : *Striga*, *Cynodon*, *Cyperus* etc), when tillage practices cannot be carried out due to close crop spacings or when it is difficult to enter fields due to wet soil conditions.

Sometimes one method enhances the effectiveness of another method. At Dehradun it has been demonstrated that in maize the efficiency of simazine on weed flora was increased by 23 percent when combined with tillage. Such combination treatments increased maize yields by 30 percent over hand weeding alone and reduced soil nutrient loss by 30 to 40 percent. At Solapur, propanil applied pre-emergence plus hand weeding gave significantly higher groundnut yields than either treatment alone. Alachlor performance was not affected by similar mechanical treatments. Atrazine at 0.3 kg/ha (ai) over the row plus two inter-cultivations have given highest yields of sorghum at Hyderabad.

The effect of year round tillage has been compared with traditional tillage practices at Hyderabad. The results suggest that year-round tillage not only leads to increased sorghum production, but also reduces the infestation of weeds in rainy season to such an extent that hand weeding and inter-row cultivations are more efficient and less time consuming.

PEST MANAGEMENT IN SORGHUM

K. LAKSHMINARAYANA

Improvement in yields generally increases the relative importance of insects. More so increased inputs and intensive cultivation of the susceptible high yielding lines have resulted in high pest populations. Pest management practices which until now not thought of to protect the low yielding local varieties, have become important and economically feasible with the high yielding cultivars. There is definite need for adopting pest management practices to achieve good yields.

Sorghum crop is attacked by more than 60 species of insects and mites. Out of these four species of insects are important :

Shoot fly	...	<i>Atherigona soccata</i>	Rondani
Stem borer	...	<i>Chilo partellus</i>	Swinhoe
Earhead midge	..	<i>Contarinia sorghicola</i>	Coq
Earhead bug	...	<i>Calocoris angustatus</i>	Lethiery

Under unprotected conditions, the estimated losses due to different pests varied from 10 to 80 per cent in different parts of India. The importance of the pest can be judged by the yield losses caused by different pests. Results on the experiments carried out during different years in the Andhra Pradesh Agricultural University to assess the crop losses due to different pests indicate that the shootfly incidence alone causes loss of 45 to 50 per cent, while the losses due to borers, sucking pests and earhead pests varied from 10 to 20 per cent, 5 to 10 per cent and 20 to 30 per cent, respectively. The losses are likely to vary from region to region. However, the shootfly is by and large considered relatively important among sorghum pests throughout India. Samarjit *et al* (1978) reported that the percentage of grain loss due to shootfly varied from 17 to 78 per cent, as the percentage of incidence of shootfly increased from 20 to 90 per cent.

Information on the effect of different insecticides on yield at different infestation levels are not available. Due attention is to be paid on this aspect for developing effective pest management strategies. It is also essential that economic injury levels are determined for pests of sorghum.

The management strategies to be adopted for some of the important pests of sorghum are as follows :

Cultural Methods

Use of resistant varieties : This is one of the most effective ways of managing pests in a cheaper way which could be adopted easily by farmers. Efforts are being made in the identification of sources of resistance and in developing cultivars resistant to the shootfly. Resistant and susceptible varieties differ with respect to the site of the larval development within the plant and there was delay of injury by 2 days in resistant varieties (Blum 1968). Roshan Singh and Narayana (1978) reported reduction in fecundity of flies reared from susceptible lines. There were also variations in larval period and adult longevity when reared from sorghums with differential susceptibility. Screening of germplasm revealed existence of resistant genotypes to stem borer and earhead bug.

Sowing time : Early planting with the onset of monsoon recorded less incidence of shootfly compared to late planting in many research centres (AICSIP 1979-80). During post-rainy season, early sown crop suffered more in areas where rainy and post-rainy season sorghum crops overlap, but in exclusive post-rainy areas early plantings have less attack of sorghum shootfly.

A study on the seasonal incidence of sorghum earhead midge indicates that early sowings recorded 11 per cent of sorghum earhead midge, while August sowings recorded more than 50 percent incidence (Table 1). Staggered sowing results in flowering being spread over longer periods which in

Table 1 : Date of sowing and incidence of Sorghum Earhead Midge at Dharwar (AICSIP 1979-80)

Date of sowing	Date of flowering	Average percentage grain damage due to midge
31- 5-1979	12- 8-1979	11.0
15- 6-1979	27- 8-1979	22.5
2- 7-1979	13- 9-1979	24.6
15- 7-1979	26- 9-1979	25.0
1- 8-1979	12-10-1979	55.3
5- 8-1979	27-10-1979	55.8
11- 9-1979	12-11-1979	23.3
1- 9-1979	27-11-1979	22.1
15-10-1979	12-12-1979	23.3
15-10-1979	27-12-1979	25.1

turn, results in high incidence of the fly. Hence, it is suggested to choose shorter duration genotypes under delayed sowings so that flowering is still synchronized.

Crop residue destruction : The first suggestion to tackle the stemborer is to check the build-up of the pest population by destroying the stubbles, and feeding the stems to cattle before the start of next season. Ample evidence is available regarding the emergence of borer moths from the stacked sorghum. The carry over of earhead midge can be prevented by destroying all the crop residues or consuming the threshed earheads and stacked panicles before the onset of next season, preferably by 30th March

High seed rate : A cultural practice recommended to mitigate the shootfly incidence is the adoption of high seed rate and removal of affected seedlings.

Spacing : Studies were conducted by AICSIIP (1978-79) to find out the percentage of loss of seedlings due to shootfly and average percentage of dead hearts due to stemborer with different spacings, keeping the plant population constant in an unit area. The results indicate that the variation in incidence due to shootfly or stemborer is negligible in the different spacings as long as the number of seedlings per unit area is the same.

Fertilization : Studies on the effects of nitrogen on shootfly incidence on five cultivars viz., CSH-1, CSH-5, 302, 604 and Local Y-75 revealed that the incidence of shootfly was more in plots which did not have any N at all as compared to the plots with optimum nitrogen. But amongst different doses of N (40, 80 and 120 kg/ha) no significant differences in the incidence of the fly was observed.

Mechanical Methods

Hand picking and destroying the caterpillars of *Cirphis* from the leaf whorls and *Heliothis* larvae from the earhead will reduce the infestation.

Light traps are useful tools for monitoring stemborer, and other leaf caterpillars. Light traps and fish meal traps are useful in monitoring shootfly and earhead midge.

Biological Control

Though information on the presence of natural enemies of the major pests of sorghum in India is available, methods for utilisation of these agents, as means of control, are yet to be developed.

Chemical Control

Carbofuran 5 percent seed treatment is found to be effective. For combating the earhead pests, the midge and earhead bug, one has to depend mainly on chemical control.

Conclusion

Control of pests on sorghum is possible with cultural and chemical methods but a strategy for pest management is to be tailored to tackle the problem in a particular region. Research is needed on biological control.

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INTEGRATED NUTRIENT
SUPPLY SYSTEMS
FOR DRYLANDS

NUTRIENT SUPPLY FROM ORGANIC SOURCES

J. VENKATESWARLU

The advantage of chemical fertilisers in drylands is well proved using the cardinal principles of use of moderate doses of fertilisers and considering the law of minimum. But their use means higher investment costs. With the risk involved in dryland agriculture, besides lesser availability of fertilisers, alternate sources of plant nutrients, at least to meet the demand partly, have to be explored.

India has about 185 million tons of plant residues, besides 288 million tons of wastes of animal origin. Further, in dryland areas legumes can become an integral part of the crop rotation, intercropping and cropping sequences. In marginal lands, ley farming and growing legume trees in association with agricultural crops show promise in supplementing nutrient requirement of crops.

Problem and Approach

The fertiliser consumption in India increased from 1.9 kg nutrients/ha in 1960-61 to 31.0 kg/ha in 1980-81. The production of fertilisers is 3.0 million tons and consumption is 5.6 million tons; the difference is imported. Imports mean huge expense of foreign exchange.

In normal years, the responses of dryland crops to added fertilisers would be equal to irrigated crops. Fertiliser use efficiency *per se* can be enhanced by placement, more so for post-rainy situations and splitting fertiliser N during rainy season. The over-riding constraints in fertiliser use in drylands are - (i) the poor small and marginal farmers, (ii) lack of availability of fertilisers at cartable distance, and (iii) the high and increasing cost of fertilisers. This, then, calls for methods for reducing the investment. Yet another factor is continuous loss of the fertile surface soil due to erosion and decline in soil fertility. Organic recycling or farming is an answer.

Organic Resources

The sources and estimated yield of various plant residues (Table 1) and animal wastes (Table 2) are about 185 and 288 million tons per annum respectively.

Table 1 : Estimated yield of plant residue of principal crops (Bhardwaj 1981)

Crop	Residue yield (in million tons of dry matter)	Percent
Rice	80.7	43.5
Wheat	45.0	24.5
Sorghum	11.6	6.3
Maize	6.2	3.3
Pearl millet	8.3	4.5
Barley	3.2	1.7
Sugarcane (trash)	15.6	8.4
Potato	5.1	2.7
Groundnut	9.6	5.1
	Total 185.3	100.0

Table 2 : Estimated yield of various animal organic wastes (Ranjhan 1981)

Source	Estimated yield (on dry matter basis in million tons)	Percent
Bovine dung	267.0	92.6
Sheep and goat faeces	15.5	5.4
Pig faeces	1.9	0.7
Poultry droppings	1.3	0.4
Others	2.3	0.9
	Total 288.0	100.0

The rice and wheat residues are up to 68 percent of the plant resources, while bovine dung is upto 93 percent of the total animal organic wastes available in the country. This is besides an estimated 650 million gallons of urine. The plant residues contribute about 8.4 million tons of fertiliser, and the bovine dung contributes about 3.0 million tons. The municipal refuse and sewage wastes are estimated to be 0.04 and 1.18 million tons, contributing another 0.17 million tons of fertiliser nutrients.

These vast potential resources have not been fully exploited. Residues are being recycled as farm yard manure and compost. Biogas plants present another possibility for recycling. But on-farm management of crop residues in conjunction with wastes of animal origin would be a better answer for fuller utilisation of those organic resources. Moreover, on-farm management avoids transport problems.

Farm Yard Manure (FYM) and Green Manure (GM)

A few experiments have been conducted by the Dryland Project on conjunctive use of farm yard manure and green manure with inorganic fertilisers (Table 3). The results point out that with the conjunctive use of fertiliser and FYM or GM the yield of crops could be further enhanced. In Bangalore, the fertiliser equivalence per ton of FYM was as much as that of irrigated finger millet.

Table 3 : Effect of green manure and farm yard manure on yield of crops

Treatments	Average grain yield (q/ha)
Finger millet (Bangalore)	
Control	12.5
GM (10 t) + Fertiliser(25—25—25)	21.5
FYM (10 t) + Fertiliser(25—25—25)	23.2
Fertiliser alone (50—50—50)	21.8
Pearl millet (Jodhpur)	
Control	8.8
FYM (10 t) + Fertiliser(10—0—0)	15.4
Fertiliser alone (40—0—0)	13.9
Castor (Hyderabad)	
Control	4.2
GM (4 t) + Fertiliser(10—30—0)	7.2
Fertiliser alone (40—30—0)	7.8

The scope of using crop residues exists in several parts of India. In fact, in certain parts of Andhra Pradesh, sorghum is taken after greengram in deep black soils wherein the legume is incorporated as a green manure. Similar possibilities exist in many regions of dryland agriculture. Experimental results on residue managements obtained in Bangalore are presented in Table 4. The results suggest the advantage of residues over control for maize crop.

Table 4: Effect of continuous application of maize residue on the yield of maize (Bangalore)

year	Yield of maize(q/ha)	
	with residue	without residue
1975	35.7	29.5
1976	11.5	7.5
1977	35.6	28.0
1978	25.2	22.3
1979	9.9	6.9
Average	23.5	18.8

Note : i. Basal dose of 50—50—50 of N, P₂O₅ and K₂O/ha
 ii. Residue @ 4 t/ha.

The use of organic residues over time are expected to alter the soil constituents. In loamy sand and sandy loam soils of Hyderabad, the physical and chemical properties were determined after a five year study (Table 5 and 6). It is clear that there is definite improvement of physical as well as chemical constituents, except in the case of available K.

Mulches : At Hoshiarpur (Punjab), six tons of mulch per ha was used on maize field. Eventhough there was no significant change in the physical environment in terms of soil moisture or temperature, the yields increased significantly (Table 7). The data imply that the partly decomposed mulch probably contributed nutrients resulting in increased yields.

Table 5 : Effect of organic recycling on physical properties of red soils (Hyderabad)

Parameter	Loamy sand		Sandy loam	
	Initial	After 5 years	Initial	After 5 years
Average stability (%)	51	77	71	77
Hydraulic conductivity (cm/h)	2.3	9.3	4.2	9.7
Soil crusting (relative penetrometer reading)	40	11	35	13
Moisture content at field capacity (%)	12.7	12.9	15.8	17.8

Table 6 : Effect of organic recycling on chemical properties of soils (Hyderabad)

Parameter	Loamy sand		Sandy loam	
	Initial	After 5 years	Initial	After 5 years
Organic carbon (%)	0.34	0.39	0.65	0.62
Available N (kg/ha)	235	286	284	316
Available P ₂ O ₅ (kg/ha)	6.6	12.9	5.5	14.6
Available K ₂ O (kg/ha)	269	257	256	258

Table 7 : Effect of mulch and fertiliser N on forage yield of maize (Prihar and Arora 1980)

Treatment	Forage yield (t/ha)		
	N level (kg/ha)		
	50	100	150
No mulch	28.0	36.3	40.7
Mulch @ 6 t/ha	36.1	43.8	48.5

Legume Component in Cropping System

Intercropping systems : In Hyderabad, cowpea was taken as an intercrop with sorghum and the results indicate some benefit of association of a legume in the intercropping system, when it was grown as fodder. In other words, even without incorporation of organic matter, either as haulms or green manure, N-effect could be achieved by taking a fodder legume in the cropping system.

Sequence cropping : The N-effect of a legume taken as fodder or grain on the subsequent non-legume crops was tested at Hyderabad and Varanasi

Table 8: Effect of legume on the yield of second crops

Centre	Sequence	Yield of second crop (q/ha)	
		without legume crop	with legume crop
Hyderabad	Cowpea (fodder)- Finger millet	8.4	11.0
Varanasi	Blackgram (grain)- Mustard	6.9	8.8

(Table 8). The advantage is evident. Such possibilities exist, for example, at Jhansi (cowpea as fodder-chickpea) and at Udaipur (cowpea as fodder-mustard).

A fodder legume like *Stylosanthes hamata* as monsoon crop resulted in a nitrogen effect to the tune of 50 kg N/ha on the following post-rainy sorghum crop at the Indian Grassland and Fodder Research Institute, Jhansi.

Use of Microorganisms in Dryland Agriculture

Experiments with rhizobia on legumes in drylands were not encouraging. However, use of *Azospirillum* on grain yield of pearl millet and sorghum was significant (Table 9). These results are significant and show increased yields by 23 and 18 percent, respectively.

Table 9 : Effect of Azospirillum on yield of crops (Hyderabad)

Crop	Yield (q ha)	
	Control	Inoculated seed
Pearl millet	13.5	16.6
Sorghum	26.7	31.5

Conclusion

The conjunctive use of farm yard manure and green manure with inorganic fertiliser has given higher yields of crops. Incorporated crop residues lead to increased yields and improvement in soil physical and chemical characteristics. Fodder legumes in the cropping system have significant N-effect on non-legume crop yields. Use of organic fertiliser, Azospirillum for increasing yields of cereals seems to be a promising approach.

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SOME ASPECTS OF NUTRIENT SUPPLY IN DRYLANDS

RAJAT DE

It is very well recognised that application of chemical fertilisers or organic manures increases the productivity of dryland crops. Sometimes it has also been said that applied in small quantities but adequate to meet the needs of a crop, the response to fertilisers is higher in drylands than in irrigated areas. This is because the nutrient depletion by continuous cropping over years has not been made good in the drylands. The nutrient status of a soil besides being determined by the rate of application of manures or fertilisers, is governed by the crops grown. Also soil and water conservation methods adopted in these areas determine not only the productivity of the crops but also the response to the added manures or fertilisers. An attempt is made in this paper to bring out the different aspects of nutrient supply in the drylands and is mostly confined to the work done at the Indian Agricultural Research Institute, New Delhi which is fairly representative of the semi-arid north western alluvial belt.

Soil and Climatic Conditions of Delhi

The soil of experimental site is sandy loam, poor in N and P status and is capable of holding not more than 150 mm of plant extractable water in the 1 m depth measured between 0.3 and 15 bars. Of the 650 mm of annual precipitation, almost 80 percent is received in the monsoon months of July to second week of September. In the post-rainy season, the rainfall expected between middle of October and end of March is 86 mm.

Fertiliser and Water Use Efficiency

As a management practice, fertiliser use increases water use efficiency by increased exploitation of soil moisture mainly due to increased root growth. Sometimes total water use is not altered by fertiliser application but the water use efficiency increases due to a change in water use pattern. Patil and De (1978) and Agarwal and De (1979) reported that in rapeseed and barley, application of N upto 60 kg/ha did not materially alter the total water used by these two crops but water use efficiency was increased. Fertiliser application did not alter the water use pattern upto the pre-flowering stage but thereafter the fertilized plots used more water than the unfertilised ones. In order that the crop does not put up too much vegetative growth, it is necessary that the

initial fertiliser application at sowing is such that it does not allow too much vegetative growth specially in the post-rainy season crops. Initial moist zone placement of two thirds of 60 kg N /ha has, therefore, been recommended by Saran and De (1979) for rapeseed. The remaining quantity of it is best utilised when applied on foliage (Table 1). In crops like rapeseed where insecticidal sprays are inevitable to control aphids, urea can be easily mixed with the spraying material to supply the nutrient at this stage.

Table 1: Rapeseed yield as affected by methods of N application (average of three years data)

Methods of 60 kg N /ha application	Seed yield (q ha)
Placement in soil at seeding	16.4
Placement of 2/3 N in soil and foliar application of the rest at flowering stage	18.3

In order to maximise the return from the input of chemical fertilisers, it is necessary that other management aspects like choice of crops, or their cultivars, their optimum sowing time and plant density or crop geometry be adopted. It is well known that deep rooted crops are more suited for the drylands. Sorghum which is well adapted to dryland situation has been shown to respond more to chemical fertiliser when the improved cultivars were used. From the experiments conducted under the All India Co-ordinated Sorghum Improvement Project for several years, Singh (1977) has reported that while the local variety of sorghum gave a response of only 7 kg grain/kg N at 50 kg N application, CSH-1 gave response of 21.5 kg grain/kg N used. Apparently the water use efficiency was very much enhanced in the improved variety.

Seeding wheat in the first week of November instead of the usual mid-October sowing in the drylands increased the yield of wheat several folds (Table 2). The difference was because of high temperatures during the middle of October (26°C daily mean temperature) as against 20°C-22°C in the first week of November. Greater tiller formation and normal period of maturity in the November sown wheat increased the fertiliser and water use efficiency.

Table 2: Yield of dryland wheat (q/ha) as affected by dates of seeding.

Cultivars	Dates of seeding		
	15 Oct.	30 Oct.	14 Nov.
C-306	32.7	34.6	39.8
Kalyansona	15.5	33.8	39.8

Another management technique which can increase the fertiliser use efficiency is the row and plant population adjustment under dryland conditions. In a rapeseed experiment, response to nitrogen increased considerably by row distance from 30 to 60 cm. Without nitrogen, highest seed yield was obtained at 30 cm row spacing but with fertiliser application at 30 and 60 kg N/ha highest seed yield was recorded in rows placed 60 cm apart (Table 3).

Table 3 : Effect on nitrogen rates and row spacings on the seed yield of rapeseed (q/ha)

Rates of N (kg/ha)	Row spacing (cm)		
	30	45	60
0	17.2	14.6	13.8
30	17.9	19.0	20.6
60	18.4	20.0	22.2
C.D.		1.30	

These differences arose from the fact that wider spacing reduced the water use during the vegetative phase and the water so conserved was utilised more effectively for grain formation. A higher harvest index (HI) was obtained in the wider row spacings; the HI increased from 0.264 in 30 cm row spacing to 0.326 in 60 cm row spacing. It is well known that in widely spaced plants unused soil water between the rows is utilised at the latter part of crop growth (Brown and Shrader 1959).

Moisture conservation practices have a great scope in increasing the fertiliser use efficiency under drylands. Meelu *et al* (1976) reported that adoption of improved moisture conservation practices like levelling and bunding the fields to avoid runoff, timely ploughing to increase water intake rate, and control of weeds during monsoon fallow period resulted in 21 mm increase in plant extractable water in the top 90 cm of profile. Grain yields of maize and wheat were 200 and 280 kg/ha more respectively under improved method of moisture conservation compared to cultivators' practice.

Control of evaporation loss of water during the crop growth period has a modifying influence on the productivity of dryland crops. Prihar and Arora (1980) demonstrated the efficiency of straw mulching under dryland conditions in increasing the productivity of crops. Agarwal and De (1979) found that mulch application increased the uptake of both nitrogen and phosphorus irrespective of the levels of nitrogen applied.

Cropping Systems

The yield of crop is normally determined by the nature of the crop preceding it. Legumes are known to increase the productivity of subsequent crops. There was, however, some doubt regarding the efficiency of grain legumes in this regard. The experiments conducted at IARI have, however, shown that some grain legumes considerably increased the soil productivity to benefit the subsequently grown non-legumes. Giri and De (1979) have shown that yield of pearl millet was increased when grown after legumes like groundnut (22.6 percent), cowpea (24.2 percent) or pigeonpea (12.1 percent) instead of after pearl millet. Benefits from previous crops of groundnut or cowpea were equivalent to 60 kg N/ha applied to pearl millet crop following a previous crop of pearl millet (Table 4)

Table 4 : Effect of grain legumes on dryland pearl millet (average of three cycles)

Previous crops	Yield of previous crops (q/ha)	Pearlmillet grain yield (q/ha)		
		Rates of N (kg/ha)		
		0	30	60
Greengram	7.2	24.9	29.0	29.7
Groundnut	11.7	28.9	31.3	32.0
Cowpea	7.0	28.8	31.3	32.8
Pigeonpea	13.6	25.2	28.9	30.1
Pearlmillet	20.5	20.1	25.5	29.5

It is obvious that the highest benefit was from the previous legume crops when the pearl millet crop was unfertilised. This benefit was due to high quantity of mineralizable N in the legume plots. The difference between the various legumes was due to higher proportion of viable nodules remaining upto the harvest of crops like groundnut and cowpea than in pigeonpea or greengram (Giri and De 1980).

Possibilities of Double Cropping

Most of the semi-arid areas with a mono modal pattern of rainfall and receiving between 600 and 800 mm of precipitation are compulsively mono-cropped. The farmers either raise a rainy season crop or after fallowing during the monsoon period grow a crop on the conserved moisture. In such situations, it is possible to increase the cropping intensity if short season crops maturing or harvested in 55 to 60 days are grown starting with the onset of monsoon rains. The tailend monsoon rains which fall after the harvest of these crops may sufficiently charge the profile to enable a succeeding crop to be successfully grown. Giri and De (1981) grew short season fodder legumes of cowpea, clusterbean, mothbean, soybean and pearl millet between the first week of July and last week of August. Within this period the green fodder yields from the various crops ranged from 8.3 to 26.9 t/ha. The monsoon rains in first fortnight of September were sufficient to charge the profile adequately. The barley crop grown subsequently yielded between 20 and 39 q/ha. The highest benefit accrued from mothbean fodder. The other legume fodders were equally effective. The benefit from some of these legume fodders was equivalent to about 40 kg of N applied to barley crop grown after pearl millet (Table 5).

Table 5 : Effect of short season fodder legumes on barley grain yield (q/ha) grown under drylands

Previous fodder crops	Yield of fodder crops (q/ha)	Levels of N(Kg/ha) to barley			
		0	20	40	Mean
Cowpea	163	31.9	35.8	34.7	34.1
Clusterbean	97	30.6	37.5	38.0	35.3
Mothbean	83	33.6	37.6	38.8	36.7
Soybean	96	29.5	35.1	31.3	32.0
Pearlmillet	269	20.4	26.5	31.0	25.7

It is interesting to note that the nitrogen response was linear upto 40kg N/ha in barley grown after pearl millet. But grown after any of the legume fodders the optimum yields were reached with only 20 kg N application to barely. These findings show that growing short season fodder legumes and harvesting them at least 10 days earlier than the expected end of monsoon rains would provide nutritious fodder to the milch and draft animals and at the same time raise the productivity of soils sufficiently to benefit the subsequent crop grown on the conserved moisture to the extent of 40 kg N/ha.

When grown in association, legumes often increase the yield of the non-legumes. Das and Mathur (1980) have reported that when maize was grown in alternate rows with greengram cowpea or black gram, there was a 14 to 19 percent increase in the yield of maize compared to its yield when grown in a sole crop situation (31.25 q/ha). Wheat (irrigated) grown after maize intercropping system with blackgram benefitted to the extent of 20 kg N/ha.

Conclusion

Fertiliser use efficiency is increased by methods of application, row spacing, plant population and moisture conservation practices. Legumes should form a component of cropping systems for increasing productivity of non-legumes.

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INTEGRATED FERTILISER USE IN DRYLANDS

RANJODH SINGH

It is now well recognised that fertiliser use has a key role to play in increasing crop yields per unit area both under irrigated as well as rainfed conditions. While the fertiliser use in the irrigated areas has appreciably increased in the recent years, its consumption in the unirrigated areas continues to be low. The yields of the unirrigated crops, thus, continue to be low and unstable. One of the reasons of low fertiliser use is that the farmer is partly making use of some organic manures. But the quantity as well as the quality of the organic manures used is inadequate to meet the nutrient requirements of the improved cropping system and it has to be supplemented with optimum doses of fertilisers with effective method of application for making the system more productive. The fertiliser use, though considered essential, is costly and for making efficient use of this input, there is a need to improve productivity per unit fertiliser applied by mobilising all the quantities of organic manures, use of green manures, suitable cropping pattern with leguminous crops and follow up of moisture conservation practices. This will not only give better yield but will also lead to a permanent increase in the fertility status of the soil. Specific scientific evidence on these lines is limited and we need to generate scientific data on the better use of integrated nutrient supply systems involving fertiliser, organic manures, green manures, intercropping systems with leguminous crops in relation to economy of nutrients for adoption by the farmers. In this paper, the different components of the integrated nutrient supply systems are discussed so as to make the existing low yielding farming system into a productive one.

Moisture Conservation and Nutrient Management

It is generally agreed that response to applied nutrients for rainfed crops is not assured and sometimes not profitable unless proper soil and water conservation practices are adopted. Lack of adequate soil and water conservation measures is, therefore, considered to be a major constraint for stabilizing the yield of rainfed crops. Proper soil and water conservation practices should, thus, form an integral part of the farming system before introducing other inputs of improved technology so as to live with the erratic distribution of rainfall. Suitable watershed treatment viz., minor smoothing, terracing, graded bunding with provision of drainage for excess water for *in situ* water conservation and broad-

bed and furrow system for *in situ* drainage brings about permanent improvement and gives confidence to the farmers to make use of the costly inputs of improved technology.

