P0269 — T376

" INFLUENCE OF MULCHES AND IRRIGATION ON MOISTURE DEPLETION, NUTRIENT UPTAKE AND YIELD OF RABI SORGHUM (*Sorghum bicolor* (L.) Moench) "

by

MAROTI GANGADHAR LANDE
M Sc (Agri)

T376

A THESIS SUBMITTED TO THE

MARATHWADA AGRICULTURAL UNIVERSITY, PARBHANI

FOR THE DEGREE OF

Doctor of Philosophy

in

SOIL SCIENCE

DEPARTMENT OF AGRICULTURAL CHEMISTRY
AND SOIL SCIENCE
MARATHWADA AGRICULTURAL UNIVERSITY,
PARBHANI.

1979

" INFLUENCE OF MULCHES AND IRRIGATION ON MOISTURE DEPLETION, NUTRIENT UPTAKE AND YIELD OF RABI SORGHUM (*Sorghum bicolor* (L.) Moench) "

BY

MAROTI GANGADHAR LANDE

M.Sc.(Agri.)

A THESIS SUBMITTED TO THE

MARATHWADA AGRICULTURAL UNIVERSITY, PARBHANI

FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

IN

SOIL SCIENCE

DEPARTMENT OF AGRICULTURAL CHEMISTRY

AND SOIL SCIENCE

MARATHWADA AGRICULTURAL UNIVERSITY

P A R B H A N I

1979

CANDIDATE'S DECLARATION

I hereby declare that thesis or part thereof has not been submitted by me to any other University or Institution for a degree or diploma.

PARBHANI

Jan. 16th, 1979

(M.G. Lande)

Dr. S.B. Varade,
M.Sc.(Ag.); Ph.D.
Head, Department of Soil
Science and Agril. Chemistry,
M.A.U. Parbhani.

CERTIFICATE

This is to certify that the thesis entitled " INFLUENCE OF MULCHES AND IRRIGATION ON MOISTURE DEPLETION, NUTRIENT UPTAKE AND YIELD OF RABI SORGHUM (*Sorghum bicolor* (L.) Moench) " submitted to the Marathwada Agricultural University, Parbhani for the award of degree of Doctor of Philosophy in Soil Science, embodies the results of a bonafide research carried out by Shri. M.G. Lande, under my guidance and supervision and that no part of the thesis has been submitted for any degree or diploma.

The assistance and help received during the course of this investigation have been fully acknowledged.

PARBHANI

Dated: Jan. 1979.

(S.B. Varade)
Guide

ACKNOWLEDGEMENTS

With a sense of high resolve and reverence, I wish to place on records of my deep sense of gratitude to Dr. S.B. Varade, Head, Department of Soil Science and Agril. Chemistry, Marathwada Agricultural University, Parbhani and Chairman of my advisory committee for his valuable guidance and constant encouragement throughout the progress of this investigation and for his help in preparation of the manuscript.

I express my deep sense of appreciation to my committee members Dr. C.P. Ghonsikar, Professor of Agril. Chemistry and Soil Science, Dr. G.U. Malewar, Reader in Soil Science and Agril. Chemistry for their valuable suggestions and constructive criticism during preparation of the manuscript.

My sincere thanks are also due to K.R. Pawar, Associate Dean, College of Agriculture, Parbhani for providing the laboratory facilities for analytical work.

I also extend my thanks to Dr. U.C. Upadhyay, Dean, Faculty of Agriculture, Marathwada Agricultural University, Parbhani for giving facilities and constant encouragements in completing this task.

I reckon with gratitude the assistance and encouragement given by Shri. A.N. Giri, Shri.P.R.Bharambe and all my friends throughout this study.

To my wife, Mangala and family, I am most grateful for the patience and encouragement extended during the completion of this investigation.

I am also grateful to Dr. V.S. Khuspe, Vice-Chancellor, M.A.U. Parbhani, for providing facilities in completing this task.

PARBHANI

Dated: Jan. 16th, 1979

(M.G. Lande)

CONTENTS

Chapter	Title	Page
1.	INTRODUCTION	1
2.	REVIEW OF LITERATURE	6
	2.1 Effect of various mulches on soil water conservation.	7
	2.2 Effect of mulches on plant growth and yield attributes.	12
	2.3 Effect of mulches on yield of sorghum and other crops.	14
	2.4 Effect of irrigation on sorghum growth and yield.	18
	2.5 Effect of soil moisture on nutrient accumulation in plants and grains.	22
	2.6 Movement of water in soil.	28
	2.7 Evaporation loss as influenced by mulches.	31
3.	MATERIALS AND METHODS	34
	3.1 Field experiments for studying moisture content at various depths for different intervals.	34
	3.2 Experimental soils.	35
	3.3 Experimental layout.	38
	3.4 Moisture distribution study.	39
	3.5 Field experiments for studying effect of moisture conserved through different mulches and irrigation.	40
	3.6 Seed material and sowing.	41
	3.7 Biometric observations	42

Chapter	Title	Page
	3.8 Chemical studies	45
	3.9 Interpretation of data.	45
4.	RESULTS AND DISCUSSION	47
	4.A Moisture relationship	47
	4.A.1 Moisture profile as influenced by various treatments.	47
	4.A.1.1 Moisture depletion.	48
	4.A.1.2 Soil moisture transmission coefficients.	53
	4.A.2 Water flux.	56
	4.A.2.1 Water flux under control, straw mulch and polyethene sheet.	57
	4.A.2.2 Effect of irrigation and irrigation+straw mulch	57
	4.A. Discussion	58
	4.B. Growth components.	62
	4.B.1. Mean height of plants.	62
	4.B.2 Mean number of functional leaves per plant.	63
	4.B.3 Mean leaf area per plant.	63
	4.B.4 Stem girth.	64
	4.B.5 Number of internodes per plant	64
	4.B.6 Total dry matter per plant	64
	4.B.7 Post-harvest observations	65
	4.B.7.1 Length of earhead	65
	4.B.7.2 Breadth of earhead	65

Chapter		Title	Page
	4.B.7.3	Weight of earhead	66
	4.B.7.4	Test weight.	67
	4.B.7.5	Yield of grain per plant.	67
	4.B.7.6	Yield.	67
	4.B.8	Nutrient content in straw at various growth phases of sorghum as influenced by mulch and irrigation.	72
	4.B.9	N,P,K and protein content of sorghum as influenced by mulch and irrigation.	69
	4.B.10	Uptake of N,P and K in fodder and grain as influenced by mulch and irrigation.	74
	4.B.	Discussion.	75
5.		SUMMARY AND CONCLUSIONS	85
6.		LITERATURE CITED	i-xxiv
		APPENDIX	I-IV

LIST OF TABLES

No.	Title	Page
1.	Mechanical and chemical composition of the experimental soils.	46
2.	Description of mulch and irrigation treatments of the field experiment.	38
3a.	Seasonal available moisture content of a root zone under various treatments during 1975-76.	49
3b.	Seasonal available moisture content of profile under various treatments during 1976-77.	50
4.	Water flux as affected by various treatments at different depths.	56
5.	Influence of mulch and irrigation on growth of rabi sorghum.	63
6.	Influence of mulch and irrigation on yield contributing characteristics of rabi sorghum during 1976-77.	66
7.	Yield of rabi sorghum as affected by different treatments during 1975-76 and 1976-77.	68
8.	Nitrogen content in straw at various growth phases of sorghum as influenced by mulch and irrigation.	70
8b.	Phosphorus content in straw at various growth phases of sorghum as influenced by mulch and irrigation.	71
8c.	Potassium content in straw at various growth phases of sorghum as influenced by mulch and irrigation.	72
9.	N,P,K and protein content in grain sorghum as influenced by mulch and irrigation during 1976-77.	73
10a.	Correlation of leaf area and earhead characteristics with yield.	77
10b.	Correlation of N,P and K uptake with fodder and grain yields (1976-77).	80

LIST OF FIGURES

No.	Title
1a.	Maximum and minimum temperature during the experimental period 1975-76 and 1976-77.
1b.	Rainfall during experimental period 1975-76 and 1976-77.
1c.	Variation of maximum and minimum relative humidity during the experimental period 1975-76 and 1976-77.
2.	Moisture retention characteristics of black soil.
3.	Available water depletion during growth of sorghum crop.
4a.	Volumetric water content versus depth under five treatments at four different times for 1975-76.
4b.	Volumetric water content versus depth under five treatments at four different times for 1976-77.
4c.	Seasonal trends of volumetric water contents at four depths under five treatments for 1975-76.
4d.	Seasonal trends of volumetric water contents at five depths under five treatments for 1976-77.
4d. (contd.)	Seasonal trends of volumetric water contents at five depths under five treatments for 1976-77.
5.	Unsaturated conductivity as a function of water content.
6.	Soil water diffusivity versus soil moisture content.
7a.	Yield of rabi sorghum as influenced by mulch and irrigation during 1975-76.

No.	Title
7b.	Yield of rabi sorghum as affected by mulch and irrigation during 1976-77.
8.	Uptake of nitrogen, phosphorus and potassium in straw plus grain as influenced by mulch and irrigation.
9a.	Nitrogen content, uptake and yield of grains of rabi sorghum during 1976-77.
9b.	Phosphorus content, uptake and yield of grains of rabi sorghum during 1976-77.
9c.	Potassium content, uptake and yield of grains of rabi sorghum during 1976-77.
	Plan of layout.

LIST OF SYMBOLS

$D\theta$	Moisture diffusivity of soil cm^2/day.
K	Unsaturated hydraulic conductivity cm day^{-1}
θ	Soil moisture content.
θV	Volumetric moisture content (cm^3 of water cm^{-3} of soil).
α	Root absorption.
ψ	Soil moisture potential.
C	Control treatment. (T_1)
SM	Straw mulch treatment (T_2).
PM	Polyethene mulch treatment (T_3).
I+SM	Irrigation + straw mulch treatment (T_4).
I	Irrigation alone (T_5).

1. INTRODUCTION

Sorghum (*Sorghum bicolor* (L) Moench) is one of the important food and fodder crops. Sorghum is grown extensively in India covering an area of about 18.5 million hectares out of which 1.00 million hectare is under irrigation. In Maharashtra State, sorghum stands first covering an area of about 6.44 million hectares with 3.34 million hectares in rabi season and rest in kharif. An average yield of sorghum during kharif is 956 kg/hectare (with the advent of hybrids the yield of kharif has increased fairly well) while during rabi it is only 524 kg/ha. There is no breakthrough in increasing the yield of rabi sorghum which at present is poor.

Rabi sorghum is grown largely on the deep black soils (Usterts) on stored water received through rainfall. Usterts of Parbhani (deep black) are characterised by high clay content, dominated by montmorillonitic (smectite) clay (Malewar, 1976). These soils are potentially more productive and have high cation exchange capacity, moisture retentive capacity and have Ca^{++} as predominant cation. In all soils as moisture is removed by plant use and evaporation, shrinkage cracks develop, to some degree. However, the cracks developed in black cotton soils, are very large and extensive. Evaporation from these large shrinkage cracks has been believed to contribute significantly to

the total evaporation (Nagar, 1977). But little quantitative information is available. Soils are muddy and sticky in the wet season, and they are hard when they are dry. These soils are called self mulching soils which are most difficult to manage.

Though annual rainfall varies from 550 to 1550 mm with an average of 830 mm the wide fluctuations in respect to commencement and cessation of rains results in fluctuations in rainless/drought periods as well. Average rainfall received during the start of rabi season is 211.93 mm in September and the total water requirement of rabi sorghum is 340.10 mm (Kadam et al. 1978).

Sorghum cultivar M 35-1 which is grown on larger area during rabi has two peaks of moisture utilization during its life cycle (Pharande et al. 1973). First peak coincides with elongation stage while the second corresponds to the ear emergence and grain formation stage.

In years of low rainfall, carry over moisture of subsoil and recharged surface soil moisture from rainfall is not sufficient to meet water needs of the crops. Thus it leads to the creation of a dry zone in profile, thereby subjecting plants to water stress in later stages which ultimately results into low yields. As well as the crop

suffers heavily because of the moisture stress (at later stages of crop growth) caused by erratic winter rains.

Under limited moisture conditions, farmers generally do not use optimum quantities of fertilizer which causes limited nutrient supply and becomes one of the major constraint in increasing yield of sorghum.

In order to increase crop production of rabi crops in the dryland zone, we will have to adopt better management of rain water, incorporating better crop management practices. Moisture conservation practices such as contour bunding, scooping, graded ridges and furrows, conservation bench terraces, stuble mulch farming, surface mulching and vertical mulching have been suggested. Experiments at Sholapur indicate convincingly that the use of surface mulch increases yield of sorghum from 30 to 100 per cent over control.

The practice of applying mulches to soil is possibly as old as agriculture itself (Jacks _et al_. 1955). Mulches are used for various reasons, but water conservation and erosion control are undoubtedly the most important for agriculture in dry regions. Other reasons for mulching include soil temperature moderation, soil nutrient effects, soil salinity control, soil structure improvement, quality control and weed control.

With the advent of irrigation under Jayakwadi,Purna and other projects it has become possible to apply water at critical stages during rabi season. It is essential to find out the response of sorghum to irrigation.

There is a considerable gap on the effect of mulches or irrigation on yield of sorghum in this region and no data is available on movement of water within the soil under crops. The movement of water within and out of soil is of prime interest since it determines the availability of soil moisture. Sound information concerning movement of water in soil is essential for wise planning and management of irrigation project. It is equally essential, in unirrigated areas to develop control of soil desiccation, loss of moisture due to excessive evaporation and fissuration by shrinkage process in vertisol.

Evaporation of water from soils and the conditions which influence evaporation rate are important facets of the problem involving soil and water relations. Evaporation from the soil is limited either by the energy available at the soil surface for vaporisation or by the ability of the soil to conduct moisture to the surface. Evaporation from the soil may be assumed to be equal to the net radiation at the soil surface unless the evaporation is

limited by capillary flow to the surface. The capillary flow in turn is a function of the soil water content.

The present investigation was conducted in order to bridge the gap in our understanding on the response of rabi sorghum to soil water conditions as brought about by evaporative demands under various types of mulches, irrigation and irrigation plus mulch. The following are the aims and objectives in brief:

1. Response of rabi sorghum to mulches.
2. Efficiency of mulching material.
3. Influence of irrigation on yield of rabi sorghum.
4. Transmission efficiency as influenced by moisture conservation.
5. Uptake and content of nutrients as affected by mulch and irrigation.

...

2. REVIEW OF LITERATURE

In order to function as a medium for plant growth a soil must contain some water. Water in soil is one of the most important factor, that governs the yield of any crop to a large extent. Water availability in soil and management also determines largely crop production. Limited supply of water or deficit of water caused due to either low rainfall or uneven distribution of precipitation affects plant growth and yield severely. Much of precipitation that is received is lost by way of runoff and evaporation. Also some water that enters the soil evaporates before a crop is planted.

While precipitation is limited and erratic, and the evaporation potential is high, good yields could be obtained if most precipitation that occurs in dry regions would be effectively conserved and used for crop production.

Sorghum is the important food crop of Marathwada region and is grown mostly on stored water during rabi. Comparatively rainfall received during this period is very small and therefore in later stages of the crop the soil moisture becomes highly critical. Several methods are operated either alone or in combination to conserve moisture and increase water use efficiency. Out of the methods, mulching is used or if irrigation is available then irrigation is applied at particular stage.

Information on effect of irrigation and mulching on yield, nutrient uptake, water availability and movement in cropped field in vertisol in general and, in black cotton soil of semi-arid regions of Deccan plateau of India in particular, is very limited. The present review of literature, therefore attempts to understand the phenomena of water conservation due to mulching and effect of extra conserved moisture on yield and nutrient uptake. The literature review are grouped under the following heads:

2.1 Effect of various mulches on soil water conservation.

2.2 Effect of mulches on plant growth and yield attributes.

2.3 Effect of mulches on yield of sorghum and other crops.

2.4 Effect of irrigation on sorghum growth and yield.

2.5 Effect of soil moisture on nutrient accumulation in plants and grains.

2.6 Movement of water in soil.

2.7 Evaporation loss as influenced by mulches.

2.1 Effect of various mulches on soil water conservation.

Numerous studies have been conducted to determine the influence of mulches on soil water storage. Field experiments using mulches have shown beneficial effects of mulches in conserving and economising water use by crops ranging from 10 to 50 per cent, depending upon the crop in which it is used, type and colour of mulches,

type of soil, rainfall and amount of water added, wind velocity and temperature of both air and soil (Ali and Prasad, 1975; Bansal _et al_. 1971; Chowdhary and Chatterjee, 1967; Dheshi _et al_., 1964; Dixit and Agrawal, 1971; Mandal and Vamadevan, 1975; Misra, 1965; Patil _et al_. 1972; Prihar _et al_. 1968; Rajput and Singh, 1970 and Singh _et al_. 1967). Many different materials like organic mulches (Stover, straw, rice husk, saw dust etc.), light coloured and light reflecting mulches like aluminium foils, black, gray and transparent mulches and especially petroleum products in the form of emulsion, or sheets like polythelene, have been used, but the most widely, researched materials are plastic films and organic mulches.

2.1.1 Effect of polyethene mulch.

(Includes polyethene, polyvinyl chloride and similar films, but the term 'plastic' will be used hereafter)

In Europe, Linden (1963), Manescu and Ciofu (1970) and Pusztai (1963) reported increased soil water contents due to plastic films, there being increases up to 32 per cent (Manescu and Ciofu, 1970). In North America,plastic films resulted in higher water contents than bare soil in most cases (Army and Hudspeth, 1960; Lippert _et al_.1964; Liptay and Tiessen, 1970; Willis _et al_. 1963) but Schales (1964) reported a lower water content,apparently

due to the film preventing infiltration. The higher water contents in soil resulted from reduced evaporation, induced infiltration, reduced transpiration by weeds, or a combination of these factors (Austin, 1964; Hanks, et al. 1961; Linden, 1963; Lippert, et al. 1964; Liptay and Tiessen, 1970; Willis, 1962 and Willis et al. 1963). The effectiveness of plastic films depends upon the amount of surface covered (Austin, 1964; Lippert et al. 1964; Willis, 1962; Willis et al. 1963). Rajput and Singh (1970) reported the efficiency of different mulches in conservation of soil moisture in cotton and concluded that during rainless pre-monsoon period of 1962 polyethene mulch conserved soil moisture to the extent of 55 per cent and peteroleum mulch to the extent of 15 per cent.

2.1.2 Effect of straw mulch.

Although plastic films generally resulted in higher water contents and reduced evaporation as compared to bare soil, they are relatively expensive and difficult to manage, especially under large scale field conditions for low value crops. Consequently less expensive and more readily applicable materials have been sought.

The greatest amount of research with mulches involved crop residues and other plant waste products (straw, stover, rice husk, leaves, corn cobs, saw dust, wood chips etc.). These materials are cheap and often readily

available and they permit water to enter the soil readily. When maintained at adequate levels, these materials resulted in increased water contents and reduced evaporation. (Adams, 1966; Mannering and Meyer, 1963; Moody et al.1963; Jone et al. 1969; Wiegand et al. 1968; Paul Unger,1976; Bansal et al. 1971; Hanks and Woodruff, 1958).

Similar type of trend for increase in water content due to application of straw mulch was observed in India (Prihar et al. 1968; Masood Ali and Rajendra Prasad,1974; Mandal and Vamdevan 1975; Sachan et al. 1977). Rajput and Singh (1970) reported that straw mulch conserved soil moisture to the extent of 40 per cent. In Maharashtra, Umrani et al. (1973) reported that even application of 5 tonnes grass (Dichantium annulatum) mulch per hectare between the rows of sorghum crop, was effective in conserving soil moisture during the growth periods.

However, residue production in dry regions often is inadequate to result in substantial water conservation. Even where most or all residues from dryland crops were maintained on the soil surface, through stubble mulch, tillage and chemical fallow, rather dismal water storage often occurred (Black and Power, 1965; Harris, 1963; Johnson and Davis, 1972; Mathews and Army,1960; McCalla and Army, 1961; Unger, 1972; Wiese et al. 1967; Zingg and Whitfield, 1957). Major reasons for the poor water storage

were the production of inadequate residues to enhance infiltration and suppress subsequent evaporation in complete weed control with tillage and chemicals.

Significant increases in water storage resulted from the application of a cotton bur (Gossypium hirsutum L.) mulch in a loam soil (Koshi and Fryrear, 1971). Each higher mulch level (5.6, 11.2 or 22.4 tons/ha) resulted in increased water storage over control. Storage efficiencies ranged from 36 to 46 per cent with no mulch to 66 to 80 per cent with 22.4 tons mulch per hectare in 1968 and 1969 respectively.

The studies of Bond and Willis (1969,1970 and 1971) although conducted under laboratory conditions with soil columns initially wetted to a given level, suggest that water storage can be increased where residue levels are adequate to reduce initial evaporation and thus permit water from precipitation to penetrate to greater depth. However large amounts of surface residues are required to obtain water savings over an extended period.

The effectiveness of various other materials for use as mulches has been investigated. Those materials have favourably influenced soil water content and evaporation in many cases. Materials studied included gravel, stones, desert pavement, bituman and similar granular material,

and manure. (Adams, 1966; Doncer, 1964; Lyford and Qashu, 1969; Mustafaev 1964; Nerpin and Pakshina, 1965; Qashuba and Evans, 1967; Unger,1972).

2.2 Effect of mulches on plant growth and yield attributes.

One of the most critical periods in the life cycle of a plant is the period of germination, emergence and seedling establishment. Viable seeds, must be placed in a favourable seed-soil environment with respect to water supply, temperature and aeration in order to favour germination. After germination the seedlings must emerge and become established. Due to their small size and tenderness, seedlings can easily be adversely affected by an unfavourable environment. Mulches can aid germination, emergence and seedling growth by moderating or improving the soil and aerial environment to which the seeds and seedlings are subjected.

Higher soil water contents and reduced evaporation were major reasons for improved germination, emergence and seedling growth due to mulches (Army et al. 1961;Kowsar,et al. 1969; Mustafaev, 1964; Sole, 1966 a,b; Takatori et al.1971; Unger, 1971 b; Wann, 1969). Straw, peteroleum, gravel, stones and plastic films increased germination and early growth, but the plastic films had to be slit or removed for continued growth.

Higher soil temperatures due to mulches also improved germination, emergence and seedling growth (Adams, 1962; Dhesi et al. 1964; Miller and Bunger, 1963; Mustafaev, 1964; Sale, 1966 a,b; Willis et al. 1957). The higher temperatures either alone or in combination with higher water contents, were also effective in promoting later plant growth and hastening maturity (Bowers, 1968; Linden, 1963; Miller, 1968; Miller and Bunger, 1963; Mustafaev, 1964; Sale 1966 a,b; Takatori et al. 1964; Willis, et al. 1957).

Lower and more constant temperature which was maintained by surface mats after irrigation than any other material was effective in improving early potato (Solanum tuberosum L.) growth (Dhesi et al. 1964). In other cases lower temperatures due to mulches reduced germination and early plant growth (Allmaras et al. 1964; Burrows and Larson, 1962; Moody et al. 1963; Vanwijk et al. 1959). However, later growth sometimes was better on mulched than on bare soil due to improved water conditions under the mulch (Moody et al. 1963).

In India, Ravindranath et al. (1974) conducted a trial on sorghum at Agricultural College Farm Rajendranagar, Hyderabad. The data of trial clearly indicate the magnitude of mulch effect on growth, yield and yield attributes. Mulching caused significant increase in plant growth characters namely plant height, leaf area and

root-shoot dry matter production and also increase yield attributes such as number of grains and weight of grains per ear etc. Mandal and Vamadevan (1973) also reported that higher yields of barley with mulches was associated with higher number of earheads and spikelets than control plots.

2.3 Effect of mulches on yield of sorghum and other crops.

A majority of the reports indicated higher yields when crops were grown with rather than without mulches, with most materials being effective in increasing yields. (Adams, 1965,1970; Austin, 1964; Bowers,1968; Carter and Funning, 1965; Dixit and Agrawal, 1971; Evenson and Rumbaugh, 1972; Griffin et al. 1966; Harrold et al. 1959; Lehne, 1961; Linden, 1963; Macmillan and Millette,1971; Moody et al. 1963; Onchov, 1960; Puszta, 1963; Sale 1966 a,b; Taylor et al. 1964; Willis et al. 1963; Zakharov and Semikina, 1964). Although the yield increases generally were moderate at times substantial increases were reported (Moody et al. 1963; Puszta, 1963; Sale, 1966 a; Zakharov and Semikana, 1964), which ranged from about 50 to 300 per cent.

Yield response to mulches, although primarily related to soil water and temperature, was also affected by better plant population, (Sale, 1966 a,b; Takatori et al.1971) reduced root-rot (Lavee, 1963) and reduced soil salinity

(Carter and Funning, 1965; Heilman *et al.* 1968). Undoubtedly, mulch effects on soil structure, nutrients, microbial activity, root distribution etc, also played an important role in the higher yields.

Reduced crop yields due to mulches have been related to some specific condition, generally soil temperature. Corn apparently is very sensitive to low temperatures under a straw mulch early in the season when temperature normally limits plant growth. (Allmaras *et al.* 1964; Burrows and Larson, 1962; Moody *et al.* 1963; Van-Wijk *et al.* 1959). The adverse effects of low temperatures were reflected in lower yields. (Allamaras *et al.* 1964; Burrows and Larson, 1962; VanWijk *et al.* 1959). A straw mulch in Alberta (Canada), however delayed maturity and reduced wheat yields due to lower soil temperature and increased soil shading and occasionally due to lower nitrate production (Anderson and Russel, 1964).

A gravel mulch in Texas (U.S.A.) reduced grain sorghum yields, but the yield reduction was not due to lower soil water contents or lower temperatures. Water was adequate and a straw mulch resulted in even lower temperature than the gravel, but yields with straw were higher than with gravel. Plants on the gravel mulch plots, appeared nitrogen deficient, but the soil nitrogen content was not determined. Lower soil nitrate nitrogen may have

been a factor, but the quality and intensity of reflected radiation from the gravel may also have been factors contributing to the reduced yields (Adams,1965). Apparent nitrogen deficiency symptoms were also observed by Unger (1971 b) for forage sorghum grown in gravel mulched plots. The N deficiency symptoms disappeared after application of ammonium nitrate.

Irrigated crops such as wheat and sorghum or paddy which are grown on extensive areas produce large quantities of residue, when maintained as a mulch on the surface, resulted in increased water storage during fallow when weeds and volunteer crop plants were controlled with herbicides (Music et al. 1973; Unger et al.1971) or for increasing yields of subsequent dryland crops (Unger and Parker, 1974).

In India also the effect of mulches on yields of sorghum and other crops is reported by some of the scientists. Kolandaiswamy et al. (1967) compared the yields of sorghum and cotton under (a) hand removal without disturbing the soil, (b) weeding and hoeing, (c) applying straw mulch and (d) two sprayings of peteroleum resin water emulsion as a liquid mulch,were compared in irrigated and rainfed sorghum whereas treatment (d) 2 sprayings of peteroleum resin water gave the highest

grain and straw yields from the irrigated crops. The higher yield of rainfed cotton resulted from (d) where the irrigated crop gave similar yields from all treatments. Kashyap et al. (1967) recorded that yields have been increased by different mulches except in case of saw dust which indicated adverse effect on the yield and growth of onion. Among all the mulches used paddy husk seems to be more effective than other mulches in providing favourable conditions to the crop. Moreover it is cheap and easily available and also easy in handling. Since it is not easily decomposed, it does not result in undue increase in the bacterial population which competes with the crop plants for N as in case of saw dust and paddy straw. Umrani et al. (1973) in trial using sorghum grown under dryland condition reported that application of 5 tons grass mulch per hectare was effective in increasing yields of sorghum up to 1.73 tons grain, 6.39 tons fodder per hectare compared to 1.36 and 5.43 tons per hectare respectively on plots given 3 inter row cultivation instead of mulch.

