EFFECT OF TILLAGE INDUCED SOIL PHYSICAL PROPERTIES AND SOIL MOISTURE REGIMES ON PERFORMANCE OF SUNFLOWER (*Helianthus annuus* L.) IN RICE BASED CROPPING SYSTEM

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THESIS SUBMITTED TO THE
ACHARYA N.G. RANGA AGRICULTURAL UNIVERSITY
IN PARTIAL FULFILMENT OF THE REQUIREMENTS
FOR THE AWARD OF THE DEGREE OF

DOCTOR OF PHILOSOPHY
IN THE FACULTY OF AGRICULTURE

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CERTIFICATE

Mr. P. GURUMURTHY has satisfactorily prosecuted the course of research and that the thesis entitled **"EFFECT OF TILLAGE INDUCED SOIL PHYSICAL PROPERTIES AND SOIL MOISTURE REGIMES ON PERFORMANCE OF SUNFLOWER (*Helianthus annuus* L.) IN RICE BASED CROPPING SYSTEM"** submitted is the result of original research work and is of sufficiently high standard to warrant its presentation to the examination. I also certify that the thesis or part thereof has not been previously submitted by him for a degree of any university.

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No part of the thesis has been submitted for any other degree or diploma. The published part has been fully acknowledged. All assistance and help received during the course of the investigations have been duly acknowledged by the author of the thesis.

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DECLARATION

I, **P. GURUMURTHY** hereby declare that the thesis entitled **"EFFECT OF TILLAGE INDUCED SOIL PHYSICAL PROPERTIES AND SOIL MOISTURE REGIMES ON PERFORMANCE OF SUNFLOWER (*Helianthus annuus* L.) IN RICE BASED CROPPING SYSTEM"** submitted to the **ACHARYA N.G. RANGA AGRICULTURAL UNIVERSITY** for the degree of **DOCTOR OF PHILOSOPHY IN AGRICULTURE** is the result of original research work done by me. I also declare that any material contained in the thesis has not been published earlier.

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ABSTRACT

In order to develop suitable soil management practices for alleviating soil physical constraints and efficient utilization of irrigation water to increase the productivity of sunflower, grown after puddled rice in rice based cropping system, a field experiment was conducted for two years during *late rabi* season of 1997-98 and 1998-99 at Agricultural College Farm, Rajendranagar, on sandy clay loam soil. Effects of different tillage treatments viz., zero tillage (T_1) country plough twice + bullock drawn cultivator twice (T_2), country plough twice + power tiller operated rotavator twice (T_3), MB plough once + cultivator twice, both tractor drawn (T_4) and disc plough once + rotavator twice, both tractor drawn (T_5) and four soil moisture regimes created by scheduling irrigations at IW/CPE = 0.6 (M_1), 0.8 (M_2), 1.0 (M_3) and 1.2 (M_4) were studied to in split plot design to find their optimum combination. The experiment was laidout in strip plot design with three replications.

The effects of tillage treatments on soil physical properties viz., depth of tillage, mean weight diameter of dry clods, bulk density, pore space, hydraulic conductivity, infiltration rate, penetration resistance, soil temperature and soil moisture contents were assessed. The effects of these tillage induced soil physical properties and soil moisture regimes were studied in terms of seedling emergence, dry matter production, seed yield, nutrient (N, P and K) content and uptake, total water use by the crop (seasonal crop ETa mm) soil moisture extraction pattern and water use efficiency.

Tillage with rotavator, either of tractor drawn (T_5) or power tiller operated (T_3), resulted in smaller size clods indicated by low MWD (20 mm) and low

bulk density compared to secondary tillage with cultivator (T_2 and T_4). Depth of tillage was more (upto 22 cm) in tractor drawn treatments (T_5 and T_4) compared to 11 cm depth with country plough (T_3 and T_4). Tillage treatments (T_2 to T_5), in general, favourably improved the soil physical environment as compared to zero tillage (T_1).

Finer seed bed created in T_5 and T_3 resulted in significantly higher seedling emergence compared to T_2, T_4 and T_1. The favourable soil physical conditions created by tractor drawn disc plough + rotavator (T_5) significantly increased the root growth. Dry matter production, leaf area index, head size, 1000 seed weight, seed yield and oil yield of sunflower were improved with deep and fine tilth. Next best tillage was MB plough and cultivator (T_4). Though individual plant yield in T_4 was at par with T_5 (indicated by head size and test weight), the low plant population in T_4 significantly reduced the yield as compared to that of T_5. Wettest soil moisture regime (M_4) and next wet (M_3) produced yields, which were statistically at par. However, highest seed yield was recorded in M_4 and lowest in M_1. T_5 M_4 combination produced highest yield, which was at par with that of T_5 M_3 and both were significantly superior to other combinations. T_5 M_2 recorded yield at par with that of T_4 M_3 and T_3 M_4 which lead to a saving of two irrigations (120 mm) compared to T_4 M_3 and four irrigations (240 mm) compared to T_3 M_4. The yield in T_5 M_2 was at par with that of T_4 M_3, and the yield difference between T_3 M_2 and T_2 M_3 was not significant indicating the importance of fine seedbed preparation with implements like rotavator (T_5 and T_3). Deep and fine tillage resulted not only higher seed yield but also high water use efficiency

Deep fine tillage (T_5) and wettest soil moisture regime (M_4) both individually and combindly resulted in higher crop water use, followed by tractor drawn MB plough + cultivator (T_4), country plough twice + power tillage rotavator (T_3), country plough twice + bullock drawn cultivator (T_2) and zero tillage (T_1)), in descending order. In general, bulk of the moisture required was extracted from surface layer (0-15 cm). However, with increase in depth of tillage, extraction of water from deeper layers relatively increased. Irrespective of depth of tillage, with an increase in soil water application (M_1 to M_4), contribution from the sub surface soil layers (15-30 and 30-45 cm) decreased. In general, WUE was higher in deep tillage treatments (T_5 and T_4). Irrigations given at IW/CPE = 0.8 (M_2) recorded highest WUE than with other soil moisture regimes.

Based on the results, tractor drawn disc plough once + rotavator twice coupled with soil moisture regime created by giving irrigation (6 cm of water at each irrigation) at IW/CPE ratio of 1.0, is recommended to maximise the yield of sunflower grown after puddled rice in sandy clay loam soil in rice based cropping system under Southern Telangana zone conditions of Andhra Pradesh. In the absence of heavy tractor, ploughing with country plow twice followed by + power tiller drawn rotavator twice is recommended as next best for higher yields and water use efficiency by sunflower.

LIST OF ABBREVIATIONS

^{o}C	:	Degrees centigrade
cm	:	Centimeter
CD	:	Critical difference
CPE	:	Cumulative pan evaporation
DAS	:	Days after sowing
dSm^{-1}	:	Desi Siemen per meter
ET	:	Evapotransipiration
ETa	:	Actual evapotranspiration
et al	:	and others
Fig.	:	Figure
g	:	gram(s)
ha	:	hectare(s)
hr	:	Hour
K	:	Potassium
kg	:	Kilogram
kg ha^{-1}	:	Kilogram per hectare
Kmph	:	Kilometer per hour
LAI	:	Leaf area index
m	:	meter
M	:	Moisture regime
M at T	:	Difference between two moisture regimes at the same level of tillages
MB plough	:	Mould board plough
me	:	Milli equivalents
me l^{-1}	:	Milli equivalents per litre
Mg	:	Mega gram(s)
ml	:	Milli litre
MLR	:	Multiple Linear Regression
mm	:	Millimeter
mm day^{-1}	:	millimeter(s) per day
m mhos cm^{-1}	:	milli mhos per centimeter
MWD	:	Mean weight diameter
Mg m^{-3}	:	Mega gram (s) per cubic meter

µg	:	Microgram(s)
µg H_2O cm^{-2} S^{-1}	:	Microgram of water per square centimeter per second
N	:	Nitrogen
NS	:	Non significant
%	:	Per cent
P	:	Phosphorus
q	:	Quintal
q ha^{-1}	:	Quintal per hectare
r	:	Correlation coefficient
R^2	:	Coefficient of determination
S	:	Second(s)
SDI	:	stress day index
SEm	:	Standard error mean
Sm^{-1}	:	Second(s) per meter
T	:	Tillage
USDA	:	United States Department of Agriculture
T at M	:	Difference between two tillage levels at same level of moisture regimes
USWB	:	United States Weather Bureau
WUE	:	Water use efficiency

INTRODUCTION

CHAPTER I

INTRODUCTION

There is an increasing awareness among the scientists and farmers that growing of upland crops like oil seeds and pulses after *kharif* rice instead of second rice crop in *rabi* season is advantageous because of low water requirement, better remuneration, nutritionally balanced food grain production, maintaining better soil health etc. Puddling is generally done as part of land preparation for rice cultivation. This results in several changes in soil physical conditions like aggregate break down, reduction in macro-porosity, increase in bulk density and reduction in hydraulic conductivity. It also results in the formation of dense hard pan in the subsoil with high bulk density and low permeability. After harvest of rice crop the puddled soil becomes hard on drying. Ploughing of such soil generally creates large dense clods resulting in poor emergence and plant stand of upland crops. Because of this the yields of upland crops following puddled rice are reported to be low when compared to the normal crops grown under irrigated upland conditions. The upland crops require entirely different physical edaphic environment from that of rice.

The yields of upland crops in rice based cropping system could be increased by adopting suitable tillage for creating optimum seed bed which allows better seed soil contact, good germination, stand establishment and root growth. In this system the depth of tillage is also very important because of the root restricting layers in sub soils. Provision of proper seed bed require the creation of optimum tilth in the soil using different tillage implements which may be of animal drawn, power tiller operated or tractor drawn. Tillage brings about several

changes in soil physical properties. The variations in physical properties brought about by different tillages effect the performance of crops.

In addition to providing proper seed bed, maintaining optimum soil moisture regime is also equally important for getting better yield of upland crops in rice based cropping system through irrigation water. The water requirement of these crops vary with the depth and fineness of the seed bed. Proper tillage not only results in better growth and yield of crops but also in higher input use efficiency particularly irrigation water.

Irrigation water is a scarce and costly input. Therefore, pressure for increased efficiency in use of irrigation water is mounting particularly during non rainy seasons because of shrinking surface and subsurface water resources. The water needs of upland crops following rice is to be determined for its efficient use . In addition, crops which require less water should be taken up during *rabi* season, so that more area could be brought under irrigation.

Therefore, the optimum tillage and irrigation management practices for different upland crops in rice-based cropping system in different soils and agro climatic zones are to be worked out for efficient use of irrigation water. The data generated will be useful to irrigation planners and Water Use Association (WUA) personel to estimate the likely demand of water and efficient utilization of available water resources, in addition to increasing the productivity of upland crops.

Sunflower is one of the important edible oil seed crops with its inherent benifical characters viz., short duration, wide adaptability on account of photo

and thermo insensitivity, high oil content and good quality of oil with anti cholestrol properties.

Keeping the above factors in view and in the inadequate information available the present investigation was therefore designed to study with following objectives :

1. To study the effect of tillage on physical properties of soil after puddled rice.
2. To study the effect of tillage induced soil physical properties on germination, growth and yield of sunflower after rice in rice- based cropping system.
3. To study the effect of soil moisture regimes on tillage induced soil physical properties created for sunflower grown after rice in rice-based cropping system.
4. To find out the optimum soil moisture regime for sunflower grown after rice under different tillage practices.
5. To evaluate the interaction effects of tillage practices and soil moisture regimes on growth and yield of sunflower grown after puddled rice in rice-based cropping system.

REVIEW OF LITERATURE

CHAPTER II

REVIEW OF LITERATURE

Information regarding effect of tillage practices in sunflower crop under rice-based cropping system is very meagre and hence tillage effects on other upland crops has also been reviewed. Similarly, information on response of sunflower crop grown after puddled rice in various soil moisture regimes is also extremely limited. Hence, the effect of irrigation regimes on sunflower under upland situations was also reviewed and presented in this chapter.

The research work done on the individual effects of tillage practices and soil moisture regimes on soil properties, growth, yield and water use efficiency of upland crops is briefly reviewed in this chapter under following heads.

2.1 Effect of puddling on soil properties and their effects on successive upland crops

2.2 Effect of tillage practices on soil physical properties

2.3 Effect of tillage practices on emergence, growth parameters, drymatter accumulation, yield attributes and yield of upland crops

2.4 Effect of tillage practices on soil water storage, water use and water use efficiency (WUE) of upland crops.

2.5 Effect of tillage practices on nutrient availability and uptake by upland crops

2.6 Effect of tillage practices on soil temperature and plant physiological characteristics

2.7 Effect of soil moisture regimes on soil temperature

2.8 Effect of soil moisture regimes on growth, yield attributes and yield of sunflower

2.9 Effect of soil moisture regimes on water use (crop ETa) and water use efficiency of sunflower

2.10 Effect of soil moisture regimes on nutrient uptake

2.11 Effect of soil moisture regimes on plant water relations

2.12 Interaction effects of tillage practices and soil moisture regimes on growth and yield of upland crops.

2.1 EFFECT OF PUDDLING ON SOIL PROPERTIES AND THEIR EFFECTS ON SUCCESSIVE UPLAND CROPS

According to Mathan (1989), regeneration of soil structure to provide optimum soil physical environment to the succeeding crops takes over a period of time and impedance to root development beyond the puddled layer adversely affects aeration of dry crops following rice.

Kar *et al.* (1997) in a review stated that tillage for rice cultivation comprises of prepuddling tillage followed by a soaking irrigation and stirring of the surface soil layer with water ponded at the surface, which breaks down soil structure

and reduces the proportion of macropores (transmission pores) and, thus decreases hydraulic conductivity and permeability of soil. If such soil is not loosened, the crop following rice is likely to suffer from poor aeration following irrigation or heavy rain, in addition to high penetration resistance.

Singa Rao *et al.* (1995) reported that the bulk density of 0-15 cm layer of red sandy clay loam soil increased by 0.11 g cm^{-3} from 1.56 g cm^{-3} to 1.67 g cm^{-3} with increase in intensity of puddling from two to four times with country plough, and, further increased slightly with the increase in intensity of puddling to eight times. With the increase in intensity of puddling aggregates greater than 0.25 mm, water intake rate and saturated hydraulic conductivity of soil decreased. Similar results were also reported by Aggarwal *et al.* (1997) in clay loam soils of IARI Farm, New Delhi.

Some of the benefits of puddling of soil are ease of transplanting the rice seedlings, faster establishment of roots, control of weeds, lesser water losses through percolation. Excessive puddling, however, can form a compact layer in the subsoil below the puddled layer (De Datta, 1981; Sharma and De Datta, 1985). After rice harvest, the puddled soil remains wet and in reduced condition atleast for few days (IRRI, 1986, 1987), which upon drying becomes hard and has high bulk density (Sanchez, 1976).

Rice after rice is a preferred sequence, where there is sufficient water for irrigation or rainfall. In areas where there is insufficient water for a second or a third rice crop, farmers prefer to grow non-rice upland crops after rice (Syarifuddin *et al.*, 1975; Guo, 1982). From the view point of water economy, soil health and balanced

food grain production viz., cereals, oilseeds, pulses etc., it becomes necessary and inevitable to rotate rice under lowland conditions with an upland crop like groundnut, sunflower, wheat, maize, blackgram, greengram, redgram etc. However, the tillage requirements of the upland crops are entirely different from that of low land rice. The rice crop is benefited by puddling while the non-rice upland crops prefer well aggregated aerobic condition for better growth and high yields.