The improved watershed technology has adequately been demonstrated on an operational scale on farmers' fields at Hoshiarpur for submontane region, at Hyderabad for shallow alfisol, at Indore for deep vertisols, and at Bangalore for red lateritic soils. It is a prerequisite for introducing other inputs of improved technology. Meelu *et al* (1975) observed higher initial profile water storage with a minor land treatment of bunding in Hoshiarpur region and found that above a base stored soil water of 14 cm, water conservation practices resulted in one quintal extra wheat yield per cm extra water conserved with optimum fertilisation (Table 1). Scientific data need to be built up at other centres so as to relate the watershed treatment in terms of improving profile water storage and stabilizing crop yields.

Table 1: Effect of moisture conservation practices on profile moisture and yield of crops

Treatment	Profile moisture at wheat sowing (mm/90 cm)	Wheat yield (q/ha) mean of 2 years (1970-71)
Farmers' practice	147	15.0
Minor levelling and bunding	168	17.8

Rationale of Fertiliser Use

Next to water, yields of rainfed crops are limited by nutrient deficiencies. It is known that initial fertiliser application increases crop vigour and more vigorously growing crops develop deeper root system which helps the crop to extract water from lower layers particularly during later periods of growth (Singh *et al* 1975). Results of large number of field experiments conducted at different research centres clearly bring out the profitability of the use of fertilisers (Chowdury 1979 and Tandon 1981). The response to applied fertiliser, however, is found to vary with soil type, available water storage at seeding and anticipated seasonal rainfall during the crop season (Table 2). Both maize and wheat responded to N application upto 80 kg N/ha in a sandy loam and up to 40 kg N/ha in a loamy sand soil (Singh *et al* 1975). Like wise response of wheat to P application was also found to be related to soil types (20 and 40 kg P_2O_5 /ha in loamy sand and sandy loam soils respectively) having low and medium in available phosphorus. The yield response to added nutrients

changes with a change in water supply. Below a certain level of water supply there is no response to added nitrogen. Likewise response to nitrogen exceeding 40 kg/ha is not observed until a threshold water supply is reached (Prihar *et al* 1981). These observations further suggest that fertiliser rates must be decided in relation to available water supplies to ensure an adequate fertiliser use efficiency. Critical field experiments have, thus, to be taken up so as to rationalise the use of fertilisers depending upon the soil type and the anticipated seasonal rainfall.

Table-2 : Effect of soil type, stored water and rainfall on fertiliser response in wheat

Year	Soil type	Storage (cm/180cm)	Winter Rainfall (cm)	Control yield (q/ha)	Fertilised yield (q/ha)	Response (kg grain/kg N)
1971-72	LS	26.3	13.7	8.7	11.7	10.0 (30)
1972-73	LS	24.2	14.1	16.6	24.1	25.0 (30)
1972-73	SL	27.1	14.1	19.0	35.5	20.6 (80)
1973-74	SL	24.5	6.2	23.2	33.4	12.9 (80)
1975-76	SL	28.1	15.5	23.1	35.9	16.0(100)
1976-77	LS	29.7	3.2	10.8	22.1	23.8 (40)
1977-78	LS-SL	27.6	17.3	25.7	39.7	17.5 (80)
1978-79	LS-SL	23.6	27.1	19.1	40.0	26.1 (80)

Figures in parenthesis indicate optimum level of response.

SL : Sandy loam ; LS : Loamy Sand

Fertiliser Use on Soil Test Basis

Response to fertiliser application, particularly phosphorus, potassium and zinc is related to soil tests and efficient use of the fertilisers can only be made if these nutrients are applied on soil test basis. While information on this aspect is available for irrigated crops, it is not adequate for rainfed crops. The use of fertiliser on the basis of soil test has become all the more important due to its prohibitive cost and for making efficient use of this costly input. The soil test data of surface as well as lower layers may help to explain some of the reasons for lack of response in certain situations. The results suggest that economic use of fertiliser can be practised better on the basis of soil test for individual fields rather than that of regional recommendations.

Fertiliser Requirement and Cropping Sequence

The general fertiliser recommendations pertain to individual crops and do not keep in view the crop sequence; so, residual effect of the fertiliser applied to the first crop is not taken into account. The residual effect under limited water conditions is likely to be more and there can be some saving of fertiliser required for the following crops. It may particularly be appreciable, if the year happens to be a drought year. In rainfed agriculture organic manure, in general, is applied to the rainy season crops and in this case additions of inorganic P and K may not be required particularly to the short duration crops, if the soil test reveals the availability of these nutrients is not low. In irrigated agriculture there is a saving of 60 kg N and 30 kg each of P_2O_5 and K_2O per ha to wheat crop with the application of 12-15 t/ha of FYM to maize in maize-wheat sequence in Punjab (Table 3). In another experiment, it was observed that it is more remunerative to apply phosphorus to wheat in maize-wheat sequence and its application to the following maize can be omitted (Table 4). The build up of soil phosphorus and potassium will, however, depend on the quantity as well as the quality of the organic manure added. The economy of nutrients through farm-yard manure is determined by its quality and it is generally rated as poor. The quality, thus, needs to be improved by including leguminous fodders in the cropping patterns for improving the fertiliser use efficiency of the applied fertiliser.

Table 3: Effect of organic and inorganic fertiliser on maize yield

Treatment	Maize yield (q/ha) Mean of 3 years (1974-76)
Control	16.4
120 kg N/ha	29.7
FYM (12 tons/ha)	22.8
FYM+60 kg N/ha	27.8
FYM+90 kg N/ha	30.0
FYM+60 kg N+30 kg P_2O_5 +30kg K_2O /ha	29.5
No. of trials	44

Table 4 : Effect of phosphorus on crops in maize—wheat sequence (Mean of five years (1968-73))

Treatment	Grain yield (q/ha)		
	Maize	Wheat	Total
60 kg P ₂ O ₅ /ha applied to maize only	31.6	34.8	66.4
60 kg P ₂ O ₅ /ha applied to wheat only	31.7	42.5	74.2
30 kg P ₂ O ₅ /ha applied both to wheat and maize	33.3	39.3	72.6

In a crop sequence where a pulse crop is followed by a cereal, phosphorus application benefits the pulse crop and it appreciably economises the use of nitrogen for the following crop. Detailed studies are, however, needed to quantify the N saving through the use of organic manures and inclusion of pulse crops in a crop sequence.

Farmers of the rainfed areas traditionally go in for inter/mixed cropping systems as a strategy for increasing crop intensity and to stabilise crop production. This practice is one of the integrated cropping systems of the farmers to economise the nutrient needs also. On deep vertisols at ICRISAT, sorghum requirement for nitrogen is less if it is grown in an intercropping system as compared to sole sorghum. Some nitrogen is likely to be transferred from pigeonpea to sorghum (Sahrawat et al 1979). Similar observation was apparent from a series of field experiments conducted with wheat + chickpea as mixed crops in Hoshiarpur (Punjab) region and there is atleast a saving of 20-40 kg N/ha (Table 5). There is need to quantify extent of N transferred from legume to cereal in an intercrop system so as to derive full potential of biological N fixation by the legumes.

Green manuring, Mulching and N Economy

There are extensive current fallow areas in the rainy season in the assured rainfall areas and introduction of green manuring crops in these vast areas will be of significance particularly for conserving soil against erosion by acting as a cover crop and by improving native fertility of the soil through N fixation and N addition. Different leguminous crops vary in their N fixing capacity and it is reported that about 40-80 kg N/ha can be turned under by the green manure

Table 5 : Response of wheat+chickpea mixture to N and P applicaton

Treatments	Sandy loam		Loamy sand	
	1978-79	1979-80	1977-78	1979-80
Rate of N (kg/ha)				
0	22.2	18.0	16.3	15.7
20	26.2	21.5	20.3	19.0
40	31.4	27.5	22.7	19.9
60	36.8	28.0	26.6	20.4
C.D. (0.05)	2.1	3.6	2.5	2.7
Rates of P ₂ O ₅ (kg/ha)				
0	28.5	23.3	18.1	18.6
20	29.7	24.0	22.9	19.5
C.D. (0.05)	NS	NS	2.5	NS
Available P (kg/ha)	20.2	23.5	16.2	18.6

crops (Raychaudhuri 1977). How best it can form as part of the farming system in the drylands needs attention. Growing of greengram with early monsoon showers is a conventional practice with some farmers in August sown sorghum tract of Andhra Pradesh, where greengram is taken as a legume prior to sorghum. The other legumes like cowpea, blackgram, soybean, can be grown for grain and the residues incorporated.

In assured rainfall regions in North India, growing of eight week duration green manuring crop of "Sunhemp" on marginal soils in the fallow-wheat sequence increases yield by acting as a cover crop as well as by improving the native fertility of the marginal soils. Long term studies carried out by CAZRI Jodhpur revealed that a saving of 20 kg N/ha to pearl millet could be effected in the greengram - pearl millet sequence. In Bangalore region, growing of cowpeas with an addition of FYM at the rate of 10 t/ha helped in saving of 25 kg each of N, P₂O₅, and K₂O per ha for finger millet (Singh et al 1981). In areas where long duration crops like castor is grown, cowpeas could be grown as an intercrop for a six week period and incorporated *in situ* as a green manure; the contribution through green manure is upto 30 kg N/ha (Venkateswarlu 1980). Results obtained at other research centres are also encouraging and need further elucidation for their specific role in N economy and improvement in physical properties of soils.

Wherever it is not possible to grow green manure crops, planting of leguminous shrubs and trees on road sides and around the field boundaries should be considered. The leaf from these plants can be cut and utilised for green manuring or as fodder. The twigs of the plants will also serve as source of fuel (Subba Rao and Rao 1979).

Recently, it is established that in a low input system on vertisols, pigeonpea can be grown successfully as a post-rainy crop and this practice is being investigated at a number of places in India, including ICRISAT. The cropping system consists of growing a crop of pigeonpea (planting around October) harvesting it by ratooning in late February or March and leaving the plants in the field. Owing to their deep root system and perennial nature, many of them survive the summer and, with the onset of monsoon rains quickly establish a full canopy. A good normal season crop is harvested in December, and a further ratoon harvest can be obtained from the same plants by February or March, when the stocks are removed from the field. The feasibility of this system has recently been demonstrated by the scientists of the pulse physiology group at ICRISAT and it is indicated that on the basis of fallen leaf material, it is likely to add 40-50 kg N/ha to the following crop of sorghum.

Mulching rainfed crops with organic residues is known to help increase soil moisture and increase fertiliser use efficiency indirectly and even soil mulch proved useful in increasing yield of post-rainy sorghum grown on black soils of Bijapur. The advantage was not quite apparent in the red lateritic soils of Bangalore.

In highly impermeable soils like those of Bellary, vertical mulching at 4 meter interval was found to be extremely useful. In light textured soils, application of organic mulches (4—6 t/ha) delayed the rate of surface drying and when applied over the seeded rows of pearl millet, mitigated ill effects of surface crusting and resulted in good crop establishment (Singh *et al* 1981).

Application of surface mulch in the standing crop of maize in the last week of August or in the fallow plots was found to benefit the post-rainy crops. The increase in wheat yield with mulching in the previous crop of maize is attributed to greater residual moisture after maize particularly in the seed zone and enrichment of soil with nutrients (Prihar *et al* 1981.) In wheat following mulched maize, the yields with 0 and 40 kg N/ha were comparable to those with 40 and 80 Kg N/ha in the absence of mulch. It, thus, suggests a saving of fertiliser N to the extent of 40 kg N/ha to the succeeding crop of wheat (Table 6).

Table 6: Mean wheat yield (q/ha) as affected by mulch and N application

Treatment	N rate (kg/ha)					
	Loamy sand			Sandy loam		
	0	40	80	0	40	80
Control	19	26	30	25	36	46
Mulch	26	32	35	37	45	47

Mulch applied in standing maize and N rates to wheat crop

Efficient Method of Fertiliser Application

For maximising fertiliser use efficiency of the limited fertiliser input, it is essential to apply the fertiliser at proper location and time. Deep placement (8-10 cm) below the soil surface is considered essential particularly under receding moisture conditions. Split application of nitrogen, however, is beneficial to the rainy season crops. Foliar fertiliser application and set row application have also been shown effective under certain situations (Singh *et al* 1981). Proper placement of fertiliser on farmers' fields is one of the constraints in the traditional system and there is urgent need for a low cost seed-cum-fertiliser drill to improve fertiliser use efficiency and other inputs of improved technology.

Conclusions and Future Projections

The fertiliser use has to play a key role in rainfed agriculture but its consumption till now is low. The farmer is using some organic manures, but the efficiency of his system is so low that the soil productivity is seriously impaired. The fertiliser is costly and for making efficient use of this input, the integrated nutrient supply system should form an integral part of the farming system to improve productivity per unit fertiliser applied by mobilising all the available quantities of organic manures, scheduling optimum doses of fertilisers in crop sequence in relation to water supply, suitable cropping patterns, other management practices including placement of fertiliser with effective follow up of moisture conservation practices. Scientific evidence on the use of the integrated system is limiting and there is a need to generate data on its better use so as to make the low yielding farming system a more productive one. The following aspects should receive thrust during the 80's:

- i. Suitable water-shed treatment for *In situ* water conservation and surface drainage needs to be taken up before introducing any input of improved technology.

- ii. The response to fertiliser use is variable and the fertiliser dose must be decided in relation to available water supplies.
- iii. The general fertiliser recommendations need to be modified on the basis of soil test so as to economise the use of P and K fertiliser.
- iv. Fertiliser schedules for different crops need to be worked out in a cropping sequence.
- v. The quality of organic manures used, in general, is poor and needs to be improved through suitable conservation measures.
- vi. In the intercropping system, there is need to quantify the extent of N transferred from legume to cereal so as to derive full potential of biological N fixation.
- vii. Growing of green manure crops/pulse crops will be of significance in the extensive fallow areas in the rainy season to check soil loss and to improve native soil fertility.
- viii. Role of green manure/crop residues needs further elucidation for their specific role in nutrient economy and improvement in physical properties of soil.
- ix. For maximum fertiliser use efficiency the fertiliser should be always placed in the moist soil zone. A low cost seed-cum-fertiliser drill is needed.

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RUNOFF MANAGEMENT

RUNOFF MANAGEMENT

K. VIJAYALAKSHMI

In many parts of India, a rather low percentage of annual rainfall is used for crop production due to various reasons. This tells adversely on the productivity of crops and makes rainfed agriculture a risky proposition. Thus the first and foremost consideration in the rainfed farming should be to conserve and efficiently utilize the rain water. Attempts have been made in the Dryland Project and elsewhere to conserve the rain water where it falls, as much as possible, and also to collect and reuse the excess runoff water.

Moisture Conservation *in situ*

As moisture is one of the most limiting factors in dryland for crop production, every effort should be made to conserve as much rain water as possible, at a place where it falls. Surface mulches, stubble mulches, tillage and land configuration are being considered with this in view and have been found useful for specific conditions. In spite of all these efforts, runoff is still a certainty. The emphasis in this paper is on runoff management.

Runoff Harvesting

Low rainfall areas (< 700 mm rain): In areas with low rainfall, many a time crop failures occur. Due to the risk involved, cash inputs like fertilizers, hybrid seeds and pesticides which, in turn, boost up production do not find ready acceptance with the farmers. In these areas, stable crop production is possible by cropping only a part of the area in the watershed. Studies on this aspect have been carried at Jodhpur (Table 1). The advantage of draining water from upper reaches and using this extra water for crop production is evident.

Table 1 : Effect of Inter-plot water harvesting on grain yield of pearl millet

Catchment to cropped area	Yield(q/ha)
	(Mean of two years)
1 : 1 (Slope on one side)	25.1
1 : 1 (Slope on two sides)	28.0
1 : 2 (Slope on two sides)	20.8
control	18.5

However, more work needs to be done to find out :

- i) how many years the crop failures occur, based on the analysis of rainfall
- ii) how to make the, draining, catchment more productive
- iii) what is the proportion of catchment to cropped area.
- iv) what mechanical measures are needed to ensure that soil erosion is within permissible limits.
- v) what would be the best crop, cropping system and management practices for ensuring stability in production.

It has been found at Jodhpur that catchment can be cropped with *Zizyphus mauritiana*. Fruit trees, legumes, fodder trees etc in the 'draining catchment' could add to the total income of the micro-catchment and at the same time, assure sustained cropping in lower areas.

The second approach for these areas is to conserve more moisture in furrows by adopting ridge-furrow or bed furrow system and planting the crop in the furrows. Treatment of the sides of ridges has also been tried to increase the runoff into the furrows (Table 2). In order to use this system more profitably,

Table-2 : Inter-row water harvesting in Sierozems on yield of pearl millet in Jodhpur

Inter-row treatment	Yield (q/ha) based on cropped area
Tank silt over ridge	6.8
Polythene sheet between rows	8.4
FYM in ditches (3 t/ha)	9.1
Sowing on the sides of ditches	5.6
Sowing on raised seedbed	3.4

emphasis should be on :

- i) the artificial methods that could be used. Compaction is a simple practice that can help. Treatments with bitumen/paraffin etc can also be effective.

- ii) how often do these extra practices have to be done i.e. are they permanent ?
- iii) the best crop, cropping system and management practices.

In fact, both the inter-plot and intra-row water harvesting systems can be implemented by individual farmers.

Areas with moderate rainfall (700-1000 mm): In these areas the first attempt is to conserve as much of water as possible where it falls. For this mechanical and cultural practices are needed. However, the excess water that cannot be conserved in the root profile is to be collected. This area has been receiving serious attention at Dryland Research Centres and at ICRISAT. The available information from different areas covers:

Work on sealants : Natural silting has been found to reduce seepage in large tanks (Table 3). However, in small dug out ponds the natural silting will have very little practical application as this would reduce storage space considerably.

Table 3: Effectiveness of natural silting in farm ponds

Research Centres	Year	Seepage as percentage of first year
Rajkot	1st year	100
	3rd year	25
	5th year	14
Dehra Dun	1st year	100
	5th year	38
	10th year	24

Efforts to find cheap and easily available sealants have not been very successful. But some promising materials found good at different dryland centres are given in Table 4.

Table 4 : Some effective sealants

Research centre	Material used	Seepage as percentage of control
Bangalore	Clay + sodium chloride + sodium carbonate (20: 5: 1)	19
	Soil : Cement (5: 1)	30
	Soil : Cement (10: 1)	42
Dantiwada	Plastic lining overlaid by brick work	9
	Lime mortar (1:6) with asphalt lining	11
	Cement : sand (1:6)	19
Hyderabad	Plastic sheet overlaid by brick work	0
	Brick lining overlaid by cement + plastering	0
	Asphalt	31
Ludhiana	Bottom polythene	5
	Sides polythene	31
Rajkot	Soil + cowdung + straw (7:2:1)	11
	Soil compacted to high bulk density	43
Ranchi	Clay	56
	Coal tar	44
Varanasi	Black polythene	4
	Brick lining	4
	Soil : Cement (10:1)	24

Till today, none of the sealants have been found to be as efficacious as cement-concrete on a long range basis. There is a need to intensify the work. It may be advisable to do some research on choosing the material or the effective proportion of mixtures under laboratory conditions and then test only one or two successful ones in dug outs. This is necessitated due to operational problems. However, final testing needs to be done in the natural watersheds.

Supplemental Irrigation

Information from most of the centres are available on the response of crops to different quantities of water (Table 5)

Table 5 : Effect of supplemental irrigation on yield of crops

Crops	Level of irrigation (cm)	Yield (q/ha)	Yield response to irrigation (%)	Research centre
a. Short duration rainy season crops				
Sorghum	0.6	25.1	560	Hyderabad
Maize	1	26.6	15	Jhansi
	2	44.3	40	
Finger millet	5	23.2	43	Bangalore
Soybean	8	20.5	14	Indore
b. Long duration rainy season crops				
Castor	5	13.2	31	Hyderabad
Pigeonpea (Sole crop)	3	1.7	240	Jhansi
	5	3.3	560	
Pigeonpea (as intercrop with pearl millet)	2	0.4	100	Hyderabad
	4	0.8	300	
Tobacco	6	1.8	800	Dantiwada
	-	13.0	58	
c. Post-rainy season crops				
Wheat	2	15.8	35	Dehra Dun
	4	20.6	78	
	6	26.0	123	
Rape seed	1	3.5	40	Ranchi
	3	4.6	84	
	5	5.4	116	

Scheduling irrigation to moisture depletion, or according to the need of the crop taking into account cumulative pan evaporation would help in increasing the efficiency of water use. But these approaches are mainly useful for post rainy season.

Irrigation at Critical Stage

Information on a limited scale is available for the most critical stage for water application. This would ensure the efficient application of the scarce resource of water (Table 6).

Table 6 : Effect of critical irrigation on sorghum in Hyderabad

Stage of crop	Yield (q/ha) (Mean of two years)
Control	13.9
Vegetative phase	17.4
Flowering phase	19.2

The data clearly point out the need to time irrigation and to give it at specific crop stages. Thus, it would be essential to know the critical stages, the quantity of water most economical etc for each crop to make the best use of the supplemental water.

Size and Shape of Pond

At present, the size has been very arbitrarily chosen for the ponds located in the watershed. The first need is to quantify the runoff. The existing runoff and sediment prediction equations do not give reliable estimates. Intensive efforts and extensive studies are needed to generate the hydrological information about small watersheds. This would help in setting up simple and fairly reliable mathematical models. Such models then can be extrapolated for planning and designing water harvesting systems. The size of the pond then can be tailored to the runoff water without much of ecological imbalance. As a corollary to the size, the shape and storage capacity could be decided keeping in view the minimum loss of cropping area.

Lifting Devices

Not much attention has been paid to lifting devices yet. Many pumps are available, but the cost is prohibitive. The use of lifting devices will have to be relooked into to cut down costs and at the same time be efficient.

Method of Application

Another area of interest is in application of the water. The quantity being limited, the application methods have to be very efficient. Work done at Hyderabad in red sandy loam soil indicate some advantage of confined alternate furrows with very small quantities of water.

Modifications of drip, sprinkler etc also need to be studied as these as such, are of little value, being costly. Moreover, the runoff water generally contain, suspended silt and clay, thus making it very difficult to use conventional drip or sprinkler.

Our efforts are to increase cropping intensity through intercrop and sequence crop systems, it would be appropriate to find out the best cropping systems for supplemental irrigation. This would mean that yield per quantity of water in a system is important. The water collected can also be used for growing vegetables for home consumption or for sale particularly in areas near a city where demands are high. Yield responses of different vegetables to supplemental irrigation are very encouraging in studies conducted at Bangalore and Hyderabad

Fodder crops : Diversification of water use is essential. In times of stress, it is the fodder component that suffers badly. Also, it is an accepted fact that there are very little legumes in our pastures; so, one of the ways of using the harvested water could be for growing legumes for fodder as second crop (Table 7).

Table 7 : Supplemental irrigation to a legume

Fodder crop	Level of Irrigation (cm)	Yield (q/ha)	Research Centre
Cowpea	0	60.7	Bangalore
	5	114.3	
Cowpea	1	7.1	Hyderabad
	2	8.1	
Horsegram	1	3.4	Hyderabad
	2	8.5	

Other Alternate Uses

- i. It has been found at Hyderabad Operational Research Project that the farmers used this water for spraying purposes.
- ii. Water can also be used for the requirement of cattle.
- iii. If water can be stored for a few months in the pond, there is possibility for fish culture. This is an area that needs further exploration.
- iv. During off-season, it was noticed that the farmers in Operational Research Project (Hyderabad) respread the accumulated silt in pond thus offsetting to some extent the erosion disadvantage.

Future Needs

As evaporation losses are high from ponds, inexpensive methods need to be tried in order to cut down evaporation. Use of wind barriers, shading the water surface etc should be thought of.

All the methods emphasize the collection and reuse of the water in the donor catchment. However, in some areas, instead of surface collection, it may be more profitable to recharge the ground water. Thus, the water collection ponds would be percolation tanks. However, it is essential to remember that the water thus recharged into the wells should be used for stabilising crop production extensively rather than for limited area under irrigated crops

Another approach would be to construct check dams and gully plugs in the watershed and to use this extra water for growing fruit trees to augment the income of farmers.

High rainfall areas (> 100 mm)

In this areas, double cropping is a distinct possibility. However, in rainy seasons, crops suffer due to temporary water logging. The crop drainage can be provided either through inter-plot or inter-row water harvesting systems.

Studies conducted for five years at Dehra Dun clearly show that a combination of paddy + maize does better, as the extra water from maize is used profitably by rice (Table 8). This concept need to be explored in high rainfall areas to stabilize a system with rice especially.

The extra harvested water in ponds can also be used for stabilising a second crop. Time of application, quantity and the crop needs are to be worked out depending on specific areas.

Table 8: Yields of paddy-maize combination in a watershed at Dehra Dun

Watershed crops	Yield (q/ha)		Total yield (q/ha)
	Paddy	Maize	
All paddy	19.4	—	19.4
1 Maize : 1 paddy	11.4	12.1	23.5
2 Maize : 1 paddy	9.4	14.7	23.8
3 Maize : 1 paddy	8.2	16.6	24.8
All Maize	—	20.0	20.0

Water for Increasing Fertilizer Efficiency

Generally, in drylands, medium fertility levels are recommended because of risks involved. With supplemental watering, fertilizer use can be made more effective as can be seen in Table-9. This area needs to be further explored to schedule fertilizer application depending on moisture status of soil and available water for supplemental irrigation.

Table 9: Nitrogen fertigation studies on the yield (q/ha) of wheat in Dehra Dun (Mean of 4 years)

Time of application	Qty. of water (cm)	Level of nitrogen (Kg/ha)				Mean
		0	50	100	150	
Control	0	14.8	17.0	19.8	22.1	18.4
Pre-sowing	5	26.8	33.2	36.1	42.0	34.5
Crown root Pre-sowing +	5	26.4	31.0	35.9	39.3	33.1
Crown root	10	30.7	39.8	44.9	51.9	41.8
Mean		24.7	30.2	34.1	38.8	

in a watershed, a part of the area may be unfit for cultivation. Either we have to protect the soil with a vegetative cover or we can also think of treating the soil, so that maximum water is allowed to runoff without soil erosion. Bitumen/paraffin etc can be used for this purpose. These provide proper binding to and check soil erosion.

Conclusion

Work on different aspects of runoff management is already on the ground. There are a few missing "Bricks" that have to be "fixed in". Also, the possible alternate uses have been elaborated. Needless to say that runoff management in totality has to be linked to not only moisture conservation but also crop management to make it a viable technology for use on real farm situations.

RUNOFF MANAGEMENT ON SMALL AGRICULTURAL WATERSHEDS: THE ICRISAT EXPERIENCE

S.M. MIRANDA, P. PATHAK and K. L. SRIVASTAVA

The average annual rainfall in several parts of the semi-arid tropics would seem sufficient for one or, in some cases, two good crops per year. However, the rainfall patterns are erratic and extended droughts are frequent. Much of the rain occurs in high intensity storms often resulting in runoff and erosion even on relatively flat lands. There are cases when the storage capacity of the soil profile is exceeded; then percolation of water to deeper layers takes place. Thus this situation in which only a portion of the rainfall is available for crop use has resulted in unstable food production and continued low yield levels in much of the semi-arid tropics (SAT).