Masood Ali and Rajendra Prasad (1974) concluded that mulches (straw, dust and no mulch) significantly increased soil moisture and consequently barley yield. They further reported that straw mulch was better than all other mulches and reflectants. Similar results were obtained by Mandal and Vamadevan (1973) on barley and gram wherein they found

that two mulches viz. husk and straw mulch were statistically similar in effect. Higher yield of barley with mulches was associated with higher number of earheads and spikelets than control plots. Dahiya and Kanwarsingh (1977) reported that mulching in pearl millet proved beneficial and increased grain production by 9.4 to 2.8 per cent with an extra income of Rs 10.10 to 92.30 per hectare. The similar trend was observed in case of yield attributes, but the variation was not significant.

2.4 Effect of irrigation on sorghum growth and yield.

It is observed that the crop yields are adversely affected when stress is created due to evapotranspiration. Wherever irrigation is available the water deficits are controlled through irrigation application.

Yield of sorghum increased more greatly than that of wheat with increasing evapotranspiration, the latter crop being much affected by stage of growth and maturity by the irrigation from the late boot to the early heading stages of growth. (Jensen and Musick, 1960). Irrigation when 10 per cent available moisture remained in top 2 feet of soil was as effective in increasing grain yields as irrigation when 50 per cent available moisture remained in top 2 feet of soil. It also increases the average daily rate of moisture use which was higher with irrigation than

without, but there was no difference between the low and high levels of irrigation (Brown *et al.* 1964). Griffin *et al.* (1966) in an experiment examined the effect of two irrigation scheme common to the high plains and the effect of plastic film, asphalt film and asphalt coated paper, soil covers on grain sorghum yield and soil moisture efficiency. Conventional irrigation at physiological plant growth stages did not insure maximum yields. Maximum yields and consumptive use and minimum water use efficiency were obtained by maintaining the soil profile above 50 per cent available moisture with this high soil moisture condition. Exceptionally good yields, minimum consumptive use and water use efficiency were achieved by eliminating soil surface evaporation with a complete plastic film. Partial soil surface covers of plastic film, asphalt film and asphalt coated paper proved equally effective in reducing surface evaporation and increasing water use efficiency. Reduced yields were obtained from plots where the grain sorghum plants were allowed to show visual signs of moisture stress. Under semi-arid conditions, Plant *et al.* (1969) studied the effect of soil moisture regime and row spacing on grain yield of B 610 sorghum (*sorghum bicolor*) in 1964 and 1965. They concluded that the highest grain yield in each year resulted from three

irrigations or from two irrigations when the second was applied between heading and milk stage. The latter gave highest water use efficiency, one irrigation applied at heading was better than a single application made earlier or later. Irrigation increases sorghum grain yields over unirrigated plots by 23 per cent and also herbage production was affected similarly (Vega G. 1972).

The soil water potential when allowed to drop to -12 to -13 bars during one stage of growth only while being maintained above -0.7 bar during the remainder of growing seasons, this level of soil water deficit resulted in yield reduction of 17, 34 and 10 per cent when the deficit occurred during the late vegetative to boot stage; the boot through bloom stage, and the milk through soft dough stage respectively (Lewis _et al_. 1974).

Fuchring and Finkar (1974) reported that increased frequency of irrigation as determined by evaporation range from a class A weather pan resulted in reduction of yield. In irrigation trials at cloby Kansas in 1970-73 on medium textured soils, grain sorghum yields ranged from 100.7 bu/acre for plots irrigated pre-sowing only (irrigated in autumn to fill the soil profile to field capacity 6 ft deep) to 111.6 bu/acre for plots irrigated with 4.6 in.water in July and 4.6 in. in August. Differences in yields

T376

between plots receiving same irrigation in July were small indicating that high soil moisture content is important as grain sorghum goes into the reproductive stage of growth. Delaying irrigation until August reduced yield. Total water used ranged from 17.5 in. for plots irrigated pre-sowing only to 27.1 in.for plots irrigated pre-sowing and in July-August and September at 4.6 in./month. Water use efficiencies ranged from 222.lb grain/inch (pre-sowing + July + August + September) to 329 lb/inch (July only). The results indicated that the highest water use efficiency in North-West Kansas would be achieved at a total seasonal water use of 17-18 in. (Bordovsky and Hay,1975). Yield and water use efficiency of grain sorghum under high frequency irrigation decreases mainly by water deficit at booting and flowering stages. Irrigation at or before germination was more valuable than a similar amount of water applied later if soil water content was <150 mm (Howell, 1975). Inuyama _et al_. (1976) reported that water deficit decreased growth and deficit during booting decreased grain yields to a greater extent than deficit during vegetative growth. Deficit treatments which decreased the number of grains per ear did not decrease 1000 grain weight. It was concluded that the critical period for drought stress in grain sorghum was from the boot stage until flowering.

2.5 Effect of soil moisture on nutrient accumulation in plants and on uptake of grains.

It is a well recognised fact that moisture availability affects the uptake and content of nutrient in plants. Therefore nutrient content of grain as influenced by soil moisture is briefly reviewed.

2.5.1 Nitrogen uptake and content.

The changes which are brought about in nitrogen metabolism of plants due to water shortage do not seems to be well defined. However it is the general observation that total uptake of nitrogen in plants increases in presence of adequate soil moisture (Power et al. 1961; Pearson, 1963; Raming and Roades, 1963; Fabricius and Naleweja, 1968; Doss and Scarsbrook, 1969; Sharma, 1969). At the same time it is also observed that percentage nitrogen content of plant decreases with increase in moisture (Humphries, 1962; Mathur and Singh, 1967; Mehrotra et al. 1970), Shaw (1952) stated that under conditions of adequate nutrient supply, plants that are limited in growth by a relatively low level of soil moisture would have a higher content of nutrients than plants under comparable fertility but not limited in growth by soil moisture. Gates (1957), Canbell et al. (1960), Coic et al. (1964), Luebs and Laag (1967) reported

that the concentration of nitrogen increased in drier soils. On the other hand, Hernado et al. (1968) reviewed the effect of soil humidity on the mineral nutrition of plants and concluded that the concentration of N in the plant increases with the increase in soil moisture. Similarly increase in total nitrogen in presence of higher soil moisture is attributed to increased dry matter production (Sharma, 1969).

Growth ratios under dry and wet conditions suggested that high soil moisture reduces N absorption or N availability at low levels of nitrogen and the inhibitory effect of high soil moisture on N uptake is overcome by application of higher rates of nitrogen (Thomas and Heilman, 1967).

Moisture stress at a particular stage has a definite relation to nitrogen content of the plant. Storrier (1965) noted that when irrigation in wheat was applied after anthesis the decrease in N content was normally shown by maturing wheat crop and irrigation during jointing and milking stages increased the uptake of mineral nitrogen by the crop. While the distribution of N in grain and straw depends on the fertilizer application and the time of drought (Sowinski, 1966). He found that drought at shooting stage increased the nitrogen content in grain.

Eck and Musick (1977) determined nutrient concentration, dry matter and nutrient accumulation patterns for stressed and unstressed grain sorghum (Sorghum bicolor (L) Moench) plants. Plant water stress reduced N concentration in leaves and increased its concentration in stalks and heads. Concentration of NO_3 -N was not affected. Rates of accumulation of nutrients were near constant from 40 days after planting until flowering and then slowed down. Stress effect on nutrient accumulations was related to portion of total quantity of nutrient that had been accumulated at time stress occurred. Nitrogen was affected more than potassium and calcium. In India Kashyap et al (1968) while working on effect of mulches cited that the available nitrogen in soil was found to increase due to mulching (Chate, 1961; Awal, 1962; Jytoshi and Bhalla 1967; Dubey, 1961). Joshi and More (1969) reported that the N content decreased in the stems and leaves and increased in the grain with age. Nitrogen uptake by leaves and stems increased up to 105 days after sowing subsequently there being decline. Rajgopal (1969) conducting experiment on ragi reported that total nitrogen significantly decreased with decreased soil moisture stress at all stages of plant growth and also in the grain. Further he reported that ratio of protein N to total N increased with decreased soil moisture stress and was highly significant at the seedling

and flowering stages and in the grain. The quality of grain as judged from the content of nutrients was poor from the plants grown under moisture regimes of less than 50 per cent as compared to those obtained from plants grown in more moisture.

2.5.2 Effect of moisture on protein content.

It is generally accepted that moisture stress leads to accumulation of soluble nitrogen compounds with a concomitant decrease in protein content (Stocker,1960). Josulski et al. (1963) reported that the grain protein content of wheat was affected mainly by soil moisture and was highest under periodic wilting. Hutcheon and Paul (1966) demonstrated that protein content in spring wheat could be effectively controlled by N supply and moisture stress. In the protein range 11 to 16 per cent it was possible to increase protein and yield concurrently,protein content higher than 16 per cent were obtained only where a growth factor such as soil moisture was below optimum for maximum yield, Vanseelhorst (1911), Steward and Greaves (1909), Thatcher (1913), Neiding and Synder (1922,1924,1926), Greaves and Carter (1923), Greaves and Nelson (1925), Hopkins (1935), Clements (1937), Scharrer (1939), Simirnoya and Bogordskii (1949), Tombesi and Fortini (1951), Fernadez and Laird (1959), Pohjanchemmo and Heinonen (1960), Austin and Miri (1961), May et al.(1962)

Jensen and Sletten (1965), Sichkar and Volkova (1965), Wood and Fox (1965), Pulfi and Juhasz (1968) and Terman et al. (1969) have recorded increase in protein under drought conditions and decrease in protein but increase in yield when moisture was available to plants through irrigation or rains. Thus it can be said that protein content in plants varies inversely with moisture. Upadhyay and Varade (1978) also reported that application of sprays of simazine increased the N and protein contents significantly.

2.5.3 Effect of moisture on phosphate-nutrition.

Although the phosphate ion may accumulate in plants limited in growth by low soil moisture supply (Miller and Dubey, 1925; Janes,1948), there is also evidence that plants so affected may have a relatively low content of phosphate (Thomas et al. 1942), Emmer, 1936). Thus the effect of soil moisture on phosphate nutrition is far less consistent than that observed for nitrogen or potassium. This seems to be indicative of the wide variation among soils in their fixing power for phosphorus as conditioned by soil moisture content. Miller and Duley (1925) grow corn on fertile siltloam from an alluvial bottom along the Missouri River. These soils were conducive to phosphate accumulation under low moisture supply.

Thomas et al. (1942) studied tomatoes presumbly grown on a Hagerstown silty clay loam that was differentially fertilized and Haddock grew beets on a calcareous soils Millville silt loam, these two experiments yielded evidence that the phosphate content of plants was reduced by diminishing the soil moisture supply. It is quite probable that these various soils differ considerably in their fixing power for phosphate and that this variation is related to the observed effects of soil moisture supply on phosphate content of plants.

Eck and Musick (1977) reported that plant water stress for grain sorghum (Sorghum bicolor (L)) reduced phosphorus concentration in leaves. At flowering plants had accumulated 72 per cent of their total P.

Kashyap et al. (1968) quoted that the available P in soil was found to be increased due to mulching (Chate,1961; Awal, 1962; Jyotshi and Bhalla 1967; Dubey, 1961).

2.5.4 Effect of moisture on potassium nutrition.

Wimmer et al. (1947) studied nutrient content of two varieties of sugarbeets at different soil moisture levels and reported that one variety showed the conventional decrease in potassium content with decreasing moisture supply, whereas the other variety showed the reverse trend under the same conditions. If this observation is

verified it will indeed be a remarkable case of specificity in ionic entry between two varieties of a given crop.

Eck and Musick (1977) reported that concentration of K, Ca and Mg were not affected by moisture stress or supply. They further stated that at flowering plants had accumulated 90 per cent of their total potassium in plants. Potassium and calcium uptake is affected less than other nutrients like N, P and Mg.

2.6 Movement of water in soil.

2.6.1 Liquid transfer in soil.

Many of the concepts of liquid flow in saturated and unsaturated solids were largely implicit in the work of Buckingham (1907). Richard (1931) developed a general partial differential equation describing isothermal liquid flow in porous media taking water potential (Ψ) instead of moisture content (θ) as the dependent variable.

Childs andCollis-George (1948) utilized Darcy's law in deducing a concentration dependent diffusivity function and derived a general partial differential equation describing isothermal liquid flow in porous media when ψ was a single valued function of θ. The capillary conductivity can be evaluated from water retention data. The basic concepts of this procedure were given by Childs and Collis-George (1950), Marshall (1958) and

Millington and Quirk (1960,1961,1964). Childs and Collis-George (1950) proposed a method of calculation of capillary conductivity based on the probability of inter connection of water filled pores of varying sizes. Philip and deVries (1957); deVries (1958) and Philip (1958) formulated a general theory of liquid movement in porous media under temperature and moisture gradients. They separated the liquid flux components due to moisture gradient, temperature gradient and gravity.

$$q\ liq = -DT\ liq \nabla T - D\theta\ liq \nabla \theta - Ki \quad .....(i)$$

Where,

Dt liq and Dθ liq are thermal and isothermal liquid diffusivities. The liquid flux as influenced by the moisture gradient and was discussed in detail by Klute (1952 a,b) and Philip (1955,1957).

2.6.2 Water flux in liquid phase.

The general equation for calculating total soil moisture flux (Jw) as influenced by temperature and moisture gradients (Philip 1957, 1958; deVries, 1958; Cassel, 1969 and Jackson, 1974,1975) is given by:

$$Jw = -D\theta\ l \nabla \theta - D\theta\ v \nabla \theta - DT\ l \nabla T - DT\ v \nabla T - Ki \quad ....(ii)$$

Where,

Dθ l is isothermal liquid diffusivity, Dθ v is isothermal vapour diffusivity, DTl is the thermal liquid diffusivity and DT v is the thermal vapour diffusivity.

2.6.3 Capillary conductivity and soil water diffusivity.

Rechards and Moore (1952) and Ogata (1957) stated that " at low suction the capillary conductivity value progressively increases with depth, which is consistent with the fact that the water retentivity and specific surface increases with depth. "

According to Childs and Collis George (1950) the flow of water in unsaturated media is a function of θ v or ψ , Philip (1957) explained this phenomenon as follows "a) The total cross sectional area available for flow decreases with θ.

b) The largest pores are emptied first as θ decrease since the contribution to permeability per unit area varies as the square of the pore radius, K may be expected to decrease much more rapidly than θ.

c) As θ decreases, the change of water occurring in pores or wedges isolated from the general three dimensional net work of water films and channels increases. Once continuity breaks down, there can of course, be no flow in the liquid phase. "

Gardner (1958) found that the diffusivity, which was a function of water content, varies over a wide range of values also but not quite to the extent that the conductivity did.

Dhanpal and Varade (1976) reported that in black cotton soil, the soil water diffusivity attained the maximum value at initial moisture content but decreases with further increase in the moisture content.

2.7 Evaporation loss as influenced by mulches.

Evaporation of soil water from wetted soil may be characterised by three stages (Bond and Willis, 1969; Lemon, 1956; Philip, 1957).

Hanks and Woodruff (1958) and Hanks et al. (1967) indicated that wind has a definite influence on water vapour transfer in soil, gravel and straw mulches. The water vapour transfer was greater in gravel and straw mulches than in soil. The increase in wind velocity from 0 to 25 miles/hour affected increase in evaporation rates 2 to 6 times in soil mulches and 10 to 15 times in straw mulches.

Hanks (1958) showed direct relationship between porosity and water vapour flow rates and inverse relationship between depth and dry soil and water vapour flow rates was observed.

Benoit and Kirkham (1963) conducted an experiment to investigate the comparative effectiveness of a dust, a ground corn cob and gravel mulch in inhibiting the evaporation of soil water under different radiation

condition and air movement. They showed that dust mulch proved to be the least effective.

Moody et al. (1963) observed that the wheat straw mulch effect on soil temperature, soil moisture, and yield of the corn crop. Soil temperature at 4 inch depth was lower throughout growing season under the mulch conditions.

Bond and Willis (1969,1970) measured the evaporation with time under uniform daily evaporative potential as influenced by various rates of surface residue. They found that evaporation rate was decreased with increasing residue rates, during the initial constant rate of drying stage and after prolonged falling rate of drying,cumulative evaporative losses were nearly equal irrespective of surface residue. A linear relationship was observed by log plotting the duration of first stage drying versus first stage evaporation. Willis (1962) found a linear relationship between initial evaporation rate and percentage of surface area covered. Measurement of cumulative evaporation showed that moisture conservation is better when surface cover provided is continuous rather than as strips.

Ekern (1967) observed that the plastic mulch was much better vapour barrier than the paper mulch when less than 60 per cent of the surface area was covered.

As the soil moisture reaches the field capacity the rate of water loss falls to about 1/3rd that of the pan evaporation.

Qashu and Evans (1967) showed that application of mulch in a 10 cm strip reduced evaporation at 10 cm water table below the surface. The soil layers under the mulch and at the 2.5 cm depth retained higher water content.

Adams (1966) observed that 2 inch straw mulch and the dioctadecyl diamethyl ammonium chloride (DDAC) treated soil reduced evaporation significantly from 0 to 6 inches depth during a hot rainless 10 days period. He emphasized equality of effectiveness of straw, gravel and DDAC treated soil mulch in evaporation control over a period of one month.

Greb (1966) applied 1120, 2240 and 3360 kg/ha of wheat straw equivalent to 30, 60 and 90 per cent of soil surface coverage and observed that respectively 16, 33 and 49 per cent water losses were reduced from a wet soil surface by solar distillation in a period of 20 days, as compared to soil without straw mulch.

...

3. MATERIALS AND METHODS

This chapter is divided into two parts. The field experiment on effect of various mulches and irrigation on moisture content at various depths for different intervals under rabi sorghum for two years is included in Part I and Part II deals with the field experiments for studying effect of different mulching and irrigation treatments on growth characteristics and yield of rabi sorghum.

Part I

3.1 Field experiments for studying moisture content at various depths for different intervals.

3.1.1 Site description.

The experiments were conducted on the experimental farm of the Marathwada Agricultural University, Parbhani. The farm is situated within the Godavari drainage basin in the central part of India between 76°45' East longitude and 19°16' North latitude.

3.1.2 Climate.

The area comes under semiarid to sub-humid monsoon type of climate. The average rainfall of this region is 830 mm, mostly concentrated during the monsoon months from June to October. Maximum rainfall occurs in the month of July and August. The annual mean of maximum temperature ranges from 29.1 to 41.1 °C and minimum temperature ranges

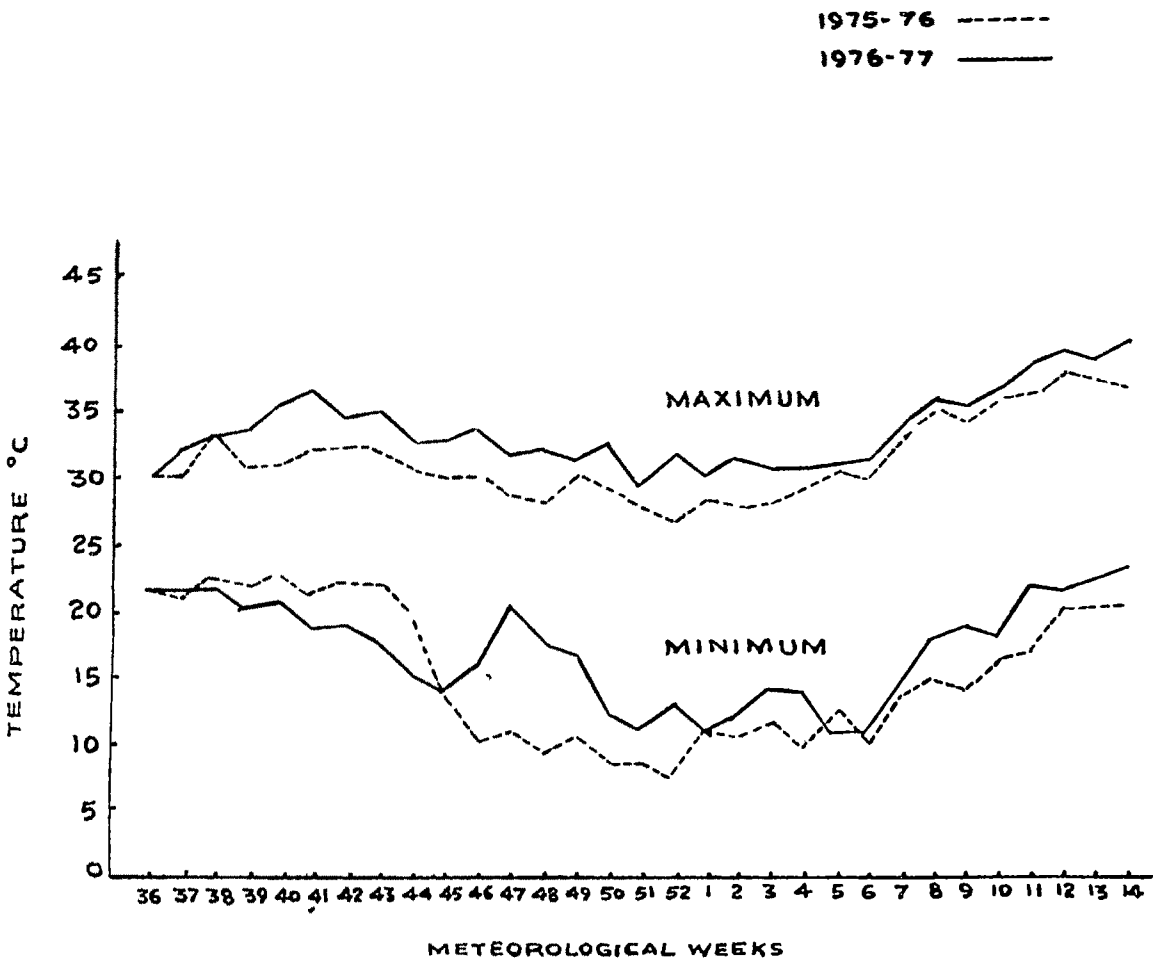


FIG 1a MAXIMUM AND MINIMUM TEMPERATURE DURING THE EXPERIMENTAL PERIOD 1975-76 AND 1976-77

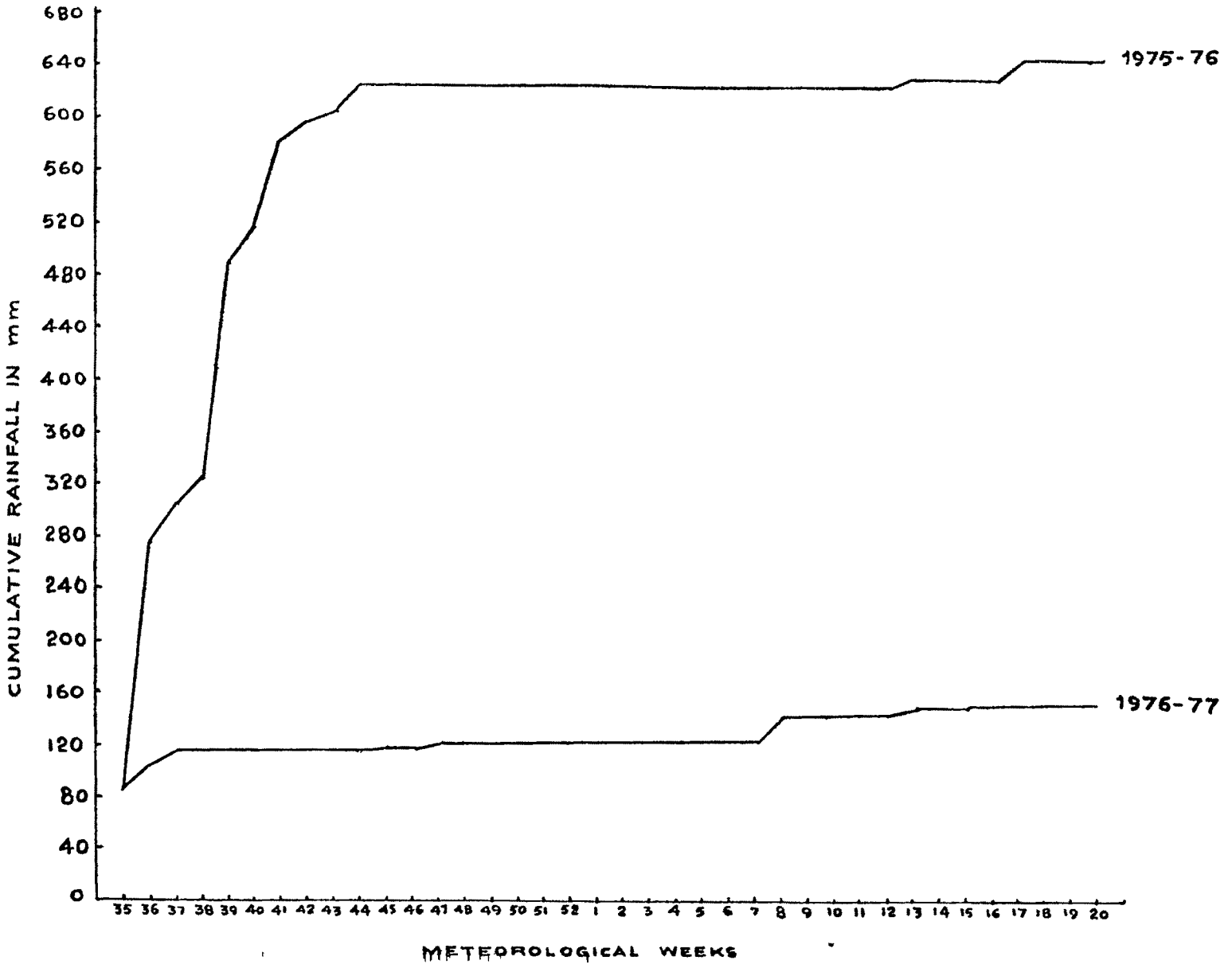


FIG 1 b RAINFALL DURING EXPERIMENTAL PERIOD 1975-76 AND 1976-77

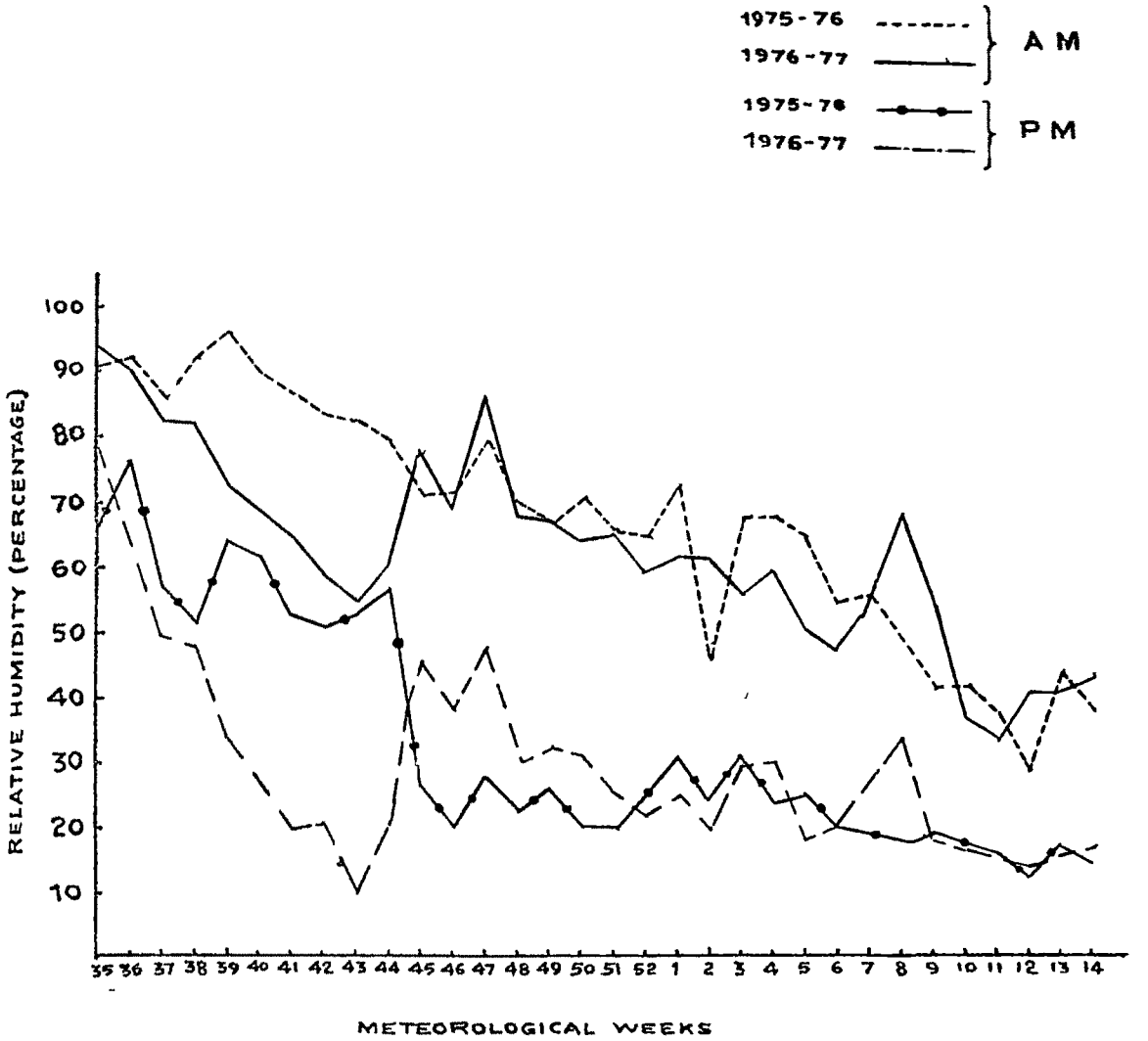


FIG 1c VARIATION OF MAXIMUM AND MINIMUM RELATIVE HUMIDITY DURING THE EXPERIMENTAL PERIOD 1975-76 AND 1976-77

from 21.1 to 24.5 °C in May and December respectively. The mean minimum and maximum relative humidity varies between 25 to 63 per cent and 85 to 96 per cent respectively. The variation of ambient temperature and rainfall distribution and humidity during the experimental period are given in Fig. 1 a,b,c.