Results of field experiments have shown that the yield of upland crops following puddled rice were lower than those of their normal yields under upland conditions. Reddi and Reddy (1979) have reported that low yields of groundnut crop following rice under Nagarjuna Sagar project of Andhra Pradesh (among other problems), have been attributed to improper seedbed preparation, consequential lack of optimum stand establishment and reduced plant population. The productivity of non rice crops grown after puddled transplanted rice will depend largely on successful crop establishment and availability of soil water in the growing season (Zandstra, 1982; Greenland, 1985; Eswaran, 1985).

In rice-upland crops sequence, selection of suitable crop for rice-based cropping systems, which can grow and yield better under limited water supply, is very important. Based on two years experience rice followed by groundnut or sunflower with 3 to 4 irrigations and rice followed by pigeonpea or sorghum with presowing and life saving irrigations was found to be a remunerative cropping system for semi-arid region of Hyderabad, India (DOR, 1987).

2.2 EFFECT OF TILLAGE PRACTICES ON SOIL PROPERTIES

In order to better suit the non-rice crops in rice based cropping system, management techniques have been developed which generate the soil structure that has been destroyed by puddling. Tillage is one such method for alleviating soil physical constraints. Tillage breaks the massive structure and reduces the clod size, increases porosity, reduces soil strength (Klute, 1982), increases gaseous exchange, hydraulic conductivity and loss of surface soil moisture (Sanchez, 1976; Zandstra, 1982), controls weeds, incorporate plant residues, and can establish a desired surface configuration and degree of compactness for root growth. However, different tillage methods have different effects on soil properties.

2.2.1 Clod size distribution

Baver (1956) reported that ploughing soil when it is too wet or too dry produced larger clods; the same operation when the soil was at optimum moisture produced smaller clods. Johnson and Taylor (1960) found that three passes of a mould board plough resulted in increased proportion of aggregates of bigger sizes (> 19 mm) in silty clay loam soil.

Page *et al.* (1964) observed that rotary tilling was too distructive as the structural stability of the soil was too low to resist the vigorous mechanical action in silty loam soil of Ohio, USA, while Kozlova *et al.* (1965) reported that aggregates less than 0.25 mm were slightly higher in rotary tillage than those when the soil was ploughed. Bhushan and Ghildyal (1971) while comparing different implements reported that larger aggregates were formed under mould board plough

than with narrow line and horizontal blade implements. Bhushan *et al.* (1973) observed that mean weight diameter (MWD) of clods was maximum under disc plough, followed by mould board plough, and minimum with rotary tiller.

Khan (1984) recorded a greater percentage of larger clods and a lower percentage of smaller clods with a MWD of 11.32 mm by ploughing with tractor drawn disc harrow compared with a MWD of 4.52 mm with tractor drawn rotary tiller in a lateritic sandy loam soil of West Bengal. From the tests on tillage conducted on sandy clay loam soil, Mandhar (1989) observed that after ploughing, one rotovation with power tiller or harrowing with tractor resulted in better seed bed preparation.

From the field experiments conducted in rice fallows at Hyderabad, it was observed that the lowest MWD of aggregates (24.33 mm) was obtained by ploughing twice with country plough followed by rotavation twice by rotary tiller (AICRP on SPCIP, 1987-1989). Prasadini *et al.* (1993) found that in sandy loam soil with 0.11% organic carbon, the MWD of aggregates was highest (45 mm) when ploughing was done twice with bullock drawn country plough and lowest MWD of 16 mm was recorded when power tiller operated rotavator was drawn twice after country ploughing.

Singa Rao *et al.* (1995) from their field study stated that type of tillage significantly influenced the clod size distribution. Big clods of 10 cm diameter were found in country ploughing twice treatment. They also reported that the clods of 5 cm diameter were the highest (43.3%) in country ploughing and lowest (7.7%) in country ploughing followed by power tiller operated rotavator

treatment. Medium size aggregates (≥ 0.5 cm and < 2 cm diameter) were more with rotavator followed by bullock drawn disc harrowing, tractor drawn disc plough and country ploughings. Relatively uniform size distribution and highest proportion of finer aggregates were obtained with rotavator due to its pulverising effect.

Secondary tillage with rotavator treatment resulted in higher percentage of finer fraction (< 2 mm) clods and lowest mean weight diameter compared to disc harrow and cultivator treatments (AICRP SPCIP, Hyderabad Centre, 1995-96 and 1996-97).

2.2.2 Bulk density and penetration resistance of soil

Bhushan *et al.* (1973) stated that the tillage treatments reduced the bulk density considerably and it was lowest (1.06 g cm^{-3}) in the plots tilled with disc plough and was highest in those tilled with rotary tiller. In a tillage experiment carried out by Rautaray (1983) on clayey soil at CIAE Farm, Nabibagh, compared to blade harrowing (four times) and cultivator (twice), the mould board ploughing (once) + disc harrowing (twice) recorded maximum depth of ploughing (12.15 cm), low bulk density (1.19 g cm^{-3}), better pulvarisation and lower penetration resistance (0.29 to 3.72 kg cm^{-2}) from 2.5 to 15 cm depth of soil.

Khan (1984) reported less bulk density and penetration resistance with mould board ploughing compared to other tillage treatments like zero tillage and harrowing. Studies on evaluation of tillage methods suitable for light textured Alfisols at ICRISAT, Hyderabad by Awadhwal and Thierstein (1984) showed that lower bulk density (1.35 g cm^{-3} at 0-20 cm soil depth) and lower cone index values

(5.17 kg cm^{-2} at 10 cm soil depth) with bed splitting followed by strip ploughing with mould board plough compared to strip ploughing with mould board plough, chiselling in crop rows followed by blade harrowing and shallow tillage with duck foot showels. It is interesting to note that the difference in cone index values and bulk density of above tillage treatments was significant soon after tillage but later the differences diminished and became non significant by the end of crop growing season due to consolidation of soil.

Chaudhary *et al.* (1985) recorded a decrease in bulk density and penetration resistance values with deep tillage treatments viz., subsoiling, digging and MB ploughing compared to conventional tillage (one disc harrow followed by two cross runs of a line cultivator followed by planking) in loamy sand soil of Fatepur, Punjab. Deep tillage operations slightly decreased the bulk density of soil (from 1.60 to 1.51 g cm^{-3}) at all working depths (upto 30 cm) and also decreased the soil penetration resistance in the 20-40 cm layer to one-tenth of that in control (conventional tillage).

The results of the study carried out by Gill *et al.* (1996) on tillage, mulch and irrigtion effects on corn in loamy sand soils of Ludhiana, Punjab revealed that, deep tillage significantly reduced soil strength (cone index) compared to conventional tilling (harrowing soil to 10 cm depth). At seeding, the cone index was less by 1.49 MPa at 20-30 cm depth and 1.71 MPa at 30-40 cm depth in deep tillage treatment compared to conventional tillage. Even at harvest, cone index in the sub soil was observed to be less with deep tillage than with conventional tillage

indicating that the effects of deep tillage on soil strength persisted throughout the growing season.

Tillage with rotavator reduced the soil bulk density by 0.083 g cm^{-3} followed by disc plough (0.042 g cm^{-3}) and cattle drawn disc harrow (0.0266 g cm^{-3}) compared to control (1.643 g cm^{-3}) treatment (ploughing with country plough). In the above study country plough + rotavator treatment recorded lowest penetration resistance followed by disc plough once + disc harrow twice, country plough twice + disc harrow twice, and control (country plough twice) (AICRP SPCIP, Hyderabad Centre, 1995-96).

Gajri *et al.* (1997) reported that deep tillage decreased the bulk density and soil strength and increased the depth and density of rooting of wheat crop in deep alluvial soil at Ludhiana, Punjab. Deep tillage significantly decreased soil bulk density and cone index in the tilled zone at seeding time, the reduction varied in different layers from 0.02 to 0.11 Mg m^{-3} for bulk density and from 0.03 to 2.33 MPa for cone index.

Deep tillage loosed the soil, decreased bulk density and penetration resistance to a depth of 40 cm compared to 10 cm in conventionally tilled plots. The penetration resistance recorded in chiselled furrows was 25-58 per cent in loamy sand and 32 to 64 per cent in sandy loam compared to untilled zone in conventional tillage (Meharban Singh and Chaudhary, 1998).

2.2.3 Hydraulic conductivity

Profile modification to a depth of 90 and 150 cm on silty clay loam was resulted in increased hydraulic conductivity, the mean hydraulic conductivities for the last permeable depth increments were 0.04, 0.19 and 0.23 cm hr^{-1} for the control, 90 and 150 cm, respectively (Paul, 1970). Chiselling at 1 m interval in shallow soils with high bulk density at Coimbatore increased the hydraulic conductivity from 9.1 to 14.7 cm hr^{-1} in 0-20 cm layer and from 1.9 to 4.2 cm hr^{-1} in 20-40 cm layers due to chiselling (AICRP on SPCIP, Coimbatore Centre, 1984).

Aggarwal *et al.* (1997) recorded higher hydraulic conductivity values with chiselling and disc ploughing than with minimum tillage after puddled rice in clay loam soil of New Delhi. The hydraulic conductivity at sowing was 1.38 and 1.02 x 10^{-6} m s^{-1} for 0-15 cm and 15-30 cm, respectively, with chiselling; 1.33 x 10^{-6} and 1.00 x 10^{-6} m s^{-1} for respective depths with disc plough, while it was 0.55 x 10^{-6} and 0.41 x 10^{-6} m s^{-1} for respective depths at sowing with minimum tillage. The tillage effects were also found to follow the same trend at the harvest of wheat crop.

2.2.4 Infiltration

Vittal *et al.* (1983) studied the effect of deep tillage in red soils of India under dryland conditions and reported that infiltration and depth of penetration of the wetting front increased considerably with deep tillage. Infiltration rate was observed to increase from 0.3 cm hr^{-1} for conventionally tilled treatment to 1.4 cm hr^{-1} in subsoil treatment in an Alfisol near Hyderabad (ICRISAT, 1984). Pratibha (1992) recorded significantly higher infiltration rates in mould board ploughing

(3.51 cm hr^{-1}) and mould board ploughing + rotavator tillage plots (3.52 cm hr^{-1}) compared to zero tillage treatment plots (1.3 cm hr^{-1}).

Aggarwal *et al.* (1997) reported that the final infiltration rates after imposition of different tillage practices in succession to puddled rice in clay loam soils of New Delhi were higher with chisel ploughing at sowing (5.27 x 10^{-6} m s^{-1}) and harvest (4.77 x 10^{-6} m s^{-1}) of wheat followed by disc ploughing (4.44 x 10^{-6} and 3.47 x 10^{-6} m s^{-1} for respective periods), while, minimum tillage recorded lowest rates (1.38 x 10^{-6} m s^{-1} and 0.77 x 10^{-6} m s^{-1} for the respective periods).

2.3 EFFECT OF TILLAGE PRACTICES ON EMERGENCE, GROWTH PARAMETERS, YIELD ATTRIBUTES AND YIELD OF UPLAND CROPS

2.3.1 Germination and seedling emergence

Seedling emergence determines the density of crop stand, influence weed infestation and affects yields. Unless the success of this early phase of good emergence is assured, the entire crop may be doomed from the outset (Hillel, 1972). In semi arid zones, wheat yields are often limited by poor stand,establishment and low plant density (Bouaziz and Bruckler, 1989). The seedling emergence per cent is governed by soil physical properties, which inturn are influenced by tillage methods.

Soil physical properties are the major determinants of seedling growth upto the time of emergence, nutrient status of the seed bed is of secondary importance because seedlings do not become independent of the seed reserves for nutrient supplies until the third leaf begins to emerge (Milthorpe and Moorby, 1974). The ease with which the water moves to the seed is determined largely by the structure of the seed bed. Research has shown that the optimum seed bed is

composed of aggregates in the range of 1-5 mm diameter with upto 15% (Russel, 1973). In addition to this it is important to ensure that there is adequate seed-soil contact to facilitate water movement into the seed, mechanical character of the seed bed is the most important of all factors affecting germination emergence and plant establishment (Bouaziz, 1987).

Bhushan *et al.* (1973) observed highest emergence of wheat seedlings when the soil was tilled with rotary tiller to produce aggregates of 4-6 mm diameter which provided a better seed-soil contact and increased availability of moisture. Seedling emergence was lowest when soil was tilled with mould board plough and disc plough, which resulted in bigger size clods. Similar results have also been reported by Emerson *et al.* (1978) and Khan and De Datta (1983). Shetty and Moody (1984) reported the problem of heavy weed infestation, regrowth of harvested rice and poor establishment of crop in zero tillage system which resulted in lower yields of mungbean in rice-mungbean cropping sequence.

At 15 DAS the emergence of groundnut sown after puddled rice was highest in pulverised soil using disc harrow, and was lowest in raised seedbeds. The poor germination in raised seedbed system was attributed to formation of bigger size clods resulting in poor seed soil contact (AICRP on SPCIP, Hyderabad Centre, 1986-87). Kumar (1991) in an experiment in sandy loam soils of Rajendranagar, Hyderabad observed maximum seedling emergence with power tiller operated rotavator and tractor drawn implements due to creation of optimum soil physical conditions.

Nasr and Selles (1995) reported that increase in bulk density and aggregate size of seed bed decreased and delayed the emergence of wheat seeds in silt loam soils of Cairo, Egypt. Fast and more complete germination was achieved in seed beds with bulk densities of 1.2 Mg m^{-3} or lower, with aggregates of GMD $\leq$ 4.0 mm or with a penetration resistance of < 1.4 MPa. Bulk density affected seedling emergence through changes in the volume and continuity of pores in the seed bed, while the effect of aggregate size was through changes in the path length from the seed to the soil surface.

In contrary, based on the results of their study on soil physical constraints to establishment of mung beans in rice soils (clayey soil 41% clay) of IRRI, Philippines, Cook *et al.* (1995) opined that tillage in fine textured soils following rice is an added expense, both in terms of equipment and fuel, as tillage, generally did not enhance mung bean emergence. However, the potential benefits of tillage obsereved was reduced soil strength and fractured soil structure for easy root penetration.

Omer and Elamin (1997) from Sudan reported that chisel ploughing and 10 m distance contour diking treatment interaction provided adequate stand (1,14,000 plants ha^{-1}) of sorghum and significantly differed from other treatments. No till and no contour interaction provided the lowest stand of 37000 plants ha^{-1} in sandy clay loam soil. The chisel, broad bed and furrow, ridge furrow and no till systems provided plant stands that were about 95%, 68%, 48% and 42% of the theoretical stand (1,05,000 plants ha^{-1}), respectively.

2.3.2 Growth parameters

2.3.2.1 Root growth

Sharma *et al.* (1988) studied the effect of zero, minimum and conventional tillage in clay loam and sandy loam soils in Philippines, and reported that tilled plots had higher root length by 60 and 61% compared to zero tillage for mung bean and maize, respectively. In clayey soil the root extension of sorghum in early part of the growth in previously puddled transplanted rice soil was faster in the tilled plots and reached 30 cm depth in 20 days after sowing compared to 10 cm depth in no tillage treatments (Gupta *et al.*, 1984).