From the very outset water was consciously recognized by ICRISAT scientists as the major constraint to improved farming system in the SAT. Alleviation of the effect of this barrier, therefore, has been the central focus of the major activities of the Farming Systems Research Program. In the process, the watershed has been adopted as the basic unit in optimising the development, storage and utilization of water in improving every phase of the crop production system. This has led to efforts in developing systems of land and water management aimed at promoting the maximum *in situ* utilization and conservation of water, and reducing to a minimum the effects of high intensity rains or loss of soil by erosion and temporary waterlogging. Specifically, the following areas have received primary research attention.

1. The development of land management technology that would result in an improved moisture environment for crops control runoff and erosion and where necessary, increase infiltration of rainfall without causing drainage problems:
2. The development of a surface drainage technique that would result in a better growth environment for plants and improve the workability of the soil during the monsoon without resulting in undesirable runoff.

3. The development of a waterway system that would safely convey excess water from the land with minimum interference to agricultural operations, contributing to the overall productivity of the system of farming.
4. The development of alternative technologies for the use of available surface and groundwater on upland crops, resulting in increased benefits through stabilization of rainfed agriculture and by lengthening the growing season.
5. The development of a superior system for runoff collection and reutilization to increase the available water resource on a watershed basis

Clearly implied is the importance given to runoff management and control in the development of a more productive and dependable farming system for the farmers of the SAT.

Small Agricultural Watershed Approach

The small agricultural watershed approach involves an attempt to optimize the use of watershed precipitation through improved water, soil and crop management. Better utilization of water has been tried by one or more of the following methods (Kampen, 1979): (1) directly by improving infiltration into the soil and thus making more water available for plant use; (2) through drainage, collection, storage and reutilization of runoff; (3) by water recovery from wells after deep percolation beyond the root profile. At ICRISAT, initially six natural watersheds were developed for monitoring of the water balance and intensive data collection for different land and water management techniques. They represented a number of alternative land treatments from traditional field-banded rainy season and dry season cropping to double-cropped land which was smoothed and ridged before planting. Different furrow slopes were tried, i.e. 0.4, 0.8 and 1.0 percent. A "watershed-based" system of land and water management has evolved from these studies and is found potentially effective for vertisols. The land surface is formed into broadbeds and furrows of 150 cm amplitude and with a gradient of 0.4 to 0.8 percent along the bed and furrows. The furrows lead to waterways which, being grassed, safely conduct excess surface runoff into tanks and/or natural drainage channels. Velocity of runoff is controlled by the directions and slope of the bed and furrow system which act as "minibunds", preventing concentration in large overland flow. Since the bed and furrow system can be a semi-permanent land feature, it provides protection against soil erosion on a year-round basis and adequate drainage during prolonged rains. It also facilitates supplemental irrigation

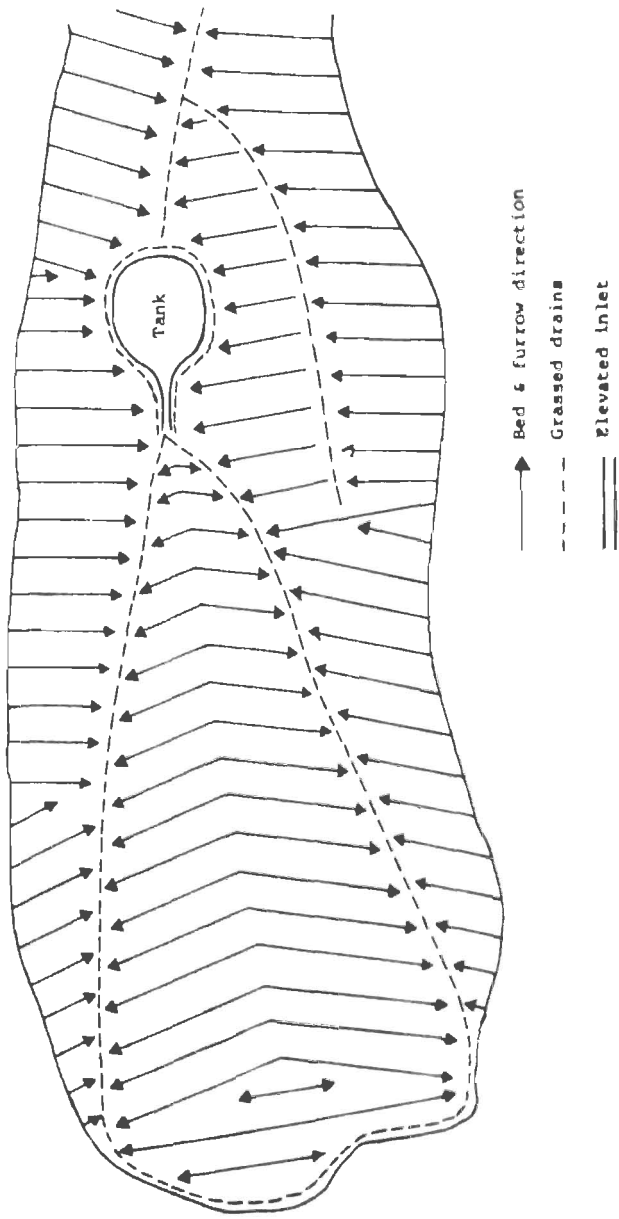


Fig. 1 : Small agricultural watershed with some of the key elements shown

when needed. Figure 1 shows a small watershed with graded broadbed and furrow system and with grassed waterways and a tank for storing runoff.

Results from 1976 to 1981 in small agricultural watersheds in vertisols at ICRISAT indicate that this system which has improved the management of land and water resources has also made possible double cropping of cereals and pulses.

Runoff Characteristics

Vertisols (black soils) and alfisols (red soils) which are two of the most abundant soils in the SAT are conveniently found in the ICRISAT Research Centre. Although they may occur in close association, their management requirements and runoff characteristics are very different. The most striking example is the fact that farmers crop alfisols during the rainy season and vertisols mostly only during post-rainy season. Runoff is observed to occur earlier on alfisols and later on vertisols. Their contrasting nature is attributed primarily to differences in types and amount of clay moisture holding capacity, workability and other associated characteristics.

Because of the differences in their clay mineralogy, vertisols tend to shrink and form cracks when dry while alfisols tend to form surface crust while drying after heavy rains. Their infiltration is greatly influenced by this behaviour. In spite of the low infiltration rates of vertisols, the water intake rate early in the monsoon is high due to the deep cracks and high water holding capacity. The cracks continue to exist as such until sufficient wetting occurs and then the infiltration decreases sharply. In contrast, the initially high infiltration rate of alfisols drops down quickly and often is greatly reduced during the early rainy season by surface sealing caused by the impact of rain drops on the bare soil.

It is becoming evident from results obtained from ICRISAT watersheds that a change in the land management and cropping systems on these two soils can influence their infiltration characteristics and consequently, their runoff generating properties. Data were gathered from two vertisol and two alfisol watersheds under two different land management treatments (traditional flat cultivation with bunds and broadbed and furrow system). Very little runoff is generated from vertisols and slightly more from alfisols under dry antecedent soil conditions. However, relatively greater runoff is produced from vertisols than alfisols under saturated conditions. There is little less runoff in the broadbed and furrow system in the vertisol watershed; the reverse is true for alfisols with the traditional flat cultivation with contour bunds producing less. The same

trend is shown in the average monthly runoff in Figure 2. It is likewise shown that greater runoff is generated in alfisols during the early part of the rainy season and in vertisols towards the middle of the monsoon season when the soils are already saturated. The mean seasonal runoff caused by various levels of seasonal rainfall (Figure 3) follows the general trend of the broadbed and furrow system reducing runoff in vertisol watersheds, and the opposite being observed in alfisol watersheds. From the foregoing, it is indicated clearly that the broadbed and furrow system provides scope for improving the management of runoff in vertisols. By reducing the runoff by one half, the soil is drastically decreased accordingly to about one sixth. Leads as to why this so for vertisols and the opposite is true for alfisols are being investigated.

In the broadbed and furrow systems, a separate raised bed cropping zone and a traffic zone on the furrow portion are created. The cropping zone remains loose and friable in vertisols. The traffic zone where the wheels and the bullocks pass becomes compacted in both soils. Compaction is normally associated with a decrease in infiltration rate. Rough exploratory measurements on furrows in alfisols confirm this: the infiltration rate is much lower on the furrow portion than the bed portion. This should also hold true for vertisols except that it is now observed that more compaction induces the formation of wider and deeper cracks on the furrows portion when the soils dry up. The resulting larger cracks on the furrows could be the reason for runoff occurring much later in the monsoon in vertisols under the broadbed and furrow system as compared with the traditional flat cultivation. In the case of alfisols, because of their non-expanding kaolinite clay, the furrows become more compact with the infiltration rate progressively decreasing which, in turn, probably induces more runoff to flow.

Water Harvesting Work

High storage efficiency was aimed at in designing the required storage tanks for runoff collection. Seepage and evaporation were two major water loss components that were considered. Also, considered was the possibility that seepage losses could be reduced through judicious selection of suitable sites and soils or through the application of appropriate sealants. Some circular designs were tried to reduce the wet surface area in relation to the quantity of water stored. Attempts to minimize the evaporation losses were made by making the tanks deeper within acceptable excavation to storage ratio. Table 1 and 2 present the tanks developed in vertisol, vertic inceptisols and alfisol watersheds, respectively, with some of the pertinent descriptive details.

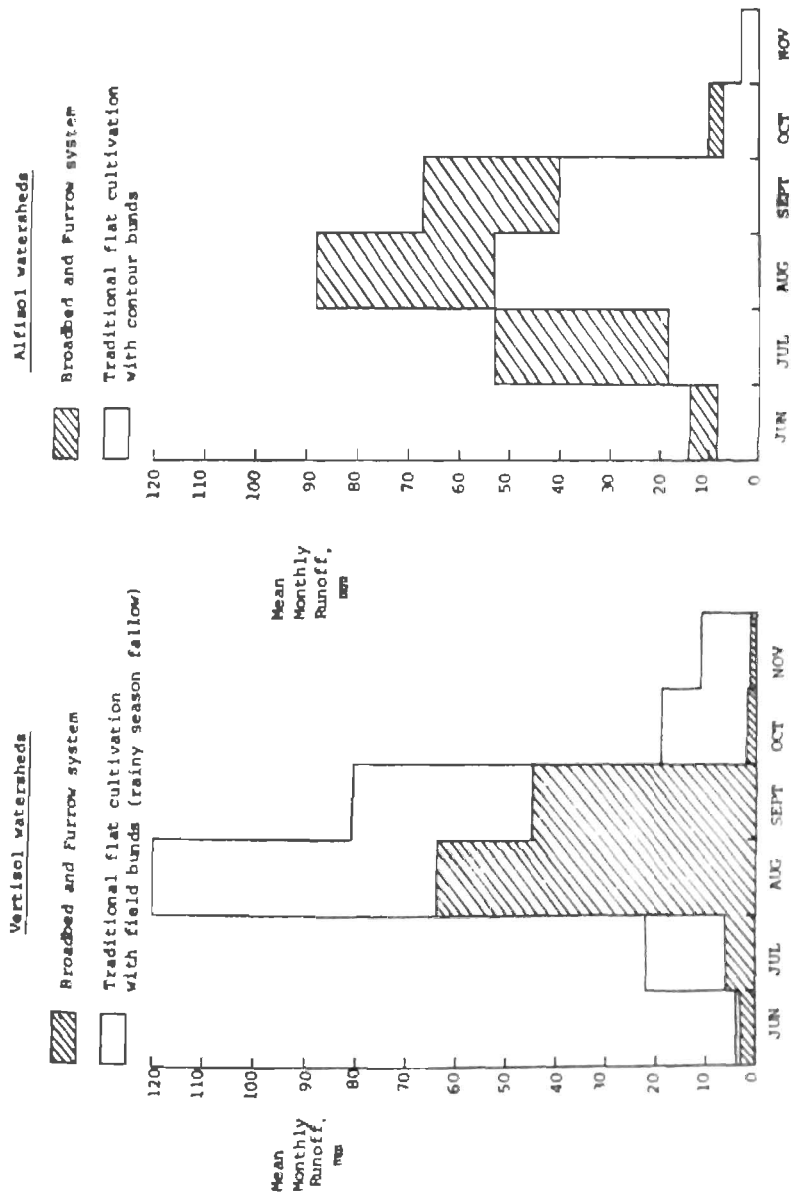


Fig. 2 : A comparison of monthly runoff generated by alfisol and vertisol watersheds under two different land treatments, 1975-1980

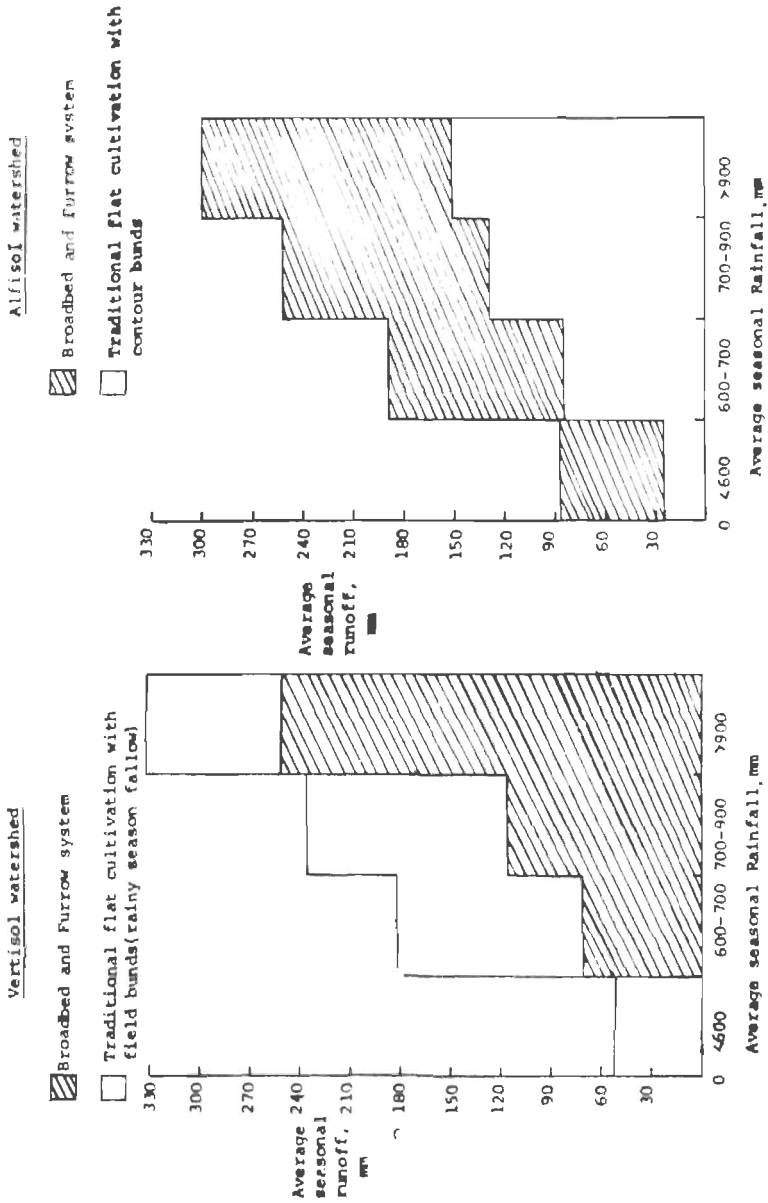


Fig. 3 : A comparison of average seasonal runoff generated by vertisol and alfisol watersheds under two different land treatments, 1975-80

An analysis done on the performance of the different collection tanks in meeting the demand for supplemental irrigation, particularly during extended rainless periods for both the rainy and post rainy seasons, revealed the following :

1. Deep dug type tanks in vertisols showed that in most years they can provide a minimum of 30 mm of supplemental irrigation water for the whole donor catchment area for post rainy season crops. Their relatively low seepage rate of less than 5 mm/day is ascribed to be mainly due to the low saturated hydraulic conductivity.
2. The performance of tanks located in vertic inceptisols was unsatisfactory. This is due to the high seepage rates of greater than 25 mm/day which is caused by the presence of permeable layers in the tank bed and also to low runoff potential of these soils because of their high infiltration rates.
3. Where the seepage rate was less than 15mm/day in tanks located in alfisols, it was found that collected water was available for one or two supplemental irrigation during the rainless periods of the monsoon season. However, when seepage rates become excessive which can be greater than 55mm/day water can be collected but can not be stored to meet supplemental irrigation on needs during the dry spells.
4. Lining materials like PVC were found not effective in controlling seepage because of their tendency to puncture when installed.

Life Saving Irrigation

Harvested water from the watershed that is stored in tanks is treated as a scarce commodity. It is used sparingly only for "life saving" irrigation at the most critical stages of crop growth or for extending the cropping season. In principle, alfisols which are drought in nature because, they have less water holding capacity but produce more runoff early in the monsoon season would benefit more from the application of water during the dry spells occurring during the monsoon. In vertisols which have higher water retention capacity and generate runoff more towards the latter part of the monsoon when the soil is already fully recharged or nearly saturated, collected runoff water can be put to better use in establishing a sequential post-rainy season crop or in irrigating the same crop at the most critical stage, such as at flowering.

Yields of sorghum and maize on alfisols were approximately doubled when 5cm of irrigation was applied during a 30 day drought in late August and early September, 1974. During the following year post-rainy sorghum in verti-

Table 1 : Tanks on Vertisol and Vertic inceptisol watersheds with pertinent descriptions

Tank	Type and shape of tank	Soils on catchment	Area under tank Ha	Capacity Ha-m	Catchment Area Ha
BW3A	Deep dug type rectangular	Vertisols	0.27	0.40	4.81
BW5A	Deep dug type, rectangular	Vertisols	0.19	0.42	6.41
BW5B	Shallow, trapezoidal	Vertisols	0.50	0.52	12.15 and spillover of BW5A tank
BW6	Shallow, rectangular	Vertisols	0.75	0.62	4.46 and spillover of BW5B and BW7 tanks
BW7A	Medium deep, circular	Vertisols	0.13	0.20	3.3
BW7B	Deep (with raised inlet system), circular	Vertic Inceptisols	0.20	0.225	2.87 and spillover of BW7B tank
BW7C	Medium deep, semicircular	Vertic Inceptisols	0.20	0.175	2.30
BW7D	Medium deep, Trapezoidal	Vertic Inceptisols	0.35	0.41	4.13 and spillover of BW7B and BW7C tanks
BW7F	Medium deep dug, semicircular	Vertic Inceptisols	0.05	0.05	0.73
BW8	Medium deep (with raised inlet system), circular	Vertic Inceptisols	0.4	0.48	13.72

Deep tank > 2m depth

Medium deep tank < 1m but > 2m depth

Shallow < 1m depth

sols responded to supplemental irrigation at the grain-filling stage with an increase in yield from 2,570 to 3,570 kg/ha. In the 1980-81 post-monsoon crop of chickpea, also in vertisols, the yield was increased from 817 to 1441 kg/ha with one irrigation at flowering stage.

Table 2: Tanks on Alfisol watershed with pertinent descriptions

Tank	Type & shape of tank	soils on catchment	Area under tank Ha	Capacity Ha-m	Catchment Area Ha
RW1	Deep dug, irregular	Medium deep Alfisols	0.26	0.29	3.55 Area outside of ICRISAT 8.00 Uncultivated area 7.00 Cultivated area <hr/> 18.55 (Total)
RW2A	Deep, dug, rectangular	Medium deep to shallow Alfisols	0.80	1.2	30.37 Areas outside of ICRISAT 4.90 cultivated area <hr/> 35.27 (Total)
RW3A	Deep tank, rectangular	Medium deep to shallow Alfisols	0.30	0.39	5.05
RW3B	Deep tank, rectangular	Medium deep to shallow Alfisols	0.39	0.51	3.8

Low Cost Tank Sealing Techniques

Since the success or failure of water harvesting was found to be related with the capacity to keep water in the tank, tank sealing studies were initiated to solve the the problem of high seepage rates. Early studies in small pits at ICRISAT showed asphalt to be promising in controlling seepage. Asphalt was applied at the rate of 4 l/m². The seepage reduction in alfisols varied from 97 per cent to 47 per cent when compared with the control (seepage rates for control varied from 24.7 to 50mm/day). The large variation in seepage reduction is indicative of how uncertain the effectiveness of asphalt was. In vertisols there was no significant reduction in seepage rates.

A seepage reduction of about 70 percent was obtained with a treatment of Na₂CO₃ + straw in vertisols. However, use of straw presented a problem after sometime because, with its decomposition, a porous structure of lining resulted. In another study, silt + Na₂CO₃ and clay + CaCl + CaCO₃ (20:5:1) were successful in cutting down seepage losses by 55 percent. But the cracking of lining remained the main problem in vertisols in addition to the necessity of reapplication of salts after 3-5 years.

Very recently, Maheshwari (1981) tried the use of soil dispersants, soil cement lining and improvement of soil gradation as the three basic methods to reduce seepage rates in alfisols and vertisols. He observed that soil cement lining was the most effective lining on alfisols. The seepage rate was as low as 8.2 l/m²/day, which meant a reduction in seepage of 97.2 percent. However, cracking was found to occur when the tank was emptied and the lining exposed to the sun increasing the seepage rates when the tank was refilled. The performance of different linings including those for vertisols are shown in Table 3. No satisfactory lining was obtained for vertisols.

Research Thrust in the Eighties

Looking back at our experience in the seventies certainly helps in looking ahead at the eighties in formulating our research thrust on runoff management. It is very clear that our approach to improved land and water management on alfisols needs reassessment. We shall, however, accelerate our efforts to operationally test the small agricultural watershed concept with the broadbed and furrow system on vertisol regions with similar rainfall patterns as Hyderabad. On the ICRISAT station, evaluation of the relative usefulness of small tanks in meeting the requirements of supplemental irrigation for various situations will be continued. With the help of some available rainfall-runoff models, soil

moisture models and hydrologic data, the probability of getting given quantities of water during the course of growing season, and tank failure at varying levels of seepage losses will be studied. We would like to join hands with colleagues in the national research system in seeking effective tank sealants and water lifting devices to meet the feasibility requirements of a complete runoff harvesting and recycling system. At the same time, we would like to invite all concerned and interested parties to collectively look for innovative improvements of runoff management in traditional tanks to bring these existing resources back to their usual rightful role in increasing and stabilizing production in Indian SAT farming.

Table 3 : Performance of different lining treatments in experimental tanks in alfisol and vertisol areas

Lining treatment	Bulk density of lining g/cc	Seepage rate 1/m ² /day	Seepage reduction (when compared with control) %
Alfisols			
1. Control (without any lining)	-	290	-
2. Red soil + coarse aggregate (1:1)	1.64	145	50
3. Red soil* (compacted)	1.62	115	60
4. Red soil + black soil (1:2)	1.73	27	90
5. Soil cement (10:1)	-	8	97
Vertisols			
1. Control (without any lining)	-	130	-
2. Black soil (compacted)	1.50	128	2
3. Black soil + Na ₂ CO ₃	1.47	87	33
4. Black soil + red soil	1.69	82	33

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ALTERNATE LAND USE
SYSTEMS FOR
DRYLANDS

ALTERNATE POSSIBILITIES FOR DRYLANDS

K. A. SHANKARNARAYAN

The major problems confronting the drylands may be considered under three broad heads, namely: a) Environmental constraint : such as low and erratic precipitation, frequent drought, intense radiation, high wind speed, and resulting erosion; poor soil conditions; limitation of water for human, livestock and irrigation; sparse vegetative cover, soil salinity and blackish ground water. b) Biotic: Pressure of human and animal population on marginal and submarginal lands; low plant productivity due to environmental, biotic pressures; damage due to insect and rodent pest. c) Socioeconomic : inadequate exposure or adoption to modern farming techniques and merits of conservation of natural resources, lack of alternate vocation other than cropping and animal husbandry, fragmentation of holdings, nomadism etc.

To such problem areas, King (1979) has ascribed the term "fragile" ecosystem because their equilibrium appears to be easily upset and because they become ecologically degraded if certain forms of landuse particularly sedentary agriculture are practised on them.

It has been estimated that 65 per cent of the land in the world lies in "fragile ecosystem" areas. The number of people who depend upon these areas for their food or livelihood is 35 per cent of the total population of the developing countries (King 1979).

Traditionally, the population living in these areas have coped with these extreme environment by practising forms of landuse that were extensive by being mobile and by being part of a social system that was based on economic interdependence. Today, the rapid increase in population and the introduction of inappropriate technologies have resulted in the removal of protective tree and shrubs for fuel and shelter and the cultivation of soil that are ill suited to arable agriculture. Moreover, many of intensive farming practices that have been attempted, although increasing in yield in the short run, have made the soils vulnerable to erosion and have indeed led to land degradation.

Agricultural Instability

Table 1 illustrates the ill-effect of existing land use in different rainfall zones and varying topography conditions. Such a situation logically calls for alternate land uses, if we are to avert degradation of the ecosystem to a entropy.

Table 1.: Ill effects of grain crop agriculture in different rainfall zones and topography in Rajasthan

Rainfall Zone (mm)	Topography	Existing land use	Location	Effects
Below 200	Sandy plain sand dune areas	Rainfed agriculture	North western Jaisalmer district (about 200 sq.km) in isolated pockets not exceeding 50-70 ha) around Miyajlar, Halaur and Narula surrounded by sand dunes, interdunal depression.	Menace of soil erosion and shifting of sand- Area is infested by active sand dunes.
200-300	Marginal dunny lands.	Formerly uncultivated but now under dry farming cultivation	Banayana Phalsund tract south of Pokran.	Soil erosion and formation of drifting sand and dunes.
300-400	Sand dunes and marginal lands	Base, upper and lower flanks cultivated	Eastern Nagpur and Churu district	Deposition and accumulation of fresh sands in adjoining fertile lands (eg. At Ghatwara in Nagaur district, on Aravallies along Sambha gap.

Contd. Table-1

Rainfall Zone (mm)	Topography	Existing land use	Location	Effects
300-400	Martinal lands and flat lands	Lift irrigation and irrigated farming	Lunkatansar area Bikaner district	Seepage problem in adjacent area in Churu district
300-400	Alluvial plain marginal land and sandy areas	Irrigated farming single to double cropped areas	Gang Canal and Rajasthan canal areas	Seepage problem water logging and rise of water table in canal command area
300-400	Alluvial plain marginal land and sandy areas	Irrigated farming single to double cropped area	Bhadra-Nohar area in Ganganagar	Increase of water logged areas and sandy hummocks Vertical increase of sands on sand dunes in Churu district towards south
400-500	Foot hills of Aravallis (upland) and riverine plains deserted river beds	Cultivation-double cropped (well-irrigated)	Pushkar-Govindgar tract	shifting of sands towards the east of Aravallis likely to spread and affect adjacent fertile lands

In the dryland ecosystem, conservation, as a policy for sustained yield should receive the primary of place in any program. Towards this end, five main principles involved are: 1 maintaining the integrity of the ecosystem 2. collaboration rather than confrontation with the ecosystem 3. careful timing of use 4. careful distribution of use and 5 matching of uses and resources. This would imply that comprehensive planning is necessary for maintaining the all important integrity of the ecosystem. Traditional land use strategies are often but not always, integrated with the ecosystem and their change may endanger even quite remote facts of the system. In this context the land capability assessment is a basic tenet of any conservation policy, but such a policy should be both dynamic and flexible.