3.2 Experimental soils.

3.2.1 Parbhani series.

The black soils on which the experiment was conducted are characterised by dark brown (10 YR 3/3) to very dark greyish brown (10 YR 3/3) colour, high montmorillonitic clay content, low organic matter content, high coefficient of expansion and shrinkage and deep cracking during dry season. The soil is formed from basaltic material orginating through volcanic eruption (Srinivasan et al. 1969). The rocks are compact, very hard, greyish in colour and subjected to spherodial weathering under the influence of seasonal fluctuation in temperature.

As per the 7th approximation the black soils in Deccan plateau are classified under the order 'vertisol'. On the basis of the length of period during which cracks remain open the black soils are grouped under suborder 'Usterts'. Further the black cotton soils are placed under the great group of 'chromusters' as the most chromas are more than 1.5 (Srinivasan et al. 1969).

3.2.2 Profile characteristics.

3.2.2.1 Parbhani 1 series.

Parbhani series consist of moderately well drained, deep to very deep soils, dark brown to very dark greyish brown, silty clay calcareous soils occurring on nearly level to undulating mid lands.

The description of the profile horizons(+) is given below:

Horizons	Depth(cms)	Description
A 11	0-23	Dark brown to very dark greyish brown (10 YR 3/3),clay,0.5 to 1.0 per cent irregular lime coated concretions, moderate, fine granular; blocky,hard,friable, sticky,abrupt wavy boundary.
A 12	23-41	Dark brown (10 YR 3/3),clay with 0.5 to 1.0 per cent irregular,lime coated concretions,moderate,medium angular blocky,hard; friable; very sticky, common,fine tubular,pores, fine and medium inped and exped roots,abrupt wavy boundary.
A 13	41-61	Dark brown (10 YR 3/3),clay, 0.5 to 1.0 per cent irregular,lime coated concretions,coarse,angular blocky, very plastic continuous, thin, slickensides, few, fine, tubular pores, few gradual boundary,very fine inped and exped roots.
A 14	61-119	Dark brown (10 YR 3/3),clay, 0.5 per cent irregular lime coated concretions of about 2 to 5 mm, angular blocky,continuous,thin slickensides,very sticky and plastic,gradual boundary.
A 15	119	Very dark greyish brown(10 YR 3/3), clay,coarse,strong,angular blocky, prominent parallelepeds and slickendides,few fine calcareous particals.

3.2.3 Pertinent properties.

Soil samples from 0 to 22.5 cm depth were collected from randomly selected spots from the site before laying out the experiments. A composite sample for each site was prepared and was analysed for various physico-chemical properties.

(i) The particle size distribution of the soil was analysed by the International pipette method (Piper,1952) using sodium hydroxide as the dispersing agent and the results are presented in Table 1.

(ii) The organic carbon in soil was determined by the modified Walkley-Black rapid titration method and organic matter was obtained by multiplying per cent organic carbon by the factor 1.724 (Jackson, 1958).

(iii) Cation exchange capacity (CEC) of the soils was determined by leaching the soil with neutral normal ammonium acetate (pH 7.0), absorbed ammonia being removed by a final washing with ethanol the displaced ammonia in potassium chloride leachate was distilled with magnesia and estimated (Piper, 1952).

iv) Standard methods (Piper, 1952) are followed for the estimation of total N, P and K.

(v) The pH of the soil was determined by Elico pH meter at 1:2.5 soil water suspension (Jackson, 1967). The electrical conductivity (EC) of 1:2.5 soil water extract was determined using conductivity bridge

(Jackson, 1967).

The pertinent properties of the soils are presented in Table 1.

3.3 Experimental layout.

The experiments were laid out in randomised block design with four treatments and five replications during first year (1975-76) and with five treatments and four replications during second year (1976-77). One treatment of polyethene mulch was included in second year in addition to previous treatments (Fig. 2 b).

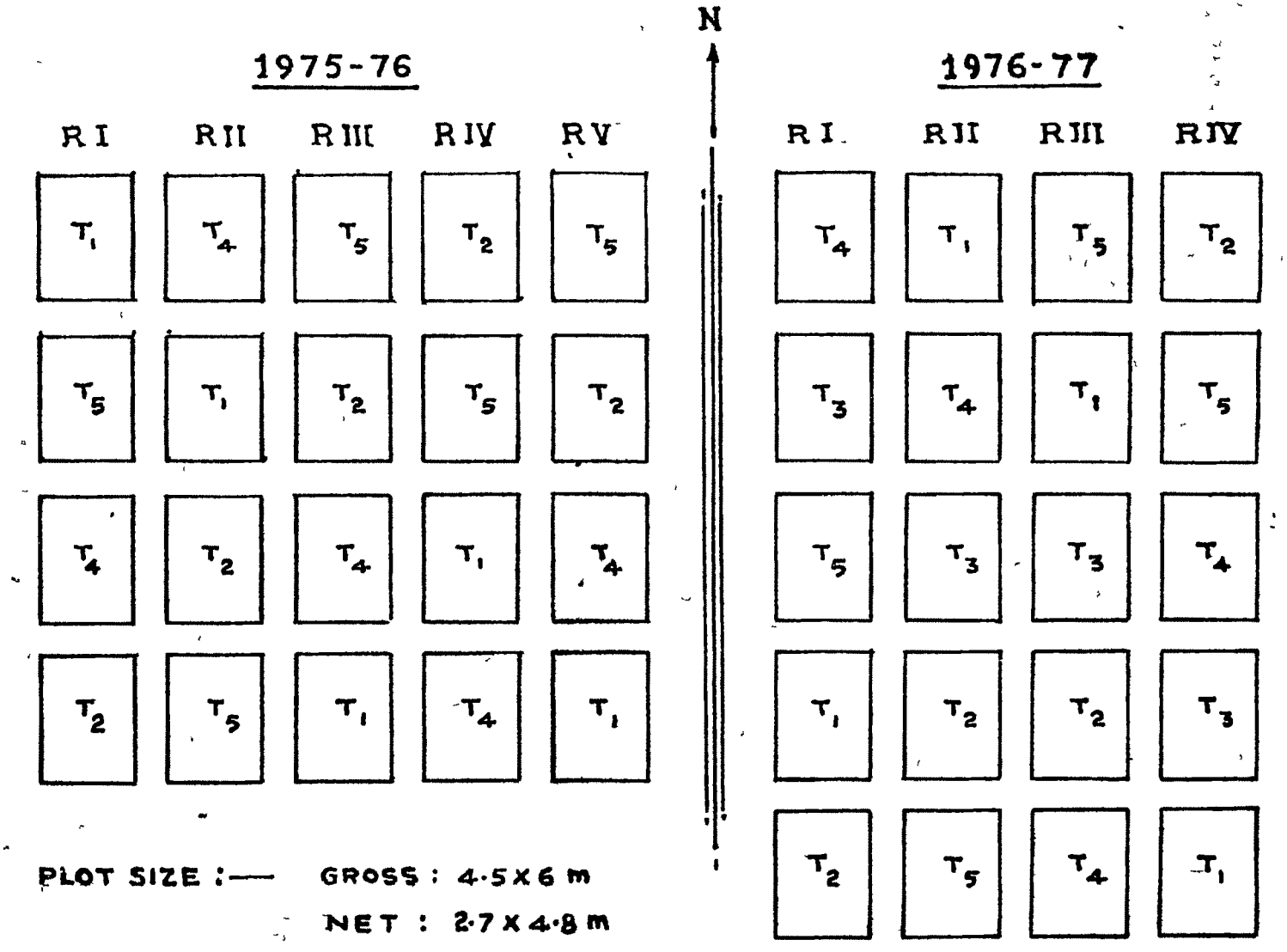
3.3.1 Treatments.

Details of treatments are given in Table 2.

Table 2: Description of mulch and irrigation treatments of the field experiment.

Treatment symbol	Treatments	Description of the treatments
T_1	Control	Beds were prepared for sowing.
T_2	Straw mulch	Paddy straw was utilized as a mulch at the rate of 10 tons per hectare.
T_3	Polyethene mulch(only for second year)	Polyethene strips were applied within the rows of sorghum plants.
T_4	Irrigation + straw mulch	One irrigation one month after sowing and application of straw mulch at the rate of 10 tons/ hectare was done.
T_5	Only irrigation	Irrigation one month after sowing was given.

Note: Fallow plot of 5 x 5m was kept 10 m aside to record observations on moisture content at various depths during 1975-76.



PLOT SIZE :— GROSS : 4·5 X 6 m

NET : 2·7 X 4·8 m

T_1 : CONTROL
T_2 : STRAW MULCH
T_3 : POLYETHENE MULCH
T_4 : IRRIGATION + STRAW MULCH
T_5 : IRRIGATION

FIG. 2 b. PLAN OF LAYOUT

3.4 Moisture distribution study.

3.4.1 Sampling.

Soil samples for moisture studies were drawn with the help of screw augers from fixed depth of 15 cms interval up to 60 cmsduring 1975-76 and up to 75 cms during 1976-77 before sowing as well as two and half month after sowing during first year and after one month during second year every after two days interval respectively in between the plant rows randomly selected. The sampling during 1975-76 was started late due to less depletion because of more rainfall during early rabi season. The water content was determined gravimetrically, and converted to volumetric basis by multiplying the gravimetric data with appropriate soil bulk density (1.3 g cm^{-3}).

3.4.2 Soil moisture retention characteristics.

The pressure plate apparatus (15 BAR ceramic plate extractor, Soil Moisture Equipment C0.3005, Dela Vera Street, Santa Barbara, California, U.S.A. located at Akola, Maharashtra) was used to evaluate the moisture retention characteristics in the range of 0.1 to 15.0 bar tension (Fig. 2a)

3.4.3 Unsaturated conductivity and diffusivity.

Utilizing the soil moisture and metric potential distribution data, the capillary conductivity was evaluated

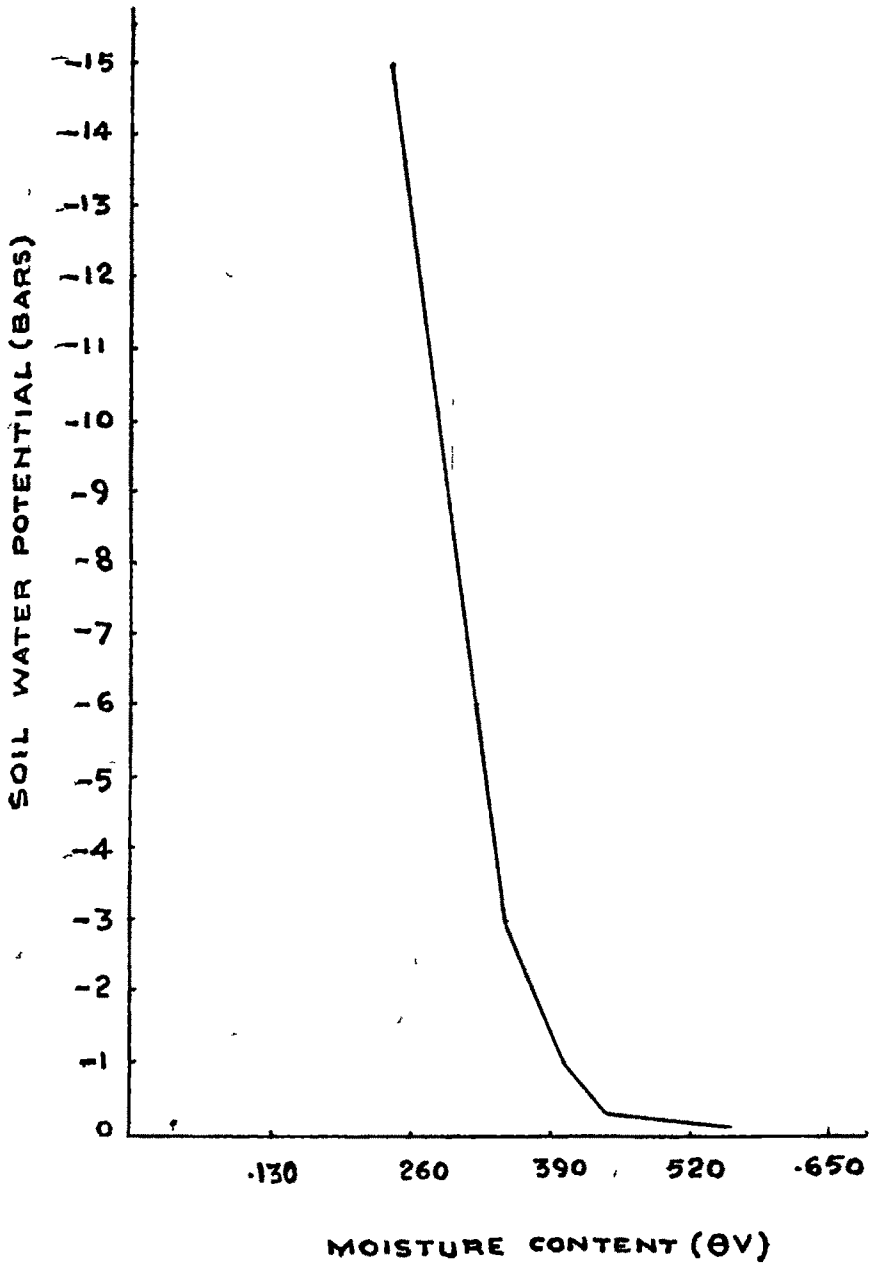


FIG. 2a. MOISTURE RETENTION CHARACTERISTICS OF BLACK SOIL

from the data on averaged soil water flux and potential gradient. Soil water flux (q) was calculated from the following equation proposed by Flocker et al. (1968).

$$q\,(x_n + \tfrac{1}{2}) = \frac{-\delta}{t}\; W\,(x_n + \tfrac{1}{2}, t)$$

$$= \frac{-W\,(x_n + \tfrac{1}{2}, t_2) - W\,(x_n + \tfrac{1}{2}, t_1)}{(t_2 - t_1)}$$

Where,

$W\,(x_n + \tfrac{1}{2}, t)$ represents at any time t the amount of water per unit area within the column from the bottom ($x_0 = 0$) to any height $x_n + \tfrac{1}{2}$, ($t_2 - t_1$) is the time interval over which the flux is calculated. From the equation $q = -D\,\left(\frac{d\theta}{dx} + \frac{d\theta}{dp}\right)$ value of D is calculated by substituting the values of $\frac{d\theta}{dx}$ and $\frac{d\theta}{dp}$ which are calculated from the slope of the soil water characteristic curve given in Fig. 2.

Value of K is calculated from the equation $K = D\,\frac{d\theta}{dp}$

Part II

3.5 Field experiment for studying effect of moisture conserved through different mulches and irrigation.

3.5.1 Observations.

Observations on yield were recorded from same experiments of moisture distribution and additional

observations on growth and yield contributing characteristics were recorded only during 1976-77.

3.5.2 Other details of the experiment.

Gross plot size 4.5 x 6 $(m)^2$

Net plot size 2.70 x 4.8 $(m)^2$

The plan of layout with necessary details is given in Fig. 1 a,b.

3.6 Seed material and sowing.

3.6.1 Seed material.

The certified seed of sorghum M 35-1 was obtained from Sorghum Research Station, Parbhani.

3.6.2 A brief description of the variety M 35-1.

It is a full growing drought resistant variety. It matures in 130 days in rabi season. Its grain is medium to bold in size having creamy white colour.

3.6.3 Fertilizer application.

A fertilizer schedule of 20 kg N, 10 kg P_2O_5 and 10 kg K_2O per hectare through ammonium sulphate, superphosphate and potassium sulphate was adopted. All the quantity of required fertilizer was applied as basal dose.

3.6.4 Sowing.

The crop was sown on 13 December during 1975 and on 17th November during 1976 by hand dibbling in the row spacing of 45 cm. Plants were spaced 15 cm apart.

Gap-filling was done on 10th day after sowing in order to maintain required plant population.

Plants were thinned to one per hill 15 days after sowing.

3.7 Biometric observations.

Ten plants were randomly selected from each plot. These plants were labelled and all biometric observations were recorded on them.

3.7.1 Growth observations.

(A) Pre-harvest studies.

i) Emergence: The total number of seedlings emerged per net plot was counted on the 10th day after sowing.

ii) Height of plant: The height of plant was measured from the base of the plant i.e. ground level to the ligule of the fully opened top leaf. After earhead emergence, height was measured up to the tip of the earhead.

iii) Number of functional leaves: The total number of functional leaves i.e. fully opened and green leaves per plant borne on sampled plants were recorded at different stages of crop growth.

iv) Leaf area: Area of functional leaves per plant was calculated by taking maximum length and broadth of all green leaves. The formula given by Stickler et al. (1961)

was used for calculating leaf area.

Leaf area = Max. length x Max. breadth x 0.747.

v) Girth or circumference of stem: The circumference of the third internode from the base axis measured at various growth stages.

vi) Total dry matter accumulation per plant: For dry matter study five plants were selected for the first observation and one plant each for subsequent observations from each net plot, the plants were selected randomly. At the heading stage, earheads were separated from stem along with the peduncles. At the harvesting stage, the heads were air dried and then separated into grains and bhoosa. The plants were packed in paper bags, properly labelled and dried in oven at 65 - 70 ^{o}C. The last constant weight was recorded as the dry weight.

(B) Post harvest studies.

i) Length of earhead: The length of earhead was measured from the basal whorl of spikelets to the tip of the penical.

ii) Breadth of earhead: For measuring the breadth of earhead, it was kept between two blocks having rectangular faces placed on the meter scale and they were brought together so as just to touch the earhead on either side, without pressing it. The distance between the touching

faces was recorded as the maximum breadth of the earhead.

iii) Weight of the earhead: Tagged plants were harvested and dried separately earhead weights were noted and the mean earhead weight was calculated.

iv) Grain yield per plant: The earheads were threshed together from labelled plants, grain separated, cleaned with hand winnowers and weighed. The mean grain weight per plant was then calculated.

v) Test weight: A random sample of 1000 grains from total grain produce of each net plot, was taken at random and its weight was recorded.

vi) Straw weight per plant: Obtained from the straw weight of labelled plants after sun drying.

vii) Grain yield per plot: Dried and weighed cobs were threshed with hand threshers and grains were separated and cleaned with hand winnowers and weights were recorded. The grain yields inclusive of sample plants were used for converting grain yields into q/ha.

viii) Straw weight per plot: After the harvest of cobs, the plants were dried in sun for some days and their weights were recorded. The plot weights of straw inclusive of sample plants were reported as straw weights in q/ha.

3.8 Chemical studies.

3.8.1 Nitrogen, potassium and phosphorus estimation from plants.

The plants sampled for dry matter studies were used for chemical studies. The dried samples were ground and preserved in paper bags, suitably labelled for estimation of total N, P and K.

i) Total nitrogen: The Kjaldhal's method (Piper, 1952) was followed for determination of nitrogen.

ii) Determination of P_2O_5: Proparation of plant extract: after digesting the plant material, using tertiary acid mixture (HNO_3: H_2SO_4: $HClO_4$) in the ratio of 10:1:4 and estimated P_2O_5 by vandomolybdophosphoric yellow colour method in HNO_3 system (Jackson, 1967).

iii) Determination of K_2O : Determined by Parkin Flame photometer (Jackson, 1967).

Similarly N, P and K content of grain sorghum is also determined using same methods.

3.9 Interpretation of the data and statistical analysis.

The results of the growth observation, yield and uptake of N, P and K at different stages were analysed statistically by the standard statistical method known as Fisher's method of Analysis of variance. Appropriate standard errors were worked out. The critical differences at 5 per cent level is given wherever required. Data have been suitably illustrated by graphs and charts at appropriate places.

Table 1: Mechanical and chemical composition of the experimental soils

Ingredients	Percentage
(a) Mechanical composition.	
1. Calcium carbonate	10.3
2. Coarse sand	1.5
3. Fine sand	13.1
4. Silt	19.0
5. Clay	55.5
6. pH	7.8
7. 1/3 bar SMT %	34.37
8. 15 bar SMT %	18.40
9. Bulk density	1.3 g /cm^{-3}
Textural class	Clayey
(b) Fertility constituents.	
1. Total nitrogen	0.063 per cent
2. Organic carbon	0.598 per cent
3. Available potash	0.045 per cent
4. Available phosphoric acid	0.003 per cent
5. Total potash	0.480 per cent
6. Cation exchange capacity m.e. /100 g of soil	48.90 [illegible]

4. RESULTS AND DISCUSSION

4.(A) Moisture relationship.

Experiments on the influence of various mulches and irrigation on moisture content at various depths were conducted in the winter season (rabi) of 1975-76 and 1976-77 to study the soil water plant relations. Moisture conservation, depletion and movement as affected by various treatments were studied.

4.(A).1 Moisture profile as influenced by various treatments.

The data on available soil moisture distribution in profile is shown in Fig.3. During the two years experiment the moisture retention increased in the order, control < irrigation < straw mulch < polyethene and < irrigation plus straw mulch. During 1975-76 the highest moisture retention occurred in fallow plot as compared to any other treatment. This may be attributed to low evapotranspiration ratio as there would not be loss due to transpiration. Polyethene cover, paddy straw with and without irrigation ~~and with irrigation~~ approximately increased the moisture content of the soil. Adams (1966) concluded that 2 inch straw mulch reduced evaporation significantly from 0 to 6" depth during a hot rainless 10 days period. However, these treatments had negligible effect on the moisture contents at 45, 60 and 75 cm depth. It is

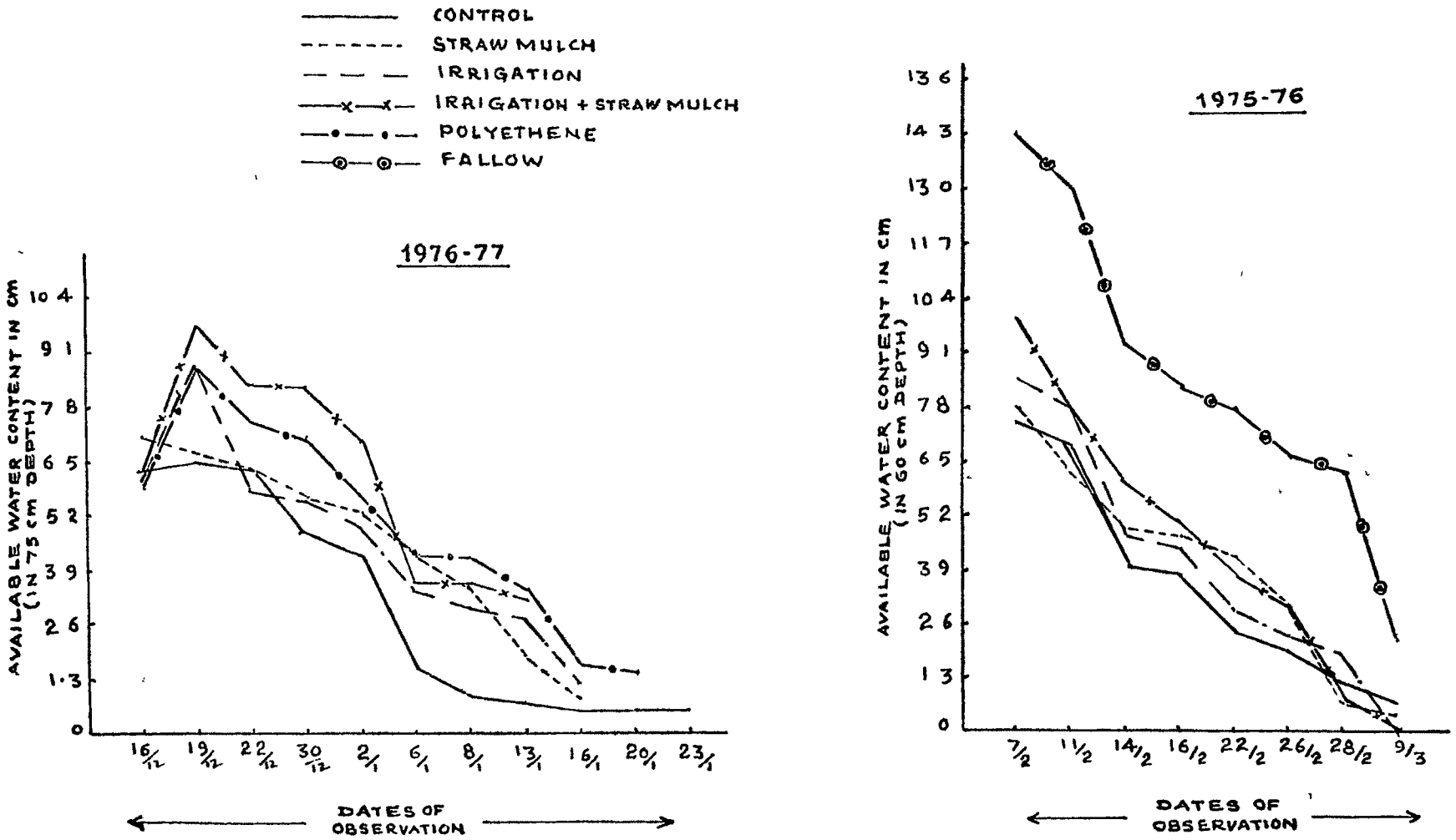


FIG. 3. AVAILABLE WATER DEPLETION DURING GROWTH OF SORGHUM CROP

evident that the use of artificial mulches greatly obstructed evaporation by protecting the soil from the direct rays of the sun and from wind currents. Consequently, the soil was kept cool and the vapour pressure of the air within the mulch was more nearly the same as within the soil air (Baver, 1976). Bond and Willis (1971) also concluded that no significant differences between 20 and 60 cm soil depths as a result of treatment with wheat straw mulch. Irrigation in combination with straw mulch helped in retaining maximum moisture, though irrigation alone increased soil moisture in the beginning, after 30 days, the greatest amount of moisture being under straw mulch followed by irrigation. This may be attributed to higher rates of evaporation from soil surface under bare condition where moisture is not limiting.