The root density of wheat was higher (1.92 cm cm^{-3}) with discing than chiselling (1.48 cm cm^{-3}) in the 0-15 cm layer of sandy loam soil and in 15-30 and 30-45 cm layers it was 0.59 and 0.85 and 0.49 and 0.63 cm cm^{-3}, respectively for these two tillage treatments. However, the grain yield did not vary between these two tillage methods (AICRP on SPICP, Hyderabad Centre, 1984-85). Kumar (1991) reported that tillage with rotavator and tractor drawn implements resulted in creation of optimum soil physical conditions which in turn significantly favoured the root growth and nodulation of groundnut.

Gill *et al.* (1996) reported that root length index (RLI) below 10 cm depth with deep tillage was greater than the conventional tillage (shallow tillage) in loamy sand soils of Punjab. About 35% of the corn root length in the 2-100 cm portion of the soil profile was found below 60 cm depth in the deepest tillage,

whereas, less than 5% was below 60 cm in control (no tillage) in silty loam soils of Illinois, USA (Varsa *et al.*, 1997).

2.3.2.2 Above ground portions

Sharma *et al.* (1988) observed 18 and 42% higher plant heights of maize with minimum and conventional tillage respectively compared to zero tillage treatments in clay loam soils of Philippines. Mung bean grown after rice showed increased plant height, leaf area and yield with increase in tillage (IRRI, 1984). Sowing cotton seeds under seed row tillage practices soon after the harvest of rice recorded significantly higher plant height than the other tillage practices viz., no tillage immediately after harvest of rice, no tillage – 20 days after harvest of rice, two ploughings – 20 days after harvest of rice, one ploughing – 20 days after harvest of rice (Solaiappan and Mohammed Sheriff, 1994).

Gill *et al.* (1996) reported that plant height, leaf area index (LAI) and dry matter production of maize with deep tillage was significantly greater than conventionally tilled plots (shallow tillage) in loamy sand soils of Punjab. Omer and Elamin (1997) reported that sorghum plant height in chissel ploughed plots was taller by 24, 32 and 45 cm than broad bed and furrow, ridge and furrow and no till, respectively. Salih *et al.* (1998) reported that significantly higher values of plant height, shoot dry weight of cotton were recorded at all crop growth stages with deep tillage (sub soiling and disc ploughing) compared to shallow tillage (disc harrowing) in vertisols of Sudan.

2.3.3 Yield attributes and yield

Lal (1989) in a review opined that soils which developed massive structure due to puddled – transplanted rice cultivation had low infiltration, low porosity, low plant available water reserves, poor root growth and low yields. Periodic soil conversion involving both primary and secondary tillage operations can restore the crop productivity in such situations. Nye and Greenland (1964) and Nicou (1974) reported that no tillage system has been shown to cause severe yield depression of sorghum, maize and peanut and cotton in arid and semi-arid tropics.

Talati and Mehta (1963) reported that grain yield of pearl millet in sandy loam soils of Anand was more than doubled in deep tillage (5.3 q ha^{-1}) over shallow tillage (2.5 q ha^{-1}). Kaul *et al.* (1970) reported that deep tillage in sandy loam soil increased the yield of maize by 3.4 q ha^{-1} over shallow tillage. Higher yields of *Brassica campestris* var. toria in silty loam soil of Dehradoon was recorded with deep tillage (7 q ha^{-1}) against shallow tillage (6 q ha^{-1}) due to better root development leading to efficient utilisation of stored soil moisture (Bhushan *et al.*, 1973). Deep tillage and its residual effects on yield of various crops was studied by Anderson (1980) in shallow red loamy soils of Ananthapur and he observed that bajra, castor and redgram yields increased with deep tillage in the first year and residual effect continued for the next two years.

Equivalent yields of maize, cowpea, sorghum and sunflower were obtained from minimum tillage to those produced by mould board or chisel tillage to a depth of 20 cm or strip ploughing to a depth of 30 cm (BDFRS, 1982). Bhatnagar *et al.* (1983) reported favourable water conservation and best yields of wheat and

peanut by a combination of minimum tillage (one disc ploughing and one harrowing to a depth of 15 cm) and mulching (5 t ha^{-1}) on irrigated coarse textured soils of Punjab, India.

Anazado *et al.* (1983) investigated the effects of tillage in clay and sandy loam soils on the yield of corn and reported that chiselling, mould board ploughing followed by disc harrowing and subsoiling treatments resulted in significantly higher seed yield compared to the untilled compacted treatments in both the soils due to reduction in bulk density and penetration resistance and increase in soil porosity. Rautaray (1983) reported that the tillage system involving the combination of MB plough once and disc harrow twice resulted in faster plant growth of sorghum crop. Deep tillage to a depth of 30 cm by discing followed by two rotovations in a fine textured soil had 40 per cent increase in fresh weight yield of corn ears compared to zero tillage and shallow tillage to a depth of 15 cm by rotavator (Lindsay *et al.*, 1983). Shetty and Moody (1984) reported that optimum tilled plots had increased mungbean yield compared to zero tillage in puddled transplanted rice fields but not much in direct seeded rice fields.

In sandy soils of Ludhiana, grain yield of maize was doubled due to deep tillage (40 cm depth) (18.9 q ha^{-1}) compared to conventional tillage (8.6 q ha^{-1} (AICRP on SPCIC, Ludhiana Centre, 1984). Khan (1984) from Kharagpur, reported that maximum yield of peanut pods (3.22 t ha^{-1}) was obtained in inversion tillage treatment using mould board plough and disc harrow which facilitated the creation of favourable porosity, relieved the restrictions of low infiltratioin rate, low plant available water reserve, poor root growth and low yield in residual soils with

clayey B-horizon and low organic matter content. The increase in yield was 67 and 78 per cent over the 2.33 and 2.16 t ha^{-1} by rotary tillage and no tillage, respectively.

Research work at IRRI (1984, 1985, 1986, 1987 and 1988) has advocated strip tillage for various non-rice crops following irrigated rice. A subsoiler tine (narrow tine or winged tine, or narrow tine with two shallow leading tines) broke the compacted zone and distributed the soil to 35 cm depth along widely spaced parallel strip. The cloddy tilth produced by this tillage was alleviated by rolling the area along the tined strips or by subsequent shallow cultivation. This prompted root growth below the compacted layer and resulted in higher mung bean yield of 2.1 t ha^{-1} even without irrigation or fertilizer, compared to 1.9 t ha^{-1} from mould board ploughing followed by harrowing. In red chalka soils of Hyderabad sorghum yields increased by 18.3 per cent in deep tillage plots upto 20 cm depth over shallow tillage, whereas, bajra did not show such significant difference with deep tillage (CRIDA, 1985).

Sharma *et al.* (1988) reported that conventional tillage significantly increased maize and mung bean grain yield by 242% and 78% respectively in clay loam soil compared to no tillage treatment. Verma *et al.* (1988) from Birsa Agricultural University, Ranchi, showed that conventional tillage after puddled-transplanted rice gave 70 per cent more grain yield of wheat than no tillage system. However, the benefit-cost ratio was higher by 14.5 per cent under no tillage system than conventional tillage. Wilcut *et al.* (1990) reported that conventional tillage produced 800 to 1900 kg ha^{-1} higher peanut.

Bhattacharya *et al.* (1991) reported that mean yields of sunflower cv. EC 68414 grown in the Gangetic delta region, West Bengal were 0.88, 1.25 and 1.35 t ha^{-1} with zero, minimum and normal tillage practices, respectively.

Prasadini *et al.* (1993) obtained higher peanut yields in rice fields by breaking the subsoil hard pan and creation of smaller aggregates using tractor drawn implements compared to bullock-drawn implements. The yield was also higher in rotavator treatment because of small and uniform aggregate and low soil strength.

From the results of three year experimentation at Cotton Research Station, Srivilliputtur, Tamil Nadu, Solaiappan and Mohammad Sheriff (1994) reported that pre sowing tillage practices significantly affected the yield and yield attributes. Sowing cotton seeds under seed row tillage practices soon after the harvest of rice recorded significantly higher seed cotton yield than the other tillage practices. The same treatments also significantly increased the plant height, sympodia per plant, bolls per plant and boll weight resulting in increased yield of seed cotton. In clay soils of Navasari, Gujarat deep tillage had a favourable effect on most of the growth attributes (plant height and dry matter) and yield attributes (pods per plant and grains per pod) of greengram. The increase in the grain yield in deep tillage over shallow tillage (7.5 cm) was 11.60 and 19.32 per cent under 15 and 22.5 cm depths, respectively (Trivedi *et al.*, 1994).

Mehta *et al.* (1996) reported that in silty loam soils of U.P., late sown wheat after flood prone rice recorded highest grain yield of 37.2 and 31.0 q ha^{-1} in 1991-92 and 1993-94, respectively under desi ploughing twice and tractor drawn cultivator twice, while, the treatment desi plough twice + mould board plough twice

recorded 29.7 and 29.6 q ha^{-1} in the respective years. Lowest yields were received (22.6 and 25.1 q ha^{-1} in the respective years) from the tillage treatment of three times with three tyned cultivator.

Gill *et al.* (1996) from their 3 years experimentation at Punjab Agricultural University, Ludhiana reported that the mean yield of wheat increase with deep tillage (40 cm) over conventional tillage (10 cm) varied from 10 per cent for the normal season crop in 1992 to 238% for early season crop in 1993. This variation in yield response to deep tillage was related to amount and distribution of rainfall in relation to pan evaporation. Intensive tillage (cultivator twice + discing twice) resulted in higher test weight and yields of sunflower (5.3 g per 100 seed and 1078.4 kg ha^{-1}, respectively) followed by reduced tillage (cultivator twice + discing once) (52 g/100 seed and 1051.1 kg ha^{-1}, respectively) and no tillage (4.1 g/100 seed and 915.1 kg ha^{-1}, respectively) in sandy loam soils of Hyderabad (AICRP SPCIP, Hyderabad Centre, 1996-97).

Omer and Elamin(1997) reported that in sandy clay soils of Sudan the three year mean grain yield of sorghum for chisel ploughing produced 1448 kg ha^{-1} which was greater by 72, 107 and 384 per cent over broad bed and furrow, ridge furrow and no till treatments, respectively.

Kar *et al.* (1997) reported that wheat responded to physical edaphic conditions created by tillage through their effect on root growth and water intake and stated that tillage resulted not only in higher grain yield of wheat followed by rice but also higher input use efficiencies.

Aggarwal *et al.* (1997) stated that the average grain yield of rabi wheat grown after puddled rice in clay loam soil at IARI, New Delhi was significantly higher (34.00 and 44.40 q ha^{-1} for 1991-92 and 1992-93 with chisel plough and 31.92 and 43.63 q ha^{-1} for 1991-92 and 1992-93 with disc plough) than minimum tillage (28.93 and 36.00 q ha^{-1} for 1991-92 and 1992-93).

Salih *et al.* (1998) noticed increased cotton yields with subsoiling over disc harrowing and disc ploughing in vertisols of Sudan. However, the increase in cotton yields with subsoiling was not significantly different with disc plough, but disc ploughing and subsoiling treatments were significantly different from disc harrowing treatment.

2.4 EFFECT OF TILLAGE PRACTICES ON SOIL WATER STORAGE, SOIL WATER USE AND WATER USE EFFICIENCY (WUE) OF UPLAND CROPS

Tillage systems directly influence soil moisture regimes through their effects on infiltration, redistribution, storage and movement in the soil.

Decrease in bulk density by tillage practices increases total porosity and hence, increases the amount of water held at lower potential (Elrick and Tanner, 1955; Young and Dixon, 1966; Klute, 1982). However, the amount of water retained also depends on soil texture and structure. Unger (1975) showed that destruction of the natural structure decreased the water retention in coarse textured soil but increased in fine textured soil as compared to undisturbed soil at a matric potential of –0.033 MPa. At a matric potential of –1.5 MPa, disturbed soil sample of all textures retained more water than undisturbed sample, but the percentage

change in retention of water was greater for coarse textured soil than the fine textured soils.

Talati and Mehta (1963) reported that in sandy loam soils of Gujarat, deep tillage preserved higher moisture throughout the season. It was 1.56 and 1.47 per cent more compared to that under shallow tillage at the time of sowing and harvest, respectively. Bhushan *et al.* (1973) reported that the larger aggregates resulting from disc and mould board ploughings increased the rate of moisture depletion by increasing evaporation through increased exposure of surface area of the clods. Water retention increased when bigger clods were disintegrated by irrigation during the later phases of crop growth because of less exposed surface area of smaller particles and settling of particles.

Bhushan *et al.* (1977) reported that deep tillage in a silty loam soil helped in efficient utilisation of stored soil moisture (96 mm from 90 cm soil profile against 67 mm in shallow tillage) due to better root penetration of *Brassica campestris* var. toria. The moisture used by the crop in the study period was 50 per cent higher under deep tillage compared to shallow tillage. Dixit *et al.* (1981) observed 42 per cent more moisture storage at 30-60 cm depth in an Alfisol with deep tillage (12.27%) compared to shallow tillage (8.59%). Similar trend with deep tillage was also reported by Vittal (1987) in an Alfisol profile at Hyderabad.

Lindsay *et al.* (1983) found consistantly higher moisture content in deep tillage treatment than other two tillage methods viz., zero tillage and shallow tillage by rotovator (15 cm depth) in a soil containing 40 per cent clay. Brahmbatt and Patel (1983) reported that under semi arid conditions of Gujarat, initial

ploughing upto 30 cm depth following formation of ridges and furrows of 45 cm width was superior to shallow ploughing (10 cm depth) and deep ploughing (30 cm depth) in conserving soil moisture during the growth period of sorghum and castor crops. Formation of ridges and furrows in shallow hardening red chalka soil of Rajendranagar with castor crop increased the moisture retention (7.6%) over control (7.0%) (AICRP on SPCIP, Hyderabad Centre, 1984). Sharma *et al.* (1988) also reported the differences in matric suction between zero, minimum and conventional tillage plots in a clay loam soil. Low matric suction was found in conventional tillage plots.

Arora *et al.* (1991) stated that crop in deep tillage (30 cm) plots extracted more water from the soil profile than shallow tilled plots (10 cm) in loamy sand soil of Punjab. The crop in deep tillage plots extracted water even beyond – 1.5 MPa. Masand *et al.* (1993) reported that deep tillage improved water use efficiency (WUE) of maize crop by 15.7 kg cm^{-1} ha^{-1} (16.2%) and 16.4 kg cm ha^{-1} (24.1%) during first and second years of the study in sandy loam soils at Palampur, Himachal Pradesh compared with minimum tillage.

Trivedi *et al.* (1994) reported that increased water storage capacity, better aeration and porosity with deep tillage (22.5 and 15 cm depth) resulted in increased grain yield over shallow tillage (7.5 cm) was 11.60 and 17.32 per cent under 15 and 22.5 cm depths, respectively. In Alfisol of Himachal Pradesh, the improved water use efficiency (WUE) of wheat crop under deep tillage treatment was 17 kg cm^{-1} ha^{-1} (45.8%) in 1981-82 and 19.8 kg cm^{-1} ha^{-1} (41.6%) in 1982-83 over minimum tillage (Masand *et al.*, 1994).