Against this background, it follows that consideration of any form of land use should be preceded by an accurate assessment of the resources in dryland ecosystem, their extent and distribution so that these could be harnessed efficiently for productive exploitation towards total human welfare. This calls for undertaking multidisciplinary integrated surveys of natural resources such as land, climate, soil, water, vegetation and land use. The resource data so generated are further transformed to composite land units defined by land attributes, present land management and productivity and the scope for improvement including the pragmatic suggested treatments for realising these goals.

Thus, the proposed land utilisation map would be the consistent with the policy of conservation and would help to maintain the ecological equilibrium. Such maps while providing a clear picture of lands where limited cultivation can be undertaken also indicates which lands need to be considered for diversion for other alternate land uses.

Present Land Use

Table 2 gives data on the present land use in arid west Rajasthan for period 1976-1981. It will be observed that highest percentage of land (44%) is under single crop. The sandy waste (culturable waste) assumes quite a high percentage (24.5%) next only to cultivated area indicating prevalence of adverse climate environmental conditions. Subsistence farming more than anything else among local population, has been driving the force in maintaining such a high percentage of land use in cultivation although predominantly single cropped. The inter annual variation in land use studied from 1976 to 1981 did not show any perceptible change in land use. Crop yields in such regions are not only miserably low but highly uncertain. Notwithstanding this situation, the permanent pasture in addition to rocky and sandy waste etc. which can also be considered as grazing ground constitute about 42 per cent. The area is sizeable. In view of this situation even Nature seem to have distributed the best breed of

cattle (Tharpakar and Rathi) and sheep (Nail and Marwari) so that animal husbandry may be the most appropriate enterprise in this region. Therefore, lands, which cannot sustain cultivation must be adequately safeguarded by prescribing appropriate land use and needed practices.

Table 2: Present land use in arid Rajasthan (1976-77 to 1980-81)

Land use	Area (ha)	% of total
Forest	285683	1.7
Settlement and water features	685659	3.3
Rocky waste and stony waste	987579	4.7
Sandy waste (culturable waste)	5129338	24.6
Permanent pasture	846894	4.0
Orchards and plantations	28270	0.1
Cultivated lands		
Single cropped	9072278	43.7
Double cropped	805449	3.8
Long fallow	1542910	7.4
Short fallow	1393150	6.7
	20777210	100.0

Three Alternate Land Uses in Dryland Ecosystem

Consistent with the policy of conservation and desirability of preserving the integrity of the ecosystem, agro-forestry, pastoralism and tourism including wild life represent three alternate land uses depending upon land capability.

Agro-forestry: The concept of agro-forestry in fragile ecosystems envisages a sustainable land management system which increases the overall yield of the land, combines the production of crops and forest plants or animals simultaneously or sequentially on the same unit of land and applies the management practices that are compatible with the cultural practices of the local population (King 1968; 1979).

A study conducted on cultivation of greengram and clusterbean inter-row space of *Heloptelia integrifolia* tree (lopped and unlopped) at CAZRI, Jodhpur during 1977 revealed that maximum grain yield was obtained in greengram (252

Kg/ha) followed by clusterbean (244 Kg/ha) in lopped polt compared with control. Unlopped gave the lowest yield. Again in a drought year such as 1981, clusterbean when intercropped between rows of *Eucalyptus* species has yielded 101 Kg/ha compared with 125 Kg/ha in control. Further, preliminary trails of intercropping Guayule (*Parthenium argentatum*), an economic plant of industrial value, in between rows of *Eucalyptus* species have shown great promise for arid regions.

In a dryland ecosystem, agriculture alone would not be a stable system and has necessarily to seek the crop of forestry into the farming system in order to impart stability and generate assured income to the farmer. Agroforestry, however, seem to have the potential to compel a multiple land use management which eschew the false dichotomy between agriculture and forestry and at the same time conserve the ecosystem in order to provide both wood and food, fibre and fruit in an otherwise delicate ecosystem.

But more organised and systematic research is required to further improve and refine the system. The shade tolerance of various agricultural species require to be tested. Forest species which project the soil but do not reduce the energy levels on the under storey must be identified. Optimum spacing, thinning regimes to enhance yield of both tree and agricultural crops require to be evolved. Little is known of the allelopathy and complementary aspects of species. Above all, research is needed on breeding programmes designed to obtain in both forest tree species and crops those characteristics and attributes that the necessary for successful and efficient intercropping.

Pastoral Land Use : As shown by land use data in arid Rajasthan, although only 41 per cent of the area is under permanent pasture, more than 41 per cent of the area including the vast sandy and rocky waste is used as grazing ground i.e. a form of pastoral use. Besides the above, pasture development has considerable scope in the dominantly single cropped agriculture tract also. A number of studies by the CAZRI in this tract have shown that in a number of situations, lands of very low use capability, namely, dune flanks, piedmont slopes, shallow soils and so on are being ploughed. From consideration of resource conservation, such lands ought to be brought under a permanent cover. It is incredible but true that about 30 per cent of arid Rajasthan is affected dunes. Fortunately the arid region is richly endowed with highly adapted grasses, shrubs and trees which are capable of surviving through extended drought and yet are efficient producers of useful nutritious biomass during favourable interludes. *Cenchrus*, *Lasiurus* and *Panicum* among grasses, *Zizyphus* among shrubs and *Prosopis* and *Acacia* among trees are some of the most notable indigenous wealth.

Crop production alone in dryland system has given a negative economic return after pricing family labour. On the other hand, the benefit-cost ratios and net profit worked out at CAZRI for promising strains of *C. ciliaris*, *C. setigerus*,

L. indicus, and *antidotata* for the years 1971-74 appear encouraging. Table 3 shows that B-C ratio was greater than one and the highest (3.27 and 3.47) was for strains of *C. setigerus*, because of its inherent ability to withstand moisture stress as evidenced by highest green fodder of 160 q/ha during drought years of 1973-74. It has, therefore, been concluded that even without considering intangible benefits, the economics of growing grasses is attractive enough to commercial farmers, and to policy makers for the desirability of promoting grass-land farming in dryland areas.

The value of pasture enterprise for arid region is self evident when one considers the comparative performance of crops versus pasture in a year like 1981 which represents the third consecutive drought year. Whereas the pearl-millet crop, the staple cereal of this region, totally failed 1981, the pasture grasses have given a dry forage yield ranging from 1.5 to 3 tons per ha.

What is needed is systematic screening to exploit the full genetic potential of the native grasses for realising increased animal production. Screening trials at CAZRI during 1981 have shown that out of ten strains evaluated, Billoela strain of *C. ciliaris* yielded the highest dry matter (26.6 q/ha), followed by strain No 75 (22.5 q/ha) even in a drought year.

In *C. Setigerus*, the strain 76 has shown highest dry matter yield (18.9q/ha) surpassing the check 175, while in *Lasurus indicus*, the King of desert grasses, cultivar No 553 gave highest dry matter yield of 23.4 q/ha compared with 18.9 q/ha from the check 319 which was hitherto the standard recommended strain. Application of nitrogen to this grass gave a linear response and the dry matter yields increased as the level of nitrogen was raised from 0 to 45 kg/ha. For seed yielding characteristics, strain 358 (*C. ciliaris*) and strain 569 (*C. setigerus*) were the best.

The *in vitro* dry matter, digestibility (IVDMD), crude protein (CP) and digestible crude protein (DCP) of various indigenous grass and legumes show that all the three quality attributes have high values in preflowering stages but decline gradually through ripe and dead ripe stage. Surprisingly, *Indigofera cordifolia* shows highest IVDMD, CP and DCP even in the dead ripe stage. *Burchiaria ramosa* and *Aristide* species, though showing comparatively high IVDMD at dead ripe stage, showed lower CP and DCP compared with perennial grass *Lasurus indicus* and *Eleusina compressa* at corresponding stages. These data on quality attribute vis-a-vis stage of growth can easily be exploited for planning grazing schedule to derive maximum benefit for the livestock production.

The improved strains of grasses identified and developed thus represent non-cash inputs for increasing forage productivity in arid lands for bridging the

Table 3 : Benefit-cost ratios for different fodder grasses, Jodhpur 1971-74

Grasses	Strains	Total accumula- tion of benefits (returns)	Total accumula- tion of costs	B-C ratio	
				1970-73 prices (3-4)	1978-81 prices* at 10% discount
<i>Cenchrus ciliaris</i>	357	7223	4536	1.59	1.60
	358	6986	4536	1.54	1.56
<i>Cenchrus Setigerus</i>	175	14841	4536	3.27	3.30
	296	15718	4536	3.47	3.50
<i>Panicum antidotale</i>	340	4426	4536	0.97	0.98
	341	4280	4536	0.94	0.95
<i>Lasiurus sindicus</i>	317	6919	4536	1.53	1.53
	353	7159	4536	1.58	1.58

* Rs. 7/- per man day, Rs. 30/- per tractor hour, Rs. 10/- per kg of seed Rs. 100/- per ton of FYM, Rs. 1.5/- per kg of urea and Rs. 1.8/- kg of Superphosphate. Green forage is valued at Rs. 20/- quintal; seed is valued at Rs. 10/- per kg.

gap in demand and supply position. To make grass farming still more lucrative, intensive research is required for increasing the genetic potential of the grasses multidisciplinary efforts for such attributes as quality, digestibility, high dry matter yield, vigour and regeneration ability which are incorporated in the genotypes. Despite two decades of research a suitable legume component has not been identified for natural pastures for which research efforts are urgently necessary in the eighties. Studies on forage preservation like hay making and storage in good to very good rainfall years for use in drought periods needs critical examination in relation to livestock needs and thus prevent migration of live stock.

Tourism: Tourism as a means of exploiting and developing the potential of arid and semi-arid areas needs careful consideration. Such developments are embryonic in most desert areas. The wildlife flora and fauna of the arid region is a unique resource. They are worthy of receiving attention of wildlife conservationist, so that more and more desert national parks are developed which will attract the tourism industry. This will also directly help in preserving the endangered fauna and flora in the arid regions where it is critical. Sen and Shankar:narayan (1977) have already drawn attention to the prospects to develop tourism and its associated industries in the coastal desert of India.

The following aspects of desert have tourism potentials:

- I. Wildlife
- II. The unique environment of desert offer scope for detailed examination of certain aspects eg. wild food.
- iii. Health spas (tourist going to dry region for health reasons)

However, before embarking on this programme, it is essential to have a careful evaluation of the impact on residents of dry ecosystem and the relative benefit for them (eg. employment, investment opportunity, etc) in order to ensure that there is a substantial benefit to the local people. Tourism development calls for a good infrastructure including network of roads, transport, food services, health services and water supply.

Conclusion

The foregoing is not to deny crop farming its due place in dry ecosystem. All that is needed is to restrict its role in dry ecosystem to such areas strictly on the tenets of land capability leaving the remaining areas to the three alternate land uses: agro-forestry, pastoralism and tourism. The dryland areas are

potentially productive in their own rights in terms of equity and utility. All that is required is the integration of economics so that the development of the dry ecosystem should be an integrated operation with other ecological zones, not a mere rip off of minerals, people and animals. The aim should be to rediscover, at higher and more equitable levels of productivity, the old complements between dry regions and neighbouring ecological zones.

Acknowledgements

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ALTERNATE SYSTEMS FOR DRYLANDS

C.J. ITNAL and R. HAMPALAH

As a consequence of population explosion, more and more land has been brought under cultivation by indiscriminate felling of natural forests to meet the basic needs of mankind, food, fuel and fodder. Often times farmer can hardly get back his seed from the field he cultivates. This indiscriminate use has led to severe soil erosion problems, silting up of reservoirs and consequent occurrence of flash floods. So, the importance of utilizing land based on land use capability is evident.

In Indian agricultural production systems both fuel and fodder are becoming increasingly deficit. It is estimated that 100 million m³ of fuel wood will be in deficit by 1990. As an alternative to fuel wood, unfortunately valuable cowdung, which otherwise can be utilised as manure, is being diverted as fuel to an extent of 60-80 million tons of dried dung. In the case of animal feed, it is estimated to be two-thirds in deficit to feed 340 million livestock. The problem is more aggravated in drylands during summer and in traditionally drought and flood prone areas.

According to the National Commission on Agriculture Report 1976, only 23 per cent of the area in India is under forests as against 33.3 per cent as suggested in our Forest Policy Resolution to maintain the ecological balance and to combat the ever increasing problem of environmental pollution. The effect of enormous demands on already denuded and depleted or exhausted natural resources, especially in arid regions would mean further degradations unless their productive capacity were to be maintained through improved management and conservation measures. In order to achieve greater efficiency in utilising the resources in drylands, to combat 'energy crisis' and deficiency of animal feed, alternate land use systems for drylands are to be looked for. Major approaches in this direction are:

1. Putting the land (class iv and above) under suitable grasses, legumes and fodder crops and integrating with animal productivity systems (pasture and animal productivity systems).
2. Using the same land or a portion of it simultaneously or sequentially for food, fodder and fuel, paying due attention to interaction among various uses. This approach aims at obtaining sustained increase

in production and securing both immediate benefits and long term environmental harmony (agro-forestry systems).

Pasture-Animal Productivity system

These systems envisage putting the marginal lands under suitable legumes and grasses and integrate with animals like sheep, goat and milch cattle, for production of milk and mutton. These will give scope for efficient plant animal-human food chain systems unlike the plant-human food chain systems.

Studies on identification of suitable legumes and grasses for drylands were carried out at many locations. Different legume species from genera *Dolichos*, *Macroptilium*, *Leucaena*, *Clitoria*, *Desmodium*, *Centrosema*, *Glycine*, *Calopogon*, *Vigna*, *Tephrosia*, *Alysicarpus*, *Indigofera*, *Crotalaria*, *Cassia*, and *Stylosanthes* have been evaluated with or without grasses for their potential yields. In all locations, the only ideal legume which was found to be excellent in high yield persistency, nutritive value and palatability was *Stylosanthes* species, particularly *S. hamata* and *S. scabra*.

Different grasses from genera *Dichanthium*, *Cenchrus*, *Lasiurus*, *Chloris*, *Urochloa*, *Panicum*, *Pennisetum*, *Setaria*, *Chrysopogon*, *Paspalum*, *Digitaria*, *Heteropogon*, have been evaluated. Of these *Dichanthium*, *Urochloa*, *Lasiurus*, *Cenchrus ciliaris* and *Setaria nervosum* gave higher yields in all agroecological situations.

Besides providing continuous supply of nutritious fodder in drylands, pasture legumes help in restoration of soil fertility by adding nitrogen and organic matter. They provide congenial soil environment for microbial activity and help improving general soil health. Pasture legumes and grasses reduce runoff and soil loss. The investigations carried out at Hyderabad revealed that the runoff and soil losses from bare-fallow plot were the highest while these losses were minimum in case of grass plot having a good stand of *Cenchrus ciliaris*.

Agro-forestry Systems

Agro-forestry is one of the several types of integrated systems for combined use of natural resources of arid and semi-arid regions and capable of giving higher productivity on sustained basis. Agro-forestry is to be termed as an umbrella term which embraces (i) Agro-silviculture system (ii) Silvi-pastoral systems (iii) Agro-silvi pastoral systems (iv) multipurpose forest tree productive system. Agro-forestry systems, although aim at judicious land use for maximum productivity, give long term benefits such as improved soil fertility, soil and water conservation, providing protection to crops, dwelling and infrastructures, creating greater employment opportunity, rehabilitation of environment, protection of endangered wild life species and appreciation of natural resources.

For these systems to be more productive, the criteria are :

- a. Tree-crop grass/legume compatibility
- b. Tree density-crop/forag yield relationships
- c. Tree canopy characteristics and lopping practices
- d. Economics and other benefits from agro-forestry systems

Tree-crop/grass/legume compatibility : Selection of suitable tree species and compatible crop/legume/grass species based on growth criteria, palatability of fodder, soil type and rainfall characteristics is the first step in the management of agro-forestry systems. Criteria for selection of these species for agro-forestry systems are :

- multi-purpose which can give loppable fodder, fuel and timber
- adapt well in a wide range of environment, establish easily and require less care
- rapid growth, ability to coppice, vertical crown canopy and preferably nitrogen fixing ability
- plants for problem environments such as arid zones, saline and alkali soils, steep hill slopes, ravines etc.

Work done at Hyderabad on the effect of association of field crops and multi-purpose leguminous tree *Leucaena leucocephala* revealed that the yields of crops like pearl millet, castor and sorghum, increased in association with *Leucaena* as compared to the yields of same crops grown pure. Similar complementary effects of the tree species on associated field crops were also reported by Mishra and Prasad (1980).

Experiments conducted at Hyderabad revealed that out of 44 *Eucalyptus* varieties tried, *E. camandulensis* proved more suitable and out of 12 *Acacia* species evaluated, *A. auriculiformis* and *A. nilotica* were found to be promising. Studies initiated at Bellary in the black soils under rainfed conditions to assess the potential of growing grasses with *A. nilotica* revealed that *C. ciliaris* recorded the highest average yield followed by *Dichanthum annulatum* and *Chloris bournii*.

Experiments at Bijapur in deep black soils with *Leucaena*, *Sesbania* and grass *Pennisetum massium* planted at 4, 8 and 12 m apart and growing winter sorghum between the strips showed that moisture content near the strip was higher but the winter sorghum rows nearer the strips got affected due to the roots of the tree and grass species. It is therefore, considered that a small

trench may have to be provided to reduce the root effect on winter sorghum. Crops like safflower, chickpea and other pulse crops can also be grown in association with *Leucaena* and *Sesbania grandiflora*. An understanding of the yield relationship between tree density and crop/forage is essential. The regulation of tree/shrub canopy either by spacing or coppicing affects the growth and production of crops/grasses. To make the agro-forestry systems more productive, it is necessary to manage the canopy of the components. Studies on the effect of canopy cover of different tree species on the air-dry forage yields of ground flora revealed that there was a progressive reduction in total forage yield with increase in canopy cover. At Hyderabad, it was found more economical to grow *Eucalyptus* at a spacing of 2 x 2 m and grass below.

Tree canopy brings about considerable change in microclimate in respect of relative humidity and temperature. Ecological and soil chemical and physical characteristics undergo changes (Aggarwal *et al* 1976). Singh and Lal (1969) reported comparatively higher status of organic matter, total nitrogen, available phosphorus and soluble calcium and better soil physical conditions upto 120 cm depth under *Prosopis cineraria*.

Agri-horticultural systems are similar to agroforestry. The trees also yield fruits in addition to fuel wood. *Zizyphus species*, *Psidium guava*, *Mangifera indica*, *Tamarindus indica*, *Embllica officinalis* etc can be integrated with crops, legumes and grasses.

Future lines of Research

The following are future approaches which need attention for proper resource utilisation :

1. Identification of suitable trees/shrubs and crop and their combinations for the formulation of efficient agro-forestry system.
2. Rational proportion of tree cover to crop cover in various agro-climatic regions.
3. Exploring the possibilities of tree canopy manipulation through balanced goat grazing.
4. Introduction and evaluation of indigenous and exotic tree, shrub and grass species for agro-forestry system.
5. Evaluation of agro-forestry systems not only in terms of dry matter production but also in terms of solar energy capture efficiency.
6. Integration of these systems for an efficient plant-animal-human food chain.

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EFFICIENT USE OF
ENVIRONMENT

EFFICIENT USE OF ENVIRONMENT

V. V. DHRUVA NARAYANA

Man's involvement in the use of environment, often resembles that of an over-successful parasite which in killing its host, also reaches its own point of no return. The quality of our environment is determined by the intricate manner in which we utilise our water, food, land and air resources. The changes produced in the quality and quantity of these four essential elements directly affect our health, comfort, aesthetic senses and efficiency.

In our anxiety to follow the way of the increasingly consumer oriented civilisation, we are destroying our environment even though we have immense knowledge about the fate of the previous civilisations in our documented history. We are, therefore seeing today that our demands on our environment are reaching their peak when our supply is nearing its extinction. In people's mind, yesterday's luxury is becoming today's necessity. This is a frightening proposition. The previous civilisations have left a legacy of outstanding intellectual and cultural excellence and yet starved the majority of our people because they could not sustain their agriculture leaving eroded and barren lands as permanent monuments that contrast with their art and poetry.

Recent advances in space exploration have confirmed that we will have to rely only on mother earth for our increasing requirements of food and water. Productive capacity of land and water must, therefore, be improved. Several rivers of sorrow must be converted into streams of wealth. The genetic resources of plants and animals must be conserved and utilised in a co-operative manner. The march of destruction of the biological potential of land can be arrested in many cases through regional and international co-operation. Arrangements for global and regional weather watch must be made to minimise the damage to crops by whether fluctuations, pests and pathogens. These are the steps which we must take to efficiently utilise our environment.

Actual implementation of these steps will require greater risk taking with our nature, cultivating and harvesting every piece of land that is available including planting the steeper hill slopes after denuding them. Extra food can also be produced through enhanced utilisation of fertilisers and selective weed killers and so on. All these actions may have potentially dangerous prospects because these are bound to interfere with nature and it is also known that nature will resist and retaliate against any undue abuse of the natural laws. Of all the

resources we are taking in these efforts, the fertile soil is the most precious resource. It takes thousands of years to create or to regenerate the lost soil.

All the countries of the world, therefore, met at a recent FAO conference in Rome and have decided to declare a World Soil Charter to highlight the problems of land degradation and to sensitize the decision makers and land users to the imperative need to maintain and improve the production base for agriculture, rangeland and forestry for the generations to come. It was decided to take better care of the land resources and highlight the need for maintaining and improving its productivity for the survival of the mankind. The principles contained in the charter and the related actions were excellent guidelines for promoting the effective management, conservation and reclamation of lands and for combating desertification.

When we are determined to implement these principles, we are accepting an immense challenge of creating decent living conditions in our rural areas, bridging the large gulf between haphazardly growing and congested urban areas and ravaged rural environments, and bringing social justice and equity to the poor at present living under pitiable conditions. This symbolises the measure of our resolve to efficiently utilise our environment.

Land Use

The total land use picture of our country is presented below :

Urban and other non-agricultural uses	18 M ha
Barren and uncultivated lands	21 M ha
Culturable wastes	17 M ha
Fallow conditions	23 M ha
Forests and permanent pastures	83 M ha
Agricultural lands	143 M ha

Although 40 M ha (culturable wastes and fallow lands) are capable of production by definition, they are lying unproductive, because of the degradation they may have suffered over the years. It is also known that only about 35 M ha out of the 83 M ha described as forests and permanent pastures, are having some good tree and grass cover and the remaining area of 48 M ha is, more or less, completely denuded. In other words, nearly 88 M ha, constituting approximately one third of the total relevant area is completely unproductive.

Further, nearly three-fifths of our agricultural lands are degraded to a greater or lesser degree and producing practically nothing. The National commission on Floods has also brought out a fact that around 40 M ha of valuable

agricultural lands are now devastated by floods as against 25 M ha above 30 years ago. Waterlogging and salinity is a serious hazard in many of the newly created irrigation command areas.

Soil Erosion

It has been estimated that out of our total land area of 320 M ha about 175 M ha are in need of soil conservation measures. Since 1951, we have been able to adopt soil conservation measures only in 25 M ha. It has also been estimated that about 6000 M tons of soils are displaced through erosion every year from about 80 M ha of the cultivated lands. Along with this, nearly 8.4 M tons of valuable nutrients are also being washed away every year from our agricultural lands. This shows that our record in the field of adopting soil and water conservation practices, which are essential means of improving our environment, has rather been slow. This is apparent now only from the visual evidence of the decline in the quality of our environment in the form of denuded hill sides, ravines, waterlogged and saline lands, droughtstricken villages and drying wells encountered in almost every part of the country, but also from the desperate shortages we are facing in respect of food, fibre, fuel, timber, animal products and indeed everything we can obtain from our lands.

The most serious soil erosion problem in our country is in the form of sheet erosion (Fig. 1), which is one of the serious constraints in agricultural production programmes in red soils, covering an area of 72 M ha. The depth of these soils is, in many parts, around 20 cm. The lateritic soils, which are associated with rolling or undulating topography, also suffer from this form of erosion because they are located in the regions of relatively higher rainfall. Due to high intensity rain storms, these soils are estimated to lose annually about 40 t/ha of valuable top soil, particularly in the absence of any soil conservation measures. The black soils occupying nearly 64 M ha are usually utilised for crop production under rainfed conditions. Surprisingly, these lands are normally cultivated and kept fallow during the intense rainy season, thus making them prone to serious hazards of water erosion.

The most spectacular erosion is observed in the form of badly eroded gullied lands (ravines) along the banks of Yamuna, Chambal, Mahi and other west-flowing rivers in Gujarat (Fig.2). Nearly 4 M ha of such lands are engulfed by shallow, medium and deep gullies (Tejwani and Narayana 1961). The Himalayan regions are in highly deteriorated conditions, through intensive deforestation, large-scale road construction, mining and cultivation on steep slopes. About 3 M ha are under serious soil erosion in the North-Eastern Himalayas. Due to the practices and hazards, our major river basins experience recurring floods of high magnitudes with very high sediment loads.