4.A.1.1 Moisture depletion.

Available water contents of the profiles under different treatments at various times are summarised in Table 3 a&b for two years. At the time of sowing moisture content in 75 cm deep profile was about same in each plot. One month after sowing the treatments were super imposed. There was a continuous decrease in water content with no differences among treatments for both the years. Further progressive reductions occurred in

Table 3(a): Seasonal available moisture content of a root zone soil under various treatments during 1975-76 (60 cm depth).

Date	Depletion time (days)	Treatments				
		Control (cm)	Straw mulch (cm)	Irrigation (cm)	Irrigation+ straw mulch (cm)	Fallow (cm)
13-12-75 (Sowing time)		15.576	15.576	15.576	15.576	15.576
7-2-76	55	7.619	7.885	8.541	9.882	14.342
11-2-76	59	6.995	6.384	7.870	7.783	13.018
14-2-76	62	4.036	5.031	4.761	6.046	9.382
16-2-76	64	3.861	4.683	4.473	5.198	8.403
22-2-76	70	2.488	4.265	2.921	3.701	7.836
26-2-76	74	2.025	3.036	2.375	3.064	6.704
28-2-76	76	1.245	0.895	1.937	0.988	6.250
9-3-76	85	0.664	0.460	-	0.148	2.228

the control (from 15.57 to 0.6643 cm of water during 1975-76 and from 12.28 to 0.637 cm of water during 1976-77) and in the irrigated treatments (from 15.57 to 1.93 cm of water during 1975-76 and from 12.28 to 1.2584 cm of water during 1976-77) of sorghum plots right up to the harvest.

Table 3(b): Seasonal available moisture content of a root zone soil under various treatments during 1976-77 (75 cm depth).

Date	Depletion time	Treatments				
		Control (cm)	Straw mulch (cm)	Irrigation (cm)	Irrigation + straw mulch (cm)	Polyethene (cm)
17-11-76 (sowing time)		12.285	12.285	12.285	12.285	12.285
16-12-76	29	6.4415	7.273	6.216	6.295	6.009
19-12-76	32	6.506	6.853	8.773	9.972	8.908
22-12-76	35	6.493	6.488	5.959	8.525	7.564
30-12-76	43	4.826	5.768	5.606	8.323	5.929
2-1-77	46	4.343	5.395	5.005	7.046	5.690
6-1-77	50	1.599	4.316	3.451	3.666	4.368
8-1-77	52	0.956	3.655	3.082	3.668	4.160
13-1-77	57	0.838	2.013	2.821	3.369	3.630
16-1-77	60	0.520	0.980	1.258	-	1.587
20-1-77	64	0.508	-	-	0.364	1.492
23-1-77	67	0.637	-	-	-	-

The slightly higher values of the water content in irrigated treatments up to 32 days during 1976-77 reflects the effect of the first irrigation given to those plots 30 days after sowing and in case of plots treated with irrigation plus

straw mulch up to 58 days. This may be due to checking of evaporation due to application of straw mulch. In the fallow plots during 1975-76 there was little profile depletion up to 59 days after sowing. Lack of profile depletion in the fallow plot during that period indicated that either surface evaporation was negligible or that it was not greater than the amount of water that moved into the profile from lower moist zone. Late season losses from the unirrigated fallow plots were finite during 1975-76 but smaller than those from the cropped plots. This indicated that under the high evaporative demand during this period, surface evaporation exceeded the rate of upward water flow into the profile but the combined loss by transpiration and evaporation was substantially greater than evaporation alone in the corresponding period.

The patterns of change in available moisture content in the soil profile during the season may be compared in several ways. For this purpose the data are presented in different ways in figures. Figure 4 a,b,c and d clearly shows the progressive moisture depletion under the five contrasting treatments. Significant depletion occurred at all depths under each treatment although the seasonal depletion under fallow was only about half of that from the cropped plots.

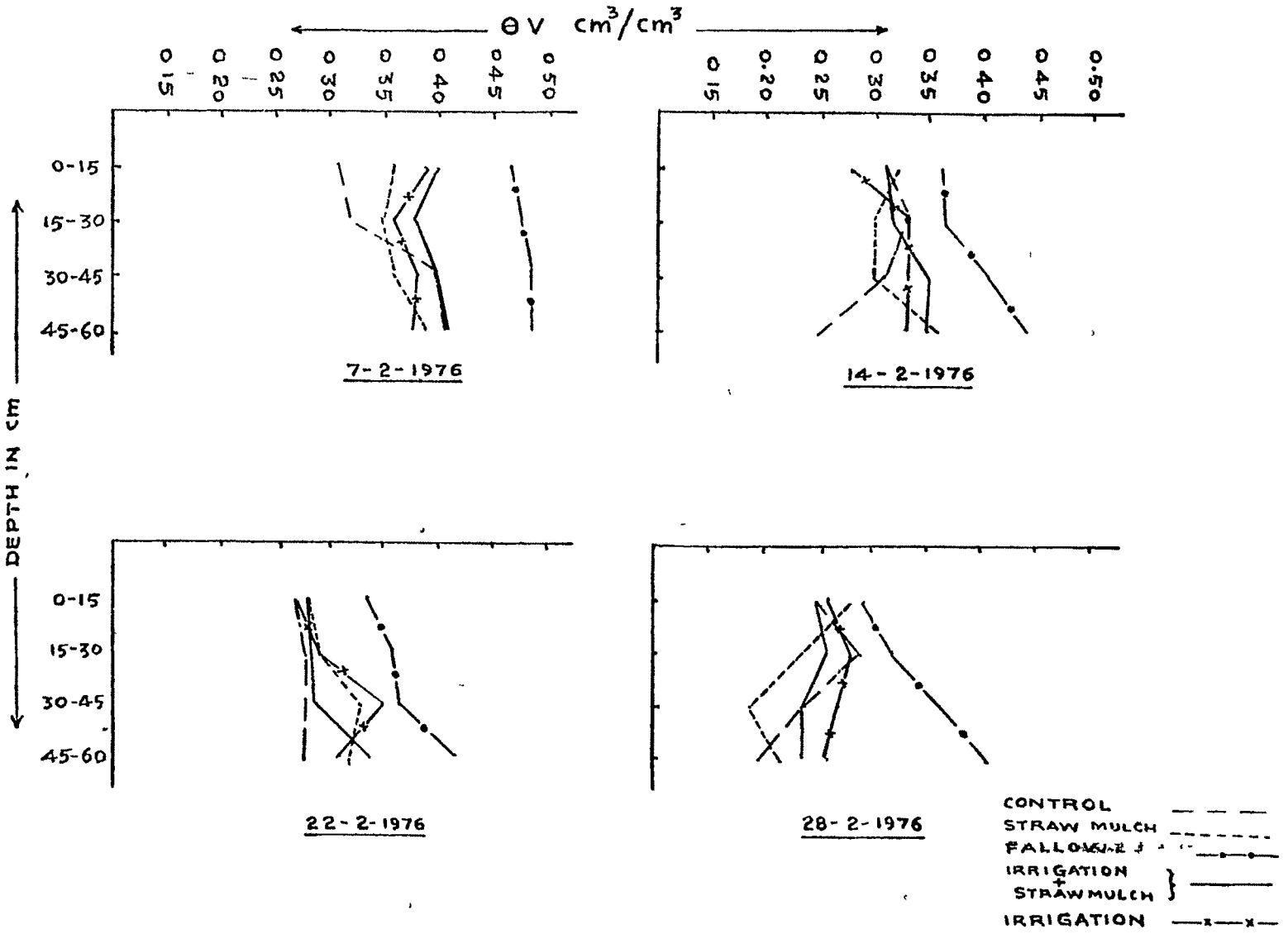


FIG 4 a VOLUMETRIC WATER CONTENT VERSUS DEPTH UNDER FIVE TREATMENTS AT FOUR DIFFERENT TIMES FOR 1975-76

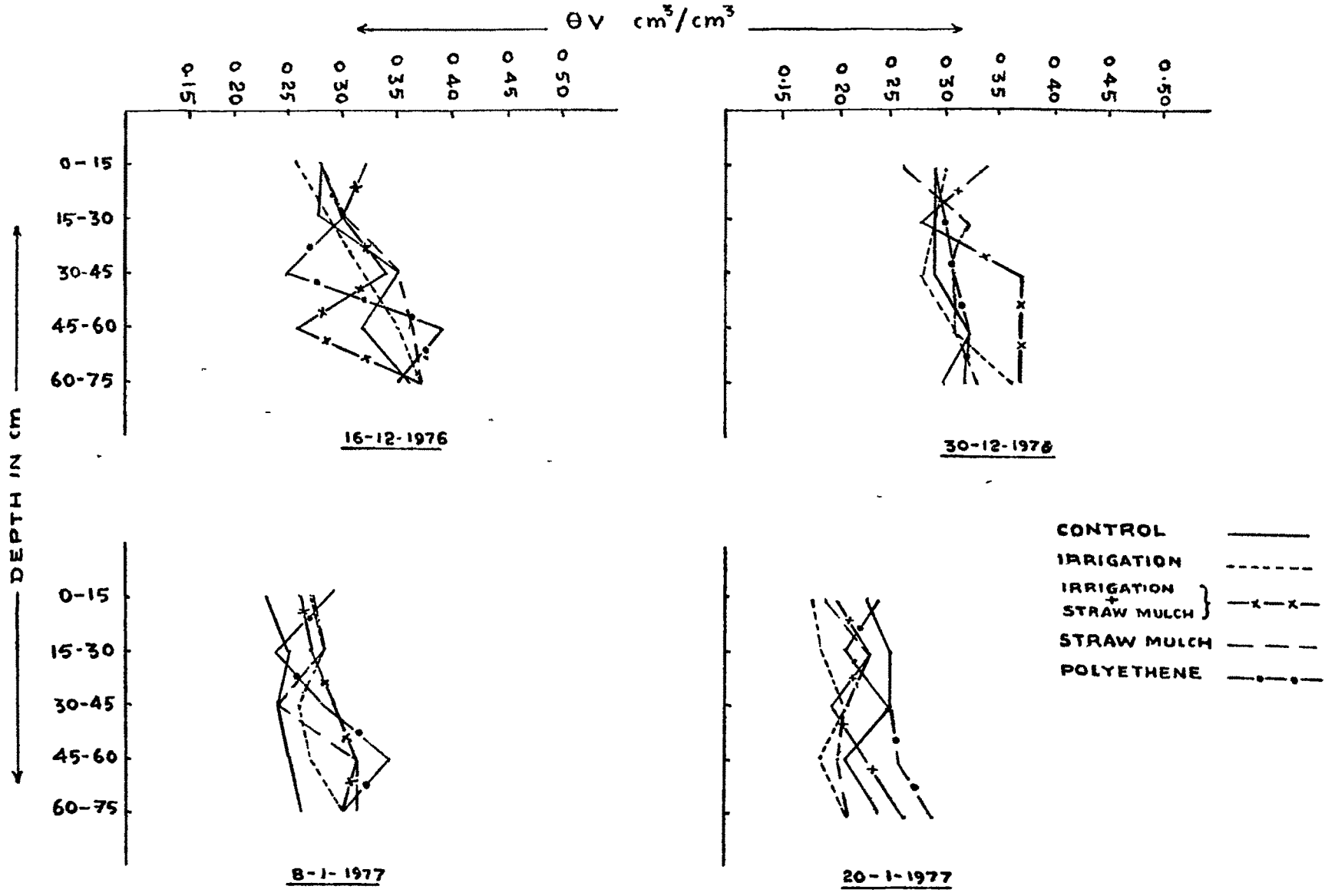


FIG 4 b VOLUMETRIC WATER CONTENT VERSUS DEPTH UNDER FIVE TREATMENTS AT FOUR DIFFERENT TIMES FOR 1976-77

The general pattern of depletion through-out the profile and throughout the season was very similar under the control, mulch and irrigation treatment. The moisture content curves at various depths under different treatments move in nearly parallel fashion from left to right at more or less equal rates particularly during either seasons. Maximum depletion occurred in lower zones as it contained more available water (0.4195 cm^3 cm^{-3} during 1975-76 and 0.3640 cm^3 cm^{-3} during 1976-77). The depletion from 0-15 cm layer (from 0.3179 to 0.2201 cm^3 cm^{-3}) was less as compared to deeper depths since the initial water content is less due to fast depletion ; as it is exposed to atmosphere which has to satisfy evaporative demand. Similar trend was observed in all other treatments.

In fallow plots during 1975-76 much less profile depletion occurred below 30 cm depth during the early and middle parts of the growing season. In the case of the fallow plots this reflects the low rate of surface evaporation and/or the importance of upward water flow into the profile during the period when the evaporative demand of the atmosphere was low. During the last six weeks of the growing season when the atmospheric evaporative demand was steadily increasing depletion occurred at all depths even from fallow plots.

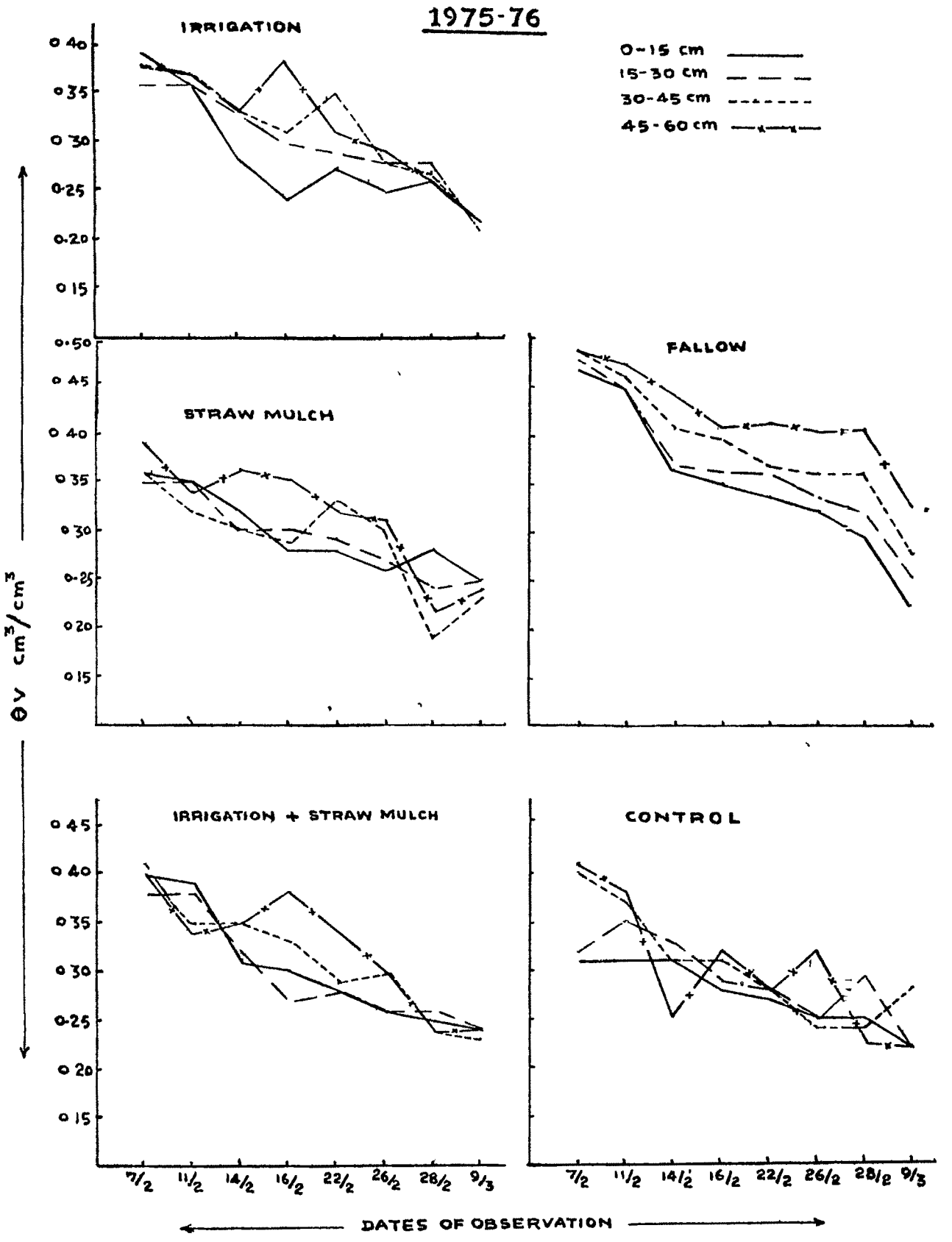


FIG 4 C SEASONAL TRENDS OF VOLUMETRIC WATER CONTENTS AT FOUR DEPTHS UNDER FIVE TREATMENTS FOR 1975-76

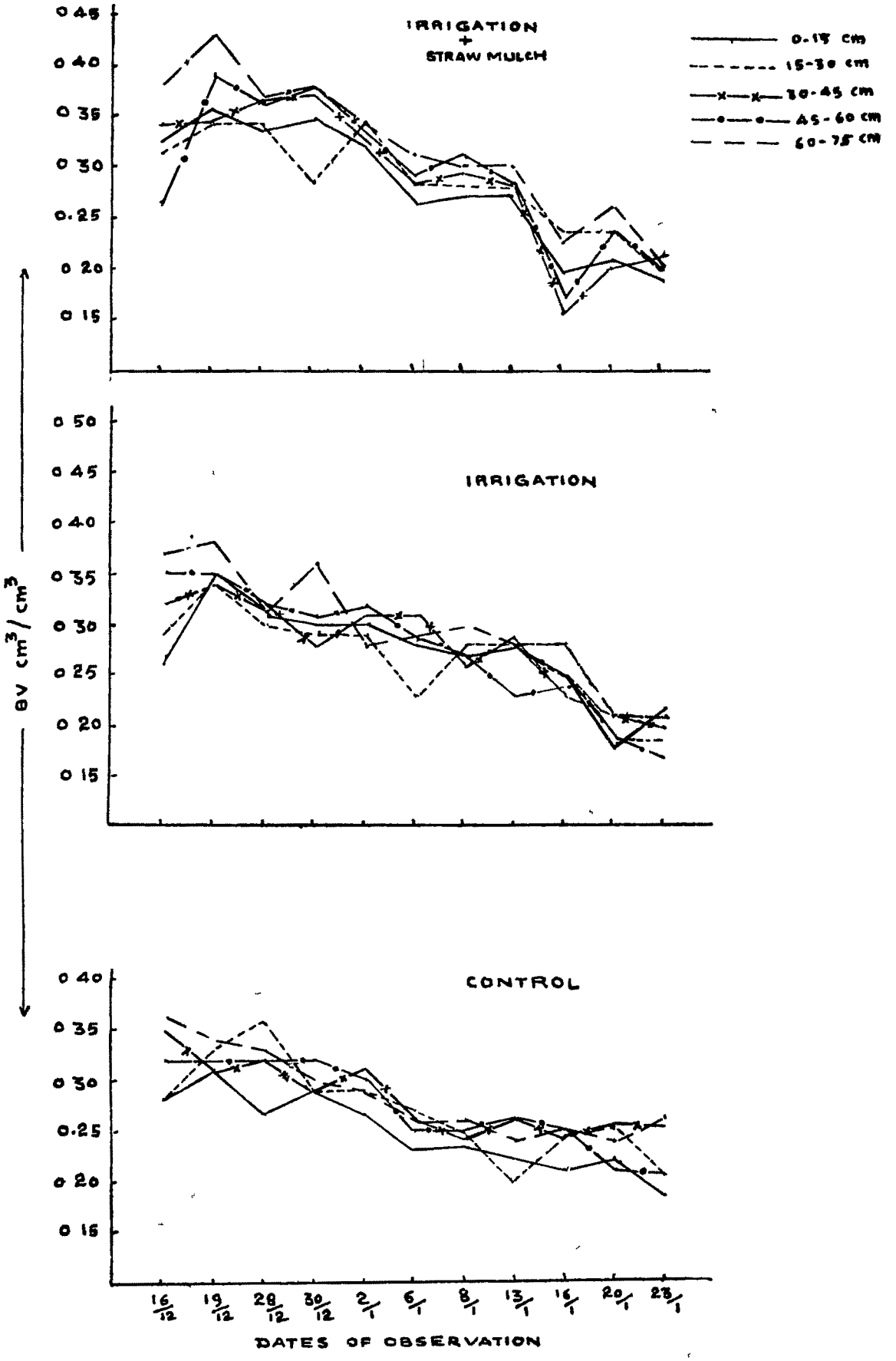


FIG 4 d. SEASONAL TRENDS OF VOLUMETRIC WATER CONTENTS AT FIVE DEPTHS UNDER FIVE TREATMENTS FOR 1976-77 (CONTD ON NEXT PAGE)

CONTD..

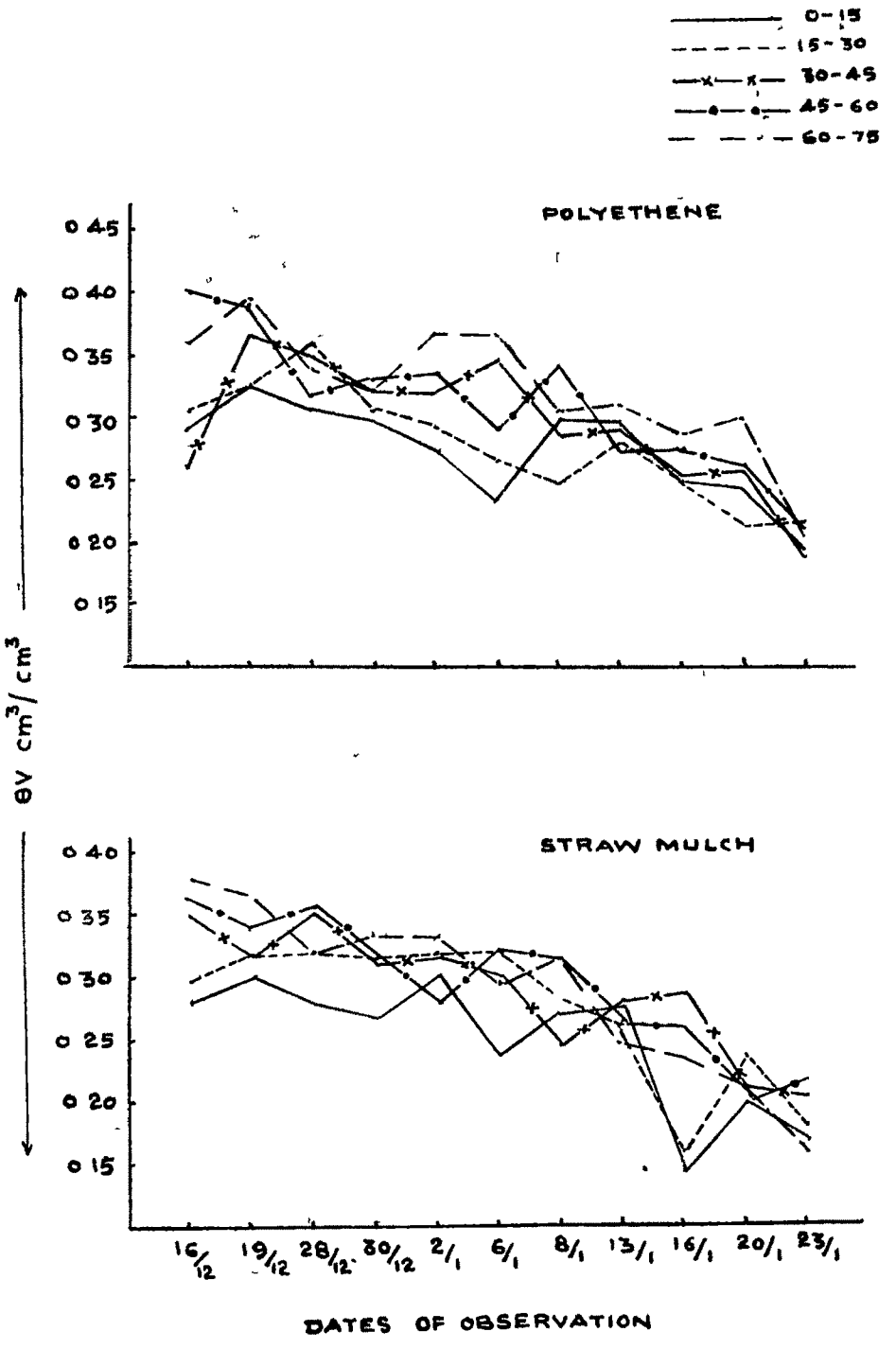


FIG 4 d SEASONAL TRENDS OF VOLUMETRIC WATER CONTENTS AT FIVE DEPTHS UNDER FIVE TREATMENTS FOR 1976-77

The comparison among treatments of their profile moisture patterns at different time during the season are revealed by the curves in Fig. 4 c & d. The curves show general uniform depletion that occurred throughout the profile in all treatments.

It is evident from the figures that water content at various depths changes but depletion curve in fallow treatment and the lines of different depths run parallel. This may be due to, at various depths roots which are active in moisture absorption, vary. This variation causes upward or downward water movement causing variation in content at different intervals.

4.A.1.2 Soil moisture transmission coefficients.

Unsaturated conductivity (K) and soil water diffusivity (Dθ) are two important coefficients. The unsaturated water flow parameters were computed from the data on soil moisture as a function of depth and time, according to the method proposed by Flocker _et al_. (1968). It was deemed necessary to assess the changes in unsaturated conductivity (K) and soil water diffusivity (Dθ) with decrease in moisture content (θV) during drying cycle. With this end in view the relationships between unsaturated conductivity and diffusivity with volumetric water content in a drying soil profile under sorghum crop is presented graphically in Fig. 5 and 6.