Gill *et al.* (1996) reported increased water storage in soil and efficient water extraction by the crop due to deeper and denser rooting. The early and normal season crops utilised 16 and 11 mm more water in deep tillage (40 cm) than in conventional tillage (10 cm) plots, respectively, from the 60-120 cm soil layer. They also observed greater transpirational demand by the crops in deep tillage treatments than conventional tillage treatments which might be due to greater leaf area index noticed in deep tillage treatments. Gajri *et al.* (1997) reported that mean water use by wheat with deep tillage (40 cm depth) in deep alluvial sands of Punjab was 17 mm greater than that of conventional tillage (10 cm depth) in 1992-93. During 1993-94, wheat under deep tillage utilized 24 mm more water than under conventional tillage. Water depletion was 12 mm and 9 mm greater for the 60-120 cm and 120-180 cm soil layers, respectively, under deep tillage.

Salih *et al.* (1998) reported 25 and 13 per cent increase in water use efficiency (WUE) of cotton with deep tillage (subsoiling to 40 cm) over that of disc harrow treatment (7 cm deep) and disc plough (15 cm deep) treatment, respectively in clayey soils (55% clay) of Sudan. Meharban Singh and Chaudhary (1998) found that the profile water distribution was higher in deep tillage (40 cm deep) plots as compared to conventional tillage (7.5 cm depth) plots, irrespective of water stress. In deep tillage plots it was observed that depletion of water was more uniform throughout the profile, whereas in conventional tillage plots the depletion was more from surface. Increased soil water use efficiency in deep tillage treatment resulted in saving of 1 to 3 irrigations depending on soil texture and water stress conditions.

2.5 EFFECT OF TILLAGE PRACTICES ON NUTRIENT AVAILABILITY AND UPTAKE BY UPLAND CROPS

In a long term study at Anand on effect of deep and shallow tillage on sandy loam soil, the nitrate content in soils under deep tillage was four times higher (3.2 mg 100 g^{-1}) than that of shallow ploughing (0.8 mg 100 g^{-1}). The exchangeable potassium content of soil under deep tillage plots (13.1 mg 100 g^{-1}) was significantly higher than in shallow tillage plots (11.3 mg 100 g^{-1}), whereas available phosphorus content was not affected by depth of tillage (Talati and Mehta, 1963). Prasad (1987) observed better root system of maize in deep tilled plots which caused greater nitrate depletion in loamy sands of Punjab.

Vittal (1987) reported significant reduction in nitrogen requirement of castor crop under deep tillage compared to shallow tillage. He further noted that the apparent recovery of applied nitrogen was nearly twice (33.6%) in deep tillage treatments over shallow tillage treatments.

Vijayakumar (1991) observed significantly higher uptake of nitrogen, phosphorus and potassium by groundnut crop when subjected to deep ploughing (disc plough + disc harrow, both tractor drawn) compared to shallow tillage (country plough twice + disc harrow twice, bullock drawn). Control treatment (country ploughing twice) recorded lowest uptake of nutrients. However, deep ploughing was on par with the country ploughing + roto tilling treatment. Gajendra Singh and Omprakash Singh (1992) recorded highest, nitrogen uptake (35.1 kg ha^{-1}) in the plots which received 4 ploughings compared to other two tillage treatments

(Paraquat spray 30.7 kg N ha^{-1} and stubble removed 32.4 kg N ha^{-1}) in clay loam soils of Uttar Pradesh.

In a 11 year study, Nyborg *et al.* (1995) reported that nitrogen uptake and barley yields under zero tillage were lower than under conventional tillage in Malmo silty clay loam soil in Canada. Total uptake of N, P and K by the component crops (sorghum and greengram) of the intercropping system under various tillage systems was significantly higher than that under zero tillage. Disc ploughing was superior to rest of the tillage treatments for nutrient uptake followed by chisel plough, conventional tillage, minimum tillage and zero tillage in sandy loam soils of Rajasthan (Laddha and Totawat, 1997).

2.6 EFFECT OF TILLAGE PRACTICEES ON PLANT PHYSIOLOGICAL CHARACTERISTICS

Sharma and Acharya (1994) reported that the wheat plants in deep tillage plots (0.3 m soil depth) maintained 4.6% higher xylem water potential and 11.3% lower leaf diffusion rate over those in shallow tillage (upto 0.1 m) at flowering stage. Greater uptake of water under deep tillage as a result of improvement in soil physical properties and consequent better root growth maintained higher plant water status. The canopy temperature of wheat under deep tillage (0.3 m) was 2-3°C lower than the crop where the tillage was done upto 0.1 m.

Greater water uptake with deep tillage (40 cm) compared with conventional tillage (10 cm) from the soil profile is reflected by a better plant water status as inferred from low plant canopy temperature of 0.9 to 2.7°C with early

season crop in deep tillage, compared to conventional tillage in coarse textured soils of Punjab (Gill *et al.*, 1996).

2.7 EFFECT OF SOIL MOISTURE REGIMES ON SOIL TEMPERATURE

Ramnik Sharma *et al.* (1999) reported that the mean (minimum + maximum/2) soil temperature under the different irrigation treatments on potato crop differed significantly. Soil temperature decreased with increase in irrigation level in sandy loam soils of Lahaul Valley of Himalayas, whereas no variation in soil temperature was found due to irrigation regimes in clayey soils of Navasari, Gujarat (Patel and Patel, 1993).

2.8 EFFECT OF SOIL MOISTURE REGIMES ON GROWTH, YIELD ATTRIBUTES AND YIELD OF SUNFLOWER

2.8.1 Plant height

Variation in soil moisture regime are reflected on the growth parameters like plant height, leaf area and dry matter production of the crop. Stalk elongation (plant height) was shown to be directly correlated with turgor of plant, which inturn depended on a favourable soil water content. Hence maximum plant height (184 cm) was produced when irrigations were scheduled at 1.1 IW/CPE ratio as compared to 0.9, 0.7 and 0.5 IW/CPE ratio (Patel and Singh, 1981). Abdel Gawad *et al.* (1987) reported that reducing the irrigation interval from 18 days to 10 days increased the plant height at 36, 54 and 90 days after sowing (DAS) but not at 72 DAS.

Vivek and Chakor (1992) observed significant positive influence on plant height of sunflower crop with an intensive irrigation schedule of 0.9, 0.3 and 0.6 IW/CPE ratios. Plant height at harvest was significantly more when irrigations were scheduled at a constant IW/CPE ratio of 1., however, reducing water application by adopting an IW/CPE ratio of 0.4 or 0.6 or 0.8 at vegetative periods and an IW/CPE ratio of plus 1.0 later did not cause any significant reduction in plant height (Venkanna *et al.*, 1994).

Chamundeshwari and Praveen Rao (1998) recorded significantly higher sunflower plant height in treatments which received adequate water supply (Eta = Etm) and withholding irrigation at vegetative stage compared to other treatments viz., withholding irrigation at flowering, withholding irrigation at seed filling and withholding irrigation at flowering + seed filling in sandy loam soils of Hyderabad.

2.8.2 Leaf area index (LAI)

One of the important consequences of water deficits is reduced cell enlargement and reduction in leaf area (Hsiao, 1973). Rollier and Pierse (1975) reported that moisture stress effects on sunflower were more pronounced on leaf area index (LAI). Patel and Singh (1981) in their investigation on a clay loam soil at Udaipur observed significantly higher leaf area index (4.23) when irrigations were scheduled at 0.7 IW/CPE followed by 1.1 (4.16), 0.9 (4.15) and 0.5 IW/CPE (3.25) ratios. Rawson and Turner (1982) showed that withholding of water during the initial 45 days until the leaf water potential dropped to –0.5 MPa resulted in the production of larger leaves in the upper canopy than frequently irrigated crop in

which, the leaf water potential did not drop below –0.3 MPa during corresponding period. They also opined that the seed yield was strongly correlated with leaf area at anthesis.

Hegde (1988) while working with moisture stress effects imposed at different crop growth periods of sunflower under Bangalore conditions observed that LAI and leaf area duration (LAD), were greatly reduced, however, they were enhanced again after the restoration of normal water supply. Increase in LAI and LAD was greater when moisture stress was imposed during early growth period (0-21 DAS). Vivek and Chakor (1992) observed that leaf area index was significantly reduced under no irrigation treatment, however, application of water at 0.3, 0.6 and 0.9 IW/CPE ratios significantly and linearly increased the LAI. Dahiphale and Pawar (1993) reported that leaf area was significantly more by scheduling irrigations at 1.0 IW/CPE ratio; whereas irrigations given at 0.8 and 0.6 IW/CPE ratios were at par and were significant superior over 0.4 IW/CPE ratio.

Significant differences in LAI of sunflower were observed at 90 DAS with different irrigation levels (0.4, 0.6 and 0.8 IW/CPE ratios). The IW/CPE ratios of 0.6 and 0.8 showed equal effects on LAI at 90 DAS and were significantly superior to 0.4 IW/CPE ratio (Tomar *et al.*, 1997)

2.8.3 Drymatter accumulation

In sunflower, drymatter accumulation which reflects the net photosynthesis production (photosynthesis – respiration) was slow in the initial period of crop growth, rapid during 61-75 DAS and slowed down thereafter, the

absolute growth rate had a distinct peak of 21-96 g/plant/week during 61-75 DAS (Andhale and Kalbhour, 1978). Pahalwan and Tripathi (1985) opined that for higher total drymatter production/plant irrigations at 0.6 IW/CPE were essential than irrigations at critical growth stages.

The work of Cox and Jolliff (1986) revealed that the total drymatter production in fully irrigated treatment (irrigations at 0.05 MPa) averaged close to 1400 gm^{-2} across the year, whereas deficit (30-50 per cent less water than fully irrigated control treatment) and dryland treatments produced about 1100 and 700 gm^{-2} of drymatter respectively. Venkanna *et al.* (1994) reported that total drymatter production was significantly more when irrigations were scheduled at 1.0 IW/CPE ratio throughout the crop life as compared to either 0.4, 0.6 and 0.8 throughout the crop life or combinations at vegetative + reproductive periods (0.4 + 0.6, 0.4 + 0.8, 0.4 + 1.0 and 0.6 + 0.8 IW/CPE ratios), however, 0.6 + 1.0 and 0.8 + 1.0 IW/CPE ratios were on par with 1.0 IW/CPE ratios. Similar observations were made by Tomar *et al.* (1997).

2.8.4 Capitulum diameter

Pal and Yadav (1974) reported that the treatment which received irrigation at 1.0 IW/CPE ratio produced capitulum having maximum diameter (17.88 cm) with bold seeds when compared with an unirrigated treatment (10.11 cm). Sarkar and Bhattacharya (1980) reported that scheduling of irrigations either at 60 or 80 per cent available soil moisture (ASM) registered higher capitulum diameter when compared to the irrigations scheduled at 40%, 20% ASM and no irrigation. At Bangalore, irrigations scheduled at 40% DASM recorded significantly higher

diameter of capitulum over 80% DASM, while no significant difference between the above treatments was observed at Akola, Maharastra (DOR, 1985 and 1987).

Cox and Jolliff (1986) observed a 20 and 30 per cent reduction in capitulum area under deficit and dryland treatments, respectively when compared to fully irrigated control treatment. Similar results were obtained by Human *et al.* (1990). Capitulum diameter increased linearly and significantly with increase in levels of irrigation and was highest at 0.8 IW/CPE ratio (Singh *et al.*, 1995).

2.8.5 1000 seed weight

Seed test weight is an important indicator with respect to seed yield and quality. Raghu and Choubey (1978) reported that three irrigations at 4-6 leaf stage, flowering and grain filling stage recorded highest 1000-seed weight (51.5 g) when compared to irrigations given at other growth combinations. The work of Somasundaram and Iruthayaraj (1981) indicated that irrigations scheduled at 1.05 IW/CPE ratio, 60 per cent ASM and 0.9 IW/CPE were equally effective on test weight but significant over 0.75 and 0.6 IW/CPE ratios. The increase was attributed to increase in seed size and seed filling at high soil moisture regimes. Unger (1983) indicated that in general the test weight was higher for sunflower irrigated at late flowering than at earlier growth stages, emphasizing the importance of adequate water supply during seed development for obtaining higher seed density.

Tripathi and Sawhney (1989) reported that irrigation levels had no significant effect on 1000 seed weight in the first season of experimentation but in the second season when weather during reproductive phase happened to be dry,

irrigations at 1.05 IW/CPE recorded significantly higher 1000 seed weight over 1.0, 0.75 and 0.6 IW/CPE ratios. Venkanna *et al.* (1994) observed that scheduling of irrigations at 1.0 IW/CPE ratio recorded highest test weight (46.5 g) which was however, on par with 0.8 + 1.0 IW/CPE ratio but significantly superior to other irrigation schedules (0.4, 0.6, 0.8, 0.4 + 0.6, 0.4 + 0.8, 0.4 + 1.0, 0.6 + 0.8 and 0.6 + 1.0 IW/CPE ratios). In similar way Singh *et al.* (1997) reported that irrigations at an IW/CPE ratio of 0.8 recorded significantly higher 1000 seed weight compared with irrigations at 0.6 and 0.4 IW/CPE ratios.

On the contrary irrigations scheduled at different levels of DASM did not exhibit significant influence on 1000 seed weight (DOR, 1984 and 1987).

2.8.6 Seed yield

Simanskij (1966) stated that sunflower responds well to irrigation and he noticed that any shortage of water during the period of flower head formation and seed development reduced seed yield significantly. Rohelin (1967) observed highest sensitivity of sunflower crop to moisture stress 20 days before and after flowering. Pal and Yadav (1974) showed that seed yield increased significantly with increasing levels of irrigation, the highest and lowest being recorded at 80 and 20 per cent ASM (2080 kg ha^{-1} and 1038 kg ha^{-1}) respectively.

The results of the study carried out at Digraj revealed that two irrigations one at flowering and one at seed development stages have increased the seed yield significantly over one irrigation given either at seed development stage or at sowing (DOR, 1977). Bhan and Khan (1980) reported that irrigations at 1.0

IW/CPE ratio with 5 cm depth of water at each irrigation to sunflower crop resulted in maximum seed yield.

The data from the experiments on soil moisture supply conducted under AICRPO indicated that the yields were highest when irrigations were given at 40 per cent DASM and the yield was markedly reduced when the crop was irrigated at 80 per cent DASM (DOR, 1985). Hegde (1988) reported that irrigations based on stress day index (SDI) method was found to be superior in terms of seed yield (1788 kg ha^{-1}) over conventional critical stages approach (1708 kg ha^{-1}) on red sandy loam soils of Bangalore. The greatest reduction in seed yield (27.3%) occurred when stress was imposed during late flowering followed by stress at seed filling (23.5%), vegetative stage (16.4%) and early flowering (14%) as compared to no stress (Hegde and Havanagi, 1989).

Tripathi and Sawhney (1989) observed that the highest seed yield of 1452 kg ha^{-1} was obtained with IW/CPE ratio of 1.5 which was 16.7, 23.0 and 44.7 per cent higher than that obtained at IW/CPE ratio of 1.0, 0.75 and 0.6,respectively. Human *et al.* (1990) stated that moderate and severe stress during budding significantly lowered the seed yield. Venkanna *et al.* (1994) recorded significantly higher seed yield (1.58 Mg ha^{-1}) when irrigations were scheduled at IW/CPE ratio of 1.0 in comparison to 0.4, 0.6 and 0.8.