Fig. 1 Sheet Erosion in Black Soils

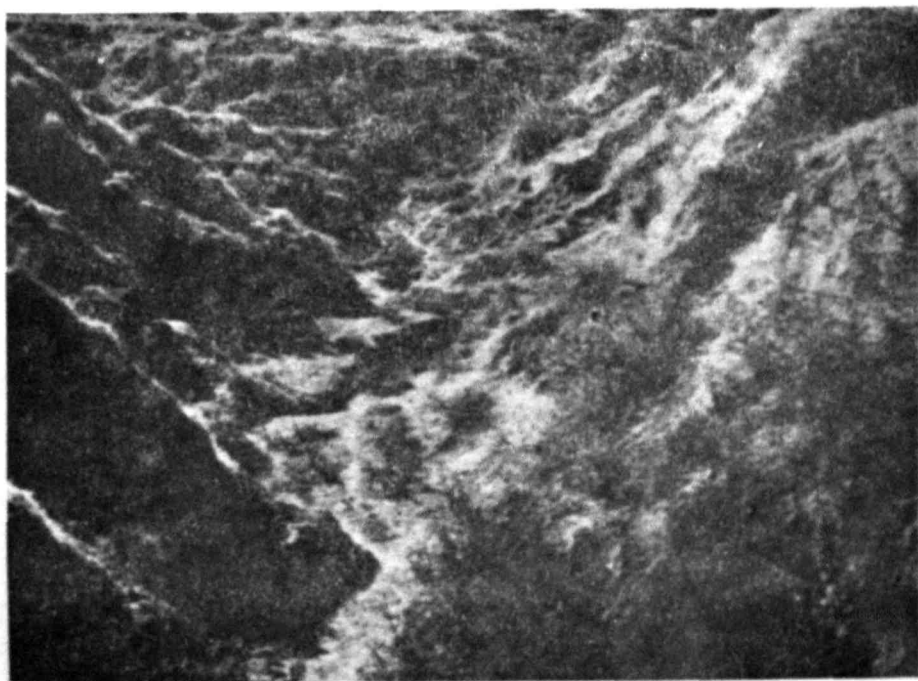


Fig. 2 Ravine areas

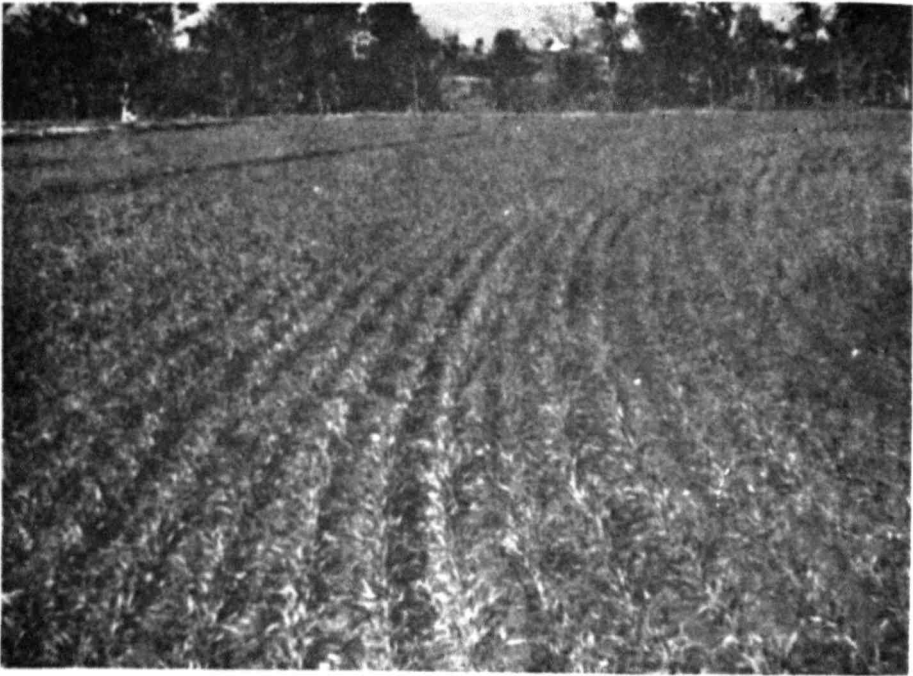


Fig. 3 Contour farming



Fig. 4 Bunding for moisture conservation and erosion control

Soil and Water Conservation Research

Soil and water conservation measures are the necessary steps to utilise our environment very efficiently. Soil and Water Conservation work has been taken up in our country since 1951. Upto the end of the Fifth Five Year Plan, our country has invested nearly 5000 millions of rupees to treat about 22 M ha of the land with soil and water conservation measures. In the earliest phases, these programmes were mainly confined to the improvement of the lands and principal activity was execution of contour bunding programmes. However, during the last two Plans, the concepts of integrated land use programme on watershed basis were introduced. This was mainly the result of the establishment of a chain of Soil Conservation Research Demonstration and Training Centres during the first and the early second Five Year Plan for conducting research on various aspects of soil and water conservation in the different problem regions. We have now many organisations like All India Co-ordinated Dryland Research Project, the International Crops Research Institute for Semi-arid Tropics, the ICAR Complex for the North-Eastern Region, the National Bureau of Soil Survey and Land Use Planning, the Central Arid Zone Research Institute and the last but not the least, the Central Soil Salinity Research Institute, which are trying to provide solutions to the problems of our land resources. There are equal number of organisations which are concerned with devising ways and means of efficiently utilising our environment. These Centres, during the last 25 years, have identified the soil and water conservation problems of the country and produced some viable methodologies for field application.

Soil and Water Conservation Technology

Rational utilisation of our soil and water resources essentially means proper land utilisation, protecting the land from deterioration, building and maintaining soil fertility, conserving water for farm use, provision of proper drainage facilities, flood protection and erosion control.

The soil and water conservation practices for agricultural lands include

1. Contour farming (Fig. 3), broad beds and furrow systems on lands having slopes upto 3 per cent.
2. Mechanical measures such as bunding (Fig. 4) graded bunding and contour ditching in areas with slopes between three and six per cent : bench terracing on lands and hill slopes ranging between 6 to 33 per cent.
3. Runoff harvesting in cropped land and in storage ponds and recycling them to crops when needed.

These measures have shown to reduce runoff and soil losses considerably and correspondingly increase the crop yields by conserving soil moisture and nutrients. Contour bunding can be adopted generally in almost all the soils except perhaps in deep black soils. Graded bunds and contour ditches are found to be more effective in deep black soil regions of Karnataka. Bench terraces are recommended for relatively steep lands (6-33 per cent slopes).

The non-agricultural lands (land capability classes V, VI, VII and VIII) have limitations of slope erosion, stoniness, shallow soils, wetness, flooding etc. The research work done at our Institute and Regional Centres have shown that these lands can be put to productive use as pastures and forest lands by adopting the following steps :

1. Closure of the area to grazing and biotic interference : Poor annual grass species are replaced by valuable perennial grasses. These ecological changes bring in a chain of favourable responses in reducing runoff and soil losses, and increasing grass yields.
2. Fuel-fodder plantations: By adopting modern agroforestry techniques, it is possible to raise jointly fodder and fuel species of economic values.

Ravine areas have small, medium and deep gullies (Tejwani and Narayana 1961). The small and shallow gullies can be reclaimed to agriculture by clearing, minor levelling and putting up a series of bunds with appropriate drainage escapes. The medium gullies can be reclaimed by constructing check dams along the gully beds and terracing the sides. The deep gullies are utilised for raising fuel and fodder plantations.

Salt-affected soils comprise alkali soils, coastal saline soils and inland saline soils. Alkali soils are reclaimed by application of gypsum, adoption of three-tier system of drainage and good agronomic practices with rice and wheat rotation. These soils can also be put to fuel fodder plantations with proper rain water management, adoption of suitable species and planting techniques.

Soil Conservation Extension

Watershed management has an important role in this endeavour. It can be defined as the control of water transfer from the upper catchment to the lower portions of a basin or watershed. Naturally, various management practices in the upper catchment of a river basin will have a control on the flood magnitudes, the sediment load it carries and its dry season flow. Thus, the practices in the upper catchment, will have serious consequences for the management of the arable lands in the lower reaches of the river basin. Most of our rivers originate in the high lands where rainfall is generally in excess. They run through the regions where the rainfall is less than the potential evapo-transpiration

for most of the year and this limits the agricultural productivity in these regions for lack of water in the entire growing season. Agricultural productivity of the lower areas can, therefore, be raised by using some of the surplus water from the upper areas.

The solution lies in the development of new or improved methods of land uses that are profitable to the local community as well as give a better control of the flow regime in the watershed. In principle, it may not be difficult to get some of these practices adopted by the people if they are able to produce such commodities or products which have greater demand and can be exported from the region. What is required in such a case is an efficient technical man-power and necessary administrative policies. However, if the local population is living at a subsistence or semi-subsistence level, it will be difficult to implement new and more conservative systems involving increased inputs of labour and finance because they may not be sufficiently profitable in the immediate future.

Such methods, can, therefore be adopted if only the institutional finances can be brought into the area in the forms of subsidies and grants in kind. In general, the farmers in the upper reaches of a watershed do not accept the responsibility for any damage their system of land use may cause to the farmers in the lower reaches. Also the lower reach farmers have rarely considered that they have a duty to help finance the upper reach farmers to adopt better systems of land use for their benefit. An exception to this general approach has been the work done by the Chandigarh Centre of Central Soil and Water Conservation Research and Training Institute at Sukhomajri and Nada (Haryana State) where organisational infrastructure has been developed so that the benefits as well as the expenditure of an improved soil and water conservation programme have been shared on an equitable basis both by the upper and lower catchment farmers in a micro watershed. There is, therefore, a need for more of such demonstrations in all parts of our country.

Conclusion

It is generally accepted that in order to deal with environmental problems, appropriate education of the scientists, field workers and the masses is essential and indispensable. Soil and water conservation education must, however, be practical in nature and demonstrate, at operational level, how soil conservation could sustain the community, generate the employment and create health, wealth and welfare for the people. It will have to be such that it lays emphasis on adopting the natural parameters to improve our environment. What we must do is to study these natural laws intently hoping to emulate the ability of nature to sustain and improve a natural process. Patience is required and one must think of the long-term effects of whatever we do. So, apart from the

scientific aspects, there is a need for incorporating judiciously the elements of institution, sensitivity and experience for arriving at a degree of compromise with our environment and nature in our action programmes.

The sources of energy which we usually talk about are the Sun, the sea, the bullocks, the woods, the wind, the water that flows and the manure that gives us life. The other source of energy, perhaps the most important one, renewable and precious, the one that grows with a little warmth, that multiplies just by joining forces and that does wonders with motivation is the energy and devotion of the people, the human resources, ours and that of all those with whom we work (Dudal, 1981).

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EFFICIENT USE OF POWER
IN DRYLANDS

POWER REQUIREMENTS IN DRYLANDS

D. S. RAJPUT

Power is defined as rate of doing work. It is an essential requirement for doing any farm job. It makes the application of farm inputs possible in a desired manner with the help of farm tools, implements and machinery. The experience of both developed and developing countries has been that there is a definite and positive relation between farm power availability and farm productivity. A study on the relationship between the yield and power per ha lead to the conclusion that more power is required to get higher levels of agricultural production in the USA (Table 1). But in India the available power with the farmers of drylands is low. Also the requirement of food is increasing due to increasing population. In order to produce more from the drylands with limited power available, it becomes very important to make the efficient use of power so as to increase the productivity of these lands.

Table 1 : Relationship between crop yields and power (Science Advisory Committee 1967)

Power (hp)	Yield (t/ha)	Yield to hp ratio
0.13	0.8	6.2
0.16	1.0	6.3
0.26	1.5	6.3
0.37	2.0	5.4
0.53	2.5	4.7
0.87	3.0	3.4
1.37	4.0	2.9
1.74	5.0	2.9
2.05	6.0	2.9

In dryland agriculture, tillage, seeding, fertilising, interculture and plant protection are the five major farm operations which require good attention of the

farmers to perform them timely. Any delay in the operations due to limited power, non-availability of suitable implements or aberrant weather conditions causes reduction in crop yields. Rain is the only source of water in drylands; progress of the farm operations is largely dependent on the rainfall. Rainfall being very erratic in nature and unpredictable, the amount of time available for carrying out the farm operations is uncertain and limited.

In this paper, an attempt has been made to briefly review the status of farm power available for dryland agriculture and also cover some important aspects related to efficient use of power in drylands. As 86.5 per cent land holdings in India are less than 5 ha (ISAE 1978) and farmers of this category have mainly bullock power, discussion in this paper are limited to cover human and animal power only. Area operated by these holdings is 48.2 per cent of the total cultivated area.

Status of Farm Power in Drylands

In Indian Agriculture, human, animal, mechanical (tractors, power tillers, and diesel engines) and electrical (electric motors) are the major sources of farm power. Due to several reasons, use of mechanical and electrical power is mostly confined to irrigated lands and farmers with large holdings. In some areas their use is increasing in drylands also.

Average farm power in the country from all sources was 0.35 hp/ha in 1971 (Table 2). In drylands, most of the farmers use human and bullock power and the average power available for these lands is nearly 0.22 hp/ha. This is very low considering the heavy demand of power in short periods to complete critical farm operations in the limited time available due to their dependence on rainfall.

Table 2 : Farm power availability on Indian Farms in 1971 (Ministry of Agriculture and Irrigation, 1976)

Source of power	Number available (million)	hp/ha	Percentage contribution
Human labour	87.40	0.04	11.6
Draft animals	63.30	0.18	50.8
Irrigation pumps	2.41	0.11	31.6
Tractors and power tillers	0.07	0.01	3.8
Other machinery	0.34	0.01	2.2
Total		0.35	100.0

It may be seen in Table 1 that the rate of increase in yield per ha shows a gradual decline and attains a constancy beyond 0.87 hp. It has been concluded in the study that the power range for satisfactory yields should lie between 0.5 and 0.8 hp/ha. However, it is considered that besides dependence of crop yields on power, there are many other factors which influence the productivity of the land. Therefore, there appears to be a good scope for substantially increasing the crop yields without increasing the level of power. And, improved tools and implements and cultivation practices can play a very vital role in achieving the target. Low power availability may considerably delay a farm operation. This could be overcome either by employing more power or by using improved and wide width implements.

Work Capacity

Work capacity of both human and animal power is limited. On an average, a man can do the work at a rate of 0.075 kWh (64 kcal/h) whereas a pair of bullocks can do as much as 0.75 kWh (642 kcal/h). The average force a man can exert is equal to about one tenth of his own weight. Similarly, a bullock can also exert an average force equal to one tenth of its own weight. For short periods, they can develop four times more power than average values (Hopfen 1969).

In terms of physical output, the amount of work done by the power units will depend upon the type of tool, implement or machinery engaged to carry out a given operation as also the prevailing soil moisture and weather conditions. *The approaches and concepts for efficient use of power in drylands* is discussed below.

Tillage

All tillage operations should be carried out at optimum soil moisture condition when resistance to tillage tools is low resulting in lower draft and power requirement. For example, black soils of Bhopal region are worked better at about 23 per cent soil moisture. At higher as well as at lower moisture, workability of the soil is very poor. At higher moisture, it sticks to the soil working/engaging tools and at lower moisture, clods are formed and need more number of passes to bring the soil tilth to the desired level. It has been observed that at 23 per cent surface soil moisture, one mould board ploughing and two harrowings only are required to achieve clod size of 6 to 8 mm mean diameter whereas at 18 to 19 per cent soil moisture one mould board ploughing plus 2 to 4 disc harrowing plus 2 to 6 harrowing are required to achieve the same degree of tillage. It may therefore be observed that, it is desirable to perform all tillage operations at optimum soil moisture to make efficient use of power in the black soils. However, in dryland agriculture soil moisture varies

with occurrence of rains and optimum soil moisture conditions are available for a very limited time. In view of this, use of improved and higher capacity implements will be required to cover more area in the limited time available and make the best and efficient use of the available power.

Depth of tillage and number of tillings have been found to significantly affect the total energy requirement. Minimum should be done to keep the total energy requirement minimum without reducing the crop yields. Studies on effect of depth of tillage and number of tilling on yield and total energy requirement of dryland crops are required for optimization of depth and amount of tillage necessary to achieve an optimum level of production and minimum energy requirement.

Development of minimum tillage practice for dryland crops may be rewarding, as there is limitation of power. It will help in completing different operations (tillage, seeding and fertilising) timely.

Sowing of crops in line helps in efficient management of the crops. Weed control in broadcast crops is difficult. In such fields, weeds are removed with manual labour once only. Due to this, the weeding is not effective and the operation gets delayed resulting in non-timeliness and loss of yield. In line sown crops, this problem does not arise as manual weeders and bullock drawn implements can be used to control the weeds effectively and timely.

Improved Tools and Implements

The country yoke commonly used by small and marginal farmers results in very low harnessing of bullock power. The use of improved harness would result in higher speed of operation of a given implement and thereby increases area covered in a given time ensuring timeliness of operation. Improved *bakhar* blade developed at Central Institute of Agricultural Engineering (CIAE) gave higher field capacity and field efficiency and lower unit draft in comparison to local straight blades (Table 3). It thereby improved the power use efficiency in blade harrowing.

Table 3 : Effect of shape of *bakhar* blade on its performance (CIAE 1980).

Parameter	Shapes of <i>bakhar</i>	
	V 120°	Local
Field capacity (ha/day)	0.547	0.434
Field efficiency (%)	62.620	54.460
Unit draft (kg/cm ²)	02.71	0.310

Improved harrow (tilting hook type) developed at CIAE gives higher field capacity, and lower draft than that with fixed hook. The improved harrow gives therefore higher power use efficiency than the fixed hook *patela*. Many other implements have been evaluated for their performance at a number of locations. Use of the improved implements have increased the working efficiency of man and

Table 4 : Field capacity of man and animal with local and improved implements in red lateritic soils (Singh 1980).

Power source	Operation	Tool/implement	Field capacity ha/hr
Human	Interculturing of wheat crop	a. Hand hoe	0.0067
		b. Wheel hoe	0.0287
Pair of bullocks	Ploughing	a. Indigenous plough	0.0254
		b. M. B. Plough	0.0500
Pair of bullocks	Sowing of wheat	a. Indigenous plough	0.0495
		b. Three-row seeddrill	0.1277

bullock power (Table 4). The working capacity of man increased with use of wheel hoe for interculturing wheat crop. The bullocks gave more output of work with a mould board plough and three-row seed drill in comparison to an indigenous plough and sowing with an indigenous plough. Similar trend may be seen in Table 5 also where working efficiency of bullocks was observed higher with improved implements than with local implements. It becomes amply clear that the use of improved tools and implements can considerably improve the working efficiency of man and bullock power which are the only source of power in drylands.

Table 5 : Effect of use of improved implements on grain yield, human and total energy requirement for paddy and wheat crops under red lateritic soil (Singh 1980)

Energy Treatment	Paddy Crop			Wheat crop		
	Grain yield q/ha	Human energy kWh/ha	Total energy kWh/ha	Grain yield q/ha	Human energy kWh/ha	Total energy kWh/ha
1973-74						
a. Bullock with local implement	25.2	142.1	500.0	17.5	77.7	631.1
b. Bullock with improved implement	26.2	98.2	366.7	19.0	48.4	560.1
1974-75						
a. Bullock with local implement	26.3	135.8	489.6	15.4	74.7	446.9
b. Bullock with improved implement	29.5	101.2	392.1	17.0	45.7	348.9

Improved Cultivation Practice

Cultivation practices like wide row cultivation, year round tillage, set row cultivation, till planting and many others have been found to improve the working efficiency of animal power as it either covers more area in a given time or distributes work over an extended period. Adoption of such practices would help in increasing the power use efficiency.

Matching Implements

Use of matching size implements will improve the power use efficiency of the available power. It is seen that in some areas single row seeding device is used with a pair of bullocks whereas in other areas three to five row seed drills are used. Use of matching implements is therefore necessary for proper and efficient management of draft power.

Multipurpose Implements

Multipurpose implements permit farmers to carry out their basic operations of tillage, planting, fertilisation and weeding in a timely and precise manner to increase productivity. These implements available now in India have a wider coverage than the local implements. This is an important feature of these machines. Growing of crops with such implements adopts systems approach which helps in efficient management of crops as well as other resources with a pair of bullocks.

Crop Planning

Proper crop planning for year round and uniform use of available power will help in improving the timeliness of farm operations due to distribution of work. Some crops need to be sown earlier than others. Therefore, by proper selection of crops, an uniform demand of power could be achieved. It would then be possible to manage more land area timely with the same power resulting in improved power efficiency.

Conclusion

Available power on drylands is limited to about 0.22 hp/ha only. Although, productivity of land depends upon a large number of factors, the available power considerably influences the timeliness of operations and thereby the land productivity. Production of more food therefore requires more power. This could be achieved by introducing more mechanical power. However, this may not happen in near future due to high cost of fossil fuel and machinery and poor purchasing capacity of dryland farmers. In order to produce more from the drylands with the available power, adoption of simple and improved manual as well as bullock drawn implements and cultivation practices is necessary. A number of improved tools/implements and practices have been evolved in the country to meet the requirement of different regions and category of farmers. These may be adopted for efficient use of power in drylands for increasing the timeliness of operations and thereby the productivity of drylands.

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THE EFFICIENT USE OF POWER IN DRYLAND AGRICULTURE

G. E. THIERSTEIN

"The men and women of rural India are tied to poverty and misery because they use too little energy and use it inefficiently, and nearly all the use is secured by their own physical efforts. The transformation of rural Indian society could be brought about by increasing the quantity and improving the technology of energy use" (Revelle 1976). Considerable attention is being given to mechanization as one of the technologies that probably needs major changes in order to benefit the small farmer practicing dryland agriculture in developing countries. In this paper, mechanization is used in its broadest context to include the utilisation of machinery whether powered by human labour, animal draft, or mechanical means. Hall (1973) states that meaningful agricultural mechanization may effect land productivity and/or labour productivity. It is now being recognised more widely that machines and power, selectively and wisely used, can contribute markedly to increased yields and production of food crops (Giles 1975a).

In India there is generally a low land to man ratio with a considerable landless labour class and so major emphasis should be placed on increasing land productivity. In many parts of Africa, by contrast, there is often a high land to man ratio with a very limited landless labour class. There, the major importance should be given to improving labour productivity. Increased production can therefore result from either increasing land productivity, expanding the cropped area and/or a combination of both.

The utilisation of power thus plays a contrasting role in the two types of situations. In the Indian context it is necessary for power to be used to improve yields through such measures as improved timeliness, improved tillage, better seed and fertiliser placement, etc. In the high land to man ratio situation, the use of additional power can often be justified primarily to break labour bottlenecks which are limiting the area under cultivation, thus increasing labour productivity, although this might have considerable impact on land productivity also.

While the subject of this paper is the efficient use of power in dryland agriculture, I intend also to consider the broader energy picture since in crop production, the horsepower hours utilised are only one source of energy used. It is necessary to place the utilisation of power for agricultural production in the context of the total energy picture in order to have a better understanding of its

importance. Fertiliser is often a major source of energy input. Other energy inputs can include plant protection chemicals, irrigation, and the manufacture of farm machinery. In engineering terms, power is defined as "the time rate of doing work" and is usually expressed in horsepower or watts. Energy is "the amount of work done" or the power multiplied by time and is commonly expressed in horsepower hours, kilowatt hours, joules, calories, or British Thermal Units (BTU).

Energy

Revelle's (1976) study of energy utilisation in rural India, estimates that the total energy used in rural India in 1971 was approximately 11.4×10^{14} kcal while in the U.S.A., agriculture in 1970 used approximately 10.6×10^{14} kcal of energy. Approximately 89 per cent of the energy used in rural India was derived from local sources such as firewood, animal power, human labour, crop residue, dung used for fuel and only 11 per cent came from commercial sources. However, of this total rural energy utilisation, only 22 per cent was used for agriculture while the remainder was used for other purposes. The local energy source for agriculture comes primarily from human labour and animal draft. Commercial energy provides the fertiliser requirements and fuel for mechanical and electrical energy. In the United States almost 100 per cent of the energy is from commercial sources. Although the use of commercial energy is expanding rapidly in the developing countries, non-commercial energy remains very important in these countries, and especially their rural areas. Until recently, however, very little attention has been paid to non-commercial energy resources.

Agricultural Power

Let us look at some of the agricultural power data given in the literature and consider how relevant they are to the dryland farming situation. Table 1 shows the mechanical power that is available per unit area for a number of countries and indicates that India ranks very low. The power from mechanical source is usually taken as the rated engine power while that from draft animals is the tractive efforts. Due to various mechanical and traction losses, the tractive power available from tractors is usually estimated at about 20 per cent of the rated engine power (Makhijani and Poole 1975). If we add human and animal power (Table 2) a much more accurate picture emerges. Singh *et al* (1980) show that about 55 per cent of the power available for crop production in India comes from human and draft animals and the power available for agricultural production in India is estimated to be just over 0.5 hp/ha. This is in contrast to Japan, for example, which uses over 3.0 hp/ha and has average yields about five times as high as India (Giles 1975b). This raises the question as to whether an increase in power would have a direct and positive influence on agricultural productivity.

Table 1 : Mechanical horsepower available in selected countries (Merrill 1975)

Country	Mechanical hp per cultivated hectare *
Japan	3.09
West Germany	1.94
United Kingdom	1.57
France	1.52
United States	0.96
Italy	0.89
Uruguay	0.45
Argentina	0.31
Chile	0.23
China, Rep. of	0.15
Peru	0.15
Mexico	0.11
Thailand	0.05
Bolivia	0.03
Pakistan	0.01
India	0.01
U.S.S.R.	0.01

* Most estimates based on 1967-68 data

Table 2 : Arable land and power available for crop production (McColly 1973)

Country	Arable land (10 ³ ha)	Human power	Animal power	Mechanical power hp/ha	Total power
Sri Lanka	1,876	0.12	0.15	0.11	0.38
Taiwan	892	0.20	0.16	0.15	0.51
India	161,940	0.09	0.20	0.01	0.30
Indonesia	22,852	0.11	0.06	0.00	0.17
Iran	11,593	0.04	0.05	0.15	0.24
Japan	6,004	0.22	0.12	2.66	3.00
Korea, Rep. of	2,256	0.20	0.24	0.00	0.44
Nepal	1,831	0.25	0.48	0.00	0.73
Pakistan	26,021	0.11	0.29	0.01	0.41
Philippines	7,934	0.07	0.10	0.02	0.19
Thailand	11,267	0.11	0.18	0.05	0.34
Vietnam, S.	2,935	0.21	0.24	0.02	0.47
Total/Average	257,399	0.14	0.19	0.27	0.60

It is necessary to break down the average figures for a country as diverse as India. Table 3 compares available horsepower figures for several regions which include most of the developing countries. It then compares India and several very diverse districts. Ludhiana district has one of the highest proportions of irrigated land and is in the state of Punjab having the highest density of tractors. West Godavari is a district with a high proportion of irrigated land but where tractorisation is at a much lower level. Chittoor district is quite well advanced agriculturally but has less irrigation than West Godavari. Mahbubnagar and Adilabad are districts where mostly dryland crops are grown and the soils are not particularly good. These last four districts are all in the state of Andhra Pradesh. The difference in levels and source of power is clearly evident. It is also clear that the dryland farmer in India has much less power than his irrigated counterpart and that he relies much more on animal power.

Table 3 : Distribution of Agricultural Power

Region	Total hp/ha	Percentage of available power/ha		
		Human	Animal	Mechanical
Asia (excluding China)	0.22	26	51	23
Africa	0.10	35	7	58
Latin America	0.25	9	20	71
India	0.23	29	62	12
Ludhiana District	0.82	4	22	74
West Godavari District*	0.40	20	60	20
West Godavari District*	0.44	27	47	26
Chittoor District	0.44	23	67	11
Mahbubnagar District	0.28	18	81	2
Adilabad District	0.28	18	80	2

*There is a discrepancy in the data because of different sources.

Sources : Item 1 — 6 (Giles 1975b)

7 — 10 (Bureau of Economics and
Statistics, Government of
Andhra Pradesh 1980)

Giles (1975a) observed a positive trend between an increase in available power and food crop yield per unit area. This is particularly true at the lower end of the spectrum, where apparently a small increase in power produces a considerable increase in land productivity. However, the relationship of available horsepower to crop yields does not necessarily prove that greater power applications to agricultural operations will bring increased yields (Hall 1973). Giles (1975b) stresses that in the regions having low available power, yield increase are probably due to other energy inputs such as fertiliser and irrigation.

During the six year period 1964-65 to 1970-71, India with a very low level of power, increased its productivity by 200 kg/ha without any noticeable increase in available power/ha. During the same period Egypt, which started from a much higher base increased its land productivity by about 750 kg/ha with little change in power/ha. Conversely the United Kingdom increased its power by about 0.5 hp/ha with only a marginal increase in productivity, while Japan increased its power by about 1.75 hp/ha to achieve a productivity increase of 750 kg/ha. In view of these and many other anomalies, it is logical to ask what impact power has on crop production. Farmers utilising higher rates of power also often use more inputs of various types such as improved seed, fertiliser, and irrigation. Makhijani and Poole (1975) compared crop yields and total energy inputs for several locations in developing countries. The relationship is curvilinear indicating that increased yields might come from any one of several energy sources. It is probable that the power requirements for agricultural production are over emphasised by many engineers and scientists, since there are many other factors that also have a major effect on productivity. Higher levels of mechanization usually come after crop yields have increased (Giles 1975b).

Role of Mechanization

Does mechanization then have a role to play in increasing crop production? Giles (1975b) states that in the early stages of the introduction of tractors, it often represents merely the substitution of one form of power for another. It is not until a later stage of mechanization that more precise and timely operations such as placing seeds and fertilisers leads to higher yields. He further emphasises that "only some machines when used in some farming situations and under some management expertise contribute significantly to increase yields."