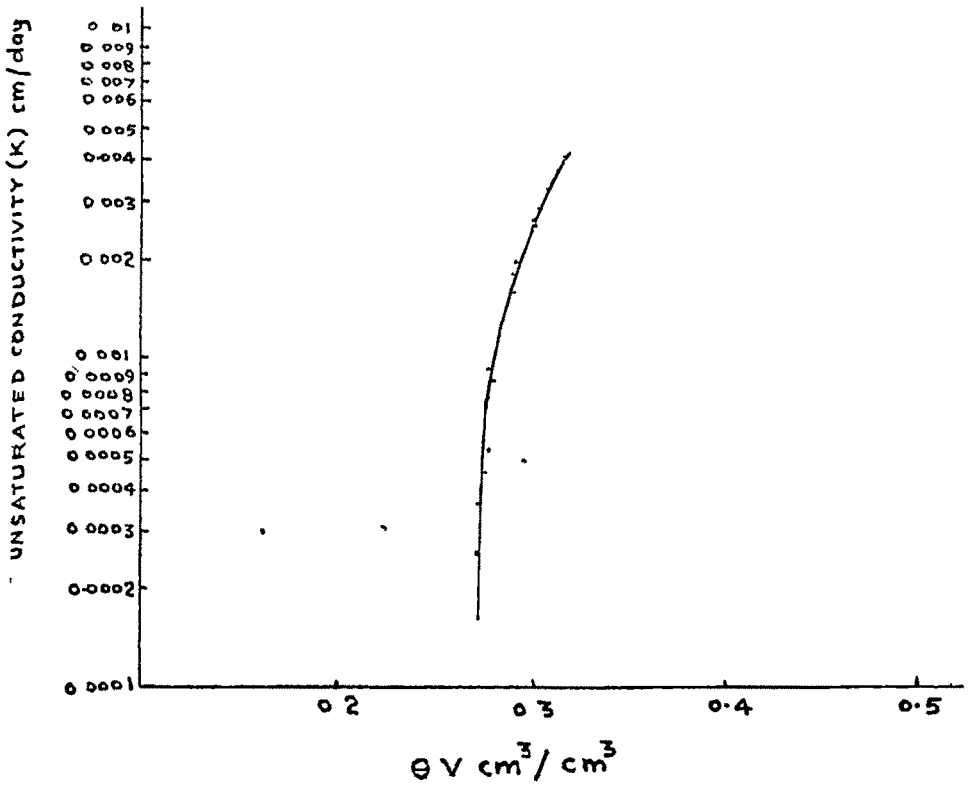


FIG 5. UNSATURATED CONDUCTIVITY AS A FUNCTION OF WATER CONTENT

It is evident that K exhibited exponential relationship ($r = 0.5387$) with θ V,K decreasing sharply with a marginal slight decline in θV throughout the soil profile. These observations are in general agreement with the results obtained by Richards and Moore (1952) and Ogata (1957) who stated that " at low suction the capillary conductivity value progressively increases with depths, which is consistent with the fact that the water retentivity and specific surface increases with depth". According to Childs and Collis George (1950) the flow of water in unsaturated media is a function of θV and Philips (1957) explained the phenomenon as follows:

"a) The total cross sectional area available for flow decreases with θ.

b) The largest pores are emptied first as θ decreases. Since the contribution to permeability per unit area varies as the square of the pores radius, K may be expected to decrease much more rapidly than θ.

c) As θ decreases, the chance of water occurring in pores or wedges isolated from the general three diamensional net work of water film and channels increases. Once continuity breaksdown, there can of course be no flow in the liquid phase (movement in series parallel with vapour movement is possible, but need not detain here) "

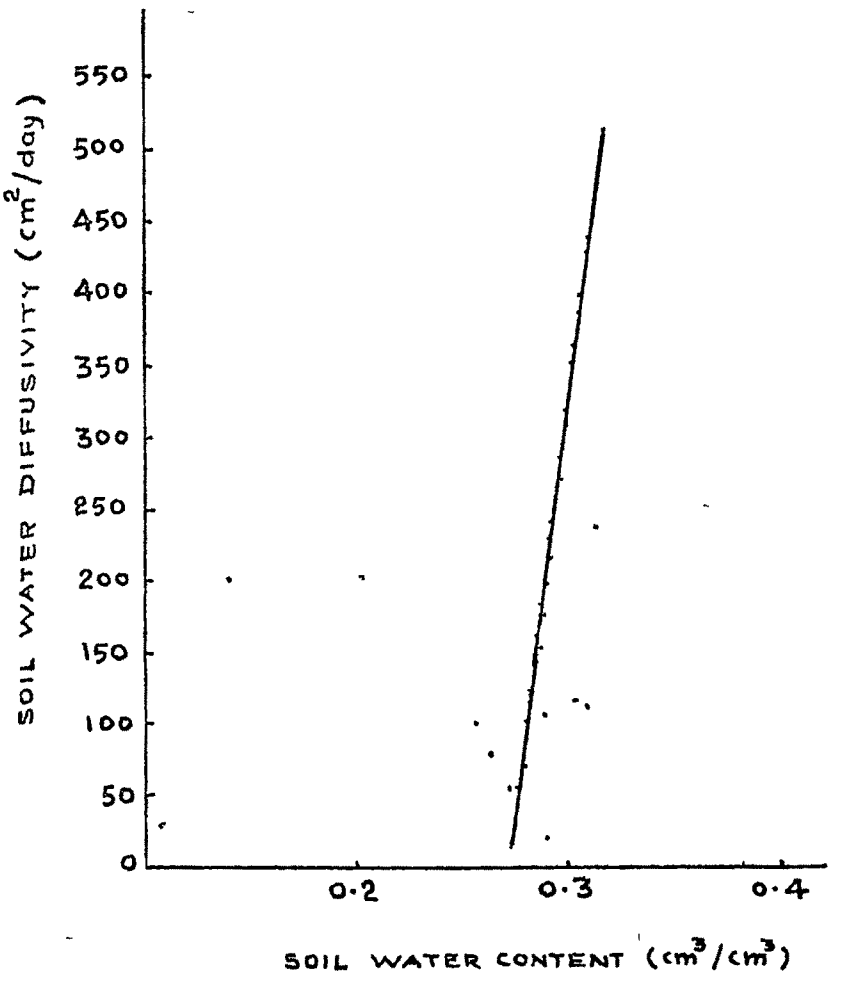


FIG 6 SOIL WATER DIFFUSIVITY VERSUS SOIL MOISTURE CONTENT

The unsaturated conductivity K of the soil under sorghum field was as high as 1.9×10^{-3} cm day^{-1} at a moisture content of 0.314 cm^3 cm^{-3}. However with the decrease in water content from 0.314 cm^3 cm^{-3} to 0.262 cm^3 cm^{-3}, there was a marked reduction in K to a lower value of 6.8×10^{-4} cm day^{-1}.

Soil water diffusivity Dθ also revealed an exponential relationship (r = 0.5407) with volumetric water content in a black cotton soil (vertisol) profile during drying cycle (Fig.6). It was found to be 239.24 cm^2 day^{-1} at θV of 0.314 cm^3 cm^{-3}. A decrease in volumetric water content to 0.2626 cm^3 cm^{-3} resulted in a marked lowering of diffusivity by 79.316 cm^2 day^{-1}. These results are substantiated by the data of Gardner (1958) who found that the diffusivity was a function of water content, varied over a wide range of values also but not quite to the extent that the conductivity did.

In black cotton soil, the soil water diffusivity attained the maximum value of 239.24; 108.39 and 79.31 cm^2 day^{-1} at 0.314, 0.290 and 0.262 cm^3 cm^{-3} moisture content. Similar results were also reported by Dhanpal and Varade (1976) and Magar (1977). In fact the maximum values of Dθ should occur at saturation but deviation is the error of the method.

4.A.2 Water flux.

The variation in total water flux with change in soil water content with time of soil profile during drying is illustrated in Table 4.

Table 4: Water flux as affected by various treatments at different depths.

Treat.	Depth (cm)	q (cm/day)							
		7.5	12.5	22.5	32.5	42.5	52.5	62.5	72.5
Control		0.028	0.048	0.083	0.115	0.146	0.183	0.219	0.244
Straw mulch		0.020	0.027	0.041	0.069	0.101	0.119	0.134	0.144
Polyethene mulch		0.033	0.047	0.071	0.104	0.142	0.176	0.196	0.204
Irrigation		0.028	0.047	0.084	0.123	0.159	0.188	0.222	0.250
Irrigation + straw mulch		0.044	0.068	0.105	0.133	0.158	0.189	0.227	0.257

As the drying of the soil profile continued for 53 days, the water flux in general decreased exponentially in the surface (0-10 cm) soil. It is interesting to note that the water flux at lower layers exceeded that in the surface soil after 32 days of drying. Jackson (1973) also observed that during the last day of experiment, the flux approached the evaporation rate or slightly higher at 9 cm and was slightly higher than at the surface on day 37.

4.A.2.1 Water flux under control, straw mulch and polyethene sheet.

The data on the effect of mulches on water flux are given in Table 4. However the water flux decreased significantly both from upper and lower layers, in the order of (1) control, (2) polyethene, (3) paddy straw cover, 0.244, 0.204 and 0.144 cm day^{-1} respectively at 72.5 cm height. This may be due to absorption of solar radiation which is influenced among other factor, to a great degree by the amount of water at the absorbing surface. Terrestrial radiation is governed by the temperature of the radiating surface. Net radiation, being the difference between solar and terrestrial radiation is therefore, controlled by the amount of water of the absorbing surface (Peters, 1960). Paddy straw and polyethene sheet produced maximum cover during high net radiation periods which limited the evaporation. According to Grob (1966), the soil surface application of wheat straw equivalent to 30, 60 and 90 per cent soil surface coverage, reduced water losses from a wet soil surfaces by solar distillation, 16, 23 and 49 per cent respectively for a 20 day period compared with no straw.

4.A.2.2 Effect of irrigation and irrigation plus straw mulch.

Application of irrigation increased water flux as compared to control (0.2501 and 0.244 cm day^{-1} at 72.5 cm

height of soil profile in irrigation and control respectively). There was not much difference in the treatment of irrigation alone and irrigation plus straw mulch (0.25 cm day^{-1} at 72.5 cm height of soil profile) but it was more than rest of the treatments both at upper and lower layers.

4.A DISCUSSION:

4.A.1 Seasonal water changes under control and straw mulch treatments.

The vertisol profile which contains about 85 to 86 cm of water in the upper two meters after the end of monsoon looses a significant amount of water, mostly from the surface 30 cm of the profile prior to sorghum sowing, and the moisture left in the seedbed often is insufficient for satisfactory emergence and stand. The crop makes a good start if sowing is followed by winter rains or if a light 'come up' irrigation is applied. Once the roots reach a few centimeters below the surface, they encounter sufficient available water to carry on normal growth during the cool winter months when the evaporative demand of the atmosphere is low. After sowing in the beginning, water extraction by roots is negligible and the profile behaves like that of uncropped land, and looses water mostly by surface evaporation. End evaporation induced suction gradients develop which result in the movement of

water from lower layers towards the surface. Under the low evaporative demand conditions prevailing at this time, such upward flow is sufficient to meet the rate of evaporation which during this period remains nearly constant and roughly equal to open pan evaporation. The constant evaporation rate is maintained as long as the increasing gradients in the sub-surface are sufficient to compensate for the decrease in hydraulic conductivity of the water transmitting layers that results from their slowly decreasing moisture content. When the roots become increasingly active, both water uptake by roots and evaporation from the soil surface occur simultaneously (Fig. 3). As vegetative growth continues and root density increases, there is a progressive increase in transpiration losses. Conversely, the evaporation losses decrease due to more and more surface cover and to the continued decline of the water transmitting ability of the soil immediately below the surface. The active root zone gradually extends into the still moist subsoil, and extracts more and more water from the deeper layers. At each depth, water depletion by roots results in the suction gradients between that layer and the less depleted lower layers which causes water flow towards the depletion zone. Such flow will, however, decrease rapidly as the moisture content of the lower layers

decreases because of the concurrent reduction in the water transmitting ability of the root free lower soil layers. Because of the reduction in the surface evaporation and the progressive reduction of moisture in the root zone, the evapotranspiration rate during the (seedling growth) period is reduced to about half of the open pan evaporation rate.

Corresponding to the premordial initiation and flowering and up to milk stage of the sorghum crop, the profile above 75 cm looses moisture at a very slow rate. This is either due to the penetration of roots below 75 cm or, alternatively to the upward water flow into the root zone from root free wetter layers, below at a rate sufficient to supply most of the transpiration demand of the crop during the flowering (premordial) stage. This uncertainty would be resolved if quantitative data on root distribution and on the presumed moisture fluxes were available. The evapotranspiration rate of unirrigated sorghum in the seedling or milk stage period is only about 1/5th of the open pan evaporation rate, if water use from below 75 cm is ignored. Beginning at the milk stage, significantly wide and deep cracks begin to develop between the sorghum rows. Such cracks and the comparatively high evaporative demand conditions during the remainder of the growing season combine to increase profile water loss from the upper 75 cm by evaporation.

4.A.2. Seasonal water losses from fallow soils.

At the end of monsoon season, the vertisol profile is completely saturated. The surface layers contain relatively higher saturation moisture content than deeper layers due to low bulk density of the surface layers. Surface evaporation and deep drainage occur simultaneously and the profile attains a moisture content of 35 to 37 per cent, a de facto field capacity in the upper two metres at the beginning of rabi season.

During the first fortnight of November, the profile at de facto field capacity looses water mostly by surface evaporation following a square root law i.e. cumulative evaporation is linearly related to the square root of time. During this period profile looses water at a rate roughly 20 per cent of open pan evaporation largely from the upper 30 cm.

If such a profile received water either from rains of light sprinkler irrigation, like 'come up' irrigation to sorghum after sowing, the evaporation and profile readjustment continue simultaneously. In the absence of further additions of water, profile drainage ceases by mid January. The fallow profile shows no change in water content throughout February because steady state upward water flow is sufficient to meet the rate of loss by surface evaporation.

4.B Growth components.

A two year experiment was conducted in the field during the years 1975 and 1976. The water content of Parbhani clay soil was measured at different depths regularly under various treatments to assess the influence of mulch and irrigation on the yield of sorghum cultivar M 35-1, treatments comprised of (i) control, (ii) straw mulch, (iii) irrigation and (iv) irrigation plus straw mulch for 1975-76 and one additional treatment of polyethene mulch was imposed during 1976-77. Significant yield variations were observed during first year. In order to find out contributory growth component susceptible to moisture deficits the observations on various growth components and yield contributing characters were recorded during 1976-77.

4.B.1 Mean height of the plants.

Data on height of sorghum as affected by mulch and irrigation are presented in Table 5. Perusal of data clearly indicate that the mean height of sorghum plant was maximum under irrigation plus straw mulch (165.3 cm), though the difference in height due to application of mulch and irrigation was not significant. The sequence of superiority, though not significant, was in the order of (i) irrigation plus straw mulch followed by (ii) irrigation, (iii) polyethene, (iv) straw mulch and (v) control. The height of plant in control where no treatment was given, was minimum i.e. 152.5cm.

Table 5: Influence of mulch and irrigation on growth of rabi sorghum during 1976-77.

Sr. No.	Treatments	Height of plant in cm	Number of leaves	Number of inter-nodes	Girth (cm)	Leaf area (dm^2)	Dry matter /plant (g)
1.	C	152.50	9.20	8.40	4.15	15.95	111.32
2.	SM	155.00	9.70	8.60	4.07	17.57	150.50
3.	PM	156.90	9.70	8.60	4.25	19.58	159.55
4.	I+SM	165.30	10.00	8.50	4.45	28.29	203.55
5.	I	163.90	9.50	8.60	4.28	23.37	174.92
6.	S.E. ±	5.647		0.084	0.162	1.16	13.36
	C.D. at 5%	N.S.	N.S.	N.S.	N.S.	3.432	39.936

4.B.2 Mean number of functional leaves per plant.

Data regarding mean number of functional leaves per plant recorded is presented in Table 5. No significant differences in the production of number of leaves per plant of sorghum due to various treatments could be traced out. Maximum number of leaves per plant (10) were borne by sorghum where irrigation plus straw mulch was applied at a time.

4.B.3 Mean leaf area per plant.

Data on mean leaf area of functional leaves per plant in dm^2 as influenced by different treatments is presented

in Table 5. The data clearly indicate significant differences in mean leaf area per plant. Sorghum plants treated with irrigation plus straw mulch had produced significantly higher leaf area (28.29 dm^2) while sorghum with only irrigation produced less mean leaf area but significantly more than rest of the treatments. Sorghum with straw mulch and without any treatments produced leaf area which was at par and significantly higher under polyethene mulch.

4.B.4 Stem girth.

Data on mean stem girth in cm per plant of sorghum as affected by various treatments are presented in Table 5. No significant difference in the mean stem girth per plant of sorghum due to various treatments occurring during crop growth. However maximum stem girth (4.45 cm) was recorded under irrigation plus straw mulch than any other treatment.

4.B.5 Number of internodes per plants.

Data on number of internodes per plant at final stage of the crop are presented in Table 5. There were no significant differences in the number of internodes per plant of sorghum due to various treatments.

4.B.6. Total dry matter per plant.

Data pertaining to the dry matter accumulation per plant of sorghum as affected by various treatments are presented in Table 5. Significant differences in the

total dry matter weight per plant of sorghum were recorded. Sorghum plots treated with irrigation plus straw mulch had the significantly higher yield of dry matter (203.55 g) than any other treatment. Irrigation application produced higher dry matter than control. Dry matter production in plots treated with straw mulch and polyethene was at par with irrigation treatment.

4.B.7 Post harvest observation.

4.B.7.1 Length of earhead.

Data pertaining to length of earhead at harvest are presented in Table 6. It is evident from the table that the length of earhead was influenced favourably due to application of mulch and irrigation. It is observed from the table that length of earhead due to application of irrigation, irrigation plus straw mulch and polyethene are at par although they are significantly superior to other treatments i.e. application of straw mulch and control.

4.B.7.2 Breadth of earhead.

While considering the breadth of earhead from Table 6 it was found that application of mulch and irrigation increased breadth significantly over control. Application of straw mulch with irrigation gave significantly more breadth than rest of the treatments. Application of irrigation also produced significantly more breadth than polyethene, only straw mulch and control treatments.

Polyethene application produced significantly more breadth of earhead of sorghum than straw mulch and control treatment.

Table 6: Influence of mulch and irrigation on yield contributing characteristics of rabi sorghum during 1976-77.

Sr. No.	Treatments	Height at earhead (cm)	Breadth of earhead (cm)	Weight of earhead (g)	Weight of 1000 grain (g)	Grain yield per plant (g)
1.	C	14.650	4.52	39.80	32.840	33.10
2.	SM	15.825	4.97	50.10	33.122	41.20
3.	PM	16.500	5.15	53.30	36.590	45.70
4.	I+SM	17.150	5.87	68.10	37.157	59.10
5.	I	16.750	5.52	58.10	36.644	45.45
	S.E.±	0.249	0.113	4.224	0.883	1.60
	C.D. at 5 %	0.736	0.332	12.488	2.616	5.004

4.B.7.3 Weight of earhead.

A glance to Table 6 indicate that application of irrigation plus straw mulch had produced significantly higher weight of earhead than only straw mulch and control treatments but it was at par with the treatment where only irrigation was given. Weight of earhead in control and straw mulch applied sorghum plots was at par and significantly lower than rest of the treatments.

4.B.7.4 Test weight (1000 grain weight).

Data on test weight of grains presented in Table 6 indicate that significantly higher test weight was observed due to application of irrigation plus straw mulch but it was at par with the treatments where only irrigation was applied but it was significantly higher than straw mulch and control. The test weights of sorghum grains in plots treated with straw mulch and control were at par.

4.B.7.5 Yield of grain per plant.

The data on grain yield per plant indicate that application of mulch and irrigation plus straw mulch produced higher grains. The yield per plant of treatment with irrigation plus straw mulch was significantly higher (59.1 g) than rest of the treatments.

4.B.7.6 Yield.

Data regarding the grain and fodder yield per hectare in kilograms for the year 1975-76 and 1976-77 are presented in Table 7.

4.B.7.6.1 Fodder yield.

The fodder yield (Fig. 7 a,b) was significantly affected due to various treatments. The fodder yield was significantly higher due to application of irrigation plus straw mulch during both years (6057 and 6072 kg/ha for 1975-76 and 1976-77 respectively) and there being lowest production

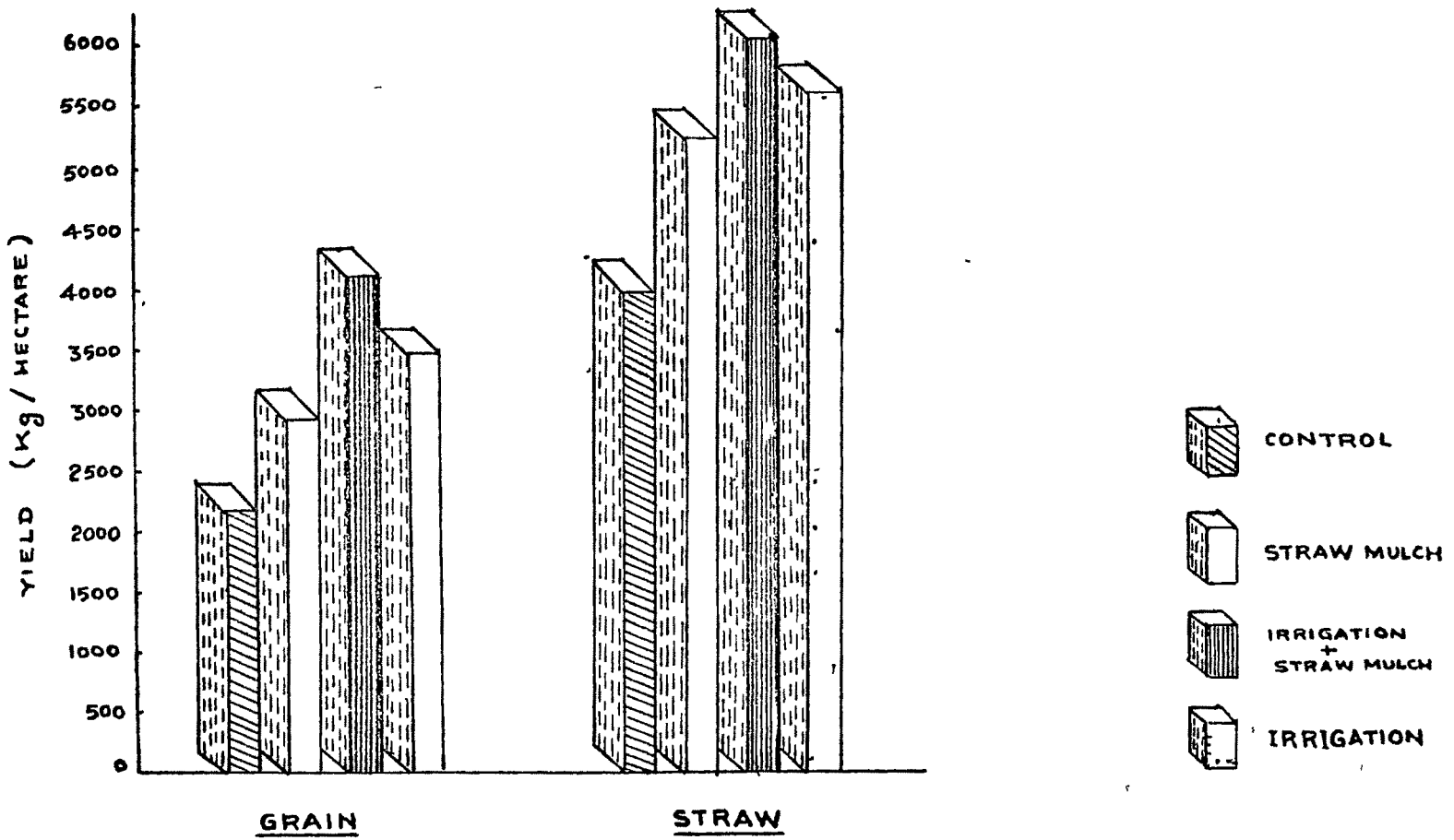


FIG 7 a YIELD OF RABI SORGHUM AS INFLUENCED BY MULCH AND IRRIGATION DURING 1975-76

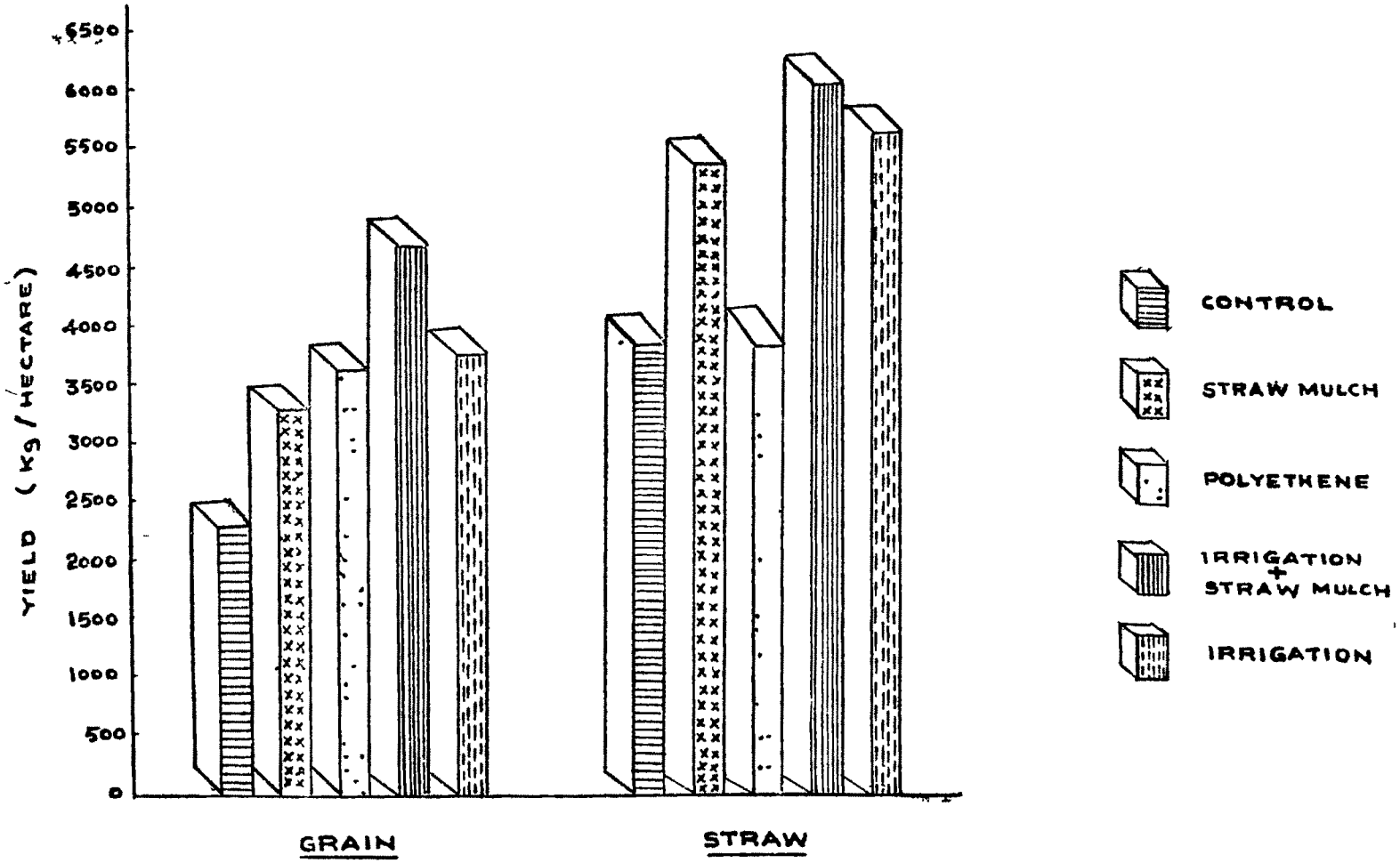


FIG 7 b YIELD OF RABI SORGHUM AS AFFECTED BY MULCH AND IRRIGATION DURING 1976-77.

without any treatment. Application of only irrigation produced significantly higher fodder yield than application of only straw mulch during 1975-76 but it was at par during 1976-77. However, it has produced significantly higher fodder than sorghum treated with polyethene mulch. Application of straw mulch produced significantly higher fodder than application of polyethene.