Singh *et al.* (1995) reported that four post sowing irrigtions to sunflower based on IW/CPE ratios of 0.8 or based on physiological growth stages viz., 25 DAS, initiation of flower buds, mid flowering and seed setting stage registered higher seed yield as compared to rainfed control, 0.6 IW/CPE ratio, two

irrigations one at 25 DAS and one at initiation of flower buds and three irrigations one each at 25 DAS, initiation of flower buds and mid flowering.

Bharambe *et al.* (1997) recorded significantly higher seed yield (926 kg ha^{-1}) of summer sunflower when soil water regime was maintained through irrigation at IW/CPE ratio of 1.0 than 0.5 (664 kg ha^{-1}) in clayey soil of Maharastra. However, the achene yields were not significantly different in IW/CPE ratio of 0.75 and irrigation at 10 day interval when compared to IW/CPE ratio of 1.0.

Shinde *et al.* (1990) reported that the seed yield due to different levels of irrigations was not significant. Likewise Khade *et al.* (1994) observed that there was no significant difference in seed yield of sunflower subjected to different levels of irrigation treatments i.e., 0.4, 0.6, 0.8, 1.0 IW/CPE ratio and irrigations at critical growth stages.

2.8.7 Harvest index

Karani (1977) observed decline in harvest index values with increase in irrigation interval from 6 days (31.73%) to 14 days ((29.10%). Similar observation were made by Rawson and Turner (1982a). Dahiphale and Pawar (1993) observed that harvest index was significantly more with wet moisture regime (1.0 and 0.8 IW/CPE ratios) than dry moisture regime (0.4 and 0.6 IW/CPE ratios). Nagavani (1995) recorded highest harvest index (41.5%) in sunflower when irrigations were scheduled at 1.0 IW/CPE ratio, compared to 0.6 and 0.8 IW/CPE ratios.

2.8.8 Oil content

According to Karani (1977) the percentage of oil in the seed varied with the irrigation interval, such that higher levels of moisture supply i.e., irrigations scheduled at 6 day interval resulted in high oil percentage in seeds. Pal (1981) observed significantly higher oil content when irrigations were scheduled at 60% ASM compared to 20, 40 and 80% ASM. Kumar *et al.* (1991) reported that scheduling irrigations at IW/CPE ratio of 1.0 (41.69%) significantly improved the oil content as compared to 0.4 (38.48%), 0.6 (40.4%), 0.8 (41.05%) and 1.2 (41.33%) IW/CPE ratios.

Babu *et al.* (1993) opined that the oil content of sunflower seed was 43.88% when the crop was irrigated at 80 mm CPE which was significantly higher than giving irrigations at 100 mm CPE (40.73%) and critical stages (39.8%). The treatments receiving irrigations at 60 mm CPE recorded 42.56% of oil in seeds which was on par with 80 mm CPE treatment. Singh *et al.* (1995) observed that four post sowing irrigations to sunflower based on IW/CPE ratio of 0.8 or four irrigations based on physiological stages at 25 DAS, flower bud mid flowering and seed setting stages resulted in high values of oil content in comparision to rainfed control, 0.6 IW/CPE ratio, irrigations at 75 DAS + irrigation of flower buds and irrigations at 25 DAS + initiation of flower buds + mid flowering.

Bharambe (1997) recorded higher oil content in summer sunflower (44.1%) when soil moisture was maintained by giving irrigations at 10 day interval compared to other soil moisture regimes viz., irrigations at IW/CPE of 1.0 (42.9%), 0.75 (42.3%) and 0.50 (41.6%) in clayey soils of Maharastra.

Oil content in sunflower seed increased with increasing levels of irrigation and maximum oil content was recorded when irrigations were given at IW/CPE ratios of 0.8 (45.27%) as compared to 0.6 and 0.4 IW/CPE ratios (Tomar *et al.*, 1996). Contrary to the above there are several reports suggesting that irrigation levels had no significant influence on sunflower seed oil content (DOR, 1983; 1984; 1985; 1987; Khanvilkar *et al.*, 1987; Shinde *et al.*, 1990 and Singh *et al.*, 1997).

2.9 EFECT OF SOIL MOISTURE REGIMES ON WATER USE (CROP ETa) AND WATER USE EFFICIENCY OF SUNFLOWER

According to Doorenbos and Kassan (1979) the water requirement of sunflower varied with the climate and length of crop growing season. The crop ETa increased from establishment to flowering and thereafter followed a logistic pattern towards crop maturity. During seed setting and early ripening stage, the ETa rates were higher. The per cent water use over different crop growth periods was of the order of 20, 55, 25 and 25 at vegetative, flowering, seed filling and ripening respectively. The corresponding crop coefficient values were 0.3 to 0.4, 0.7 to 0.8, 1.05 to 1.2 and 0.7 0.4. They also opined that the sunflower crop has the ability to withstand short periods of water deficits at vegetative stage, however severe soil

water deficits at any growth period causes leaf drying with subsequent reduction in seed yield.

Sarkar and Bhattacharya (1980) stated that the optimum water requirement of sunflower under alluvial soil conditions of Eastern India has been recorded as 20.7 ha cm. This amount of water is however to be applied in six instalments at an interval of 14 days each time with 2.7 ha cm water besides one post sowing irrigation of 4.5 ha cm.

Patel and Singh (1981) observed a progressive increase in water use of sunflower from 0.5 to 1.1 IW/CPE ratios, however, the water use efficiency (WUE) was highest at 0.7 IW/CPE ratio. The work of Somasundaram and Iruthayaraj (1981) revealed that the total water requirement of sunflower varied from 472.3 to 718.4 mm during summer on red sandy loam soils and from 325.8 to 553.4 mm in monsoon season on clay loam soil of Coimbatore under different irrigation schedules. In the above study highest water use efficiency (WUE) of 6.48 kg ha^{-1} mm^{-1} was observed when irrigations were scheduled at 0.45 IW/CPE ratio compared to other higher ratios (0.55, 0.75, 1.0 IW/CPE) and their combinations on a clay loam soil.

In a study conducted at Bangalore, Hegde (1988) noticed that by adopting stress day index (SDI) method for scheduling irrigation, although seasonal water use was not better compared to conventional methods, the water use efficiency was higher. According to Khade *et al.* (1989) the seasonal ETa increased with increase in irrigation frequency (5 to 10) and it was more when irrigations were scheduled at 40 mm CPE (328 mm) as compared to 60 mm (292 mm), 80 mm (239

mm) and 100 mm CPE (237 mm). However, in the above study the water use efficiency increased with decrease in irrigation frequency i.e., soil water supply. Like wise Tripathi and Sawhney (1989) observed that the water use increased progressively with increase in number of irrigations and it ranged from 560 to 725 mm in first year and 447 to 616 mm in second year of experimentation on a loamy sand soil. Venkanna *et al.* (1994) observed that ETa increased with increase in irrigation water supply. Minimum (16.132 cm) and maximum (30.352 cm) ETa's were recorded in the crop when irrigations were scheduled at 0.4 and 1.0 IW/CPE ratio, respectively. WUE decreased with increase in water supply. Highest WUE was recorded by the crop when irrigations were scheduled at 0.4 + 1.0 IW/CPE ratio (57.08 kg ha^{-1} cm^{-1}).

The results of the investigation carried out by Babu *et al.* (1993) revealed that the seasonal ETa varied proportionately with number of irrigations wherein the highest ETa was recorded with 60 mm CPE treatment (775.7 mm) and lowest ETa was recorded with the treatment receiving irrigations at critical stages (527.4 mm). WUE in the above study was inversely proportional to quantity of water used except in critical stage approach treatment. Thus,100 mm CPE treatment recorded highest WUE (3.74 kg ha^{-1} mm^{-1}) while in 60 mm CPE treatment it was 3.57 kg ha^{-1} mm^{-1}. Moisture depletion from the top layers (0 to 30 cm depth) was higher in frequently irrigated plots i.e., 60 mm CPE and 80 mm CPE treatments (43.43% and 42.06%, respectively) and the lowest in treatment receiving irrigation at critical stage (36.59%).

Singh *et al.* (1997) stated that the ETa increased with increase in irrigation level, maximum ETa was observed at 0.8 IW/CPE ratio and lowest in 0.4 IW/CPE ratio. A water use efficiency of 4.79 kg ha^{-1} mm^{-1} was recorded under treatment receiving four irrigations at critical stages during sunflower crop growth period than other treatment viz., 0.8 and 0.4 IW/CPE ratios. Bharambe *et al.* (1997) reported that consumptive use of summer sunflower with IW/CPE ratio of 1.0 was 542 mm, while it was 333 mm with IW/CPE of 0.5. However, in the above study water use efficiency was high (20.0%) with IW/CPE ratio = 0.5 and lowest with 1.0 (17.1%).

Ramachandra Reddy and Subbi Reddy (1998) recorded high water use efficiency of rabi sunflower (3.79) when soil moisture was supplied at 15 day interval compared to other treatments viz., irrigations at IW/CPE ratio of 0.75 (3.50), 1.0 (3.01) and 10 day interval (3.01) in sandy clay loam soils of Cuddapah (AP).

Highest ETa was recorded with 0.8 IW/CPE ratio compared to 0.6 and 0.4 IW/CPE ratios. WUE decreased with increasing levels of irrigation. WUE was highest under driest moisture regime (0.4 IW/CPE) and lowest in wettest moisture regime (0.8 IW/CPE). Bulk of the soil moisture extracted by the crop was contributed from the surface (0-30 cm) soil layer followed by 30-60 cm soil layer. Maximum soil moisture extraction (47.96%) in 0-30 cm layer was with 0.8 IW/CPE ratio. In 60 to 90 cm soil layer, maximum soil moisture extraction was found in 0.4 IW/CPE followed by 0.6 IW/CPE ratio (Tomar *et al.*, 1996).

2.10 EFFECT OF SOIL MOISTURE REGIMES ON NUTRIENT UPTAKE

Patel and Singh (1981) reported that nitrogen and phosphorus uptake by sunflower increased with increase in IW/CPE ratio from 0.5 to 1.1 while, potassium uptake was greater when irrigations were scheduled at IW/CPE ratio of 0.7. Bharambe *et al.* (1997) recorded highest N (56.5 kg ha^{-1}), P (18.6 kg ha^{-1}) and K (40.2 kg ha^{-1}) uptake by summer sunflower with IW/CPE ratio of 1.0 in clayey soils of Maharashtra, the results were on par with 10 day interval irrigations treatment and significantly higher when compared to IW/CPE ratios 0.5 and 0.75.

2.11 EFFECT OF SOIL MOISTURE REGIMES ON PLANT WATER RELATIONS

According to Tomar and Ghildyal (1973) relative leaf water content of rice dropped down to 33% before the crop was permanently wilted. Hsiao (1973) suggested that expansive growth was the most sensitive to plant water stress which he attributed to the essential role of turgor pressure in sustaining cell enlargement. Gardner and Ehlig (1965) indicated that the visible wilting in several crop species occurred in the range of –12 to –16 bars and stated that the leaf water potential decreased sharply as relative water content decreased below 100%, in the intermediate relative leaf water content range the drop in leaf water potential was gradual, but below relative leaf water content of 35% the drop in leaf water potential was again very sharp.

Plant water deficit does not seem to affect the stomatal apertures upto a point. But when the deficit exceeds a certain threshold value, stomata begins to

close partially and may close completely when stress reaches a critical level. Sandhu and Horton (1977) have reported that the leaf diffusion resistance is closely related to plant water status. In well-watered maize the leaf diffusion resistance was 3.8 sec cm^{-1} at 09-00 hr, but when irrigation was delayed for 6 days after the normal irrigation date, the leaf diffusion resistance increased to 32.4 sec cm^{-1} at 14-00 hr (Varshney, 1980). Hsiao *et al.* (1980) stated that stomata operate as safety valves in checking water loss when tissue water status becomes too low and hence minimize the development of severe water stress in the plant. But concurrently the assimilation of CO_2 also falls and the drymatter production is slowed down.

2.12 INTERACTION EFFECTS OF TILLAGE PRACTICES AND SOIL MOISTURE REGIMES ON GROWTH AND YIELD OF UPLAND CROPS

Trivedi *et al.* (1994) reported that increase in soil moisture regimes (irrigations at 0.5 to 0.76 IW/CPE ratio) and tillage depths (7.5 cm in shallow tillage, 22.5 cm in deep tillage) as individual effects significantly increased greengram plant height, drymatter production, nodules $plant^{-1}$, pods $plant^{-1}$, pod length, grain pod^{-1}, test weight and grain yield $plant^{-1}$. The interaction effects of tillage depths and soil moisture regimes showed that in heavy black soils of south Gujarat irrigations scheduled at 0.7 IW/CPE ratio and seed bed prepared with deep tillage (72.5 cm) have given higher yields of greengram.

Meharban Singh and Chaudhary (1998) from their investigation on effect of deep tillage and water stress at different physiological stages of maize on coarse textured soils of Punjab stated that deep tillage (upto 40 cm depth) encourages root growth and water extraction from deeper soil layers. Increased soil

water use efficiency resulted in saving of 1 to 3 irrigations depending on soil texture and water stress condition. Maximum yield increase due to deep tillage was in crop stressed at vegetative stage on loamy sand and at pollination stage on sandy loam soils. Deep tillage did not improve maize yield in crop severely stressed at both the two stages. In stressed crop, deep tillage benefits were more in loamy sand soil as compared with sandy loam soil.

The results of 3 year experiment in coarse textured soils of Punjab conducted by Gill *et al.* (1996) revealed that deep tillage (40 cm) had greater root length index (RLI) than conventional tillage (10 cm) with irrigations at 75 mm net evaporation. RLI below the 10 cm depth with deep tillage was greater than conventional tillage irrespective of irrigation regime.

Gajri *et al.* (1997) studied the interaction effect of tillage and irrigation regimes on growth and yield of wheat on alluvial sand in a semi arid subtropical climate. The results of the above study revealed that deep tillage (40 cm) and infrequent large irrigations increased mean grain yield by 1.0 Mg ha^{-1} over 2.7 Mg ha^{-1} obtained with conventional tillage (10 cm) and infrequent large irrigations. The corresponding increase of yield in conventional tillage with frequent small irrigations was 0.7 Mg ha^{-1}. A combination of deep tillage and frequent small irrigations increased yield by 2.3 Mg ha^{-1}. It appears that wheat under conventional tillage suffered early season nutrient and water stress and hence did not develop enough plant size to benefit from frequent small irrigations. Deep tillage and frequent small irrigation regimes modified the soil physical environment so as to favour root proliferation and thus increased the ability of the crop to utilize subsoil water and nutrients.

MATERIALS AND METHODS

CHAPTER III

MATERIALS AND METHODS

This study entitled "Effect of tillage practices and soil moisture regimes on soil properties and performance of sunflower grown after puddled rice in rice based cropping system" was carried out during 1997-98 and 1998-99. The details of the materials used and the methods followed in this investigation are presented in this chapter.

3.1 LOCATION OF THE EXPERIMENTAL SITE

The present experiment was conducted at the Agricultural College Farm, Rajendranagar, Hyderabad which is located on 17°19' North Latitude and 78°28' East Longitude at an altitude of 535 m above MSL. During both the years, the experiment was conducted in the same field at the same location.

3.2 DETAILS OF THE EXPERIMENTAL SITE

Soil samples were collected at random spots in the experimental site from 0-15 cm, 15-30 cm and 30-45 cm soil depths before laying out the experiment and were analysed for physical, physico-chemical and chemical characteristics by adopting standard procedures and the data are presented in Table 1.