The important point to remember is that it is primarily the implement which has an impact on crop yields. A seeder that meters the proper quantity of seed, places it in the correct moisture zone, and establishes good seed soil contact to enhance rapid germination can be as easily pulled by animals as by

a tractor. It should also be emphasised that improved mechanization is considered to be a viable proposition primarily in terms of its relation to the complete farming system.

There is evidence to show that the use of machinery, when properly integrated into the farming system, can be effective in terms of improving yields. Giles (1975a) reported a very substantial increase in yields, if proper seeding methods are used. Binswanger *et al* (1980) summarise the results of the steps in improved technology (SIIT) experiment at ICRISAT over two years in both alfisols and vertisols, and show that there is a substantial yield increase from good soil and crop management when high yielding varieties and some fertilisers are used.

The proposals for additional power for agricultural production usually state the following anticipated advantages :

1. Greater power allows the ability to improve the quality of operations such as deeper tillage, better placement of seed and fertiliser, better land shaping, etc.
2. Tractors might be able to reclaim land which cannot be operated by bullocks.
3. Additional power would allow more timely operations thus contributing both to higher yields and more extensive practice of multiple cropping.
4. Additional land can be brought into cultivation where power limitations are a bottleneck.

Technology for Improved Power Utilisation

Wijewardene (1980) states that the trend of mechanization has often been a matter of reducing time required to perform an operation by substituting one form of energy (often human labour) by a higher input of an alternative source whether animal or mechanical. Thus for any particular system of agriculture the product of energy and time remains roughly constant. He throws out the challenge of devising new systems that provide timeliness of operation (low in time) and yet requiring a low energy input.

Some research is being done at ICRISAT along these lines. Table 4 shows the performance of a wheeled tool carrier versus traditional implements on two management systems used by a farmer. The wheeled tool carrier used in ICRISAT's farming systems research is an animal drawn multipurpose machine to which many different implements can be attached to perform a wide range of agricultural operations and provide transportation where animals are the main source of power. The tool carrier is a metal frame mounted on two pneumatic

Table 4 : Performance of a wheeled tool carrier with improved implements vs traditional implements on two soil management systems in alfisols at Aurupalle village (1978-79)

Operations	Traditional implements on flat	Improved implements on flat	Improved implements on broad beds
	AFC & TBH* (hr/ha)	AFC & TBH (hr/ha)	AFC & TBH (hr/ha)
Chiselling	—	—	5.0
Moldboard plowing	—	—	4.3
Ridging	—	—	5.3
Cultivation I	—	8.3	5.0
Cultivation II	—	10.0	—
Blade harrowing I	12.5	—	—
Blade harrowing II	11.1	—	—
Bed shaping	—	—	3.8
Fertiliser application	—	4.3	2.8
Sowing	7.1	3.6	2.7
Seed covering	5.0	—	—
Interrow cultivation I	11.1	5.3	2.9
Interrow cultivation II	7.1	6.6	3.4
Total	53.9	38.1	35.2
		Yields (q/ha)	
Sorghum/pigeonpea	13.1/1.6	17.3/3.6	17.0/4.8
Millet/pigeonpea	2.3/0.5	5.9/2.6	5.9/2.4
Castor	3.6	5.6	6.6

*AFC = Actual Field Capacity

TBH = Total Bullock Pair Hours

tyres and has a beam to which the bullock yoke is attached. Implements are attached to toolbar on the back of the tool carrier with simple U-clamps. When using the same management system the wheeled tool carrier package reduced the machinery time required to produce a crop by 27 per cent. When changing the management system from common flat cultivation method normally used by farmers to a broadbed and furrow system the machinery time was reduced by another 5 per cent. At the same time the use of improved machinery increased yields.

Table 5 : Field performance of a wheeled tool carrier for various operations on broadbeds and flat fields (vertisols watershed, Bansal and Srivastava 1981)

Broadbed cultivation			Flat cultivation		
Operation	Man (hr/ha)	Bullock pair (hr/ha)	Operation	Man (hr/ha)	Bullock pair (hr/ha)
Rainy season			Rainy season		
Moldboard plowing	5	2.5	Cultivation	12.6	6.3
Ridging	5	2.5	Cultivation	12.6	6.3
Cultivation	7.4	4.4	Harrowing	7.0	7.0
Bed shaping	6.7	3.3	Harrowing	11.3	11.3
Planting and fertiliser application	9.0	3.0	Planting and fertiliser application	12.5	4.2
1st interrow cultivation	12.0	4.0	1st interrow cultivation	12.3	5.0
2nd interrow cultivation	8.6	4.3	2nd interrow cultivation	10.8	5.4
Postrainy season			Postrainy season		
Cultivation	6.3	3.1	Cultivation	8.4	4.2
Planting	18.0	6.0	Planting	15.0	5.0
Interrow cultivation	7.6	3.8	Interrow cultivation	10.6	5.3
Total	85.6	36.9		113.1	60.0

Harrowing was done by using a traditional blade harrow. All other operations were done with the wheeled tool carrier and attachments. Maize was grown during the rainy season followed by chickpea during the postrainy season.

Table 6 : Average values of specific draft for ploughing (Alikhani 1981)

Treatment	Ploughing depth (cm)	Specific Draft (KPa)			
		MCI*	MC2	MC3	MC4
Flat	5	34	31	27	23
	10	x**	40	33	30
	15	x	72	61	57
Broad bed and furrow	5	22	21	20	20
	10	46	36	31	30
	15	57	49	41	37
Flat	5	26	24	20	36
	10	42	36	33	52
	15	62	57	54	69
	5	22	20	19	25
	10	37	36	30	38
	15	48	46	45	48

*MC (Soil Moisture Content) varied in the profile.

MCI : 0.6-5.0, MC2 : 3.0-5.0, MC3 : 5.0-7.0, MC4 : 7.0-10.0 (Flat) and 7.0-8.6 (B/F).

**It was not possible to work deeper than 7 cm.

Bansal and Srivastava (1981) have shown similar results when comparing flat with broadbed and furrow cultivation systems on vertisols (Table 5). The broadbed system reduced the time required to cultivate a hectare by 38 per cent and at the same time yields were higher in the broadbed system. In addition to saving time, the broadbed system also reduces the draft and thus the total

energy requirements (Alikhani 1981). Table 6 shows that the maximum specific draft reduction of 30 per cent was achieved in a vertisol when ploughing 15 cm deep in wet conditions with a soil moisture of 27-28 per cent. Singh *et al* (1980) also show that the use of improved implements can reduce energy requirements by 70 to 100 per cent compared to the use of indigenous implements. In many instances improved implements have equal or lower draft than indigenous implements. Thus it is clear that there are existing methods which can assist the dryland farmer to improve the utilisation of his power.

Conclusion

While the energy utilised by dryland farmers in the form of power is minute compared to the total global use of energy, it is nevertheless an important part of the input to crop production in India. Local sources of energy play an important role in providing this power, so improved technologies must emphasise the use of available resources. Improved technologies are available to reduce power per hectare required to produce a crop and simultaneously improve yields.

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YIELD GAP ANALYSIS

YIELD GAP ANALYSIS : CONSTRAINTS AND APPROACHES

B. K. RASTOGI

During the past one decade, concerted research efforts have been made in India to develop a technology for the drylands so as to raise and stabilise crop production on such lands. To test the feasibility of the technology developed at research stations, verification trial and the demonstrations are conducted before the recommendations of research findings are released for farmers' acceptance. Despite this, the crop yields obtained by the majority of farmers tend to be considerably less than the yields obtained at experimental stations, at verification trials and at demonstrations. There are also wide variations in the yields obtained under different situations. To illustrate the point clearly, the average yields of sorghum, based on 1977 and 1978 yields under different situations in Hyderabad region (i.e same agro-climatic conditions), are given in Table 1. The data establish that under dryland agricultural conditions, there exists a reservoir of untapped yield potential whatever may be the contributing factors. The magnitude and the contributing factors for such yield gaps are listed in Table 2.

It may not be possible, even in the long run, for the scientists and/or the extension workers to raise the farmers' yield (actual) to the level of research plot or verification plot yield. But it would be desirable to raise the productivity to the levels of feasible yields (demonstration) or attainable yields. The sooner it is achieved, the better it is. As a step to narrow down these yields gaps, the need for objective diagnosis of the possible reasons or constraints is apparent. This may be done in two complimentary ways and would include biophysical constraints and the socio-economic constraints. However, the most important point emerging from the data in Table 1 relates to finding valid answers to two basic questions: (i) Why is there such big difference between research stations yield and the yields obtained in verification trails under the farmer's environment? and (ii) What are the reasons for such wide gap in attainable yield and actual yield? Some factors responsible for these differences in yield may include :

- i. The recommended technology being cost-intensive has not been fully appreciated by farmers, particularly the small and marginal farmers. Even the medium and big farmers are often hesitant to invest fully in the

Table 1 : Yield of sorghum under different situations in Hyderabad region (average of two seasons)

Situation	No of cases	Yield (q/ha)	Treated as	Remarks
1. Research Farm	—	39.7	Possible potential	Small size plots, agronomic and management practices as scheduled. No resource restriction.
2. Verification trials	9	20.9	Realisable potential	Large size farmers plots, scientist management and supervision. Production resources other than labour assured.
3. Demonstration	38	14.6	Feasible	Large size farmers' plots, management and supervision by extension workers. Production inputs other than labour assured.
4. Assured input supply	26	10.6	Attainable	Supply of recommended seed and fertiliser assured. Improved practices explained but not supervised. Farmers' management
5. Real farm situation	36	3.7	Actual	Farmer's own resources and management skills with normal practices followed in the region.

Table 2 : Magnitude of yield gaps in sorghum

Situation	Extent of yield gap		Contributing factors
	q/ha	Percent	
1. Possible potential-Actual yield	36.0	91	Resource-Management-Extension
2. Possible potential-Realisable potential yield	18.8	47	Research-Multiplicative effect
3. Realisable potential-Feasible yield	6.3	30	Judgement
4. Feasible yield-Attainable yield	4.0	27	Management
5. Attainable-Actual yield	6.9	65	Resource-Knowledge
6. Possible potential-Feasible yield	25.1	63	Judgement-Resource-Management
7. Feasible-Actual yield	10.9	75	Extension-Resources

required inputs, resulting in non-adoption or partial adoption of the technology.

- ii. Absence of adequate information on graded or intermediate technology suiting farmers of different resource base operating at different levels of skills and management.
- iii. Farmer's objectives are not necessarily maximising physical yields-particularly in an economy of subsistence based on diversified farming.
- iv. Difficulties in procuring inputs, pricing structure and market behaviour.

Yield Gaps in Different Crops

Foregoing description on yield differences relates only to single crop (*sorghum*) and for one region. It also brings home the point that it would be unrealistic to imagine that farmers' yield can be raised to a level beyond the yield level achieved under demonstrations. Even reaching this level is subjected to the proper diagnosis and tackling of constraints operating at field level. It would thus be of interest to examine the yield gaps in relation to different crops over a period of time and locations. Ratio of yields at farmers plot and that obtained under demonstrations from 1976-77 to 1979-80 are summarised in Table 3.

The ratio of yield between farmers plots and demonstration plot vary greatly between crops and years. Variation in yield ratios during different years are largely based on seasonal conditions. However, the yields under demonstrations were higher in all the years and for all the crops. This suggests that the recommended dryland technology has an in-built mechanism to reduce weather risks. Considering the average figures, we observe that the recommended technology, given the infrastructural and institutional support, can have an immediate impact in bridging the gap between farmers' field on the demonstrated yields, potential being 200 to 400 per cent higher in case of sorghum, pearl millet, castor and chickpea. In case of other crops too, there exists a scope of raising the crop yields. The farmers have already accepted the innovations to a great extent in the case of groundnut.

Gaps in Profitability

The above does not indicate the gaps or variability in net profits under high level and low level of technology. From the economist's point of view, this is rather important to know how much of the yield gap could be economically recovered. It looks logical to suggest that so long as the adoption of the improved package of practices did not lead to a fall in the net returns, it would

Table : 3 Ratios of farmers' yields to demonstrated yields for different crops

Crop	Years				Average
	1976-77	1977-78	1978-79	1979-80	
Sorghum (Rainy)	1: 5.6	1: 3.2	1: 5.5	1: 6.7	1: 5.0
Sorghum (Post-rainy)	1: 2.7	1: 1.9	1: 3.6	1: 2.4	1: 2.6
Rice	1: 1.0	1: 2.4	1: 3.0	1: 2.3	1: 1.9
Finger millet	—	1: 2.1	1: 1.7	1: 1.6	1: 1.8
Pearl millet	1: 3.2	1: 3.1	1: 3.1	1: 7.8	1: 3.6
Setaria	—	—	1: 2.1	1: 1.7	1: 1.9
Groundnut	1: 2.1	1: 1.3	1: 1.5	1: 1.4	1: 1.4
Castor	1: 3.5	1: 1.5	1: 2.3	1: 2.4	1: 2.3
Chickpea	1: 1.1	1: 2.3	1: 2.1	1: 7.2	1: 2.0

be economically sound to adopt the recommended practices. Table 4 presents the ratio of economic returns based on low management (farmers') yield and high management (demonstration) yields during the four year period given in Table 3. Data presented on gross and net returns takes into account the element of cost of cultivation under the two situations. It is observed that the ratios pertaining to net income is between farmers' and demonstration plots for gross income. Thus, inspite of higher cost of cultivation under demonstrations, the gap between the income/profits obtainable with farmer's management skill and with improved practices widens more sharply than the physical yields. Obviously, therefore, there is also a need to bridge this economic gap. The remedy to bridge the gap in physical yields and economic returns lies in popularising and adoption of the recommended technology.

Constraints

Even though it has been convincingly established (Tables 3 and 4) that the adoption of recommended technology would raise crop yields and enhance profitability, still a majority of farmers even in such villages where large size demonstrations were conducted did not take up recommendations on regular basis. The high magnitude of non-adoptions in respect of three selected practices is presented in Table 5.

It is observed that the adoption of improved seeds have made headway but the adoption of fertilizer application and use of plant protection chemicals have not yet made enough impact in the dryland areas, perhaps because of substantial cash investment. This pattern of some practices being more acceptable than others indicates that the dryland farmers do not favour the adoption of technology as a package but prefer to adopt one or two recommended practices which suit to their resource endowment, operational skill and managerial ability.

Reasons for non-adoption of improved seed, fertilisers and the plant protection chemicals are summarised in Tables 6, 7 and 8.

In general, economic factors as constraints to adoption emerge more important than either biological or technical factors. The high cost of inputs has been the major constraint for most of the crops. The fear of the farmers that improved seeds are more susceptible to pests and diseases is another important reason and can be attributed to risk factor. Similarly, the risk in case of fertilizer use is evidenced in the reporting of heavy losses in case of failure of rains. Significantly, lack of awareness or knowledge about the recommended technology as a constraint is only of minor importance. The suitable pricing policies for input and output in relation to various crops can hopefully take care of the economic factors. In addition, the research efforts are needed on

Table 4 : Ratios of economic returns based on farmers' yields and demonstrated yields for different crops

Crop	Gross returns (Rs)				Net returns (Rs)					
	1976-77	1977-78	1978-79	1979-80	Average	1976-77	1977-78	1978-79	1979-80	Average
Sorghum (Rainy)	1: 3.9	1: 2.7	1: 4.5	1: 7.4	1: 4.2	1: 10.3	1: 1.8	1: 24.9	1: 14.5	1: 7.4
Sorghum (Post rainy)	1: 2.5	1: 1.8	1: 2.9	1: 2.4	1: 2.4	1: 2.1	1: 1.3	1: 2.8	1: 2.4	1: 2.1
Rice	1: 0.8	1: 2.3	1: 2.6	1: 2.0	1: 1.8	1: 0.6	1: 5.5	1: 6.4	1: 2.7	1: 2.3
Finger millet	—	1: 0.8	1: 0.8	1: 1.5	1: 1.0	—	1: 3.2	1: 3.0	1: 0.6	1: 1.4
Pearl millet	1: 2.9	1: 2.9	1: 2.6	1: 5.5	1: 3.3	1: 4.2	1: 2.3	1: 3.2	1: 15.4	1: 4.7
Setaria	—	—	1: 1.8	1: 1.3	1: 1.6	—	—	1: 1.7	1: 1.5	1: 1.6
Groundnut	1: 2.0	1: 1.6	1: 1.5	1: 1.5	1: 1.6	1: 1.2	1: 0.8	1: 1.2	1: 5.2	1: 1.3
Castor	1: 3.1	1: 1.8	1: 2.1	1: 3.7	1: 2.6	1: 4.5	1: 1.8	1: 5.5	1: 29.3	1: 8.8
Chickpea	1: 1.0	1: 2.5	1: 2.3	1: 8.8	1: 2.2	1: 0.7	1: 3.2	1: 2.1	1: 58.6	1: 2.5

Table 5 : Percentage of partial/non-adoptors of recommended practices

Crop	Sample size (farmers)	Percentage of non-adoptors		
		Improved seed	Fertilizer application	Plant protection chemical use
Sorghum (Rainy)	928	28	75	73
Sorghum (Post-rainy)	945	15	60	58
Rice	704	44	70	82
Finger millet	396	38	31	65
Pearl millet	1515	52	72	78
Setaria	129	93	96	—
Groundnut	824	34	51	92
Castor	184	42	77	58
Chickpea	308	66	79	92

Table 6 : Reasons for non-adoption of improved seed (percentage of farmers)

Reasons given	Crops									
	Sorghum (Rainy)	Sorghum (Post-rainy)	Paddy	Finger millet	Pearl millet	Setaria	Groundnut	Cas-tor	Chick-pea	
Lack of awareness	7	0	47	18	23	39	17	27	27	
Costly seed	23	42	30	—	54	8	42	26	36	
Not suitable for local conditions	3	42	1	2	20	15	10	9	16	
Susceptibility to pests and diseases	18	50	10	1	44	8	9	33	34	
Poor cooking quality	10	0	0	4	20	—	—	—	12	
Non-availability	9	6	6	12	44	28	19	11	—	
Lack of conviction	15	21	1	—	19	—	8	24	23	
Shortage of capital	18	—	—	—	—	—	23	—	—	

Table 7 : Reason for not using fertilisers (percentage of farmers)

Reasons given	Crops								
	Sorghum (Rainy)	Sorghum (Post-rainy)	Paddy	Finger millet	Pearl millet	Setaria	Groundnut	Castor	Chickpea
Lack of knowledge	9	11	25	—	22	9	16	5	35
High prices	37	47	63	11	41	39	48	17	40
Non availability	4	2	6	—	12	—	2	3	16
Fear of heavy losses	53	44	14	56	51	22	52	71	35
Shortage of capital	36	68	45	96	34	—	48	37	33

Table 8 : Reasons for not undertaking plant protection measures (percentage of farmers)

Reasons given	Sorghum						
	(Rainy)	(Post-rainy)	Paddy	Pearl millet	Groundnut	Castor	Chickpea
Lack of knowledge	18	21	16	27	30	34	13
Non-availability	3	9	17	17	5	3	9
High cost	57	56	3	39	52	35	9
Shortage of capital	9	6	1	4	9	8	—
Lack of technical help/guidance	8	12	—	21	1	11	10
Lack of conviction	3	8	—	—	—	—	—

the use of low monetary and non monetary inputs with emphasis on management skills as a means to effect cost reduction so that technology becomes relevant to bridge the yield and income gaps and move dryland agriculture forward.

Approaches

In view of variety of crops grown and the technologies available as also the crop performance being highly site-specific and season-specific in drylands, the task of analysing yield gaps is rather difficult. Further, to what extent the technology can be transferred has not been tested with much vigour in all the regions. At few locations, however, on-farm testing of the recommended technology has been systematically undertaken.

Constraints of soil and water operating at the farm (farmer's) level and the number of management practices which are not within the direct control of the farmers individually have been some of the limiting factors for not testing the technology and its non-adoption consequently. It is not only the physical superiority of the technology which is to be tested, but also the economic viability. It implies that scientists would have to ensure that the recommended technology if adopted by the farmers would increase both yields and profits. The appropriateness of the technology would, however, depend on the representativeness of the area. Therefore, the areas or regions have to be clearly delineated for purposes of constraint analysis. This delineation may broadly fall into three groups.

- i. Where the technology have been developed and adopted by the farmers
- ii. Where the technology have been developed, but not adopted by the farmers
- iii. Where technology is still in the stage of perfection.

The scientists should develop a package of practices which are considered better than the farmers' practices and this package is tested on the farmer's field. Scientists should themselves conduct, supervise the trial, record observations and collect relevant data. Where the technology has partially been adopted, gap analysis has only little promise. The survey approach is required to understand fully the reasons of non-adoption. Such reasons may be biological or socio-economic or both. The grouping of farmers into different size holdings (marginal, small, medium and larger farmers) and adopting stratified random sampling technique could be useful in such surveys. In case of identified biological constraints, the verifications has to be through experimentation again. At the same time, the economic profitability of recommendations has to be worked out.

The gap analysis is promising in areas where the yields at farmer's field are much lower than the demonstration yields even though the technology (seed and fertilizer mainly) have been adopted (eg., finger millet at Bangalore, cotton at Akola and Rajkot, castor at Hyderabad, and maize at Indore).

Conclusions

The following aspects need investigation in yield gap analysis :

- i. Examination of the magnitude of gap in yield under different situations
- ii. Determination of the relative contribution of different production inputs when they are used individually or in combination
- iii. Estimation of the extent to which the use of the recommended inputs can profitably be increased on farmers' field
- iv. Identification of the social, economic and institutional factors preventing farmers from using known technology.

It is also to be emphasised that yield gap analysis has to be a collaborative effort of agronomists and economists, the agronomists sharing the major responsibility of experimentation and economists undertaking analysis of socio-economic constraints through the organisation of village surveys

YIELD GAP ANALYSIS : PERSPECTIVES AND IMPLICATIONS

R. D. GHODAKE AND T. S. WALKER

Yield Gap analysis is a new research methodology that emerged on a formal basis in the 1970s. Developed by the International Rice Research Institute (IRRI), it was extensively used to measure and analyse the determinants of yield gaps in farmers' fields in Southeast Asia where high yielding rice varieties have been adopted. It has gained wide-spread popularity with researchers, research administrators, and policy makers. It is easy to visualise and think in terms of yield gaps, and the simple and efficient procedures designed by IRRI provide a vehicle for potentially effective inter-disciplinary research.

Although the IRRI yield gap framework gives us a prototype to follow, it requires major modification before it can be applied to dryland agriculture. Many of these modifications were underscored in a Working Group Meeting on yield gap analysis organised by the All India Co-ordinated Research Project for Dryland Agriculture and the International Crops Research Institute for the Semi-Arid Tropics in 1980. In this paper, we evaluate concepts, considerations, approaches, and implications for yield gap analysis in dryland agriculture in the 1980s.

Concepts of Yield Gap Analysis

The IRRI Approach : The International Rice Research Institute has pioneered a methodology to identify yield gap factors and estimate their magnitude in rice production (De Datta *et al* 1978; Gomez *et al* 1979). The total yield gap is conceptually divided into two parts. Gap I represents the difference between experimental station yield and potential on-farm yield and is conditioned by 'irreducible' environmental factors. Gap II is the difference between potential and actual yield at the farm level and is caused by various biological and socio-economic factors operating at the farm and/or village level.

The main focus of IRRI research is on yield gap II and is essentially based on on-farm testing. It has been used to analyse why on-farm yields do not measure up to potential yields following the adoption of high yielding genotypes. The IRRI yield gap analysis is generally conducted for irrigated rice in an assured

production environment. An integrated approach combining both controlled agronomic experiments on farmer's fields and farm surveys is used.

The IRR1 analysis starts with a preliminary survey of 100 farmers who are selected in a random sample. The main objectives of the survey are two-fold: 1. To have a basis for selecting farms for on-farm factorial trials and 2. To gain a preliminary idea of farmers' perceptions of yield constraints. Twenty farmers are chosen for on-farm trials in each study area. Three to five location-specific test factors are identified and included in the trials for experimentation. Two levels of each test factor are tested: the farmers' level and the improved level. The farmer's level refers to what the farmer is actually doing in the current crop season, and varies from one farm to another. The improved level is one that the researchers expect will produce maximum yield in the study area. The trial design is a factorial with two to three replications and a small plot size of 4 x 5 meters. All non-test factors are managed at the farmer's level. Potential yield is estimated on plots where treatments are set at the improved level. The estimate of yield gap in the study area is computed as the difference between the potential farm yield and the actual yield as obtained on those plots where all factors are at farmer's levels. Analysis of variance techniques is used to determine individual and joint contributions of various factors. Once the main treatment factors conditioning the yield gap have been determined, adoption surveys are carried out to identify and quantify socioeconomic constraints determining the acceptance and diffusion of the main treatment factors. The IRR1 methodology *per se* does not make a methodological contribution towards understanding the underlying socioeconomic determinants of yield gaps.

General Steps in Yield Gap Analysis

On the basis of the IRR1 approach and discussions during the AICRPDA-ICRISAT working group meeting on yield gap analysis, we have divided the general process of yield gap analysis into four major steps (Fig. 1). The boxes with solid lines indicate steps; while those with dotted lines denote implicit outcome of these steps

The first step addresses the basic question of whether there is any gap in the yield and, if yes, what is its magnitude. Existing knowledge and preliminary surveys are used to answer this question. Answer will be location- and time-specific with due consideration for the type and level of technology practiced by representative farmers in a region.

In the second step the total yield gap is partitioned into two major components to obtain a benchmark for further analysis. This partitioning is performed by analysing data from preliminary surveys, on-station research, and on-farm experimentation. The first part (Yield Gap I) is attributed to environmental differences and non-transferable components to technology while the

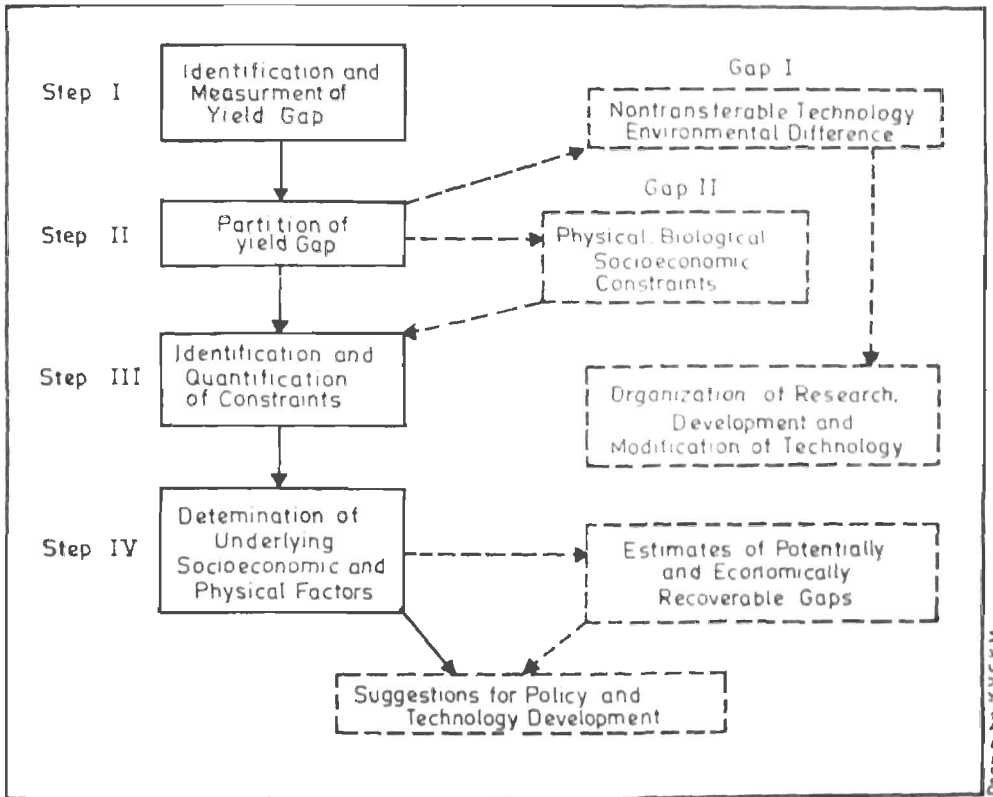


Fig. 1 : General Steps in yield gap analysis

second part (Yield Gap II) is due to inefficient cultural practices and sub-optimal input use by farmers that result in lower yields than those possible on their farms.