Table 7: Yield of rabi sorghum as affected by different treatments during 1975-76 and 1976-77.

Sr. No.	Treatments	1975-76		1976-77	
		Grain yield kg/ha	Straw yield kg/ha	Grain yield kg/ha	Straw yield kg/ha
1.	Control	2181.3	3986.8	2279.8	3858.0
2.	Straw mulch	2940.8	5255.3	3310.8	5401.2
3.	Polyethene mulch	-	-	3645.7	3858.0
4.	Irrigation+ straw mulch	4140.1	6057.8	4696.1	6072.5
5.	Irrigation	3476.8	5638.8	3779.0	5686.7
	S.E. ±	120.98	96.45	166.43	390.35
	C.D. at 5%	372.91	285.49	511.34	1202.93

4.B.7.6.2 Grain yields.

Data in table 7 reveal that the significant differences occurred in grain yield of sorghum per hectare due to various mulch and irrigation treatments. One irrigation

along with straw mulch increases yield of rabi sorghum cultivar M35-1 from 21.81 and 22.79 to 41.84 and 46.96 q/ha during 1975-76 and 1976-77 respectively. Thus about 89 to 105 per cent increase seems to be possible, only straw mulch increased yield by 34.8 to 45 per cent during 1975-76 and 1976-77 respectively. Polyethene appears to be highly effective, which increased approximately 60 per cent over control.

4.B.8 Nutrient content in straw at various growth phases of sorghum as influenced by mulch and irrigation.

4.B.8.1 Nitrogen.

Scrutiny of the data presented in Table 8 a for nitrogen content at various stages reveals that application of mulch and irrigation did not affect nitrogen content at seedling stage and grand growth period, though it increased at flag leaf and harvest stage significantly in control than irrigation plus straw mulch and irrigation alone but it was at par with the treatment of straw mulch and polyethene. Treatments of irrigation and irrigation plus straw mulch were at par at flag leaf stage and at harvest stage. At harvest stage the application of polyethene, irrigation and irrigation + straw mulch did not induce any difference in N content but it was significantly lower than control and straw mulch application.

Table 8a: Nitrogen content in straw at various growth phases of sorghum as influenced by mulch and irrigation.

Treatments / Stage	Seedling %	Flower premordia (grand growth period) %	Flag leaf to flowering %	Harvest %
Control	1.598	1.688	1.693	0.769
Straw mulch	1.644	1.620	1.614	0.669
Polyethene	1.595	1.664	1.578	0.488
Irrigation +straw mulch	1.654	1.698	1.275	0.401
Irrigation	1.627	1.591	1.422	0.455
S.E. ±	N.S.	N.S.	0.0520	0.0384
C.D. at 5%			0.1602	0.1185

4.B.8.2 Phosphorus.

As regards status of phosphorus results in Table 8b indicate that phosphorus content was not affected up to flag leaf stage in any treatment. However, significant differences in phosphorus content occurred at harvest. Phosphorus content in sorghum at harvest in plots treated with polyethene, irrigation and irrigation + straw mulch were at par but it was significantly higher over control and plots treated with only straw mulch. While considering total phosphorus content at harvest stage phosphorus availability appeared to be greater at 100 days.

Table 8b: Phosphorus content in straw at various growth phases of sorghum as influenced by mulch and irrigation.

Sr. No.	Stage / Treatments	Seedling %	Flower premordia (grand growth period) %	Flag leaf to flowering %	Harvest %
1.	Control	0.1781	0.1281	0.0546	0.0515
2.	Straw mulch	0.1562	0.1328	0.0593	0.0546
3.	Polyethene	0.1936	0.1283	0.0640	0.0778
4.	Irrigation+ straw mulch	0.1765	0.1484	0.0754	0.0793
5.	Irrigation	0.1937	0.1515	0.0687	0.0734
6.	S.E. ±	N.S.	N.S.	N.S.	0.006
7.	C.D. at 5 %	-	-	-	0.0192

4.B.8.3 Potassium.

Data regarding content of potassium in Table 8c reveal that application of mulch, irrigation and irrigation plus straw mulch did not affect K content up to flag leaf stage, though potassium increased remarkably in these treatments. Potassium content in sorghum that received irrigation and irrigation plus straw mulch was higher than rest of application but potassium content in

sorghum plots treated with straw mulch and polyethene mulch were similar to control.

Table 8c: Potassium content in straw at various growth phasesof sorghum as influenced by mulch and irrigation.

Sr. No.	Treat-ments	Stage	Seedling	Flower premor-dia(grand growth period)	Flag leaf to flowe-ring	Harvest
			%	%	%	%
1.	Control		1.518	1.325	1.112	1.131
2.	Straw mulch		1.537	1.287	1.112	1.175
3.	Polyethene		1.500	1.268	1.168	1.237
4.	Irrigation+ straw mulch		1.600	1.356	1.162	1.318
5.	Irrigation		1.593	1.318	1.200	1.293
6.	S.E. ±		N.S.	N.S.	N.S.	0.036
7.	C.D. at 5 %		-	-	-	0.115

4.B.9. N,P and K content in grains of sorghum as influenced by mulch and irrigation.

Data presented in Table 9 indicate that application of mulch, irrigation and irrigation plus straw mulch affected quality of grain as measured by N, P and K content. There was little variation in potassium content. Grain sorghum produced under control contained higher N than other treatments

Table 9: N,P,K and protein content in grains of sorghum as influenced by mulch and irrigation during 1976-77.

Treatments / Ingradients	Nitrogen %	Phosphorus %	Potassium %	Protein %
Control	1.531	0.1780	0.456	9.57
Straw mulch	1.484	0.1874	0.462	9.28
Polyethene mulch	1.400	0.2030	0.525	8.75
Irrigation+ straw mulch	1.274	0.2455	0.550	7.96
Irrigation	1.393	0.2318	0.550	8.71
S.E. ±	0.0316	0.0138	N.S.	0.19
C.D. at 5 %	0.0976	0.0436		0.61

but it was at par with grains obtained from plots treated with straw mulch. Nitrogen content of grains obtained from plots treated with irrigation plus straw mulch was significantly lower than rest of the treatments and treatments of polyethene, irrigation and straw mulch were at par.

As regards phosphorus content which was significantly higher in treatment of irrigation plus straw mulch than any other treatment except treatment of irrigation which was at par. Phosphorus content in sorghum grains was higher in plots where irrigation was applied but was at par with the plots covered with polyethene mulch. Phosphorus content of

jowar grains in control treatment was at par with straw mulch applied plots but was significantly lower than rest of the treatments.

4.B.10. Uptake of N,P and K in fodder and grain as influenced by mulch and irrigation.

Data on uptake of N,P and K is presented in Fig.8. Perusal of data in table (Appendix) reveals that uptake of these nutrient was affected by mulch and irrigation favourably.

4.B.10.1 Nitrogen uptake.

Maximum uptake of nitrogen in grains of sorghum per hectare occurred with application of irrigation plus straw mulch (59.57 kg/ha) which was significantly higher than application of straw, polyethene mulch and control but was at par with the uptake due to application of irrigation alone. Similar trend of N uptake in fodder was not observed as straw mulch induced the highest uptake. It was minimum in sorghum where polyethene was applied.

4.B.10.2 Phosphorus uptake.

Uptake of P in grains was also higher in treatments of irrigation plus straw mulch (4.86 kg/ha) which was significantly higher than, straw mulch, polyethene mulch application and control, uptake of P due to application of irrigation, and polyethene mulch was at par though numerical value due to application of irrigation is more. However,

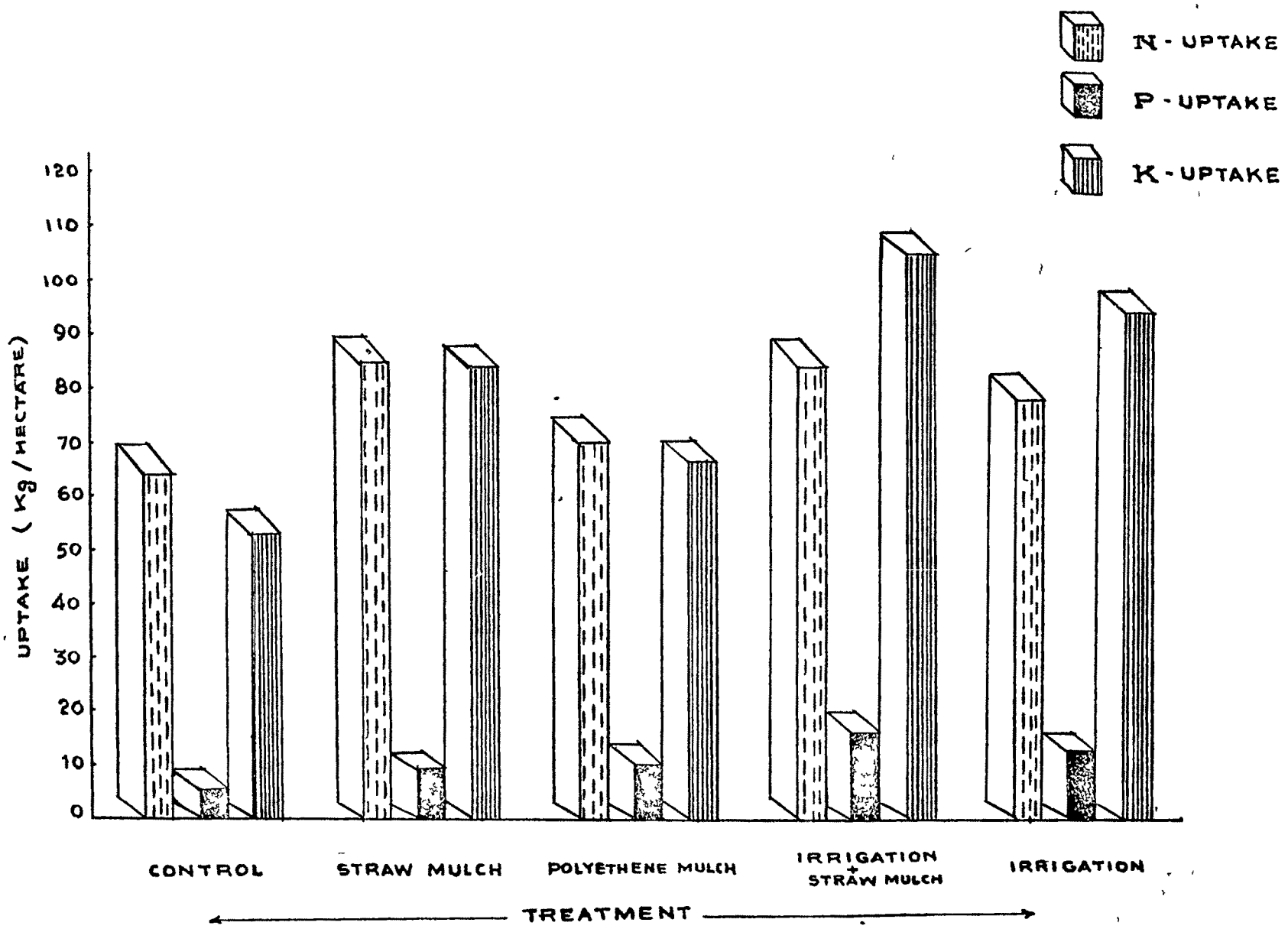


FIG 8. UPTAKE OF NITROGEN, PHOSPHORUS AND POTASSIUM IN STRAW + GRAIN AS INFLUENCED BY MULCH AND IRRIGATION DURING 1976-77.

it was significantly lower in control than any other treatment. Similar trend was observed in uptake of P in fodder except that uptake was at par in irrigation, straw mulch and polyethene mulch. It was the lowest in control (1.92 kg/ha).

4.B.10.3 Potassium uptake.

Uptake of K in grains was significantly higher (25.54 kg/ha) due to application of irrigation plus straw mulch than any other treatment. Uptake of K due to application of irrigation and polyethene mulch was at par but significantly more than application of straw mulch treatment. It was significantly lower in control (10.18 kg). Similar trend was observed in uptake of K in fodder except that it was at par due to application of irrigation plus straw mulch and irrigation alone. Potassium uptake in polyethene applied sorghum fodder was significantly lower even than straw mulch application but it was at par with control treatment.

DISCUSSION:

4.B Grain and straw yields.

The significant variations in sorghum cultivar M35-1 in grain and fodder as influenced by different materials as mulch and irrigation are attributed to better performance of growth components. Highest yield of grains occurred under irrigation plus straw mulch treatment during both

the years (4140.19 and 4696.1 kg/ha for 1975-76 and 1976-77 respectively), there being lowest in control treatments (2181.3 and 2279.8 kg/ha for 1975-76 and 1976-77 respectively). As seen from the Tables 5 and 6 it is evident that growth components such as leaf area, dry matter/plant and yield attributes like length, breadth, weight of earhead and grain index (1000 grain weight) were favourably affected due to various mulches, irrigation alone and irrigation plus straw mulch treatments as compared to control.

These growth and yield components have shown positive significant correlation (Table 10 a,b) leaf area(r=+0.7487), dry matter production (r = +0.9017), length of earhead (r = 0.7862) and weight of earhead (r = + 0.8742)borne out with grain yield. Ravindranath et al. (1974) reported that mulching caused significant increase in plant growth characters namely plant height, leaf area and root shoot dry matter production and also increase yield attributes such as number of grains and weight of grains per ear.

The effects of mulches on grain and straw yields (Table 7) were highly significant though polyethene mulch did not affect straw yield. Grain yield differences due to straw and polyethene mulch were not significant but were significantly higher than control. It clearly indicates that polyethene and straw had the same efficiency to maintain favourable soil moisture condition. Mulching improves

water conservation which favours the growth components by rendering the plants to avoid the moisture stress.

Table 10a: Correlation of leaf area and earhead characteristics with yield.

Sr. No.	Growth and yield contributing characteristics	Grain yield correlation coefficient	Dry matter correlation coefficient
1.	Leaf area	0.7487*	0.575*
2.	Dry matter	0.9017*	
3.	Length of earhead	0.7862*	
4.	Weight	0.8742*	

* Significant at 5 per cent level.

Army et al. (1961); Kowsar, et al. (1969), Mustafaev (1964); Sale (1966 a,b); Takatori et al. (1971); Unger (1971 b), Wann (1969) reported that higher soil water contents and reduced evaporation were major reasons for improved germination, emergence and seedling growth due to mulches. Bowers, (1968); Linden (1963); Miller (1968); Miller and Bunger (1963); Willis et al. (1957) reported that higher temperature alone or in combination with higher water contents due to mulches was effective in promoting later plant growth and hastening maturity. Moody et al. (1963) found that later growth of crops was better on mulched than

on bare soil due to improved water conditions. Mandal and Vamadevan(1973) also reported that higher yields of barley with mulches was associated with higher number of earheads and spikelets than control plots.

It is also evident from the Table 7 that irrigation alone and irrigation plus straw mulch produced significantly higher grain and straw yield over straw, polyethene mulch and control. Water received through irrigation at elongation/seedling growth stage enhanced growth and yield components as described above and ultimately the yield.

Singh and Saran (1969) reported that omission of the irrigation at the seedling stage reduced the yields of grain sorghum from 39.7 to 9.9 q/ha at Coimbatore, India, during summer season with two cultivars (CSH-1 and SWARNA).

Henderson and Doneen (1957) working on a pre-irrigated deep yolo loam, found that when one irrigation applied at the seedling stage, the average yield was 5950 lb/acre. Additional irrigation gave no appreciable yield increase. In this deep alluvial soil single irrigation at the seedling stage helped to develop a vigorous secondary root system which exploited the soil moisture reservoir to 2.3 metres and produced optimum yield in 1957.

Krantz, Wright and Anderson (1966) working with wheat in India also found the seedling stage to be the most critical stage for irrigation of wheat. If the surface

soil was dry at the time of the initiation of crown roots, these roots do not develop properly and yields were reduced. The present findings and the results of Singh and Saran(1969) could have important implications in rainfed sorghum grain in the rabi season in India, especially in areas where there is no rainfall during the seedling stage. The rate of water use by sorghum is at its peak at flowering stage and rises rapidly 20 days after planting till 65 days and remains almost the same till late dough stage, but later falls rapidly with advancement in maturity (Singh, 1968-69).

It is also evident that irrigation plus straw mulch produced (41.40 and 46.96 q grain yields per hectare during 1975-76 and 1976-77 respectively) which is significantly higher than irrigation alone (Table 7). This variation is attributed to the moisture conservation as effected by straw mulch following irrigation. It is natural that water loss for sometime under mulch from soil surface is reduced. This helps crop to circumvent the moisture stress that results in absence of irrigation. Irrigation increases volumetric water content to 0.314 $cm^3\ cm^{-3}$ (0.281 $cm^3 cm^{-3}$ in control) which should help to enhance flux from deeper depth to upper layers. This is evident from the data on water flux (Table 4) that indicates increase from 0.146 to 0.158 cm/day at 42.5 cm average depth.

It can be further explained on the basis of unsaturated conductivity (K) and diffusivity (D) which determined the total transmission of moisture in soil profile. Results clearly indicate that as the volumetric water content (θV) increases the K and D both increase significantly. It means that surface wetting of soil due to irrigation super imposed by checking evaporation loss through straw mulch helped to draw more water from lower depths below 75 cm.

It is interesting to note that uptake of N,P and K is favourably affected by mulch and irrigation (Fig.8). The highest uptake of N,P and K (59.5, 11.4 and 25.5 kg/ha respectively) corresponds to the maximum yield of grains achieved with the application of irrigation plus straw.

Table 10b: Correlation of N,P and K uptake with fodder and grain yields (1976-77).

Sr. No.	Nutrient uptake	Yield	
		Fodder correlation coefficient	Grain correlation coefficient
1.	N uptake	0.8511*	0.9862*
2.	P uptake	0.5778*	0.9050*
3.	K uptake	0.1344	0.9151*

* Significant at 5 per cent level

The yield of sorghum is influenced favourably by the uptake of these nutrients as monitored by soil moisture. It is further evident from the correlation coefficient (Table 10b) of uptake of N (r = 0.9862), P (r = 0.9050) and K (r = 0.9150) with grain yield that growth and yield should be better if nutrient uptake is favoured by some factors. In the present investigation, it is soil moisture monitoring that brings about higher uptake of nutrients under mulch and irrigation.

Though uptake of nitrogen in grains was more in irrigation plus straw mulch, irrigation, polyethene and straw mulch treatments but content of these nutrients was low in these treatments and was higher under control (Fig. 9a). Similar trend was reported by Mathur and Singh (1967) and Mohrotra (1970) that percentage nitrogen content of plants decreases with increase in moisture. Luebs and Laag (1967) reported that the concentration of nitrogen increased in drier soil. Joshi and More (1969) reported that the N content decreased in the stems and leaves and increased in the grain with age. Rajgopal (1969) conducting experiment on ragi reported that total nitrogen significantly decreased with decreased soil moisture stress at all stages of plant growth. The low concentration of N in grains under high soil moisture condition as maintained by irrigation plus mulch may be attributed to the dilution

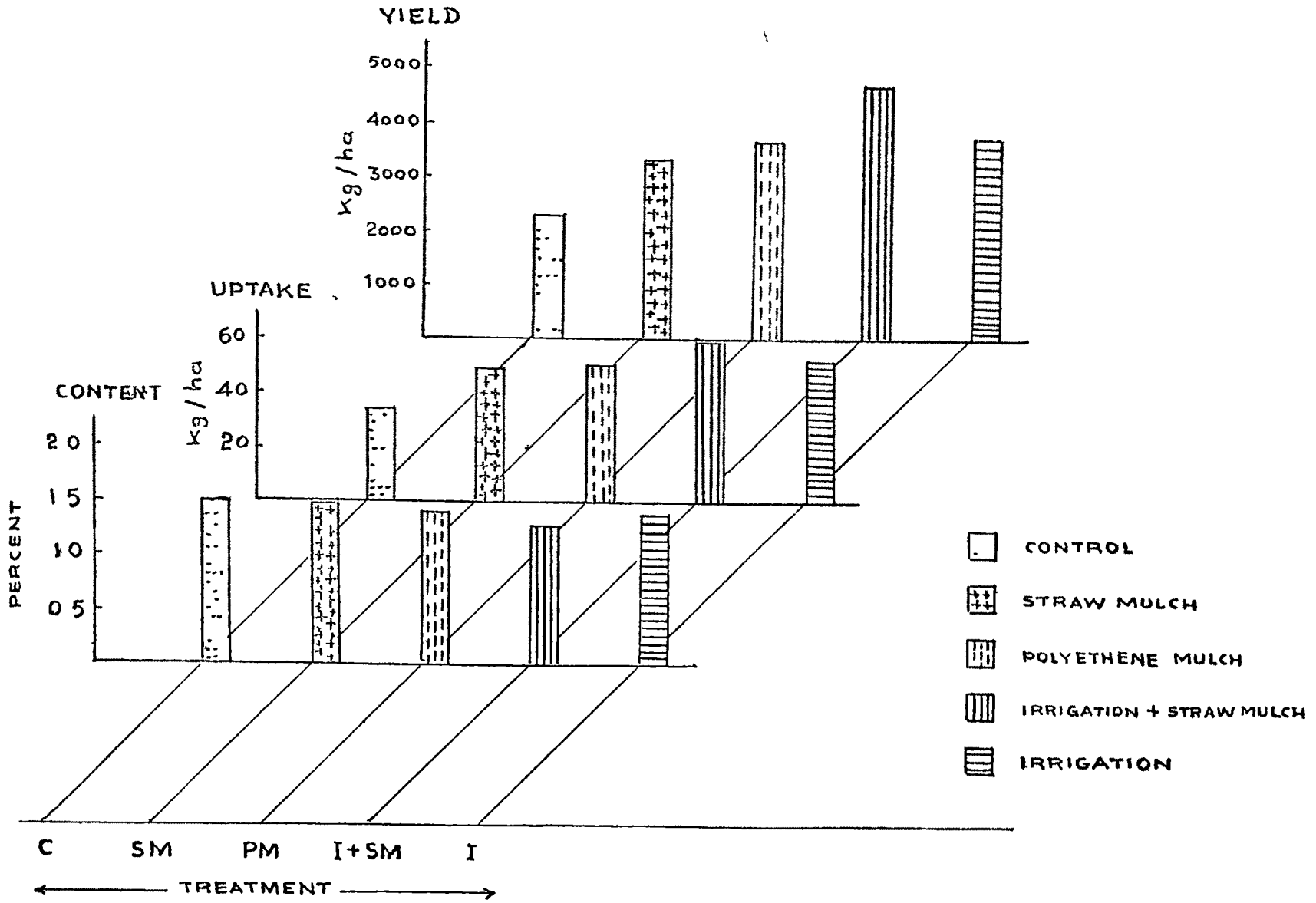


FIG 9 a NITROGEN CONTENT, UPTAKE AND YIELD OF GRAINS OF RABI SORGHUM DURING 1976-77

effect due to very high dry matter production. However the total amount of N taken-up by the crop plant may be related to the high flux of water to plants where comparatively greater moisture content (θ) improves transmission coefficient and ultimately the water uptake. Nye and Tinker (1977) have clearly brought out that N uptake increases with increasing transpiration rates as the NO_3 moves along with water stream as mass flow under sufficient moisture condition than stressed plants.