The soil was sandy clay loam in texture, neutral to slightly alkaline in reaction, non saline in nature, low in available nitrogen and phosphorus and medium in available potassium.

Table 1: Physical, physico-chemical and chemical characteristics of soil of experimental site.

Particulars	Values				Method of analysis
Soil physical characters					
1. Soil bulk density (Mg m^{-3})	1997-98		1998-99		
0-15 cm	1.47		1.51		Core sampler
15-30 cm	1.55		1.56		method
30-45 cm	1.59		1.60		(Black, 1965)
45-60 cm	1.62		1.61		
2. Porosity (%)					
0-15 cm	44.90		43.02		
15-30 cm	41.89		41.38		
30-45 cm	40.00		39.60		
45-60 cm	38.87		39.24		
3. Mechanical composition (%)	Sand	Silt	Clay	Texture	
0-15 cm	66.00	12.33	21.67	scl	Bouyoucos
15-30 cm	63.67	13.00	23.33	scl	hydrometer
30-45 cm	66.00	13.67	20.33	scl	method (Piper,
45-60 cm	72.33	11.62	16.00	sl	1966)
4. Hydraulic conductivity (cm h^{-1})	1997-98		1998-99		
0-15 cm	0.41		0.46		Core sampling
15-30 cm	0.31		0.33		method as
30-45 cm	0.33		0.34		described by
45-60 cm	0.35		0.35		Jalota *et al.*
					(1998)
5. Infiltration rate (cm hr^{-1})	1.41		1.44		Double ring infitro meter method as described by Jalota *et al.* (1998)
Physico chemical characters	1997-98		1998-99		
pH(1 : 2)					
0-15 cm	7.54		7.41		Glass elecrode
15-30 cm	7.81		7.68		pH meter
30-45 cm	7.98		7.82		(Jackson, 1973)
EC (d Sm^{-1}) (1 : 2)					
0-15 cm	0.19		0.22		Conductivity
15-30 cm	0.22		0.28		bridge method
30-45 cm	0.27		0.30		(Jackson, 1973)

Table 1 contd...

	1997-98			1998-99			Method
	0-15 cm	15-30 cm	30-45 cm	0-15 cm	15-30 cm	30-45 cm	
Organic carbon (%)	0.55	0.35	0.20	0.60	0.32	0.20	Rapid titration method (Walkley & Black 1934)
Avialable N (kg ha^{-1})	223.45	205.75	175.50	235.00	213.75	182.50	Alkaline permanganate method Subbiah & Asija (1956)
Available P_2O_5 (kg ha^{-1})	21.41	19.28	18.75	20.20	18.68	18.10	Olsen's method Olsen *et al* (1954)
Available K_2O (kg ha^{-1})	286.5	269.00	255.70	271.00	265.50	245.40	Flame photometer method Muhr *et al* (1963)

Moisture retention characters of soil

Soil depth (cm)	Soil moisture tention (bars)					Available moisture (cm)	
	0.1	1.0	5.0	15.0	B.D		
0-15	17.39	14.25	8.92	5.80	1.44	2.49	Pressure plate apparatus method Richards (1959)
15-30	16.15	11.95	7.77	5.40	1.55	2.51	
30-45	14.55	11.05	7.33	5.12	1.59	2.25	

Table 2 : Analysis of irrigation water

S.No	Parameter	Value	Method followed	Reference
1.	pH	7.32	Digital pH meter	American Public Health Association for the examination of water and waste waters, 1985
2.	EC (dSm^{-1})	0.174	Digital conductivity bridge	American Public Health Association for the examination of water and waste waters, 1985
3.	Carbonates (CO_3^{-2}) (me l^{-1})	0.52	Titration with 0.02 H_2SO_4 using phenophthalene indicator	American Public Health Association for the examination of water and waste waters, 1985
4.	Bicarbonates (HCO_3^-) (me l^{-1})	0.90	Titration with 0.02 N H_2SO_4 using methyl orange as indicator	American Public Health Association for the examination of water and waste waters, 1985
5.	Chlorides (Cl^-) me l^{-1}	7.9	Titration with standard $AgNO_3$ using $K_2Cr_2O_7$ indicator	American Public Health Association for the examination of water and waste waters, 1985
6.	Sodium (Na^+) me l^{-1}	10.23	Flame photometer	American Public Health Association for the examination of water and waste waters, 1985
7.	Potassium (K^+) (me l^{-1})	29.66	Flame photometer	American Public Health Association for the examination of water and waste waters, 1985
8.	Calcium and magnesium ($Ca^{+2} + Mg^{+2}$) me/l^{-1}	2.6	Titration with standard EDTA using EBT indicator and ammonia buffer	American Public Health Association for the examination of water and waste waters, 1985
9.	Sodium Adsorption Ratio	8.97		
10.	Residual sodium carbonate (me l^{-1})	1.18		

Water class ratios: C_1S_1

C_1 = Low salinity water, Normal for all soils and crops but leaching should be taken up in case of low permeable soils

S_1 = Residual sodium carbonate is less than 1.25 hence the water can be safely used for irrigation.

3.2.1 Soil -water relations

The soil moisture retention characteristics and bulk density values of experimental field were estimated for each 15 cm soil depth increments in the effective crop root zone depth of 45 cm by following standard procedure outlined by Jalota *et al.* (1998) and the data are presented in Table 1.

The available water of the experimental soil determined was 2.49 cm in 0-15 cm, 2.51 in 15-30 cm and 2.25 in 30-45 cm soil depth (Table 1). Throughout the experimental period the water table remained below 3.0 m soil depth (as was evident from the water table in nearby open well), hence it was assumed that it did not contribute in any way to the crop water use.

3.2.2 Quality of irrigation water

The details of the quality of irrigation are given in Table 2. The irrigation water belongs to C_1S_1 group and is safe or irrigation.

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3.2.3 Previous crop history

The cropping history of the experimental soil for the previous two years is summarised in Table 3.

Table 3: Previous cropping history of experimental site

S.No.	Year	Season	Cropping pattern
1	1996-97	*Kharif*	Rice
		Rabi	Rice
		Summer	Fallow
2	1997-98	*Kharif*	Rice
		Rabi	Present experiment
		Summer	
3	1998-99	*Kharif*	Rice
		Rabi	Present experiment
		Summer	

3.3 WEATHER CONDITIONS DURING THE CROP GROWTH PERIOD

The data on weather parameters recorded during crop growing season at meteorological observatory located at Agricultural Research Institute, Rajendranagar are presented in appendix Ia and Ib and illustrated through Figure 1 and 2.

The mean weekly maximum and minimum temperatures during the crop period ranged from 38.1°C to 31.9°C and 22.0°C to 16.9°C and 41.3°C to 31.7°C and 27.0°C to 14.6°C during 1997-98 and 1998-99, respectively.

The mean relative humidity ranged from 89 to 63 and 85 to 52 during crop growth periods of first and second years, respectively.

The mean weekly bright sunshine hours varied from 10.9 to 9.0 during 1997-98 and 10.7 to 7.7 during 1998-99, respectively. The mean weekly wind velocity varied from 4.3 to 1.7 KMPH and 4.4 to 2.1 KMPH during first and second years, respectively.

The mean weekly pan evaporation ranged from 8.6 to 4.2 mm day^{-1} and 9.1 to 4.5 mm day^{-1} during crop growth period of 1997-98 and 1998-99, respectively, with an average of 6.32 mm day^{-1} and 6.72 mm day^{-1} during the crop growth periods of 1997-98 and 1998-99, respectively.

However there was not any precipitation during the crop growing seasons in the two years.

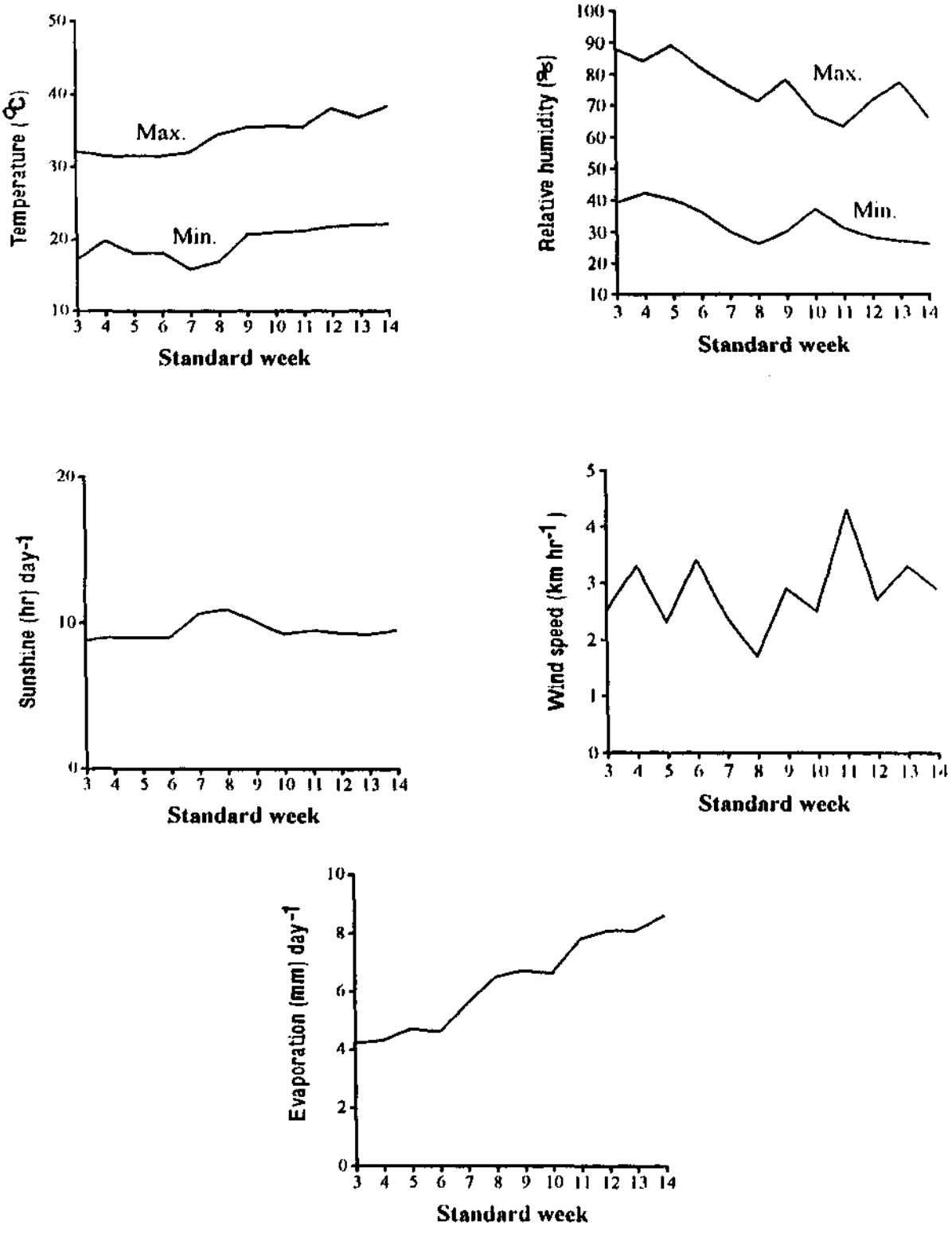
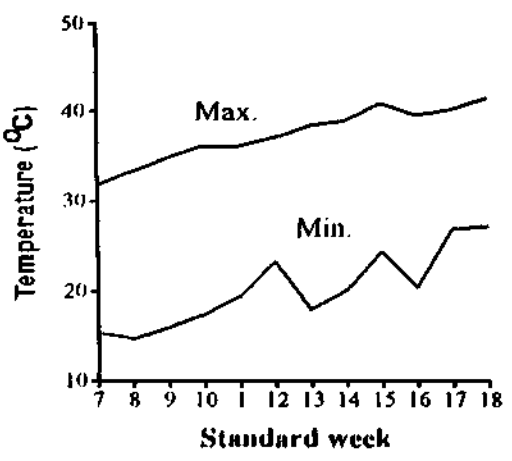
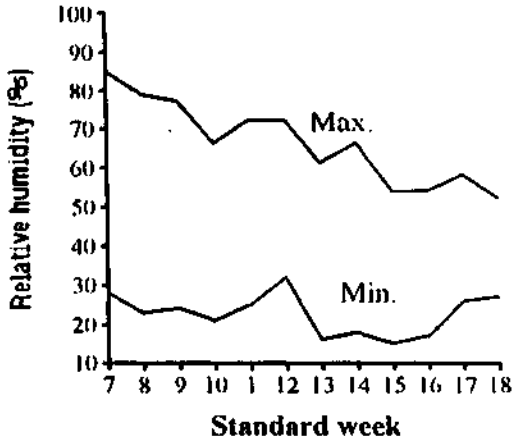
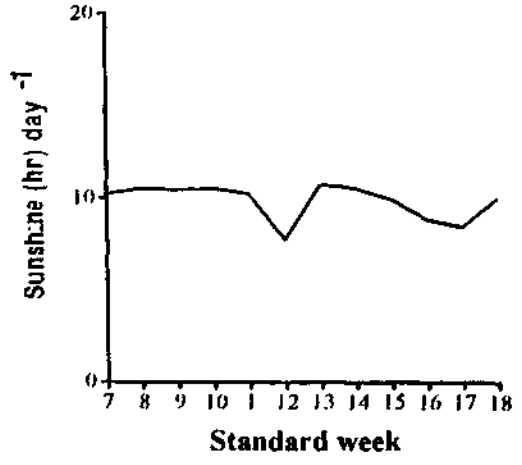
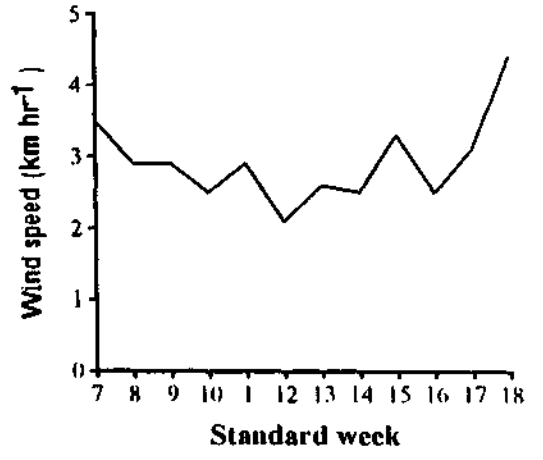


Fig.2 : Meteorological data during crop growth period during late *rabi*, 1997-98 (weekly means)









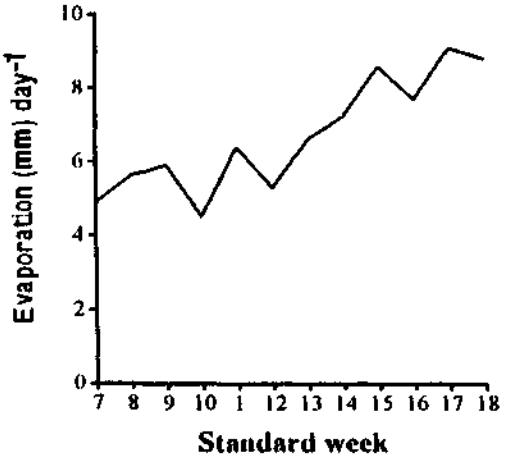


Fig. 3: Meteorological data during crop growth period during late *rabi*, 1998-99 (weekly means)

3.4 EXPERIMENTAL DETAILS

3.4.1 Experimental design and layout

Five tillage treatments formed the main plot treatments and four soil moisture regimes were selected as sub-plot treatments, constituting in all 20 treatment combinations and these were laid out in a strip plot design with three replications. Main plot treatments and sub-plot treatments were randomly allotted within each replication. The size of the gross plot was 6.6 m x 4.5 m. The layout plan is shown in Figure 3.