The third step deals with the estimation of potential yield and actual yield on farmers' fields and with the identification of factors responsible for differences between these two yield levels. How much each factor contributes to the yield gap is measured through on-farm experimentation or field observations. The analysis in this step deals with the realisation of production potential at the farm level with a given technology and has implications mainly for development strategy and technology transfer policy.

After having documented the factors and their contributions to yield gaps, the fourth and last step focuses on why farmers are not doing what is required to realise on-farm economic yield potential. There could be a number of underlying reasons such as capital constraints, profit seeking behaviour, lack of knowledge about technology risk bearing ability, and institutional and social infrastructures. In fact, these are the underlying determinants of yield gaps and need to be understood for making appropriate policy prescriptions. Feasible approaches could encompass adoption studies, whole-farm constraint analysis, and partial budgeting. As a consequence, potentially and economically recoverable gaps are estimated. The findings can be utilised to suggest policy alternatives aimed at alleviating the constraints and research priorities oriented towards the reduction of gaps.

Major Considerations in Dryland Agriculture

Because we are dealing with yield gap analysis in dryland agriculture which is different in many respects from the assured rice production environment where IRRI developed and used its methodology, we should analyse some of the more important differences. These considerations should be the basis for the selection of appropriate approaches in designing suitable methodologies for yield gap analysis in dryland agriculture. Table 1 outlines some of the major considerations by comparing and contrasting dryland agriculture with irrigated rice and presented possible implications for yield gap analysis in dryland agriculture.

In general, the lower rate of adoption of genotypes and other practices and the greater variability in the level of adoption across dryland regions compared to the irrigated rice areas suggests the need for classifying areas into relatively homogenous technology by environmental sets. Unlike the IRRI methodology with its emphasis on adoption of a high yielding variety genotype, the approach for dryland agriculture should be flexible with a focus both on genotype as well as on other practices such as soil-, water-, and crop-management technologies

Table 1 : Major considerations and implications for yield gap analysis in dryland agriculture

Consi- derations	Irrigated rice agriculture	Dryland agriculture	Implications for dryland agriculture
Stage of technology adoption	<ul style="list-style-type: none"> — Greater adoption of recommended practices — Less variability in adoption across areas 	<ul style="list-style-type: none"> — Less adoption of recommended practices — More variability in adoption across areas 	<ul style="list-style-type: none"> — Classify areas in different regions by type and level of technology adoption — Flexible approach to focus on genotype, other techniques, and level of adoption
Soil-and water-pro- duction environment	<ul style="list-style-type: none"> — Assured environment — Less variability due to environmental factors 	<ul style="list-style-type: none"> — Undependable environment — Environmental factors dominate output variability 	<ul style="list-style-type: none"> — Difficult to incorporate soil-water management practices in the analysis — Need for special-purpose experiments
Location specificity	<ul style="list-style-type: none"> — Relatively less soil variability across locations — Irrigation reduces role of environmental factors 	<ul style="list-style-type: none"> — Substantial soil variability across locations, farms, and plots — High variability due to environmental factors 	<ul style="list-style-type: none"> — Greater difficulty in selecting homogenous areas — More plots, larger-size plots and more replications — More emphasis on understanding plot specific characteristics
Time specificity	<ul style="list-style-type: none"> — Yield variability over time is less within an area than across locations 	<ul style="list-style-type: none"> — High year-to-year variability 	<ul style="list-style-type: none"> — Greater importance assigned to the partitioning of yield gap I as well as II

Table 1 : (Contd.)

Consi- derations	Irrigated rice agriculture	Dryland agriculture	Implications for dryland agriculture
Cropping system	—Sole crop	—Greater variation in soil moisture regime and its in- teractions with other factors	—More years of experimentation
	—Monoculture	—Mixed and intercrops with large number of crops	—More difficult to define optimal cropping system and to quantify test factors
	—Homogenous over large areas	—Heterogeneous over large areas	—Choice of a well defined domi- nant cropping system or crop
Valuation	—Single crop		—The cropping system may be unstable due to technological and infrastructural changes
	—Output gap in terms of yield of main product	—Possibility of many crops and byproducts in cropping system	—Higher priority to evaluate pro- ductivity gaps through whole- farm constraints analysis
			—Measurement of yield gaps in monetary terms
			—Relative price changes may lead to obsolescence of cropping system
			—Expected results are more time and location specific

Table 1 : (Contd.)

Consi- derations	Irrigated rice agriculture	Dryland agriculture	Implications for dryland agriculture
Data collection	— Some problem of measurement due to diseases and insects	— Greater difficulties in measurement — Scoring problems because of a wider array of pests by crop interactions	— Secondary and unpublished primary agroclimatic data — Field observations to generate environmental and technological plot profiles — Simulation of yield distribution
Interdisci- plinary team work	— Considerable comp- lexity — Close collaboration between economist, agronomist & statistician	— More complexities	— Wider role for interdisciplinary collaboration between agrono- mist, agroclimatologist, econo- mist, soil scientist, entomologist, pathologist, and statistician
Farmers' practices	— Difficult to simulate for non-test practices	— More difficult to simulate for non-test factors	— Field experiments to be suppl- mented by field observations
Underlying socioecono- mic deter- minants	— Relatively more deve- loped institutional infrastructure	— More difficult to visualize due to additional comp- lexity — Greater heterogeneity in institutional infrastructure	— Partial budgeting — Whole-farm constraints analysis — More difficult to handle

Table 2: Important test factors for different dryland crops and regions for yield gap analysis¹

Crop	Region	Test Factors		
		First	Second	Third
Sorghum (rainy season)	Hyderabad	Variety	Fertilizer	Weed control
	Akola	Variety	Fertilizer	Weed control
Sorghum (postrainy season)	Bellary	Variety	Fertilizer	Date of sowing and seed rate
	Ahmad- nagar	Variety	Fertilizer	Spacing and intercul- tivation
	Sholapur	Fertilizer	Plant popu- lation	Spacing and intercul- tivation
	Bijapur	Fertilizer	Date of sow- ing and plant population	Intercultivation
Pearl millet	Jodhpur	Variety	Method of fertilizer application	Management of fertili- zer application
	Hissar ²	Fertilizer	Management of fertilizer application	Weed control
	Kovilpatti	Variety	Fertilizer	—
	Anantapur	Variety	Fertilizer	Date of sowing
Finger millet	Bangalore	Variety	Fertilizer	Mixed cropping
Upland rice	Varanasi	Variety	Fertilizer	Method of sowing and fertilizer application
	Rewa	Variety	Fertilizer	Method of sowing and fertilizer application
	Ranchi	Variety	Fertilizer	Method of sowing and fertilizer application
	Bhuva- neswar	Variety	Fertilizer	Method of sowing and fertilizer application

Table 2 : (Contd.)

Crop	Region	Test Factors		
		First	Second	Third
Chickpea	Varanasi	Variety	Fertilizer	Plant protection (pod borer)
Pigeonpea	Hissar	Variety	Fertilizer	Plant protection
	Hyderabad	Inter-cropping	Plant protection	Fertilizer
	Akola	Inter-cropping	Plant protection	Fertilizer
Greengram	Jodhpur	Variety	Method of fertilizer application	
Groundnut	Rajkot	Fertilizer	Plant protection (aphids)	Variety
	Anantpur	Fertilizer	Plant protection	Deep ploughing
Castor	Hyderabad	Variety	Fertilizer	Sowing date

1. These test factors are identified by different working groups formed during the AICRPDA-ICRISAT Working Group Meeting on Yield Gap Analysis in 1980. The test factors are presented according to their importance.
2. BJ 104 Variety of pearl millet has been widely adopted in Hissar area.

or their individual components. Some of the promising crop areas, and test factors for yield gap analysis are listed in Table 2 and were identified in the working group meeting in 1980.

The dominant role played by the environmental factors, particularly variations in soil moisture regimes and their interactions with many other factors, conditions output variability in dryland agriculture and emphasises the need for identifying and quantifying determinants, not only of yield gap II, but also of yield gap I. From data presented in the working group meeting in 1980, the magnitude of yield gap I is likely to be large in dryland agriculture (Table 3). The average size of yield gap I across several crops where yield gap analysis

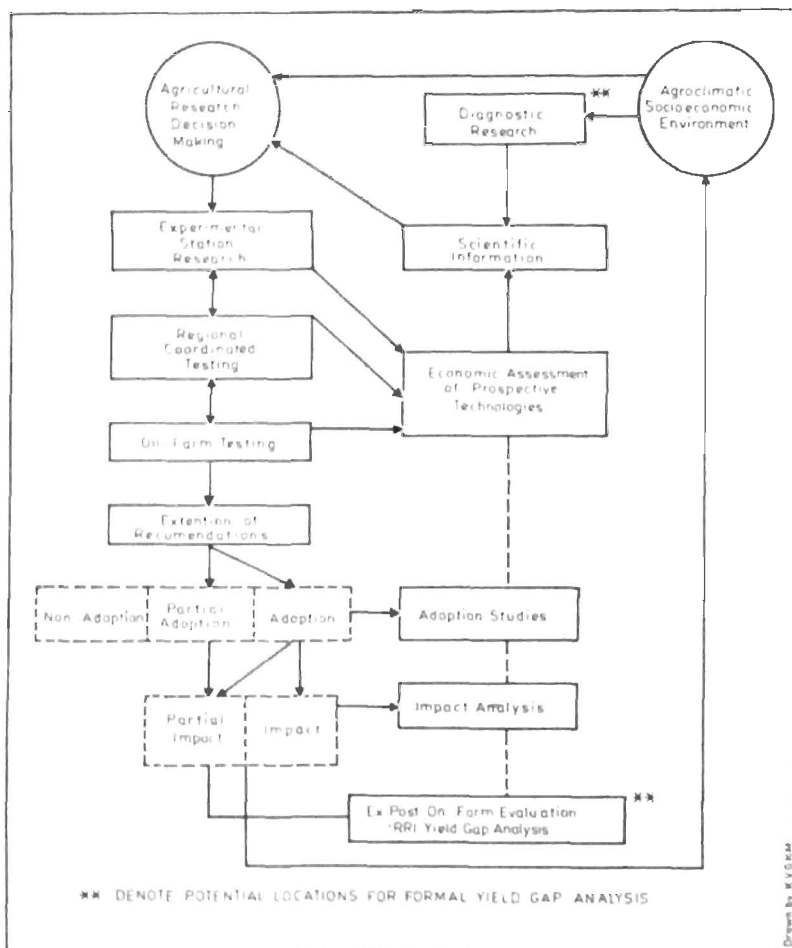


Fig. 2 : Points of intervention for socio economic analysis in the generation of technology.

was considered feasible was 61 per cent. This is probably an underestimate of yield gap I because the demonstrations may have been carried out on relatively fertile land and were not managed by farmers.

The IRRI methodology also has to be adjusted to cope with intercropping and mixed cropping, to define common and optimal cropping systems for analysis, and to measure gaps in productivity in monetary terms. Substantial soil variability across plots, farms, and regions in dryland zones will have strong implications for the choice of homogeneous regions and for experimental design. A greater number of alternative cropping activities and the complexity of dryland agriculture reinforces the need for close collaboration between different disciplines to handle the variety of interaction effects. Field experiments should be supplemented by more field observations and related measurements to generate sufficient data to simulate farmers' practices for non-test factors. Such information is also one of the essential building blocks for later steps in yield gap analysis that focus on underlying constraints.

In brief, dryland agriculture calls for a more flexible, eclectic approach to yield gap analysis. For a number of reasons sketched in Table 1, the benefits from yield gap analysis in dryland agriculture will be more time and site specific. Yield gap analysis in dryland agriculture equivalent to those carried out for irrigated rice areas will require more time, resources and skilled personnel. In terms of methodology, it will also probably not have the high degree of transferability across regions and countries that the IRRI yield gap analysis exhibited. Component parts of the framework may have fairly wide transferability, but they will have to be pieced together again to face new situations in different dryland locations.

Yield Gap Approaches and Technology Generation

Where does yield gap analysis or an analysis of determinants of yield fit into the process of technology generation and diffusion? We answer this question by charting in Fig. 2 the sequences or chronological steps followed in the generation and diffusion of dryland technology. It is merely illustrative and depicts in detail the points of intervention where different types of studies and analyses contribute information for making decisions on agricultural research. Approaches that directly relate to yield gap analysis are found in diagnostic research, in the assessment of prospective technologies and in the ex-post evaluation of technology.

Diagnostic Research : On-farm Observations and Production Function Analysis

In order to identify researchable problems and associated priorities, diagnostic research relies on several methodologies, including baseline and reconnaissance surveys, base data analysis, and on-farm experimentation. One such

Table 3 : Promising crops and regions for yield gap analysis in dryland agriculture

Crop	Regions	Observed yields (q/ha)			Yield gaps %		
		Research stations ¹	Demonstrations ²	Farmers' fields ³	Total yield gap	Yield Gap I Yield Gap II	
Rainy season sorghum	Hyderabad	36.1	13.0	4.1	89	64	
	Akola	18.4	19.5	2.4	87	0	
Postrainy season sorghum	Bellary	14.3	7.7	3.4	76	46	
	Jodhpur	18.3	13.3	4.8	74	27	
Pearl millet	Hissar	34.0	15.0	6.7	80	56	
	Rajkot	18.3	14.0	10.7	42	23	
Finger millet	Bangalore	16.1	6.3	2.9	82	61	
Wheat	Varanasi	24.0	18.6	10.2	58	23	
Setaria	Anantapur	10.4	4.0	0.2	98	62	
Upland rice	Varanasi	30.2	20.6	14.7	51	32	
Chickpea	Varanasi	34.6	16.6	15.3	56	52	
Greengram	Jodhpur	14.9	10.4	3.1	79	30	
	Hissar	11.1	10.1	9.8	12	9	
Groundnut	Rajkot	9.7	8.7	7.0	28	10	
	Anantapur	15.1	4.9	1.4	91	68	
Castor	Hyderabad	15.0	5.2	1.9	87	65	
Average :					69	42	27

1. Data available from various reports of All India Co-ordinated Research Project for Dryland Agriculture.
2. Based on results of study on recommended practices as a brief of the Agro-Economic Research of Dryland Agricultural Research Project.
3. Based on results of farm structure studies of the Agro-Economic Research of Dryland Agricultural Research Project.

Source : Constructed from data presented in the report of AICRPDA-ICR SAT Working Group Meeting, 1980.

methodology used by the Centro Internacional de Agricultura Tropical (Pinstrup-Andersen *et al* 1977) to evaluate on-farm constraints to higher bean yield in Colombia is a type of yield gap analysis that applies to situation where researchers have little information about the size of yield reducers.

This procedure is based on the collection of data from a representative sample of farms. Field measurements are taken to develop detailed environmental and technological plot profiles specific to a cropping system. Qualitative and quantitative information is gathered on the incidence and severity of each of the variables expected to limit yields in the crop for which the analysis is carried out. In general, these determinants include biological, agroclimatic, edaphic, and management variables. Yield losses are estimated from a production or response function analysis in which observed yields are regressed on factors expected to influence yields. Each regression co-efficient multiplied by the mean value of the particular yield limiting factor provides an estimate of the overall impact of this factor on sampled yields.

The success of this approach requires observations on at least 30 fields, variation in environmental and technological variables, and an inter-disciplinary team effort. Depending on the cropping system studied, field observations need to be taken during critical periods such as planting, germination, flowering, and harvesting. In order to increase management variability, some supplemental trials and demonstration plots at high levels of management may be included in the analysis.

Economic Assessment of Prospective Technologies : Whole-Farm Constraints Analysis

Whole-farm constraints analysis places yield gap analysis in a farm management perspective and evaluates the impact of resource constraints, risk, and farmers' objective on output and the allocation of resources. Because the analysis is carried out at the farm level, it is more appropriate to talk of output gaps. An example of how to partition output gaps (Gap II) into their component parts is illustrated in Table 4. Linear risk programming method was employed to analyse the productivity gaps. In this example, capital was the most important constraint, contributing about 50 per cent to the gap in potential gross returns.

Whole-farm constraints analysis is especially suited to dryland agriculture where cropping patterns are diverse and resource constraints are numerous. There exists a wide range of methods of whole-farm modelling (Hardaker 1979), including mathematical programming approaches that can be used to carry out whole farm constraints analysis. It can be argued that mathematical programming approaches particularly those that account for risk, provide the most suitable framework for whole-farm constraints analysis. The important proviso to this

argument is that reliable and suitable computer facilities are available. Until such facilities become available, reliance must be placed on intimate knowledge of farm circumstances to carry out an intuitive assessment of constraints with a whole-farm budgeting approach. Partial budgeting can also be useful especially for analysing the on-station experiments wherein farmers' technologies are simulated as 'controls'

Table 4 : Determinants of output gap II by farm size groups in Akola region
(Contribution in %)

Source of gap	Farm size					
	Small		Medium		Large	
	Returns		Returns		Returns	
	Gross	Net	Gross	Net	Gross	Net
Technical inefficiency	31	31	33	34	50	40
Allocative inefficiency	-3	1	6	11	-4	6
Capital constraints	59	53	61	55	48	40
Labor constraints	0	0	0	0	2	2
Risk aversion	13	15	0	0	3	4
Profit-seeking behaviour	0	0	0	0	0	0
Potential percentage gap	73	78	75	80	72	78

1. Output gap due to each source being measured as percentage of the potential gap.
2. Negative sign of gross return gap on small and large farms does not indicate negative contribution of allocative inefficiency; the absolute value indicates the allocative inefficiency.

Ex-Post Evaluation of Technology : IRRI Yield Gap Analysis

The IRRI-type yield gap analysis is designed for those situations of partial adoption and/or partial impact when technologies once adopted do not measure up to expectations in farmers' fields (Fig.2). The combination of on-farm surveys and experimentation recommended in the IRRI approach have been described earlier in this paper.

Less Formal Approaches

Other steps in the process of technology generation depicted in Fig. 2 can function as loci to generate valuable information for a more informal yield gap analysis. For example, on-farm trials organised along steps-in-improved technology methodology (Ryan and Sarin 1977) have been conducted both in AICRPDA and ICRISAT. These factorial trials with improved and traditional treatment combination provide information on the separate contributions of different treatments to yields and returns; if the trials are managed by the farmer they are equivalent to an ex-ante or before-the-fact IRRI yield gap analysis. Furthermore, information from secondary data, baseline surveys, and on-farm testing can be judiciously and skillfully blended to construct an insightful evaluation of the determinants of productivity gaps.

Implications for the Eighties

For the reasons cited earlier in the paper, we do not believe that researchers on dryland agriculture in the 1980s should allocate a significant share of their scarce resources for formal yield gap analysis to make it more cost effective for dryland agriculture. An interest in formal yield gap analysis should not divert researchers from the more routine tasks involved in generating a steady flow of technical information for drylands agriculture. For example, the field testing of technologies on a routine basis in dryland operational research projects has generated valuable information on the relative profitability of practices and on institutional and other constraints to adoption (Rastogi and Annamalai 1981). Yield gap analysis should complement and not substitute for these important activities

Formal yield gap analysis should continue on a pilot exploratory basis at a few locations and its progress should be reviewed annually. As more information from several sources accumulates in the 1980s, informal yield gap analysis should also become more effective.

In dryland agriculture, more attention needs to be focussed on the determinants of yield gap I than of yield Gap II. Reliable estimates over time are needed, not only on farmers' fields but also on operational sized fields on dryland

experimental stations. Location-specific supplemental trials and on-farm operational research can generate reliable estimates.

Whole-farm constraints analysis is complex and it may be advisable to adopt this approach at a few locations using whole-farm budgeting. A microprocessor for use at the headquarter's location in Hyderabad could place whole-farm constraints analysis on a sounder footing.

A team approach is indispensable to yield gap analysis in dryland agriculture. We highlighted the need to collect information on insect and disease damage and the levels of infestation. This means that entomologists and pathologists should play prominent roles in such a team, or at least participate in the training of the team.

Another way to approach yield gap analysis in dryland agriculture is to do more in-depth, problem oriented diagnostic research. For instance, diagnostic research on stand establishment may allow researchers to arrive at a preliminary indication of whether or not poor stands are important in conditioning yield gaps.

Data from many sources including farm structure studies and demonstrations can be used to arrive at estimates of the contributions of different factors to yield gap II. This type of analysis would require a production function approach and compatible data sets.

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FIELD TESTING OF
DRYLAND TECHNOLOGY

FIELD TESTING OF DRYLAND TECHNOLOGY

B.G. RAJASEKHARA

The starting of All India Co-ordinated Research Project for Dryland Agriculture in 1970 has given a new dimension to the research on dryland agriculture. The dryland technology, unlike the technology for irrigated farming, is governed by certain factors. They are :

Location specificity : The technology developed cannot be applied to the whole of agroclimatic zones due to variations within a defined agroclimatic zone in spatial distribution of rainfall.

Consistency of technology : The technology to be successful has to be tested over years, as there is vast variation in rainfall both in quantity and distribution over years.

Flexibility of technology : No one technology, however sound, can be adapted to all the conditions. Dryland technology has to have flexibility. Aberrent weather conditions have to be taken into account.

Profitability of the technology : With little or no control on moisture, the degree of response to any treatment or recommendation would be varying. Thus, the profitability would also fluctuate. Visible changes are essential for the acceptance of dryland technology.

Apart from the above, the competence of the extension staff and the farmer who accepts and adopts the technology are also important. These technical and social problems influence its adoption. Testing of dryland technology forms a vital step in the transfer and adoption of technology. Testing in farmers field help both the researcher who develops the technology and extension official who takes the technology to farmers at large. The former gets an insight into the performance of technology, which would help him to refine his technology and arrive at appropriate technology. The latter would be interested in the operational difficulties in the adoption of the technology.

Objectives

The dryland technologies were tested in locations around the research station. Later the technologies were also introduced in the Integrated Agricultural Development Projects. In these projects, the extension workers demonstrated these technologies on a compact block of 800 ha each year. It was felt that a systematic evaluation of technology has to be done by the research workers themselves so

that they could do reliable assessment, identify the bottlenecks and work as a source of feed back for research. Thus, operational research projects (ORP) were started at four centres (Bangalore, Hyderabad, Ranchi and Hoshiarpur) in the country. Thus, the ORPs formed a vital link in the transfer of technology with the following objectives :

- i. To critically study local agricultural practices
- ii. To test the research finding in farmers' fields
- iii. To find out the acceptability and transfer of technology
- iv. To find out economic feasibility of the technology under farmers' field conditions
- v. To identify socio-economic constraints.
- vi. To serve as a source of feed back to research.

The technology was tested in half to one acre plots, keeping proper control. The testing was conducted by scientists themselves with the cooperation of the farmers. Periodical observations were collected and the yields were estimated by harvesting from 100 m² plot selected at random. The technologies were at first tested on individual holding and then on microwatersheds. Valuable information was generated for use by both researchers and extension staff.

Salient Findings

Low monetary inputs like introduction of high yielding varieties, and cultural practices have given encouraging results. High yielding varieties of finger millet has given 40 per cent extra yield over local ones (ORP, Bangalore). Early tillage for sorghum resulted in 40 per cent extra yield (ORP, Hyderabad).

High yielding variety of sorghum with intra-row weeding produced 60 per cent extra yield (ORP, Hyderabad). Wider spacing using 30 cm seed drill resulted in 20 per cent higher yield over control (ORP, Hyderabad).

A non-traditional crop of groundnut, hybrid castor GAUCH-1, and pigeonpea HY 3A, were found to be good alternate crops for Ranchi, Hyderabad and Bangalore areas respectively.

Opening furrow across the slope on a grade at every 3 m gave considerable increase in the yield of finger millet (ORP, Bangalore). Graded border strip increased the yield of finger millet by 30 per cent. Keyline sowing at Hyderabad and low cost terracing at Hoshiarpur were beneficial. The latter helped in taking two crops.

The low-cost seed-cum-fertiliser drill at Bangalore and simple implement to place fertiliser at Hyderabad were found to be useful.

Adoption of Technology

The testing of technology by the ORPs have resulted in the adoption of these technologies in the ORP villages. However the degree of adoption was highly varying. Adoption of crops and varieties was fairly high. Alternate crops and varieties were adopted easily as their effects were visible and most often resulted in higher economic returns. Fertiliser, which again bring about visible changes, were adopted to a considerable extent eventhough they were not applied at the recommended dose due to resource limitations of the dryland farmer.

At Hoshiarpur, aldrin treatment for wheat against white ants was adopted widely. The land terracing, though involves higher investments, were accepted by the farmers as they increased the land value and allowed two crops to be grown.

The ORPs, besides testing the technology, also served as a source of feedback to the scientists at research station.

Conclusion

The five year experience of dryland ORPs has shown that adoption of technology depends on socio-economic condition of the farmer. It is easier to adopt the crop husbandry technologies, and for successful adoption extension support is essential. New strategies have to be developed for testing and spreading soil and water conservation technology. The contribution of individual recommendations and their interactions is worth understanding as it will help to impress the farmers. It is essential to educate the farmers on soil and water conservation as this is a pre-requisite for successful dry farming.

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OPERATIONAL RESEARCH: THE INDO-UK EXPERIENCE AT INDORE

S.R. RAJE

The Indo-UK Dry Farming (Operational Research) Project was started at Indore during 1974 with the UK collaboration. It was a multidisciplinary integrated approach on a catchment of the river Gambhir comprising about 2000 ha cultivated land covering three villages. The main objective was to test the dryland agriculture technology of black soils on the farmers fields to improve their farming and livestock by making the best use of soil and water resources. The other objectives of the project were to study the socio-economic operational constraints and the short-comings of the small plot research during the technology transfer and provide a feed back for research to make it more meaningful.

The present paper intends to discuss various aspects of field testing of dryland technology on a complete watershed basis which are useful to sharpen the focus on the planning and implementation of operational research on dryland agriculture in the eighties.

Soil and Water Resources

The soil being typical vertisol derived from basalt has high yield potential but is quite problematic. It cracks on drying and becomes difficult for cultivation. Under saturated condition it is almost impermeable and becomes highly erodable and gullies are formed particularly under clean cultivated or fallow conditions.

The annual average rainfall is 987 mm and is seasonal with several high intensity storms occurring even in drought years that cause waterlogging and erosion. About 90 per cent of the total rainfall is received during the months of July and August.