It is evident from the data presented in Fig. 9b i.e. phosphorus content was increased in mulch and irrigation treatment. Dunham and Nye (1974,1976) showed that α (root absorbing power) diminished as water potential decreased for phosphate uptake. They further stated that in wet and moist soils the root surface concentration was low, showing thereby that considerable diffusive resistance existed in the dry soil at a water potential of -3.3 bar, the root absorbing power was markedly lowered, this was the dominant effect in limiting uptake and the supply by diffusion and mass flow were well able to satisfy the greatly reduced plant demand. Drew et al (1969) and Drew and Nye (1970) measured the uptake of phosphate through 1 cm length of intact onion and determined the diffusions characteristics of soil independently. Bhat and Nye (1974) showed that when concentration of P in the

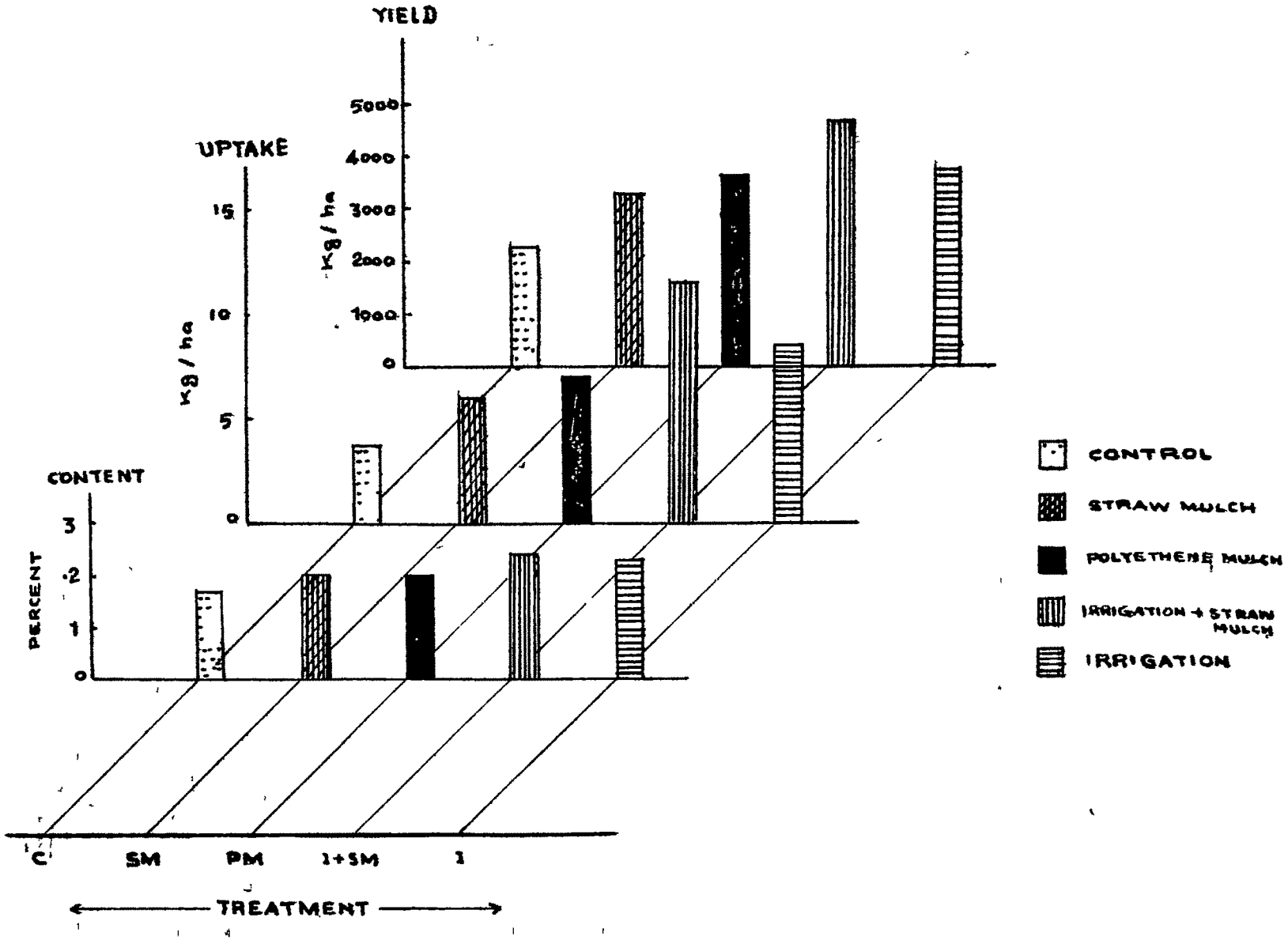


FIG. 9 b PHOSPHORUS CONTENT, UPTAKE AND YIELD OF GRAINS OF RABI SORGHUM DURING 1976-77

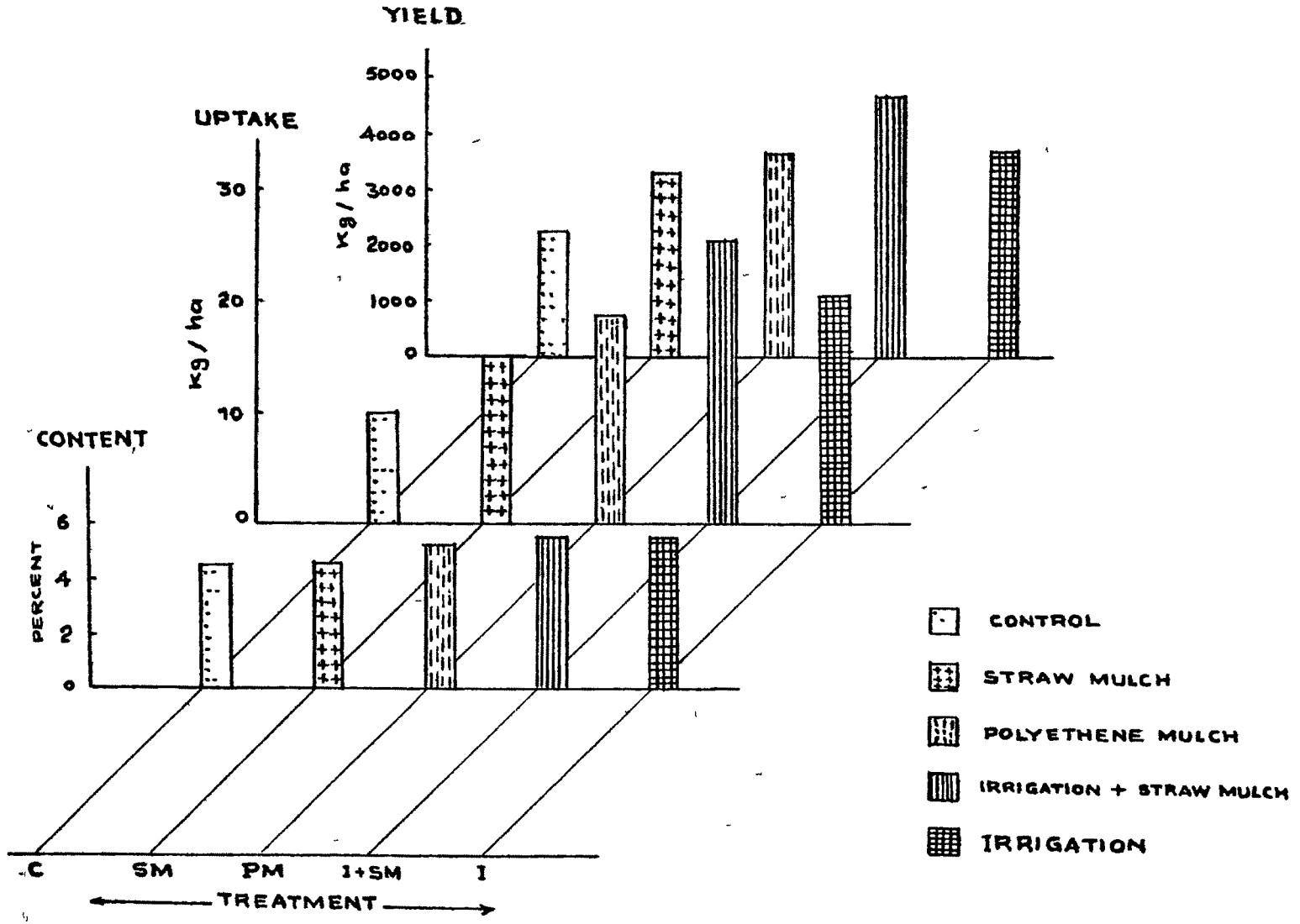


FIG 9C POTASSIUM CONTENT, UPTAKE AND YIELD OF GRAIN OF RABI SORGHUM DURING 1976-77

soil solution at the root surface is less than 10^{-6} M the value of α (absorbing power) for young roots is high and their uptake rate depends very largely on the rate of diffusion through the soils.

Low phosphorus content in control may be attributed to the fact that soil moisture depletion is conducive to the fixation of phosphorus (Neller and Cona, 1947, Trumble, 1947). Trumble (1947) concludes that it explains the relatively low phorphorus content of plants under inadequate soil moisture supply. Similar trend was also observed by Thomas et al. (1942). Eck and Musick (1977) reported that plant water stress for grain sorghum (Sorghum bicolor (L)) reduced phosphorus concentration in leaves. Kashyap et al. (1968) quoted that the available P in soil was found to be increased due to mulching (Chate, 1961, Awal, 1962; Jyothshi and Bhalla, 1967 and Dubey, 1961).

It is evident from the Table 9 that protein content was higher in control and straw mulch than rest of the treatments. This may be attributed to the facts reported by Wood and Fox (1965), Pulfi and Junhasz (1968) and Ferman et al. (1969) that increase in protein under drought condition and decrease in protein but increase in yield when moisture was available to plants through irrigation or rains. Thus it can be said that protein content in plants varies inversely with moisture.

Perusal of data shown in Appendix I shows that nitrogen uptake of plants in straw mulch treatment is highest (36.81 kg/ha) and lowest under polythene mulch (19.06 kg/ha) at harvest stage but uptake of N in grains was not higher in the same treatment. This may be attributed to water deficits which in later stages might have been caused in plants. It seems that grain formation has suffered due to low moisture and hence the nitrogen has been left out un-utilized in stover.

It is note worthy that grain quality as evidenced by seed weight improved with moisture increase (Table 6). This has substantially helped in increasing the yield.

It is evident from the table that nitrogen use efficiency was higher in irrigation plus straw mulch (202.9 and 234.8 per kg N during 1975-76) as compared to control.

It can be concluded that rabi yield of grain sorghum can be substantially increased by proper soil water management. It is also evident that grain and fodder can be increased if a compensatory irrigation is applied at seedling stage or one month after sowing. If irrigation is not available it is worthwhile to adopt straw mulch which also favours the growth and yield of rabi sorghum.

...

5. SUMMARY AND CONCLUSIONS

Yield of sorghum (*Sorghum bicolor* L. Moench) in rabi (winter) season is very low as the crop is subject to moisture stress during growth and is sustained only on stored soil moisture which depletes fast as a function of time. The present investigation was therefore, undertaken to find the response of rabi sorghum cultivar M 35-1 to types of mulches, irrigation and irrigation plus mulch. For this purpose field experiments were laid out on Parbhani clayey soil (vertisol) at experimental farm of Marathwada Agricultural University, Parbhani, Maharashtra during 1975-76 and 1976-77. Moisture conservation, depletion and movement as affected by various treatments were studied. The consequent effect of conserved moisture on growth components, yield and nutrient uptake was studied.

From the data obtained on available moisture content determined at various times during growth period of sorghum, the following conclusions can be drawn with regard to available moisture retention and depletion, induced moisture flow within soil towards root system of crop.

1) The moisture retention increased in the order of control $<$ irrigation $<$ straw mulch $<$ polyethene and irrigation plus straw mulch.

2) Irrigation in combination with straw mulch helped in retaining maximum moisture.

3) There was a continuous decrease in water content there being no differences among treatments for both the years.

4) In fallow plots, there was little profile depletion.

5) The general pattern of depletion in the profile throughout the season was very similar under the control, mulch and irrigation treatments.

The unsaturated water flow parameters were computed from the data on soil moisture as a function of depth and time.

It can be concluded that unsaturated conductivity (K) exhibited exponential relationship (r = 0.5387) with θV; K decreased sharply with a marginal slight decline in θV throughout the soil profile.

Soil water diffusivity (Dθ) also revealed an exponential relationship (r = 0.5407) with volumetric water content in black cotton soil (vertisol) profile during drying.

The variation in total water flux with change in soil water content with time of soil profile during drying was also computed.

1) As the drying of the soil profile continued for 53 days, the water flux in general decreased exponentially in the surface (0-10 cm) soil.

2) It is interesting to note that the water flux at lower layers exceeded than in the surface soil 32 days after drying commenced.

3) The water flux decreased significantly both from upper and lower layers, in the order of (i) control, (ii) polyethene, (iii) paddy straw cover, 0.244, 0.204 and 0.144 cm day^{-1} respectively at 72.5 cm height.

4) Application of irrigation increased water flux as compared to control. There was not much difference in the treatment of irrigation alone and irrigation plus straw mulch but it was more than rest of the treatments both at upper and lower layers.

From the field experiments conducted during 1975 and 1976 the influence of mulch and irrigation on the yield of sorghum cultivar M35-1 was studied. The treatments comprised of (i) control, (ii) straw mulch, (iii)irrigation and (iv) irrigation plus straw mulch for 1975-76 and one additional treatment of polyethene was induced during 1976-77. Significant yield variations were observed during first year. In order to find out contributory growth components suceptible to moisture deficits the observations on various growth components and yield contributing characters were recorded during 1976-77. The results can be summarised as follows:

1) The mean height of sorghum plant was maximum under irrigation plus straw mulch (165.3 cm) but differences due to application of straw mulch and irrigation were not significant.

2) There was no significant difference in the production of number of leaves per plant of sorghum due to various treatments.

3) There were significant differences in mean leaf area per plant. Sorghum plants treated with irrigation plus straw mulch had produced significantly higher leaf area (28.29 dm^2).

4) No significant difference in the mean stem girth per plant of sorghum due to various treatments occurring during crop growth.

5) There were no significant differences in the number of internodes per plant of sorghum due to various treatments.

6) Significant differences in the total dry matter weight per plant of sorghum were recorded. Sorghum plots treated with irrigation plus mulch had the significantly higher yield of dry matter.

7) Length of earhead was influenced favourably due to application of mulch and irrigation.

8) Application of mulch and irrigation increased breadth significantly over control. Application of straw mulch with irrigation gave more breadth than rest of the treatments.

9) Irrigation plus straw mulch had produced significantly higher weight of earhead than only straw mulch and control.

10) Significantly higher test weight was observed due to application of irrigation plus straw mulch.

11) Application of mulch and irrigation plus straw mulch produced higher grains.

12) The fodder yield of sorghum was favourably affected due to various treatments. The fodder yield was significantly higher due to application of irrigation plus straw mulch during both the years (6057 and 6072 kg/ha for 1975-76 and 1976-77 respectively).

13) Significant differences occurred in grain yield of sorghum per hectare due to various mulch and irrigation. One irrigation along with straw mulch increases yield of rabi sorghum cultivar M35-1 from 21.81 and 22.79 to 41.84 and 46.96 q/ha during 1975-76 and 1976-77 respectively. Thus about 89-105 per cent increase seems to be possible. Only straw mulch increased yield by 34.8 to 45 per cent during 1975-76 and 1976-77 respectively. Polyethene mulch increased up to 60 per cent over control.

Nutrient content of straw at various growth phases and that of grain was determined. From the results it can be concluded that:

1) Application of mulch and irrigation did not affect nitrogen content at seedling and grand growth (flower premordia) period but it increased at flag leaf (flowering) and harvest stage significantly in control than irrigation plus straw mulch and irrigation alone.

2) Phosphorus content was not affected up to flag leaf stage. However, significant differences in phosphorus content occurred at harvest.

3) Application of mulch and irrigation did not affect K content up to flag leaf stage.

4) Application of mulch, irrigation and irrigation plus straw mulch affected quality of grains as measured by N, P and K content. There was little variation in potassium content.

5) Grain sorghum produced under control contained higher N than other treatments.

6) Phosphorus content was significantly higher in grains produced from application of irrigation plus straw mulch treatment.

Uptake of N, P and K in fodder and grain was also affected due to various treatment it can be summarised as follows:

1) Maximum uptake of nitrogen in grains of sorghum per hectare occurred with application of irrigation plus straw mulch (59.57 kg/ha) which was significantly higher than rest of the treatments except irrigation alone. However, N uptake in fodder was highest in straw mulch treatment.

2) Uptake of P in grains was also higher in treatments of irrigation plus straw mulch (4.86 kg/ha) similar trend was observed in uptake of P in fodder.

3) Uptake of K in grains was significantly higher (25.54 kg/ha) due to application of irrigation plus mulch than any other treatment. Similar trend was observed in uptake of K in fodder.

The correlation coefficients of growth and yield components and uptake of nutrients with that of yield were also calculated which shows positive significant correlations, which can be summarised as follows:

1) Growth and yield components like leaf area (r=+0.7487), dry matter production (r=+0.9017), length of earhead (r= + 0.7862) and weight of earhead (r = + 0.8742) have shown positive significant correlation.

2) The correlation coefficient of uptake of N(r=+0.9862), P (r = + 0.9050) and K (r=+ 0.915) was obtained with grain yield.

The nitrogen use efficiency was higher in irrigation plus straw mulch (202.9 and 234.8 per kg N during 1975 and 1976) as compared to control.

From present findings and results application of irrigation plus straw mulch at seedling stage will be important implication in rainfed sorghum grain in the rabi season in India especially in areas where there is no rainfall during the seedling stage.

It can be concluded that rabi yield of grain sorghum can be substantially increased by proper soil water management. It is also evident that grain and fodder can be increased if a compensatory irrigation is applied at seedling stage or one month after sowing. If irrigation is not available it is worthwhile to adopt straw mulch which also favours the growth and yield of rabi sorghum.

...

LITERATURE CITED

Adams, J.E. 1962. Effect of soil temperature on grain sorghum growth and yield. Agron. J. 54: 257-61.

Adams, J.E. 1965. Effect of mulches on soil temperature and grain sorghum development. Agron. J. 57: 471-4.

Adams, J.E. 1966. Influence of mulches on runoff, erosion and soil-moisture depletion. Soil. Sci. Soc. Am. Proc. 30: 110-14.

Adams, J.E. 1970. Effect of mulches and bed configuration. II Soil temperature and growth and yield responses of grain sorghum and corn. Agron. J. 62: 765-90.

Ali, M. and Prasad, R. 1975. Soil moisture studies in fallow-barley rotation under mulches, antitranspirants and type of seedbed. J.Indian Soc.Soil.Sci.23:163-171.

Allmaras, R.R., Burrows, W.C. and Larson, W.E. 1964. Early growth of corn as affected by soil temperature. Soil Soc. Am. Proc. 28: 271-5.

Anderson, D.T. and Russell, G.C. 1964. Effects of various quantities of straw mulch on the growth and yield of spring and winter wheat. Can. J.Soil. Sci. 44:109-18.

Army, T.J. and Huds peth Jr. E.B. 1960. Alteration of micro-climate of the seed zone. Agron. J. 52: 17-22.

Army, T.J., Wiese, A.F. and Hanks, R.J. 1961. Effect of tillage and chemical weed control practices on soil moisture losses during the fallow period. Soil. Sci. Soc. Am. Proc. 25: 410-13.

Austin, R.B. 1964. Plastic mulches for outdoor tomato crops and a trial of varieties. Expt.Hort. No. 11:17-22.

Austin, A. and Miri, R.K. 1961. Effect of N and irrigation on the protein and gluten content of some new pusa wheat. Indian J. Plant Phy. 4: 150-55.

Awal, I.J. 1962. Study of effects of some kind of mulches under different intervals of irrigation on the growth and yield of garden peas. Thesis M.Sc. (Agri.) Jabalpur Univer.

Bansal, S.P., Gajri, P.R. and Prihar, S.S. 1971. Effect of mulches on water conservation, soil temperature and growth of maize (Zea mays L.) and pearl millet (Pennisetum typhoides (Burm f.) Stapf and C.E. Hubb.) Indian J.agri. Sci. 41: 467-73.

Baver, L.D., Gardner, W.H. and Gardner, W.R. 1976. The thermal regime of soils. Soil Physics, Revised edition Willey Eastern Limited, New Delhi, India.

Benoit, G.R. and Kirkham D. 1963. The effect of soil surface condition on evaporation of soil water. Soil Sci. Soc. Amer. Proc. 30: 495-98.

Bhat, K.K.S. and Nye, P.H. 1974. Diffusion of phosphate to plant roots in soil III. Depletion around onion roots without root hairs. Plant Soil 41: 383-394.

Black, A.L. and Power, J.F. 1965. Effect of chemical and mechanical fallow methods on moisture storage, wheat yields and soil erodibility. Soil. Sci. Soc. Am. Proc. 29: 465-8.

Bond, J.J. and Willis, W.O. 1969. Soil water evaporation: surface residue rate and placement effects. Soil Sci. Soc. Am. Proc. 33:445-8.

Bond, J.J. and Willis, W.O. 1970. Soil water evaporation: First stage drying as influenced by surface residue and evaporation potential. Soil Sci. Soc. Am. Proc. 34: 924-8.

Bond, J.J. and Willis, W.O. 1971. Soil water evaporation: Long-term drying as influenced by surface residue and evaporation potential. Soil Sci. Soc.Am.Proc.35:984-7.

Bordovsky D. and Hay, D. 1975. Irrigating grain sorghum in north western Kansas. Bulletin, Kansas Agril. Expt. Stn. Colby No. 592 (Field Crop Abst.30:6).

Bowers, S.A. 1968. Influence of water mulches on soil temperatures and sweet corn and green bean production. Soil. Sci. 105: 335-45.

Brown, A.R., Carlisle Cobb and Wood E.H. 1964. Effects of irrigation and row spacing on grain sorghum in the Piedont, Agron. J. 56: 506.

Buckingham, E. 1907. Studies on the water movement of soil moisture. U.S. Dept. Agr. Bur. Soils Bull.38.

Burrows, W.C. and Larson W.E. 1962. Effect of mulch on soil temperature and early growth of corn. Agron. J.54: 19-23.

Canbell, G.H., Bingham, F.T. and Garber, M.J. 1960.Effect of irrigation and phosphorus on vegetative growth and nutrient composition of tomato leaves. Soil Sci. 89: 53-90.

Carter, D.L. and Fanning, C.D. 1965. Cultural practices for grain sorghum production through a cotton bur mulch. J. Soil and Water Conserv. 20: 61-2.

Cassel, D.K., Nielson D.R. and Biggar, J.W. 1969. Soil water movement in response to imposed temperature gradients. Soil Sci.Soc. Amer. Proc. 33:493-500.

Chate, M.A. 1961. Effect of different practices and time of application of fertilizers on growth, yield and quality of potato. Thesis M.Sc. (Agri.) Jabalpur Univ.

Childs, E.C. and Collis-George N. 1948. Soil geometry and soil water equilibria Disc. Faraday Soc. 3: 78-35.

Childs, E.C. and Collis-George N. 1950. The control of soil water. Adv. Agron. 2: 233-272.

Choudhary, P.C. and Chatterjee, B.N. 1967. Moisture conservation under mulches in eroded terraced soils of Ranchi. J. Soil and Water Conserv.India.

Clements, H.F. 1940. Soil moisture and mineral nutrition to plants in Mineral Nutrition of Plants Edit by Emil Truog, Oxford and IBH Publishing Co. Bombay.

Coic, Y., Lesaint C. and Provot, M. 1964. Behaviour and mineral composition at harvest of the two organs of hard wheat and one soft wheat. Effect of late nitrogen supply and drought. Ann. Physiol. Veg. Paris, 6: 83-90 (Annals of arid zone 13:379-44.

Dahiya, D.R. and Kanwarsingh. 1977. Effect of nitrogen doses and its time and method of application of pearl millet with and without mulch in dry farming condition. Indian J. Agron. 22: 35-40.

Dancer, J. 1964. The influence of soil moisture and temperature on the growth of apple trees. I. Some observations on moisture and temperature conditions under grass, arable and mulch. Hort. Res. 4: 3-13.

de Vries, D.A. 1958. Simultaneous transfer of heat and moisture in porous media. Trans. Am. Geophys. Union. 39: 909-916.

Dhanpal and Varade, S.B. 1976. Capillary conductivity and soil water diffusivity as influenced by moisture content and texture J. Indian, Soc. Soil. Sci.24:1-7.

Dhesi, N.S., Nandpuri, K.J. and Singh, A. 1964. Effect of mulching and irrigation on the soil temperature for potato culture. Indian J. Agron. 9: 277-80.

Dixit, J.P. and Agarwal, M.C. 1971. Effect of rubber solution mulch on moisture regime of soil and growth and yield of maize. Indian J. agri. Res. 5:74-8.

Doss, B.D. and Scarsbrook, C.E. 1969. Effect of irrigation on recovery of applied N by cotton. Agron.J.61:37-40.

Drew, M.C. and Nye, P.H. 1970. The supply of nutrient ions by diffusion to plant roots in soil. III. Uptake of phosphate by roots of onion, leek and rye-grass. Plant Soil, 33: 545-563.

Drew, M.C., Nye, P.H. and Vaidyanathan, L.V. 1969. The supply of nutrient ions by diffusion to plant roots in soil. I. Absorption of potassium by cylindrical roots of onion and leek. Plant Soil, 30:252-270.

Dubey, S.C. 1961. Effect of some soil management practices on growth and yield of cauliflower. Thesis M.Sc.(Agri) Jabalpur Univ.

Dunham, R.J. and Nye, P.H. 1974. The influence of soil water content on the uptake of ions by roots. II. Chloride uptake and concentration gradients in soil. J. Appl. Ecol. 11: 581-596.

Dunham, R.J. and Nye, P.H. 1976. The influence of soil water content on the uptake of ions by roots III. Phosphate, potassium, calcium and magnesium uptake and concentration gradients in soil. J. Appl. Ecol. 13: 967-984.

Eck, H.V. and Musick, J.T. 1977. Plant water stress on nutrient accumulation and yield of irrigated grain sorghum. U.S.D.A.ARS Bushland, Texas. Agron. Abst. 197:84.

Ekern, Paul, C. 1967. Soil moisture and soil temperature changes with the help of black vapour barrier mulch and their influence on pine-apple growth in Hawaii. Soil Sci. Soc. Amer. Proc. 31: 270-75.

Emmert, E.M. 1936. Soil moisture and mineral nutrition of plants PP.411-450 in Mineral nutrition of plants edited by Emil Truog, Oxford & IBH Publishing Co.Bombay.

Evenson, P.D. and Rumbaugh, M.D. 1972. Influence of mulch on post harvest soil temperatures and subsequent re-growth of alfalfa (Medicago sativa L.) Agron J. 64: 154-157.

Fabricius, L.J. and Nalewaja, J.D. 1968. Competition between wheat and wild backwheat. Weed. Sci. 16: 204-208.

Fernandez, G.R. and Laird, R.J. 1959. Yield and protein content of wheat in Maxico as affected by available soil moisture and N fertilization Agron. J.51:33-36.

Flocker, W.J., Yamaguchi M. and Nielsen, D.R. 1968. Capillary conductivity and soil water diffusivity values from vertical soil columns. Agron.J.60:605-610.

Fuchring, H.D. and Finker, R.E. 1974. Grain sorghum production with different nutrients, populations and irrigation frequencies. Bulletin, New Mexico State Univ. Agril. Expt. Stn. No. 613 PP.24 (Field Crop Abst. 29 CU.)

Gardner, W.R. 1958. Some steady state solutions of the unsaturated moisture flow equation with application to evaporation from a water table. Soil Sci.85:228-232.

Gates, C.T. 1957. The response of young tomato plants to brief period of water shortage III. Drift in nitrogen and phosphorus, Aust. J. biol. Sci. 10: 125-146.

Greaves, J.E. and Carter, E.G. 1923. The influence of irrigation water on composition of grains and the relationship to nutrition. J. biol. Chem.58:531-41.

Greaves, J.E. and Nelson, D.H. 1925. Soil moisture and plant nutrition PP.411-450 in Mineral nutrition of plants Edited by Emil Truog, Oxford and IBH Publishing Co. Bombay.

Greb, B.W. 1966. Effect of surface applied wheat straw on soil water losses by solar distillation. Soil. Sci. Soc. Amer. Proc. 30: 786-788.

Griffin, R.H. II, Ott, B.J. and Stone, J.F. 1966. Effect of water management and surface applied barriers on yields and moisture utilization of grain sorghum in the Southern Great Plains. Agron. J.58: 449-52.

Hanks, R.J. 1958. Water vapour transfer in dry soil. Soil. Sci. Soc. Amer. Proc. 22: 372-374.

Hanks, R.J., Bowers, S.A. and Bark, L.D. 1961. Influence of soil surface conditions on net radiation, Soil temperature and evaporation. Soil Sci.91: 233-8.

Hanks, R.J., Gardener H.R. and Fairbourn, M.L. 1967. Evaporation of water from soils as influenced by drying with wind and radiation. Soil Sci. Soc. Amer. Proc. 31: 593-598.

Hanks, R.J. and Woodruff, N.P. 1958. Influence of wind on water vapour transfer through soil, gravel and straw mulches. Soil Sci. 86: 160-64.

Harris, W.W. 1963. Effect of residue management, rotations and nitrogen fertilizer on small grain production in north-western Kansas. Agron. J. 55: 281-4.

Harrold, L.L., Peters, D.B., Dreibelbis, F.R. and Mc Guinnes, J.L. 1959. Transpiration evaluation of corn grown on a plastic covered lysimeter. Soil Sci. Soc. Am. Proc. 23: 174-8.

Hellman, M.D., Wiegand C.L. and Conzalez, C.L. 1968. Sand and cotton bur mulches. Bermuda grass sod and bare soil effects on: II. Salt leaching. Soil Sci. Soc. Am. Proc. 32: 280-83.

Hernando, V., Jimeno, L. and Gracia, V. 1968. Effect of soil humidity on the mineral nutrition of plant. Agrochimica, 12: 341-52. (Field Crop. Abst.22: 1451.)

Hopkins, J.W. 1935. Influence of weather conditions on the nitrogen content of wheat. Can.J. Res. 12: 228-57.