3.4.2 Details of treatments

Details of main plot treatments (tillage practices) and sub-plot treatments (soil moisture regimes) are as follows:

A. Main plot treatments (tillage practices)

T_1: Zero tillage (seed row opening only at the time of sowing)

T_2: Country plough twice and bullock drawn cultivator twice **(farmers' practice)**

T_3: Country plough twice and power tiller operated rotavator twice.

T_4: Mould Board Plough once and cultivator twice both tractor drawn.

T_5: Disc plough once and rotavator once both tractor drawn.

B. Sub-plot treatments (Soil moisture regimes)

M_1: Irrigation at IW/CPE = 0.6

M_2: Irrigation at IW/CPE = 0.8

M_3: Irrigation at IW/CPE = 1.0

M_4: Irrigation at IW/CPE = 1.2

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3.4.3 Field water supply

The field was irrigated immediately after sowing to ensure proper germination and establishment of the crop. The soil samples collected for moisture determination one day after post sowing irrigation in different treatments revealed that the soil was recharged to field capacity. Subsequent irrigations were given as per the treatments.

The depth of water given at each irrigation was 60 mm.

The volume of water (litres) to be applied during each irrigation to each plot, as per the treatment was calculated as follows:

$$W = A \times d \times 1000$$

Where,

W = Volume of water in litres at each irrigation

A = Plot size in m^2

d = Depth of irrigation water given in meters

= 29.7 x 0.06 x 1000

= 1782 litres/plot.

The water at each irrigation was directly delivered into each plot through a 50 mm water meter attached to a main water source by fixing it to a hose pipe and shifting it from plot to plot.

The amount of irrigation water given for different treatments during the crop period is given in Table 4.

3.5 CROP HUSBANDRY DETAILS

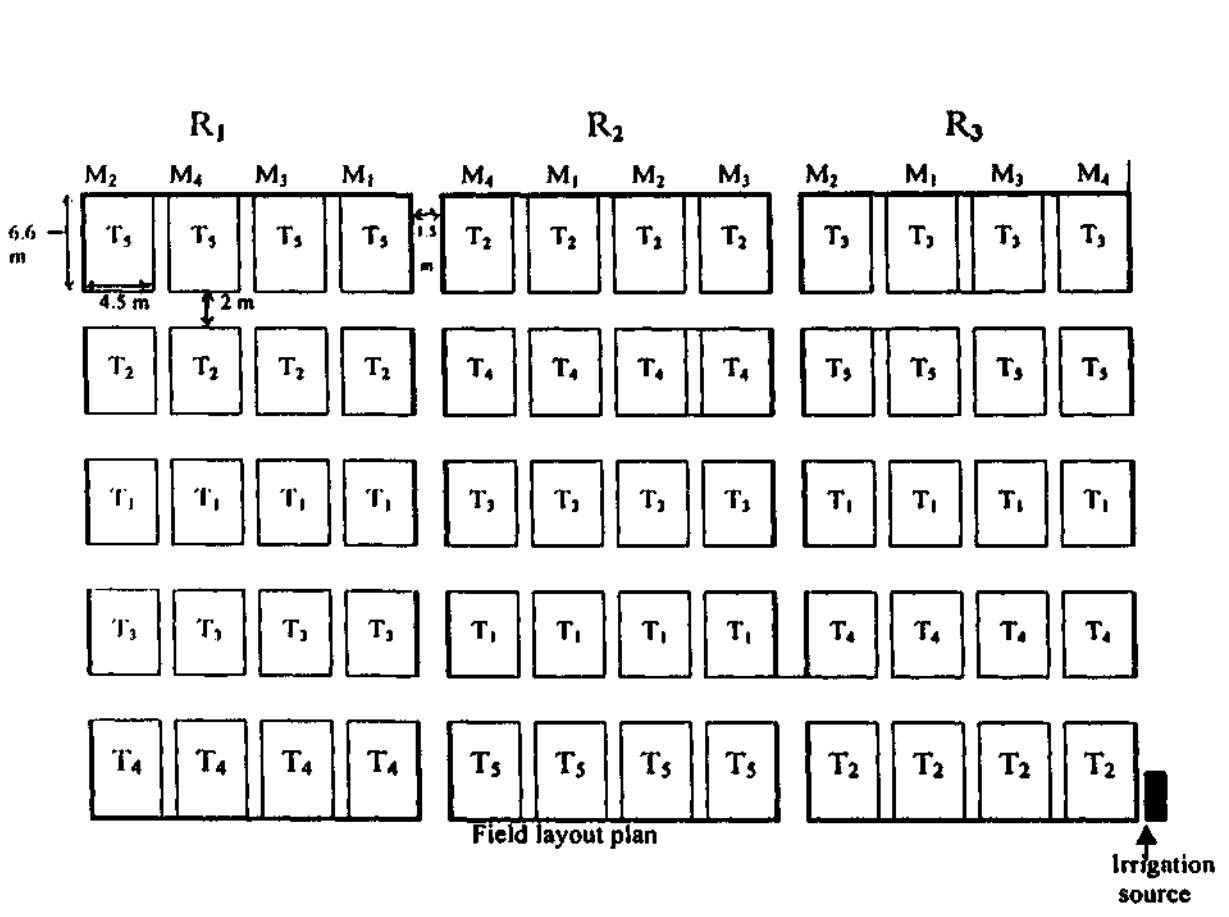
In both the years, rice crop variety Tellahamsa, was grown in kharif season under puddled condition in the experimental area. After the harvest of kharif rice the present sunflower crop was raised. The details of cultural and management practices adopted during crop growth period are furnished.

3.5.1 Preparatory cultivation

The field was ploughed as per the treatments in the main plots (tillage practices) and the experiment was laid out as per plan (Fig. 1). The depth of ploughing achieved with different tillage implements was measured after imposition of tillage treatments by removing the soil with hand. The depth of ploughing achieved in different tillage treatments is given in Table 5.

3.5.2 Fertilizer application

The recommended fertilizer nutrients viz., 80 kg N ha^{-1} as urea, 60 kg P_2O_5 ha^{-1} as single superphosphate and 30 kg K_2O ha^{-1} as muriate of potash were uniformly supplied to all the treatments. Half of the nitrogen and the entire dose of



Treatment details

Tillage treatments (T)

T1 : Zero tillage (seed line tillage only)
T2 : Country plough twice + bullock drawn cultivator twice
T3 : Country plough twice + power tiller operated rotavator twice
T4 : MB plough once + cultivator twice, both tractor drawn
T5 : Disc plough once + rotavator twice, both tractor drawn

Soil moisture regimes (M)

M1 : Irrigations at IW/CPE = 0.6
M2 : Irrigations at IW/CPE = 0.8
M3 : Irrigations at IW/CPE = 1.0
M4 : Irrigations at IW/CPE = 1.2

Replications	:	3
Gross plot size	:	6.6 x 4.5 m
Net plot size	:	6.0 x 2.7 m
Crop	:	Sunflower
Variety	:	Morden
Date of sowing	:	15.1.98 (first year) 13.2.99 (second year)

Fig. 1 : Field layout plan

Table 4 : Irrigation dates, frequency and seasonal water supply for sunflower under different soil moisture regimes 1997-98

IW/CPE ratios considered for scheduling irrigation	Irrigation dates	Irrigation frequency	Depth of water given at each irrigation (cm)	Seasonal effective rainfall (mm)	Seasonal applied water (mm)
	1998				
IW/CPE = 0.6 (M_1)	7/2 25/2 12/3 25/3	4	6.0	0.0	240
IW/CPE = 0.8 (M_2)	2/2 17/2 1/3 12/3 22/3 31/3	6	6.0	0.0	360
IW/CPE = 1.0 (M_3)	29/1 11/2 22/2 3/3 12/3 20/3 27/3 3/4	8	6.0	0.0	480
IW/CPE = 1.2 (M_4)	27/1 7/2 17/2 25/2 5/3 12/3 19/3 25/3 31/3	9	6.0	0.0	540
	1999				
IW/CPE = 0.6 (M_1)	3/3 19/3 3/4 16/4 25/4	5	6.0	0.0	300
IW/CPE = 0.8 (M_2)	27/2 12/3 24/3 3/4 13/4 22/4 30/4	7	6.0	0.0	420
IW/CPE = 1.0 (M_3)	25/2 7/3 17/3 26/3 3/4 11/4 18/4 25/4 2/5	9	6.0	0.0	540
IW/CPE = 1.2 (M_4)	23/2 3/3 11/3 19/3 27/3 3/4 10/4 16/4 22/4 28/4 3/5	11	6.0	0.0	660

phosphorus and potassium were applied as basal by following band placement 5 cm away from seed row while the remaining half of nitrogen was applied at 30 days after sowing following band placement 5 cm away from crop line.

3.5.3 Seeds and sowing

Sunflower variety Morden, a high yielding variety, was used for the study. Duration of the variety is 80-85 days with an oil content of 38-40 per cent. Its yield potential is 8-10 q ha^{-1}.

The crop was sown on 15th January 1998 in first year and 13th February 1999 in second year with a spacing of 45 cm between rows and 30 cm between plants within a row. Before sowing, the seeds were treated with carbendizim @ 3 g kg^{-1} of seed as a prophylactic measure against seed born diseases.

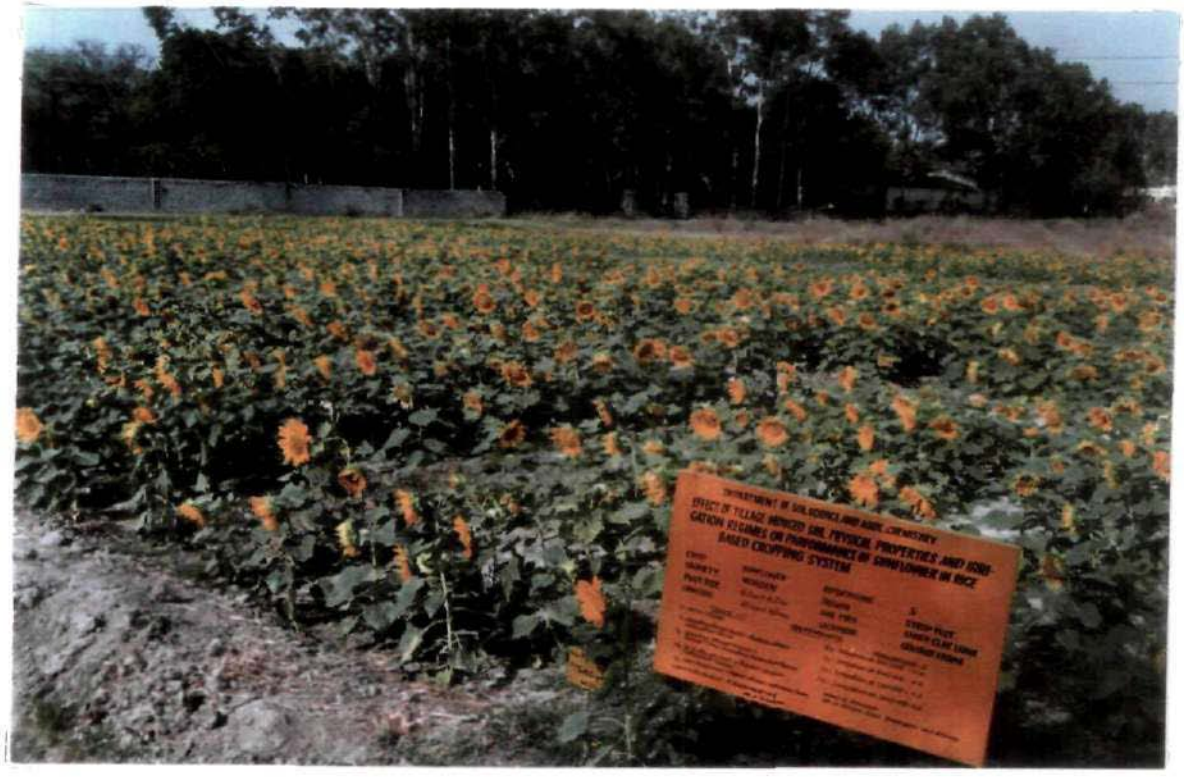
3.5.4 Cultural operations

Thinning was done on 12th day after sowing keeping one healthy plant per hill. Hand weeding was done twice during the crop growth period.

3.5.5 Plant protection

Incidence of flee beetles were noticed at seedling stages and were controlled by spraying Monocrotophos 36 EC (2 ml/litre of water). At 55 DAS a mixture of Dithane-M-45 (3 g/lit) and Dimethoate (30 EC, 1.5 ml/lit of water) was sprayed as a prophylactic measure against sucking pests and rust.

a



a

1 General view of the experiment

(a) Crop at 30 DAS (b) Crop at 45 DAS

3.5.6 Harvesting and threshing

The crop was harvested when back of the head turned to lemon yellow colour. Initially plants in the border rows were cut close to the ground and kept separately for further processing. Subsequently the plants in each net plot were harvested close to the ground.

The heads were separated from stalks, sundried and seeds were separated by gently beating the heads with sticks. The seeds were winnowed, cleaned, sundried separately for each plot. The seed weight was recorded plot wise. Similarly the stalks including the bhusa obtained after beating the heads and winnowing of seeds was sundried, the total weight (bhusa + stalks) was recorded in each net plot.

3.6 SOIL STUDIES AND ANALYSIS

Methods employed for physical and chemical analysis of soil are listed in Table 1. Methods employed in analysis of soil for physical properties are as follows:

3.6.1 Depth of ploughing

Depth of ploughing in centimeters was measured with the help of scale after the tillage practices were imposed in different tillage treatments.

3.6.2 Clod size distribution

Clod size distribution was determined by dry sieving after imposition of tillage practices. A set of sieves having openings ranging from 100.0 to 2.0 mm

(100, 50, 20, 10, 5 and 2 mm) were used. The soil was shaken gently for a minute taking care to avoid the breaking of clods. The clods retained on each sieve were weighed. The mean weight diameter (MWD) of clods was calculated according to statistical method suggested by Youker and McGunnis (1957).

$$\text{Mean weight diameter (MWD)} = \sum_{p=1}^{n} Xi\ Wi$$

Where,

n = number of fractions

Xi = mean diameter of the i^{th} fraction (mm)

Wi = proportion of the total sample weight occurring in fraction i^{th} fraction.

3.6.3 Bulk density

Soil samples were collected after harvest of rice, at sowing, 30 DAS, 60 DAS and at harvest from 0-15, 15-30 and 30-45 cm depth with core sampler of size 8 x 6 cm to determine soil bulk density by using the following formula as suggested by Black (1965).

$$\text{Bulk density (Mg m}^{-3}) = \frac{\text{Oven dry weight of soil (Mg)}}{\text{Volume of soil (m}^3\text{) core}}$$

3.6.4 Penetration resistance of soil

The strength of the soil was measured by a cone penetrometer (Davidson, 1965) at regular intervals during crop growth period.