Problems at the Inception

1. Excess water in the fields during monsoon caused severe runoff resulting in soil erosion leaving washes and deep gullies.
2. Waterlogging was caused by runoff from hillocks and upper reaches of the watershed to lower fields. It was further accentuated by erroneous field bunding done earlier.

3. Major portion (68%) of the soil was left fallow during rainy season when abundant rain water was available. It was left without cover and occasionally cultivated by local plough and blade harrow which made it more vulnerable to erosion.

4. Varieties grown on 32 per cent of the cultivated area were long duration, low yielding local varieties of sorghum, black soybean, maize, pigeonpea, green gram and black gram whose yields were adversely affected during the early cessation of monsoon around the end of August.

5. Major post-rainy crops were wheat, chickpea and linseed. Traditional varieties of these crops were often affected due to drought, rust etc which caused low yields.

6. Only single crop in a sequence of rainy season cropping-fallow-fallow-post-rainy cropping rotation in alternate years was prevalent having a cropping intensity of about 103 per cent only.

7. Double cropping was not at all followed under rainfed conditions.

8. Selection of crop varieties was done mostly according to the domestic needs, ignoring the economic aspects.

9. Use of fertiliser was very much limited to irrigated crops only.

10. No plant protection measures were followed.

11. Labour and power resources with farmers varied with the size of holding. Family labour and bullock availability per ha were respectively 3.0 and 0.55 in smallest size group (up to 2 ha) and 0.3 and 0.1 in the largest size group (above 12 ha).

12. Agricultural implements were limited practically to traditional plough, blade harrow, blade hoe and two-type seeder.

13. The general health condition of cattle and buffaloes was unsatisfactory resulting in low draft power and low milk yields. This was further aggravated by high calf mortality and scarcity of forage.

Approach for Technology Testing

Conversion, to the maximum possible extent, of fallow area into cropped area in rainy season, growing wheat, chickpea or safflower on deep soils in post-rainy season and giving protective irrigation, were the strategies to make the best use of land and water resources, and to enhance and stabilise the crop production. Rainy season activities were given the main thrust so as to raise farm income and gain the farmers' confidence, and simultaneously preserve the soil resources from erosion.

The programme of field testing was planned to be implemented with integrated efforts in three phases. In the first phase, a centrally located area of about 400 ha was selected such that it covered some portion of all the three villages to include some farmers of each village as beneficiaries and was named as ITA-75. In the second phase (ITA-76) this area was increased to 1250 ha. In the third phase, it was further increased to cover the complete area of 1981 ha.

Frequent visits and close contacts were made to establish rapport individually and collectively in meetings with the farmers to sort out their resources and problems and to find out suitable solutions. This helped in gaining their confidence so needed in implementation of the programme.

To motivate farmers, following incentives were provided at the Project's cost :

- i. Demonstrations on improved seed and fertiliser in the first year
- ii. Demonstrations with supply of improved seed to those who purchased their own fertiliser during the second year.
- iii. Demonstrations with supply of improved seed on exchange basis to those purchasing their fertiliser requirements themselves during the third year
- iv. Only hybrid seeds and fodder sorghum seeds were subsidised during the fourth year where the farmer applied the basal dose of fertiliser in the presence of project staff.

The technical guidelines for each discipline to proceed with their approved programmes were as follows :

1. Land and Water Management

- i. Drain excess water from upper reaches away from fields
- ii. Provide over-all drainage of the area through grassed waterways along natural depressions
- iii. Provide safe inlets for field run-off into the water-ways through waste-weirs
- iv. Reclaim gullies and stabilise waterways through gabion structures
- v. Construct broad-base bunds in fields with excessive length and grade of slope.

2. Appropriate Land Use

- i. Bare hill slopes : Plant trees and grasses

- ii. Shallow soils with 3% slopes : Plant grasses and trees
With 0-3% slopes : Must be cropped in rainy season with short duration varieties/crops preferably on a grade
- iii. Deep soils with 3% slopes : Plant grasses
With 1-3% slopes : Double cropping or intercropping
- iv. With 1% slopes : Plant rainy season crops with land treatment or leave fallow for good post rainy crops

3. Cropping Programme

- i. Put the maximum possible area in rainy season
- ii. Replace the long-duration local varieties with short-duration high yielding improved crop varieties
- iii. Use recommended doses of fertiliser
- iv. Sow the crop in time according to weather and soil moisture, and establish a good stand
- v. Watchout for insect/pest attack and use plant protection measure when necessary
- vi. Harvest at physiological maturity stage of crops

4. Farm Machinery Programme

- i. Introduce appropriate tillage systems, matching with available power for timely operations
- ii. Introduce efficient seeding equipment for uniform stand and good plant population
- iii. Emphasise interculture in rainy season crop till advanced stage and introduce suitable improved implements
- iv. Popularise threshing equipment for timely harvest of crop and safe grain storage to minimise postharvest losses.
- v. Educate farmers on proper operation and maintenance of their improved machines.

5. Livestock Improvement

- i. Introduce improved methods of feeding and management of local cattle at first
- ii. Attend to common ailments of animals
- iii. Control contagious diseases of animals by prophylactic vaccination
- iv. Upgrade cattle through cross-breeding by artificial insemination and natural services by half-bred jersey bulls.

Field Testing of Technology

Technology suitable for dryland farming was tested through the multidisciplinary integrated approach. The work of testing the technology was launched on community basis where it benefitted the majority of the farmers directly or indirectly.

The following soil and water engineering structures were designed and constructed which were found to be successful in the area.

1. Storm drains : Storm drains were constructed for safe disposal of runoff water from upper reaches to water-ways to protect the fields on lower side from water-logging and erosion. Over 6 km storm drains were thus constructed and 400 ha land was protected from water-logging.

2. Waterways : Runoff water, diverted through storm drains and from adjoining fields of 100 ha, was safely disposed through a net work of waterways designed and constructed for this purpose.

3. Stabilisation of storm drains and waterways : Improved grasses like *Pennisetum pedicellatum*, *Cenchrus* spp., *Dicanthium* spp. etc were tested for grassing of storm drains and waterways.

4. Waste weirs : Sixteen out of fifty nine waste weirs were constructed with reverse filters for safe drainage of runoff water from adjoining fields to the water ways.

5. Gabion structures : These structures were constructed and tested on the problematic vertisols for the first time in India for bed stabilisation of waterways and control of gullies. Twenty such gabion structures controlled secondary gully formation in adjoining fields of 400 ha.

6. Bank protection : Diversion boxes and spurs constructed from boulders and galvanised wire mesh and stone pitching were tried for protection of sensitive points of banks of waterways and were found to be effective.

7. Mini-gabion structures : Drop structures of 60 cm height constructed with reverse filter by using boulders in wire mesh as crest and loose boulders for side walls were tried and found to be quite safe if maintained properly.

8. Control of washes : Loose boulder structures (drop structures and chute structures) were tried for control of washes in the fields. Drop structures of 60 cm were found to be safe for a catchment upto 15 ha.

9. Construction and rejuvenation of tanks : A tank of 20 ha cm capacity was designed and constructed on community land for harvesting runoff from 16 ha catchment where gabion structures were safely used to form inlet and outlet. An old breached tank of 35 ha cm capacity was rejuvenated with the consent of concerned farmers to collect runoff from 60 ha catchment by construction of a cement masonry spill way and strengthening of banks. It was experienced that rejuvenation of old tanks is easier than construction of new tank provided the concerned farmers could be taken into confidence. The harvested runoff water in the tank had recharged the ground water and benefitted the adjoining wells used for irrigation.

Technology That Did Not Work

Graded contour field drains failed due to inability of farmers to cultivate along the contours.

Broad based bunds were not popular because the field boundaries created hinderance. They required more care and maintenance.

Temporary pole and brush structures to control the bank slumping were tried but were not successful due to quick decaying of the Acatia brush, thefts of the poles and limited height of crest.

Cropping Programme :

Dryland agriculture technology was tested and transferred to farmers fields and the results are summarised as follows .

1. Increase in area under rainyseason crops : The data presented in Table 1 show that the area under rainy season crops increased progressively over years.
2. Introduction of improved/high yielding varieties: The long duration local varieties have been replaced by short duration improved and high yielding varieties of different crops (Table 2).

Table 1 : Area under rainy season crops in project area (ha)

Crops	1975-76	1976-77	1977-78	1978-79	1979-80
Sorghum	173	169	320	320	368
Soybean	85	127	119	228	341
Maize	84	80	115	105	75
Rainy season cultivated area (%)	38	54	68	68	66

Table 2 : Replacement by high yielding varieties

Crops	Traditional varieties	Improved/high yielding varieties
Sorghum	Desi, piliaola	CSH-5, CSH-6
Soybean	Kalitur	T-49, JS-2, Ankur, JS-72-44
Maize	Satha	Chandan-3, Ganga-5
Wheat	Pissi, Malwi	Narmada-4, Narmada-112
Chickpea	Desi	Ujjain-21, Ujjain-24

3. Increase in double cropped area : Normally double cropping is practised where irrigation is available. But with the transfer of technology to farmer's fields the double cropped area under rainfed conditions progressively increased with the time (Table 3).

Table 3 : Area under double cropping (ha)

	1975-76	1976-77	1977-78	1978-79	1979-80
Area	190	850	1050	980*	1224**
Percentage	40	68	52	49	61

* Late rains during September 1978 did not occur

** Rains occurred during November 1979

4. Increased use of fertiliser : Fertiliser consumption increased tremendously by the introduction of improved varieties which respond to fertiliser application (Table 4).

Table 4 : Fertiliser use (kg of nutrient)

Nutrients	1974-75	1975-76	1976-77	1977-78	1978-79	1979-80
N	4260	15931	14714	16630	46126	42309
P ₂ O ₅	3326	10630	10832	10845	51624	60372
K ₂ O	712	648	840	840	1241	4708

5. Adoption of intercropping : Intercropping was readily popularised as it has been a traditional theme of Indian agriculture. Amongst the improved high yielding varieties, sorghum (CSH-5) + pigeonpea (Hy. 2), sorghum (CSH-6) + soybean (T-49), sorghum (CSH-5) + soybean (JS-2), sorghum (CSH-2) + soybean (T-49), sorghum (CSH-6) + soybean (JS-2), and maize (Ganga-5) + soybean (JS-2) combinations became popular.

6. Increase in average yields of crops : Average yields of improved varieties of crops increased considerably (Table 5).

Table 5 : Increase in average yield (q/ha) of main crops

Crops	Variety	1975-76	1976-77	1977-78	1978.*	1979.**
Sorghum	Local	4.0	4.2	4.3	2.5	3.4
	Improved	6.8	17.7	20.3	18.5	10.0
Maize	Local	3.8	4.2	5.5	3.5	2.6
	Improved	1.6	13.0	15.0	13.5	5.7
Soybean	Local	4.2	4.2	6.7	5.5	4.4
	Improved	5.6	9.3	8.6	9.7	6.3

* September rain did not occur

** Late rains in November

7. Increase in cropping intensity: The cropping intensity increased considerably by adoption of appropriate technology of dryland agriculture, in comparison with average of Indore district (Table 6).

Table 6 : Cropping intensity of project area and of Indore district

Cropping intensity (%)	1973-74	1974-75	1975-76	1976-77	1977-78	1978-79	1979-80
Project Area	103	108	114	131	140	131	139
Indore district	110	110	113	114	116	112	114

8 Technology tested but not accepted by the farmers :

- i. Dry sowing was tried for two years to increase area under hybrid sorghum but due to uncertain rains and temperature fluctuations, the germination was affected adversely. Hence, farmers did not show any interest in the next year.
- ii. The farmers were reluctant to accept the crops like groundnut and cotton, probably due to high cost of seed, susceptibility to diseases and pests, high cost of cultivation, occurrence of frost and low returns.
- iii. Sunflower and safflower were completely new in the project area. Thorny nature, susceptibility to diseases (wilting) and pests (aphids), heavy bird damage and absence of marketing facility were the reasons for farmers' reluctance.

Farm Machinery and Implements

Machines and implements were identified and collected from different black soil areas of India and UK and tested. Those found useful and accepted by farmers are as follows :

1. Bullock drawn tillage implements

- i. Kenmore tool bar with tillage attachments (UK)
- ii. Mould board ploughs
- iii. Indore Ridger
- iv. Disk harrows
- v. Agricart with tillage attachments

2. Bullock drawn sowing machines
 - i. Kenmore with SISIS seeder (UK)
 - ii. Agricart with Ebra Planter (France)
 - iii. MP seed-cum-fertiliser drill
 - iv. Till planter
 - v. Krishi Seva toolbar with sowing attachment

3. Manually operated implements
 - i. Jalo cultivator (UK)
 - ii. Rotary hoe
 - iii. Maize sheller

4. Machines modified and developed
 - i. Maini modified five tynes seed drill
 - ii. Indo-UK seeder (attachment unit)

A farm activity survey has shown human labour constraint in periods of sowing, weeding and harvesting of crops in the project area.

Animal Husbandry

Animal husbandry programme was divided into four parts to facilitate the implementation : 1. Cultivation of fodder crops, 2. Pasture improvement, 3 Treatment of miscellaneous land and 4. Breeding and health coverage. The field testing of the technology was implemented as follows :

Cultivation of fodder crops : The area under fodder crops was 9 ha with maximum yield of only 200 q/ha in the beginning. The area increased to 60 ha with the maximum production of 740 q/ha of sorghum Vidisha 60-1 (single cut) fodder.

Pasture improvement : It was decided to rejuvenate the degraded pastures and to encourage the farmers to plant improved grass species in lands having 3 per cent slope. During the process 13 legume and 12 non-legume species were tested and 5 species of each were found to be quite promising (Table 7).

Treatment of miscellaneous lands : Miscellaneous lands, viz storm drains, bunds, waterway banks, gully banks, barren hillocks and common lands, were

treated with appropriate plant and grass covers with the objectives of making their best use by way of stabilisation and reducing runoff. Thus, substantial yields of forage from fodder-fuel-fruit trees and grasses on 7 ha of land was obtained.

Table 7 : Promising pasture species

Grasses
Non-legumes
Pennisetum pedicellatum
Dichanthum arestratum
Cenchrus ciliaris
Rhodes grass
Chrysopogon fulvus
Legumes
Stylosanthes hamata
Stylosanthes scabra
Stylosanthes humilis
Clitoris ternatia
Desmanthes virgatus

Breeding and health coverage : To improve the milch quality of the local cattle, cross breeding by Jersey by artificial insemination was carried out and 98 crossbred calves were produced. A campaign was launched to castrate maximum number of local scrub bulls. Activities like pregnancy diagnosis, treatment of reproductive disorders, minor ailments, and prophylactic vaccination against contagious diseases were also incorporated and services were rendered in the village itself.

Other Activities

Recycling of organic matter : In order to utilise the cattle dung catering to the needs of fuel and obtaining decomposed manure, ten bio-gas plants were installed by the farmers. Because of the high cost of construction material, more number of plants could not be installed.

Composting : Training was arranged for men and women from different farm-families for proper utilisation of waste material from their farms. Farmers after training, have dug 18 compost pits and started making compost.

Economic Assessment

The project's stress on more rainy season cropping to fully utilise the abundant moisture and to provide an efficient soil-cover during the monsoon season have been fully realised by farmers. They are now financially better off. More than half of their over-due institutional loans have been paid back. During the tenure of this project, additional employment potential have been created. The human and bullock labour utilization increased by over 50 per cent. An additional employment of over 24 thousand man days and over six thousand bullock pair days were generated between 1974-75 and 1978-79. The cropped area under five important crops, viz sorghum, maize, white soybean, wheat and chickpea increased by 12 per cent whereas the production increased by 69 per cent. The data on investment and income are presented in Table 8. The net income increased substantially.

Table 8: Increase in investment and income (Rs/ha)

	1973-74	1974-75	1975-76	1976-77	1977-78
Investment	493	388	576	608	690
Gross income	656	560	1005	1127	1292
Net income	165	172	429	519	602

Constraints Encountered

A. Land and water Management

1. Execution of land and water management practices on catchment basis requires the consent of a number of farmers and a single odd nut can disrupt the whole programme.
2. The unsuccessful programmes of bunding executed earlier by the Soil Conservation Services of the Department of Agriculture had created suspicion in the minds of farmers and made them non-responsive in the beginning.
3. Farmers, in general did not realise that plant cover or establishment of grass in washes, etc was the cheapest and most effective method of erosion-control.
4. An enormous damage is caused by nomads and stray cattle to the land and water management works and their stabilisation may require investment on fencing.

5. Auctioning of gullies by the Mining Officer for mining makes gullies more unstable and difficult to reclaim.
 6. Nowhere could the farmers be shown an ideal management of land and water under farmers' own conditions on catchment basis before this project was launched.
 7. Proven technology on land and water management was not available as there is no soil and water conservation research centre for black soil with high rainfall.
 8. Farmers are very much attached to their land and do not relish any change in their boundary even if no loss of land is involved. They also do not like run off water from their neighbour's fields being drained through their own.
 9. Farmers, in general, are not convinced of the utility of farm ponds for various reasons and prefer open dug wells to farm ponds.
- B. Crop Husbandry
1. Dependence on outside agency for seed supply as there is no seed organisation in the state.
 2. Seed of hybrid varieties of various crops is costly.
 3. Lack of marketing facility for new cash crops.
 4. Poor capacity of the farmers to store seed.
 5. Unless grown on large areas by all the farmers together, early varieties suffer a severe bird attack.
 6. Still there is lot of ignorance amongst the farmers regarding new varieties, balanced use of fertilisers and selecting crop varieties according to the suitability of land.
 7. Training the farmers in "groups" arranged at the Farmer's Training Centre is not effective.
 8. Big farmers cannot adopt labour intensive technology as they have much less bullock power and human labour available per unit area of their holdings.
 9. Failure of co-operatives and other such institutions.
 10. Extension efforts at present is too thin to do any good.
 11. Lack of crop-weather intelligence organisation.

12. Lack of agro-based industries in villages.
13. Limitations of small plot research at intermediate operational research is lacking.

C. Farm Machinery

1. Ignorance of the farmers in knowing the optimum draft capacity of animals resulting in less output.
2. Deficiency of draft animals is more acute in peak seasons of sowing and intercultivation
3. Labour deficiency affects the sowing, intercultivation and harvesting operations adversely.
4. High prices of improved implements discourage farmers from purchase.
5. Lack of know-how of complicated machinery reduces the output and durability and increases the cost of production which comes in way of popularisation.
6. Lack of suitable low cost tools/implements simple in design and easy to operate.

D. Livestock Improvement

1. Competition between food and fodder production amongst the small farmers
2. Pitiable condition of the common grazing lands and of individual's pasture lands.
3. Practices of stall feeding of animals almost lacking.
4. Presence of scrub bulls in villages released on grounds of religion.

E. Pasture Improvement

1. Lack of restrictions on over-grazing as grazing land is limited.
2. Enormous expenditure on fencing the pasture land.
3. Non-availability and higher cost of the seeds of perennial legume grasses and improved fodder crops.
4. Lack of patience to take up long term programme for improved fodder crops.
5. Financial incapability to invest to improve the pasture land.
6. Dependence on outside agencies for seed supply.
7. Small holdings are barely sufficient to fulfil the needs of grains and thus fodder cultivation is ignored.

F. Tree Plantation

1. Lack of successful trials on miscellaneous as well as on farmers' fields has led to non-popularisation.
2. Disinterest of the farmers to take long term programme.

G. Breeding and Health Coverage

1. An-Oestrus condition due to malnutrition as a major handicap.
2. Disinterest of the villagers to detect heat of their cow.
3. Inability of the farmers to impose post-insemination restriction on the inseminated cows.
4. Inherent poor productivity of local cows leads to disinterest of the farmers.

H General Constraints

1. Lack of confidence in extension agency among the farmers.
2. Unhealthy attitude of farmers towards development projects, eg being subsidy minded and extravagant on social customs.
3. Workshops on production technology are not attended by grassroot level extension workers and most of the useful information is lost in the long channel involved.
4. Activities of the Department of Agriculture are input supply oriented rather than education oriented.

Feed Back for Research

One of the objectives of the project was to serve as a direct source of feed back to the research based on its experience. The gaps in various fields where problem oriented research is needed are listed below :

1. Land and water Management
 - i. Collection of site specific information on various factors affecting run-off peaks and volumes and erosion relationship.
 - ii. Studies on land and water management measures.
2. Crop Husbandry
 - i. Refinement of technology for aberrant weather.
 - ii. Technology for low and variable monetary inputs for marginal and small farmers.
3. Fodder Improvement

Identification by research of suitable varieties of cultivated fodders, perennial grasses and trees for fodder-fuel and fruits.

4. Farm Machinery and Implements

- i. Identification of bullock drawn seed-cum-fertilizer drill suitable for post-rainy crop
- ii. Single bullock harness suitable for farm operations in black soils.

Conclusion

The Indo-UK Dry Farming (Operational Research) Project has brought about many desired changes improving the rural farming and livestock of the Project area. Most of the available dryland agricultural technology has been successfully tested and transferred under farming conditions with the integrated efforts of soil and water engineering, cropping programme, farm machinery-implements, animal husbandry and agricultural economics. The experience has also brought forth a number of suggestions on feed back research for modification or development of appropriate dryland agricultural technology.

6

SUMMING UP

THRUST IN THE EIGHTIES

R. P. SINGH

In the Seventies, the research programmes of the All India Co-ordinated Research Project for Dryland Agriculture have led to certain justifiable claims of research achievements. The noteworthy achievements are .

- i. The most efficient high yielding crops and varieties for different agro climatic environments of India have been identified.
- ii. Agronomic production practices optimum sowing time, weed control, and economic fertiliser recommendations have been worked out for all the major dryland crops.
- iii. Productive intercropping systems have been identified for increasing crop productivity per unit area. Mostly, these systems comprise a cereal and a pulse.
- iv. Where double cropping is feasible, appropriate combinations of rainy and post-rainy season crops have been found out, with emphasis on pulse or oilseed crop in the sequence cropping systems.
- v. In case of delayed onset of rainy season, alternate (short-duration) varieties of recommended crops or alternate crops to be sown are known for various dryland regions so that dryland farmers are now assured of reasonable productivity even in unfavourable seasons and complete failure of a crop in a region can be prevented.

As a result of these findings and consequent recommendations to the farmers, significant increase in crop productivity is now possible in Indian drylands. Taking into considerations the future requirements and gaps in existing knowledge in dryland agricultural crop production, the research information generated during the Seventies by the Dryland Project and the papers presented at the Seminar have formed an excellent basis for thorough discussion amongst dryland scientists for identifying research programmes to decide which are to be continued and which should receive more emphasis. Two broad areas of research have been identified for major thrust in the Eighties. They are: 1. Alternate land use systems for maximising income, and 2. Water harvesting and reuse for enhancing crop production.

Research programmes requiring emphasis are as follows :

1. Alternate Land Use Systems

- i. Collection, introduction and evaluation of different tree and shrub species as suitable components (for fodder, fuel, timber or fruit as the case may be) of the systems for various agro-climatic zones of the country.
- ii. Optimum spacing for enhancing yields of both the components of a system.
- iii. Genetic improvement in tree characteristics for maximising the productivity of a system.
- iv. Improvement in genetic potential in yield as well as quality of grasses and legumes.
- v. Suitable management practices for efficient establishment and utilisation of pasture for enhanced animal production.
- vi. Incorporation of suitable pasture legume in the cropping system for exploitation of symbiosis of crop, pasture and animal relationships.
- vii. Long term comparative studies on the economics of alternate land use systems vis-a-vis dryland crops.

2. Water Harvesting

- i. Intensification of studies on reduction of percolation and evaporation losses in the small tanks and dug-outs.
- ii. Detailed experiments on use of stored rainwater for improving crop production through life saving or supplemental irrigation, increasing cropping intensity in rainy season cropping areas, pre-sowing irrigation for post-rainy crops, growing fruit trees cash crops in a limited area and/or fish culture.

3. Crops

A. Crop Production

- i. Refinements in intercropping systems for increasing Land Equivalent Ratio.

- ii. Refinements in sequence cropping system for increase in total productivity of the system.
- B. Crop Protection**
- i. Control of parasitic weed *striga*
 - ii. Control of perennial weeds, *Cyperus* and *Cynodon*
 - iii. Studies on integrated crop protection (weeds, insects and diseases)
- C. Crop Improvement**
- i. Evaluation of crop varieties that meet the requirements of intercropping and sequence cropping systems
 - ii. Evaluation of under utilised drought tolerant pulse crops (cluster beans, moth bean and horse gram) for improvement in yield.
 - iii. Breeding for determinate cultivars of pulse and oilseed crops of appropriate duration to match the growing season and to fit in as component of cropping system of a region.
- D. Crop Physiology**
- i. Influence of dryland environment on leaf area and yield component relationships in dryland crops.
 - ii. Genotype and environmental factors on flower production, abscission, fruit set, fruit abortion and final number of pods and grains per unit area in grain legumes.
 - iii. Knowledge on inter-relationship amongst the processes of symbiotic N fixation, photosynthesis and growth for increasing legume productivity
 - iv. Studies on pre-sowing seed treatments and morphophysiological characteristics for better adaptation of crops to environmental stress
- 4. Fertiliser Use Efficiency**
- i. Fertilizer response studies in :
 - a. crops of greater commercial value
 - b. intercropping systems
 - c. sequence cropping systems with legume component
 - d. conjunctive use of manures, fertilisers, crop residues etc.

These studies need be super-imposed on moisture conservation and data on soil moisture and nutrition levels should be collected.
 - ii. Efficient use of fertiliser under rainy and post-rainy conditions.

iii. In specific areas, nutrients other than NPK have become limiting, especially for some crops. This requires survey and experimentation for suitable recommendations.

iv. Use of bio-fertilisers

5. Soil, Water and Climate Resources

i. Long term experiments for assessing the effects of moisture conservation, nutrient supply and cropping systems on soil environment and crop productivity

ii. Over-all effects of mulches on temperature, soil moisture and organic enrichment

iii. Water use by crops in relation to edaphic characteristics

iv. Water balance calculations using rainfall and potential evapotranspiration data in conjunction with soil water storage

v. Evaluation of soil cracking in vertisols and stoniness in alfisols in relation to their water balance characteristics

vi. Studies on surface water storage on recharge of ground water

vii. Development of rainfall-runoff models for small agricultural watersheds

viii. Collection of micro-climatological data on a few defined cropping systems.

6. Agricultural Implements

i. Development of prototypes of more efficient tools and implements for :

a. Pre-sowing tillage

b. Line-sowing

c. Inter-row weeding

d. Fertiliser placement

e. Harvesting

f. Post-harvest operations

ii. Development of suitable hand-operated or bullock drawn sprayer for application of herbicides and other plant protection chemicals

iii. Improvement in pulling power of bullocks with available implements (harness, yokes, design of harrow blades etc)

iv. Tillage and energy studies for various cropping systems

v. Studies on minimum tillage

7. Agricultural Economics, Operational Research and Training

i. Detailed economic evaluation of the operational research trials at farmer's fields and impact on dryland farming

ii. Watershed approach in the operational research projects

iii. Yield gap analysis and identification of socio-economic, operational and institutional constraints in the transfer of technology

iv. Relevant research at the research farms on the basis of feed-back provided from the Operational Research Projects

v. Providing consultancy and training support to the development agencies.

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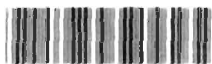
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