Howell, T.A. 1975. Optimization of grain sorghum water use efficiency under high frequency irrigation by system simulation and stochastic dynamic development. Dissertation Abst. International B. 36. (Field Crop Abst. Vol. 30).

Humphries, A.W. 1962. The growth of some perennial grasses in water logged soil. I. The effect of water logging on the availability of nitrogen and phosphorus to the plant. Aust. J. agric. Sci. 13: 414-425.

Hutcheon, W.L. and Paul, E.A. 1966. Control of protein content of Thetcher wheat by nitrogen fertilization and moisture stress. Can.J. Soil Sci. 46: 101-103.

Inuyama, S. Musick, J.T., Dusek, D.A. 1976. Effect of plant water deficits at various growth stages on growth, yield and leaf water potential of irrigated grain sorghum. Proc. Crop. Sci. Soc. Japan 45: 298-307.

Jacks, G.V., Brind, W.D. and Smith, R. 1955. Mulching. Common-Wealth Bur. Soil. Sci. (England) Tech. Comm.No.49.

Jackson, M.L. 1958. Soil chemical analysis. Prentice hall of Inc. Englewood Cliff N.J.

Jackson, M.L. 1967. Soil chemical analysis. Prentice hall of India, Private Ltd., New Delhi.

Jackson, R.D. 1973. Diurnal changes in soil water content during drying. In R.R. Bruce et al.(ed). Field soil water regime, Special Pub.5. Soil Sci. Soc. Amer. Proc. PP.37-55.

Jackson, R.D., Kimball B.A., Reginato, R.J., Idso,S.B. and Nakayama, F.S. 1975. Heat and water transfer in a natural soil environment. In 'Heat and Mass transfer in the Biosphere, Pt. I, Transfer process in plant Environment". Scripta Pub. Co. Washington, D.C.

Jackson, R.D., Reginato, R.J., Kimballa, B.A. and Nakayama, F.S. 1974. Diurnal soil water evaporation. Comparison of measured and calculated soil water fluxes. Soil Sci. Soc. Amer. Proc. 38: 861-866.

Janes, B.E., 1948. Soil moisture and mineral nutrition of plant PP.411-450 in Mineral nutrition of plants Edited by EmilTroug, Oxford and IBH Publishing Co. Bombay (Proc.Am. Soc. Hort. Sci. 51:45).

Jensen, M.E. and Musick, J.T. 1960. The effects of irrigation treatments on evapotranspiration and production of sorghum and wheat in the southern great plains. Trans. 7th Internat. Congr. Soil Sci.1: 386-93. (Field Crop Abst. 1963).

Jensen, M.E. and Sletten, W.H. 1965. Evapotranspiration and soil moisture fertilizer interrelation with irrigated winter wheat in the southern hhigher plains. Conserv. Res. Rep. 4 U.S. Dept. Agric. PP.22. (Field Crop Abst. 20: 1480).

Johnson, W.C. and Davis, R.G. 1972. Research on stubble mulch farming at winter wheat. U.S. Dept. Agr. Conserv. Res. Expt. No.16

Jones, J. Nick., Moody Jr. J.E. and Lillard, J.H. 1969. Effects of tillage, no tillage and mulch on soil water and plant growth. Agron. J. 61:

Joshi, K.G. and Morey, D.K. 1969. Effect of nitrogen levels on nitrogen uptake and dry matter accumulation by kharif jowar. Nagpur agric. Coll.Mag. 42:1-9.

Jyotishi, R.P. and Bhalla, P.L. 1967. Study of the effect of some kinds of mulches under different intervals of irrigation on growth and yield of cauliflower. J.N.K.V.V. Res. Jour. 1: 147-52.

Kadam, D.M., RamkrishnaRao, G. and Varade, S.B. 1978. On the prediction of reference crop evapotranspiration and consumptive use of different crops. Annals of arid Zone 1: 99-111.

Kashyap, R., Jyotishi, R.P. and Shrivastav, S.R. 1968. Effect of mulching on perlette grapes. Mad. Agric. J. 55: 542.

Klute, A. 1952a. A numerical method for solving the flow equation for water in unsaturated materials. Soil Sci. 73: 105-116.

Klute, A. 1952b. Some theoretical aspects of the flow of water in unsaturated soils. Soil Sci. Soc. Amer. Proc. 16: 144-148.

Kolandaiswamy, S., Rangnathan, A.K. and Srinivasan,V.1967. Preliminary trial on agricultural mulch on cholam (sorghum)and cotton. Madras agric. J. 54: 195-7.

Koshi ,P.T. and Fryrear, D.W. 1971. Effect of seedbed configuration and cotton bur mulch on lint cotton yield, soil water and water use. Agron.J. 63: 817-22.

Kowsar, A., Boersma L. and Jarman, G.D. 1969. Effects of petroleum mulch on soil water content and soil temperature. Soil Sci. Soc. Am. Proc. 33: 783-6.

Lehne, I. 1961. Mulching of arable soil with organic material. Deustsche land Wirtschalt 12:525-9. Quoted from Physiological aspects of dry-land farming Ed. by Gupta, U.S. Oxford and IBH Publishing Co. Bombay.

Lemon, E.R. 1956. The potentialities for decreasing soil moisture evaporation loss. Soil Sci. Soc. Amer. Proc. 20: 120-125.

Lewis, R.B., Hiler, E.A. and Jordan, W.R. 1974.Susceptibility of grain sorghum to water deficit at three growth stages. Agron. J. 66: 589-591.

Linden, R. 1963. Soil protection with plastic mulches. Ann. Gembl. 69: 601-8. Quoted from physiological aspects of dry-land farming Ed. by U.S. Gupta. published by Oxford and IBH Publishing Co. Bombay.

Lippert, L.F., Takatori, F.H. and Whiting, F.J. 1964. Soil moisture under bands of petroleum and polythene mulches. Proc. Am. Soc. Hort. Sci. 85: 541-6.

Liptay, A.M. and Liessen, H. 1970. Influence of polythene coated paper mulch on soil environment. J. Am. Soc. Hort. Sci. 95: 395-8.

Luebs, R.E. and Laag, A.E. 1967. Nitrogen effect on leaf area, yield and nitrogen uptake of barley under moisture stress. Agron J. 59: 219-222.

Lyford, F.P. and Quashu, H.K. 1969. Infiltration rates as affected by desert vegetation. Water Resourc. Res. 5: 1373-6.

MacMillan, K.A. and Millette, J.F.G. 1971. Influence of mulch on soil temperature and corn yield. Can. J. Soil Sci. 51: 305-7.

Magar, S.S. 1977. Some aspects of water flux in relation to crack formation in black cotton soil (Vertisol). Thesis submitted for Ph.D. degree at I.I.T. Kharagpur. India.

Malewar, G.U. 1976. Placement of black cotton soils of Marathwada in the comprehensive system of soil classification. Journal of M.A.U. 1(Addi): 195-199.

Mandal, B.K. and Vamadevan, V.K. 1975. Effect of mulches on the growth and yield of rabi crops in Mahanadi delta. Indian J. Agron. 20: 190-191.

Manescu, B. and Ciofu, R. 1970. The influence of mulching with plastic on the thermal and water conditions of soil. Lucraristiintifice Institual Agronomic N. Balcescu, Seria B, Horticultura 13: 63-72. Quoted from physiological aspects of dryland farming Ed. by U.S. Gupta published by Oxford and IBH Publishing Co. Bombay.

Mannering, J.V. and Meyer, L.D. 1963. The effects of various rates of surface mulch on infiltration and erosion. Soil Sci. Soc. Am. Proc. 27: 84-6.

Marshall, T.J. 1958. A relation between permeability and size distribution of pores. J. Soil Sci. 9: 1-8.

Masood Ali and RajendraPrasad. 1974. Effect of mulches reflectant and type of seedbed on barley (Hordeum vulgare) grown under semi-arid conditions. Annals arid zone 13:331.

Mathews, O.R. and Army, T.J. 1960. Moisture storage on followed wheat land in the Great plains. Soil Sci. Soc. Am. Proc. 24: 414-8.

Mathur, M.K. and Singh, R.P. 1967. Uptake of N by barley. Indian J. Agron 12: 16-18.

May, L.N., Milthorpe, E.J. and Milthoropo, F.L. 1962. Pre-sowing hardening of plants to drought. Review Crop Abstr. 15: 93-98.

McCalla, T.M. and T.J.Army. 1961. Stubble mulch farming. Adv. Agron. 13: 125-76.

Mehrotra, O.N., Garg, R.C. and Prasad, M. 1970. Effect of different soil moisture regimes on growth, yield and quality of tobacco, Indian J. Agron. 15:148-149.

Miller, D.E. 1968. Emergence and development of sweet corn as influenced by various soil mulches. Agron. J. 60: 639-71.

Miller, D.E. and Bunger, W.C. 1963. Use of plastic soil covers in sweet corn production. Agron. J.55: 417-19.

Miller, M.F. and Duley, F.L. 1925. Soil moisture and the mineral nutrition of plants PP.411-450 in the Mineral nutrition of plants published by Oxford and IBH publishing Co. Bombay.

Millington, R.J. and Quirk, J.P. 1960. Transport in porous media. Trans. of 5th Int. Congr. Soil Sci. Madison I: 97-106.

Millington, R.J. and Quirk, J.P. 1961. Permeability of porous solids. Trans. Faraday Soc. 57: 1200-1207.

Millington, R.J. and Quirk, J.P. 1964. Formation factor and permeability equation. Nature 202: 143-145.

Misra, D.K. 1965. Influence of soil moisture on physiological processes of plants. Indian J. Agron. 10: 331-343.

Moody, J.E., Jones Jr., J.N. and Lillard, J.H. 1963. Influence of straw mulch on soil moisture, soil temperature and the growth of corn. Soil Sci. Soc. Am. Proc. 27: 700-4.

Musick, J.T., Wiese, A.F. and Dusek, D.A. 1973. Evaluation of tillage and herbicides for grain sorghum residue management in an irrigated wheat-sorghum-fallow cropping sequence. Texas. Agr. Exp. Sta. Prog. Rpt. Quoted from Physiological aspects of dryland farming published by Oxford and IBH Publishing Co. Bombay.

Mustafaev, KH.M. 1964. A stone mulch for tree crops. Vestn. S:Kh. Nauki No.10 PP. 88-92. Quoted from Physiological aspects of dryland farming published by Oxford and IBH Co. Bombay.

Neiding, R.E. and Synder, R.S. 1922. The effect of available nitrogen on protein content and yield of wheat. Idaho Exp. Sta. Bull. 1 (Annals arid zone 13: 339-43).

Neiding, R.E. and Synder, R.S. 1924. The relation of moisture and available nitrogen to the yield and protein content of wheat. Soil Sci. 18: 173-181. (Annals arid zone 13: 339-43).

Neiding, R.E. and Synder, R.S. 1926. The relation of yield and protein content of wheat to the nitrogen content of soil under ten years of different systems of cropping. Idaho Sta. Bull. 106 (Annals arid zone 13: 339-445).

Nerpin, S.V. and Pakshina, S.M. 1965. Residues from the distillation of alcohols as effective preparations for decreasing physical evaporation from soil. Dokl. Vses. Akad. Sel-Khos. Nauk No.10 PP.4 in Physiological aspects of dryland farming published by Oxford and IBH Co.Bombay.

Nye, P.H. and Tinker, P.B. 1977. Solute movement in the soil root system. Blackwell Scientific Publication Oxford London.

Ogata, G.M. and Richard, L.A. 1957. Water content changes following irrigation of bare field soil that is protected from evaporation. Soil Sci. Soc. Amer. Proc. 21: 355-356.

Onchev, N.G. 1960. The effect of mulching on the moisture content and heat regime of soil. Khidrologiyaic Meteorologiya No. 4, PP. 43-53. Quoted from Physiological aspects of dryland farming published by Oxford and IBH Co. Bombay.

Patil, R.V., Singh, C.D., Yadahalli, Y.H. and Prabhakar, A.S. 1972. Effect of straw mulch and application of fertilizers on soil moisture conservation and yield of potato. Indian J. Agron. 17: 17-19.

Paul, W. Unger, 1976. Straw mulch rate effect on soil water storage and sorghum yield. USDA, ARS, Bushland, Texas (Agron. Abst. 1976 ann. meeting).

Pearson, R.W. 1963. Moisture and N relations of cotton plant food.Rex. Winter (Field Crop Abstr. 1976).

Peters, D.B. 1960. Relative magnitude of evaporation and transpiration, Agron. J. 52: 536-538.

Pharande, K.S., Umrani, N.K. and Kale, S.P. 1973. Moisture uptake patterns in relation to stages of crop and soil depth in sorghum. Indian J. agric. Sci.43:701-703.

Philip, J.R. 1955. The concept of diffusion applied to soil water. Proc. Nat. Acad. Sci.India 24A: 93-104.

Philip, J.R. 1957. The physical principles of soil water movement during the irrigation cycle. International commission on irrigation and Drainage Third congress.

Philip, J.R. 1958. Physics of water movement in porous-solids. Water and its conduction in soils. Highway Research Board, Special Report No.40.

Philip, J.R. and deVries, D.A. 1957. Moisture movement in porous materials under temperature gradients. Trans. Am. Geophys. Union, 38: 222-232.

Piper, C.S. 1952. 'Soil and plant analysis' (Ed.I.) reprinted from International science published Inc. New York.

Plant, Z., Blum, A. and Arnon, I.1969. Effect of soil moisture regime and row spacing on grain sorghum production. Agron. J. 61: 344-7.

Pohjanheimo, O. and Heinonen, R. 1960. The effect of irrigation on root development, wateruse, nitrogen uptake and yield characteristics of several barley varieties. Suom Maataloust. Seur. Julk 95: 1-20 (Field Crop Abst. 14: 606).

Power, J.F., Erunes, D.L. and Reichman, G.A. 1961. The influence of phosphorus fertilization and moisture on growth N uptake and moisture use. Proc. Soil. Sci. Soc. Amer. 25: 207-10.

Prihar, S.S., Singh, B. and Sandhu, B.S. 1968. Influence of soil and climatic environments on evaporation losses from mulched and unmulched plots. J. Res. Punjab Agr. Univ. 5: 320-8.

Pulfi, G. and Juhasz, I. 1968. The change in amino-acid reserves on plants due to the effect of water deficiency and saline soil. Agrokem. Talajt. 17: 243-254 (Annals arid zone. 18: 339-43).

Pusztai, A. 1963. The effect of plastic mulch on the soil and plant. Agrokem. Talajt. 12: 351-60. (Annals arid zone 18: 339-43).

Qashu, H.K. and Evans, D.D. 1967. Effect of black granular mulch on soil temperature, water content and crusting. Soil Sci. Soc. Am. Proc. 31: 429-35.

Rajgopal, C.K. 1969. The influence of soil moisture stress on the nutrient uptake of ragi. The Madras agric. J. 56: 642-652.

Rajput, R.K. and Singh, M. 1970. Efficacy of different mulches in conserving soil moisture in cotton. Indian J. Agron. 15: 41-5.

Raming, R.E. and Roades, H.F. 1963. Inter-relationship of soil moisture level at planting time and nitrogen fertilization on winter wheat production. Agron. J. 55: 123-126.

Ravindranath, E., Chari, A.V. and Mohd. Yassen, 1974. A note on effect of mulching on growth, yield and water use of sorghum CSH-1. Indian J. Agron. 19: 157-58.

Richard, L.A. 1931. Capillary conduction of liquids through porous media. Physics. 1: 318-333.

Richards, L.A. and Moore, D.C. 1952. Influence of capillary conductivity and depth of wetting on moisture retention in soil. Trans. Amer. Geophys. Union. 33: 531-540.

Sachan, S.S., Bhatia, K.S., Choudhary, H.P. and Pandey, G.N. 1977. Note on the effect of mulches and fertilization on the yield of wheat (Kalyan sona) under rainfed conditions. Indian J. agric. Res. 11: 42-44.

Sale, P.J.M. 1966a. Effect of petroleum mulch on seedling emergence, soil moisture and soil temperature. Expt. Hort. No. 14: 43-52.

Sale, P.J.M. 1966b. Effect of a petroleum mulch on the marketable yields of some vegetable crops. Expt. Hort. 14: 53-61.

Schales, F.D. 1964. A study of some physical and biological effects of various mulching materials when used with several vegetable crops. Diss. Abstr. 24: 3487.

Scharrer, K. 1939. Der. Enfluss verschiedener wasser and stick stoffver sorgang auffden Eiqeissgehalf der Gerste. Forsohungsdiemst 7: 127-140 (Annals arid zone 13: 339-345 (1974)).

Sharma, H.C. 1969. Effect of soil moisture regime, phosphorus and N on growth, yield, nutrient uptake and moisture use by barley. Ph.D. Thesis, University of Udaipur.

Shaw, B.T. 1952. Soil conditions and plant growth PP.203, Academic press. Inc. N.Y.

Singh, S., Singhal, A.K. and Nambian, K.K.M. 1967. Effect of mulching on moisture retention and yield of wheat under rainfed conditions. J. Soil and Water Conserv. India. 15: 102-107.

Sichkar, N.M. and Volkova, L.A. 1965. Effect of conditions of growth and stages of development on alteration of quality of starch and protein in grain crops. Trudy. Prekl. Bot. Genet. Selek. 37: 39-49. Soil & Fert. 29:596.

Smirnova, A.N. and Bogordskii, M.A. 1949. 'Quality of Turkemenistan wheat in irrigated and unirrigated soil' (in Russian) Selek semenovod 16: 49-52 (Gield Crop Abstr. 4: 315).

Sosulski, F.W., Paul, E.A. and Hutcheon, W.L. 1963. The influence of soil moisture, nitrogen fertilization on the quality and amino acid composition of Thatcher wheat. Can.J. Soil, Sci. 43: 219-228.

Sowinski, J. 1966. The influence of nitrogen fertilization gradation on the yield and its structure of spring barley in condition of periodical soil drought. Roozn. Nauk. roln. 91: 167-86 (Field Crop Abstr. 20: 1562).

Srinivasan, T.R., Bali, Y.P. and Tamhane, R.V. 1969. Placement of black soils of India in the comprehensive soil classification system. 7th Approximation. J. Indian Soc. Soil Sci. 17: 323-333.

Steward, R. and Greaves, J.E. 1909. A study of the production and movement of nitric nitrogen in an irrigated soil. Utah. Sta. Bull. 109 (Annals arid zone 13: 339-345 (1974)).

Stickler, F.C., Wearden, S. and Pauli, A.W. 1961. Leaf area determination in grain sorghum.Agron.J.53:187-88.

Stocker, O. 1960. Physiological and Morphological changes in plants due to water deficiency. Arid zone. Research XV. Plant water relationship in arid and semi-arid conditions. Review of Research, Pub. UNESCO (Paris) PP.63-104.

Storrier, R.R. 1965. The influence of water on wheat yield, plant nitrogen uptake and soil mineral nitrogen concentration. Aust. J. Expt. Agric. Anim. Husb.5:316.

Takatori, F.H., Lippert, L.F. and Whiting, F.L. 1964. The effect of petroleum mulch and polythene films on soil temperature and plant growth. Proc. Am. Soc. Hort. Sci. 95: 532-40.

Takatori, F.H., Lippert, L.F. and Lyoris, J.M. 1971. Petroleum mulch studies for row crops in California. Calif. Agr. Expt. Sta. Bull. No.849.

Taylor, R.E., Hays, O.E., Bay, C.E. and Dixon, R.H.1964. Corn stover mulch for control of runoff and erosion on land planted to corn after corn. Soil Sci. Soc. Am. Proc. 28: 123-5.

Terman, G.L., Raming, R.E., Dreier, A.F. and Olson,R.A.1969. Yield protein relationship in wheat grain as affected by nitrogen and water. Agron. J.61: 755-758.

Thatcher, R.W. 1913. A report on the investigations concerning the chemical composition of wheat, 1960 to 1921 inclusive Wash. Sta. Bull. 111. Quoted from Annal arid zone. 13: 339-45 (1974).

Thomas, J.R. and Heilman, M.D. 1967. Influence of moisture and fertilization on growth and N and P uptake by sweet pappers. Agron. J. 59: 27-30.

Thomas, W., Mack, W.B. and Cotton, R.H. 1942. Proc. Am. Soc. Hort. Sci. 40: 531- Quoted from Mineral nutrition of plant published by Oxford & IBH Publishing Co.Bombay.

Tombesi, L. and Fortini, S. 1951. Intensita fotosintetica a respiratoria glutazione ridotto, acido ascarbico a attivita catalusica in funzione (Annals arid zone 13: 339-345).

Umrani, N.K., Pharande, K.S. and Quamarzzaman, S.1973. Mulching conserves extra moisture. Indian Fmg. 23: 24-25.

Unger, P.W. 1971 b. Soil profile gravel layers. II.Effect on growth and water use by a hybrid forage sorghum. Soil Sci. Soc. Am. Proc. 35: 980-83.

Unger, P.W. 1972. Dryland winter wheat and grain sorghum cropping systems- Northern High Plains of Texas. Texas Agr.Exp. Sta. Bull. No.1126.

Unger, P.W., Allen, R.R. and Wiese, A.F.1971. Tillage and herbicides for surface residue maintenance, weed control and water conservation. J. Soil and Water Conserv. 26: 147-50.

Unger, P.W. and Parker, J.J. 1974. No tillage dryland grain sorghum after irrigated wheat with intervening fallow. Texas.Agr.Exp.Sta.Prog. Rpt. (Physiological aspects of dryland farming published by Oxford & IBH Co.Bombay).

Upadhyay, U.C. and Varade, S.B. 1978. Yield and quality of sorghum as affected by urea and simazine sprays. Indian J. agric. Sci. 48: 347-50.

VanWijk, W.R., Larson, W.E. and Burrows, W.C. 1959. Soil temperature and the early growth of corn from mulched and unmulched soil. Soil Sci. Soc. Am.Proc. 23:428-434.

Vega, G.J.D. 1972. Comparison of the leaf and grain yields and root growth of maize and sorghum under 2 soil moisture regimes, in XIII Informe de investigation, 1971-1972.

Vonseelhorst, C. 1911. Die. Bedeutung des wassers in Lebon der kulturpflanzer. J. landw 59: 259-291. Quoted from Annals of arid zone 13: 339-48.

Wann, S.S. 1969. Effect of cover crops and mulching on infiltration rates on sloping land. J.Agr. Ass.China No. 67: 50-57.

Wiegand, C.L., Heilman, M.D. and Swanson, W.A. 1968. Sand and cotton bur mulches, Bermudagrass sod and bare soil effects on: 1. Evaporation suppression. Soil Sci. Soc. Am. Proc. 32: 276-86.

Wiese, A.F., Burnett, E. and Box Jr. J.E. 1967. Chemical fallow in dryland cropping sequences. Agron. J. 59: 175-177.

Willis, W.O. 1962. Effect of partial surface covers on evaporation from Soil. Soil Sci. Soc. Am. Proc. 26: 598-601.

Willis, W.O., Hass, H.J. and Robins, J.S. 1963. Moisture conservation by surface or subsurface barriers and soil configuration under semi-arid conditions. Soil Sci. Soc. Am. Proc. 27: 577-80.

Willis, W.O., Larson, W.E. and Kirkham, D. 1957. Corn growth as affected by soil temperature and mulch. Agron. J. 49: 323-28.

Wood, H.L. and Fox, W.E. 1965. The interaction of nitrogen and water on yield, protein and mottling in wheat grown on black earth in Queensland Expt. Agric. 1: 107-112. Quoted from Annals of arid zone. 13: 339-345 (1974).

Zakharov, N.G. and Semikina, G.G. 1964. Investigation of the agro-physical effectiveness of mulching soil with a film of polythene. Dokl. Akad. S-Kh. Nauk. No.12: 14-16. Quoted from Physiological aspects of dryland farming Edited by U.S. Gupta, Oxford & IBH Publishing Co. Bombay.

Zingg, A.W. and Whitfield, C.J. 1957. A summary of research experience with stubble mulch farming in the Western states. U.S. Dept. Agr. Tech. Bull. No. 1166. Quoted from Physiological aspects of dryland farming Edited by U.S. Gupta, Oxford & IBH Publishing Co. Bombay.

APPENDIX I

Uptake of N, P, K in fodder and grain as influenced by mulch and irrigation during 1976-1977 in kg/ha.

Treatments	Fodder			Grain			Fodder+Grain		
	N	P	K	N	P	K	N	P	K
Control	29.86	1.92	43.67	34.88	3.93	10.18	64.74	5.86	53.93
Straw mulch	36.81	2.93	64.35	48.92	6.09	15.20	85.72	9.10	79.62
Polythene	19.06	2.93	47.68	50.85	7.17	18.90	70.22	10.33	66.66
Irrigation plus straw mulch	26.85	4.86	80.01	59.57	11.41	25.54	83.80	16.28	105.55
Irrigation	25.62	4.16	73.68	52.47	8.56	20.60	78.09	12.80	94.29
S.E. ±	2.36	0.385	3.317	2.80	0.540	1.08	4.68	0.802	3.24
C.D. at 5%	7.29	1.280	10.416	8.64	1.680	3.44	14.43	2.469	10.03

APPENDIX II

Volumetric water content ($\theta = cm^3/cm^3$) at different depths under different treatments.

Treatments \ Depths (cm)	7.5	12.5	22.5	32.5	42.5	52.5	62.5	72.5
Control	0.3001	0.2977	0.2894	0.2817	0.2869	0.2908	0.2778	0.2569
Straw mulch	0.3209	0.3348	0.3210	0.2915	0.2935	0.3000	0.2884	0.2623
Polythene mulch	0.3377	0.3561	0.3576	0.3307	0.3046	0.2893	0.3059	0.2745
Irrigation	0.3296	0.3285	0.3112	0.3036	0.3082	0.3152	0.3170	0.2783
Irrigation plus straw mulch	0.3499	0.3582	0.3444	0.3245	0.3145	0.3099	0.3119	0.2757

APPENDIX III

Diffusivity ($D = cm^2/day$) as affected by water content under different treatments.

Treatments	Depths (cm)	7.5	12.5	22.5	32.5	42.5	52.5	62.5	72.5
Control		46.482	56.419	111.025	153.237	153.032	102.398	171.185	103.956
Straw mulch		4.302	32.021	14.016	23.711	79.691	101.843	118.086	79.316
Polythene mulch		9.773	29.491	26.629	38.970	55.385	106.352	117.754	43.314
Irrigation		19.348	23.211	112.627	83.067	181.234	990.203	1120.89	47.993
Irrigation plus straw mulch		39.955	53.703	52.501	67.608	239.243	1006.429	1090.29	52.941

APPENDIX IV

Unsaturated conductivity (K = cm/day) as affected by water content under different treatments.

Treatments \ Depths (cm)	7.5	12.5	22.5	32.5	42.5	52.5	62.5	72.5
Control	0.0003992	0.000501	0.0009792	0.0013607	0.001319	0.0009174	0.001429	0.0009376
Straw mulch	0.00002818	0.000238	0.0001285	0.0002100	0.000689	0.0008758	0.000999	0.0006868
Polyethene mulch	0.0000801	0.000163	0.0001320	0.0003300	0.000493	0.0009178	0.001027	0.0003780
Irrigation plus straw mulch	0.0002493	0.000282	0.0004284	0.0005652	0.001971	0.0082420	0.009540	0.0004563
Irrigation	0.0001439	0.000183	0.0009967	0.0007509	0.001525	0.0081690	0.009830	0.0004257