3.6.5 Porosity

Porosity was calculated by using the formula.

$$\text{Porosity} = \left[1 - \frac{BD}{PD}\right] x 100$$

Where,

BD = Bulk density of soil (Mg m^{-3})

PD = Particle density (Mg m^{-3})

3.6.6 Hydraulic conductivity

Undisturbed soil samples collected in cylindrical core samples at different stages from 0-15, 15-30 and 30-45 cm depths were used for the determination of hydraulic conductivity in the laboratory using constant water head device as per the procedure outlined by Jalota *et al.* (1998). The following equation was used for the determination of saturated hydraulic conductivity.

$$\text{Saturated hydralic conductivity (K)} = \frac{QL}{HAT}$$

Where,

K = Saturated hydraulic conductivity (cm hr^{-1})

Q = Quantity of water collected (cm^3)

L = Length of the soil column used (cm)

H = Hydraulic head of water used (cm)

A = Cross sectional area of the sample (cm^2)

T = Time taken for collection of water (hr)

3.6.7 Infiltration rate

Infiltration rate was determined after harvest of rice (before tillage practices were imposed), at the time of sowing, 30 DAS, 60 DAS and after harvest of the crop with double ring infiltrometer following variable head method suggested by Bertrand (1965) and described by Jalota *et al.* (1998) and the infiltration rate was given as cm hr^{-1}.

3.6.8 Soil temperature

Soil temperature was recorded at different stages of crop growth period by employing thermister thermometer at 5 and 10 cm depths. Soil temperatures were determined one day before giving irrigation between 9.30 AM to 10.30 AM and expressed as °C.

3.6.9 Soil moisture content

Soil moisture content was estimated before and after giving irrigation following gravimetric method (Richards, 1959). The following formula was used in computing moisture content in percentage.

$$\text{Moisture content (\%)} = \frac{\text{Wet weight of the soil - Over dry weight of the soil}}{\text{Over dry weight of the soil}} \times 100$$

3.6.10 Soil moisture potential

Soil moisture potential at certain crop growing periods was computed from the soil moisture characteristic curves by interpreting respective soil moisture contents.

3.7 SEEDLING EMERGENCE PERCENTAGE

Seedling emergence percentage was calculated by using the following formula:

$$\text{Per cent seedling emergence} = \frac{\text{number of seedling present in plot}}{\text{number of hills sown in plot}} \times 100$$

3.8 RELATION BETWEEN SEEDLING EMERGENCE PERCENTAGE AND TILLAGE INDUCED SOIL PHYSICAL PROPERTIES AT SOWING

Seedling emergence percentage (dependent variable) was assumed as a function of various tillage induced soil physical properties (independent variables) and the following multiple straight line model (step down) was established by least square technique (Gomez and Gomez, 1984).

$$Y = a + b_1x_1 + b_2x_2 + b_3x_3 + \ldots + b_ix_i$$

Where,

Y = Seedling emergence percentage

a = Y-axis intercept

b = Regression co-efficient

x = Tillage induced soil physical properties [mean weight diameter of dry clods (mm)/ bulk density (Mg m^{-3})/ penetration resistance (kg cm^{-2})/ soil temperature (°C)/ soil moisture tension (bars)]

3.9 PLANT GROWTH PARAMETERS

Five representative plants in each net plot were randomly selected and labelled. All biometric observations except drymatter and leaf area were recorded periodically on the selected plants.

3.9.1 Plant height

Plant height (cm) was measured from the base of the plant to the terminal bud of the main shoot on the five labelled plants in each plot.

3.9.2 Leaf area index

Five plants were harvested from the area earmarked for destructive sampling (second row) in each plot for leaf area determination. Leaf area was measured by using leaf area meter (model LI-COR, Lincoln, Nebraska, USA) and was expressed as leaf area index (LAI) using the formula suggested by Watson (1952).

$$LAI = \frac{\text{Total leaf area } (m^2) \text{ of the crop}}{\text{Land area } (m^2) \text{ under the crop}}$$

3.9.3 Drymatter accumulation

The five plants harvested for leaf area determination were utilized for estimating the drymatter accumulation. The roots were clipped off from each selected plant, the shoot portion was cleaned, transferred to properly labelled brown paper bags and then partially dried in the sun. Later they were dried in oven at

65±2°C till constant weight was obtained and expressed as drymatter accumulation per hectare.

3.9.4 Root characteristics

The same five plants harvested for leaf area and drymatter determination were utilized for estimating root characters. The plants were carefully pulled out with roots with the help of crowbar and the root portion was clipped off carefully. The detached root portion was washed in water. Later girth of the root was estimated by measuring with thin flexible scale and expressed in cm. Then roots were dried in oven at 65±2°C till constant weight and expressed as root drymatter.

3.10 YIELD ATTRIBUTES AND YIELD

The five plants labelled for recording growth observations were also used for generating the data on the following yield attributes in sunflower.

3.10.1 Head diameter

Head diameter (cm) from labelled plants in each treatment was measured and average diameter was calculated.

3.10.2 Test (1000 seed) weight

A sample of thousand seeds were randomly collected treatment wise from each net plot produce, weighed and expressed as test (1000 seed) weight (g).

3.10.3 Seed and total drymatter yield

The plants in each net plot were harvested. the heads were separated, dried, threshed, winnowed and cleaned. The seed yield thus obtained was weighed at 10% moisture content and expressed as q ha^{-1}.

Similarly, the total above ground portion drymatter (seed + stalk + bhusa) was also weighed and expressed in kg ha^{-1}.

3.10.4 Harvest index

Harvest index was computed by dividing economic yield with total drymatter and expressed in percentage. It was calculated as follows.

$$\text{H.I (\%)} = \frac{\text{Seed yield (kg ha}^{-1})}{\text{Total drymatter (kg ha}^{-1})} \times 100$$

3.10.5 Oil content

Oil content (per cent) of sunflower seeds was estimated by Nuclear Magnetic Resonance (NMR) analyser (Jambunathan *et al.*, 1985).

3.10.6 Oil Yield

Oil yield was calculated by using the formula:

$$\text{Oil yield (kg ha}^{-1}) = \frac{\text{Oil content (\%) x seed yield (kg ha}^{-1})}{100}$$

3.11 RELATION BETWEEN SEED YIELD AND TILLAGE INDUCED SOIL PHYSICAL PROPERTIES

Seed yield (dependent variable) was assumed as a function of various tillage induced soil physical properties (independent variable) and the following straight line model was established by least square technique (Gomez and Gomez, 1984).

$$Y = a + b_1x_1 + b_2x_2 + ... + b_ix_i$$

Where,

Y = Seed yield q ha^{-1}

a = Y-axis intercept

b = Regression co-efficient

x = tillage induced soil physical properties [MWD (mm), Bulk density (Mg m^{-3}), penetration resistance (kg cm^{-2}), soil temperature(°C) and soil moisture tension (bars)]

3.12 PLANT ANALYSIS FOR NUTRIENT CONTENT AND UPTAKE

Plant samples collected at 30 DAS, 60 DAS and at harvest were analysed for their nitrogen, phosphorus and potassium contents. Nutrient content at harvest was estimated separately in haulms and seeds. Total uptake of nutrients were computed by multiplying the per cent nutrient content with drymatter produced.

3.12.1 Nitrogen content

Nitrogen content in the plant samples (%) was determined by the Micro-kjeldhal method (AOAC, 1970).

3.12.2 Phosphorus content

Plant samples were digested using triacid in 9:2:1 ratio. The triacid extract was used in phosphorus estimation using Vanado-molybdo phosphoric yellow colour method (Jackson, 1973).

3.12.3 Potassium content

Potassium content (%) in triacid extract was determined using flame photometer (Muhr *et al.*, 1963).

3.12.4 Nutrient uptake

Nutrient uptake was calculated using following formula:

$$\text{Nutrient uptake (kg ha}^{-1}\text{)} = \frac{\text{Nutrient content (\%) x Drymatter yield (kg ha}^{-1}\text{)}}{100}$$

3.13 WATER USE STUDIES

3.13.1 Crop evapotranspiration

For estimation of crop evapotranspiration (ETa), the crop period was divided into number of irrigation cycles. The first irrigation cycle begun with the date of sowing and ended with the day prior to the first application of water or occurrence of rainfall; second water period started on the next day and ended with a

day prior to rewetting and so on. The soil moisture was measured gravimetrically in each 15 cm soil layer upto 45 cm effective root zone depth. The relationship used for estimation of crop ETa was as follows (Michael *et al.*, 1977).

$$\text{Crop ETa} = \sum_{n=1}^{i=n} \frac{M_1 i - M_2 i}{10} \times \text{pbi} \times \text{Di}$$

In which,

ETa = crop evapotranspiration (mm) from the effective root zone depth within an irrigation cycle.

n = number of soil layers sampled in the root zone depth.

M_{1i} = Mass water percentage 24 hr after n^{th} irrigation in the i^{th} layer, cm

M_{2i} = Mass water percentage just before n^{th} irrigation in the i^{th} layer

pbi = Bulk density of the soil in the i^{th} layer, cm

Σ = Summation

i = Integer representing soil layer.

3.13.2 Seasonal evapotranspiration of crop under each irrigation treatment

Seasonal evapotranspiration of crop under each irrigation treatment was determined by summing up the ETa values of all the irrigation cycles in a given treatment.

3.13.3 Water use efficiency (WUE)

Water use efficiency (WUE) is the ratio of economic yield (seed) to the amount of water used by the crop in ETa.

$$\text{WUE (kg ha}^{-1}\text{ mm}^{-1}\text{)} = \frac{\text{Seed yield (kg ha}^{-1}\text{)}}{\text{Seasonal ETa (mm)}}$$

3.13.4 Evapotranspiration rate

The evapotranspiration rate was calculated by dividing the ETa of irrigation cycle by the number of days of the corresponding period and was expressed as mm day^{-1}.

3.13.5 Soil moisture extraction pattern

Soil moisture extraction pattern (SME) refers to the amount of soil moisture, expressed as percentage, extracted by the plant roots from each layer of the effective root zone depth (45 cm) during crop season. Thus, the seasonal crop ETa values obtained from each layer were expressed as a percentage of seasonal crop ETa from the entire root zone depth in a given treatment and the moisture extraction curves were constructed. The summation of soil moisture extraction in all the soil layers in the effective root zone depth gives the total extraction (100%) as given below.

$$SME_t = SME_1 + SME_2 + SME_3$$

Where,

SME_t = Soil moisture extraction from 0-45 cm

SME_1 = Soil moisture extraction from 0-15 cm

SME_2 = Soil moisture extraction from 15-30 cm

SME_3 = Soil moisture extraction from 30-45 cm.

3.14 YIELD-WATER RELATION

The response of sunflower crop in terms of seed yield to water use (ETa) was ascertained by fitting the following two functions viz., linear and quadratic.

$$Y = a + b\ ETa \quad \ldots\ \text{linear}$$

Where,

Y = Seed yield (kg ha^{-1})

ETa = Seasonal crop evapotraspiration (mm)

a = Y-axis intercept

b = linear regression co-efficients.

3.15 MEASUREMENT OF PLANT WATER STRESS

Plant water stress was measured one day before irrigation between 1300-1500 hr at regular intervals of crop growth period.

3.15.1 Relative Water Content (RWC)

Relative water content (RWC) is the actual water content of the plant when sampled relative to that at turgidity expressed as percentage (Turner, 1981). It was determined by the following relationship.

$$\text{RWC (\%)} = \frac{FW - DW}{TW - DW} \times 100$$

Where,

FW = Fresh weight of the sample
DW = Oven dry weight of the sample
TW = Turgid weight of the sample

3.15.2 Leaf water potential

Leaf water potential was estimated one day before irrigation between 1300 to 1500 hr at regular intervals of crop growth. It was estimated by using pressure chamber apparatus suggested by Scholander *et al.* (1965). Leaf water potential indicates the energy status of water in the plant cells.

3.15.3 Diffusive resistance, transpiration rate and leaf temperature

The diffusive resistance (Sm^{-1}), transpiration rate ($\mu g\ H_2O\ cm^{-2}\ sec^{-1}$) and leaf temperature (°C) was measured by Steady State porometer (Model, LI-1600) one day before irrigation in each treatment between 10.30 to 11.00 hr at crop growth periods.

3.16 STATISTICAL ANALYSIS

The data was subjected to the statistical analysis with strip plot design as suggested by Panse and Sukhatme (1978) and necessary conclusions were drawn.

RESULTS

CHAPTER IV

RESULTS

Effect of tillage induced soil physical properties and soil moisture regimes on the performance of sunflower in rice-based cropping system was studied at Agricultural College Farm, Rajendranagar, through field experiments during late *rabi* 1997-98 and 1998-99. Tillage induced changes in soil were studied in terms of dry clod size distribution, depth of ploughing, bulk density, porosity, infiltration, hydraulic conductivity and penetration resistance. The effect of these soil physical properties and soil moisture regimes on sunflower were studied in terms of seedling emergence, plant height, root growth, leaf area index, dry matter accumulation and NPK content and uptake at different crop growth stages. Effects of these induced soil changes on head size, 1000 seed weight and seed yield, oil content and oil yield were also studied. The results obtained from the study are presented in this chapter.

4.1 EFFECT OF TILLAGE TREATMENTS AND SOIL MOISTURE REGIMES ON SOIL PHYSICAL PROPERTIES

4.1.1 Clod size distribution and mean weight diameter (MWD) of clods at sowing

The data are presented in Table 5 and depicted in Fig. 4.

The data clearly indicated the influence of tillage on clod size distribution and mean weight diameter (MWD). The soil was hard and compact in T_1 (zero tillage treatment) and hence clod size distribution was not studied. In T_5 treatment (secondary tillage with rotavator in addition to primary deep tillage with disc

Table 5 : Effect of tillage treatments on clod size distribution and mean weight diameter (MWD) and depth of tillage at the time of sowing

Tillage treatments	Clod size (mm, diameter) per cent							Mean weight diameter (MWD) (mm)	Mean depth of tillage (cm)
	> 100	50-100	20-50	10-20	5-10	2-5	< 2		
				1997-98					
T_1	-	-	-	-	-	-	-	-	-
T_2	11.30	20.92	22.17	14.32	10.46	9.20	11.62	38.29	11.07
T_3	3.35	13.01	16.36	19.56	16.73	14.13	16.87	23.84	11.00
T_4	12.21	18.11	21.40	16.50	8.46	11.90	11.35	37.05	21.17
T_5	Nil	12.50	17.39	19.74	15.22	17.39	17.76	20.51	21.63
				1998-99					
T_1	-	-	-	-	-	-	-	-	-
T_2	13.39	16.07	18.75	14.29	10.71	13.18	13.61	35.69	10.93
T_3	Nil	12.97	18.41	21.17	16.57	14.64	16.23	21.42	11.37
T_4	12.86	14.86	17.71	16.57	12.00	12.57	13.43	34.29	20.67
T_5	Nil	12.16	16.37	22.34	14.17	16.42	18.54	20.39	21.40

T_1 : Zero tillage
T_2 : Country plough twice + bullock drawn cultivar twice
T_3 : Country plough twice + power tiller rotavator twice
T_4 : Mould board plough once + cultivator twice, both tractor drawn
T_5 : Disc plugh once + rotavator twice, both tractor drawn

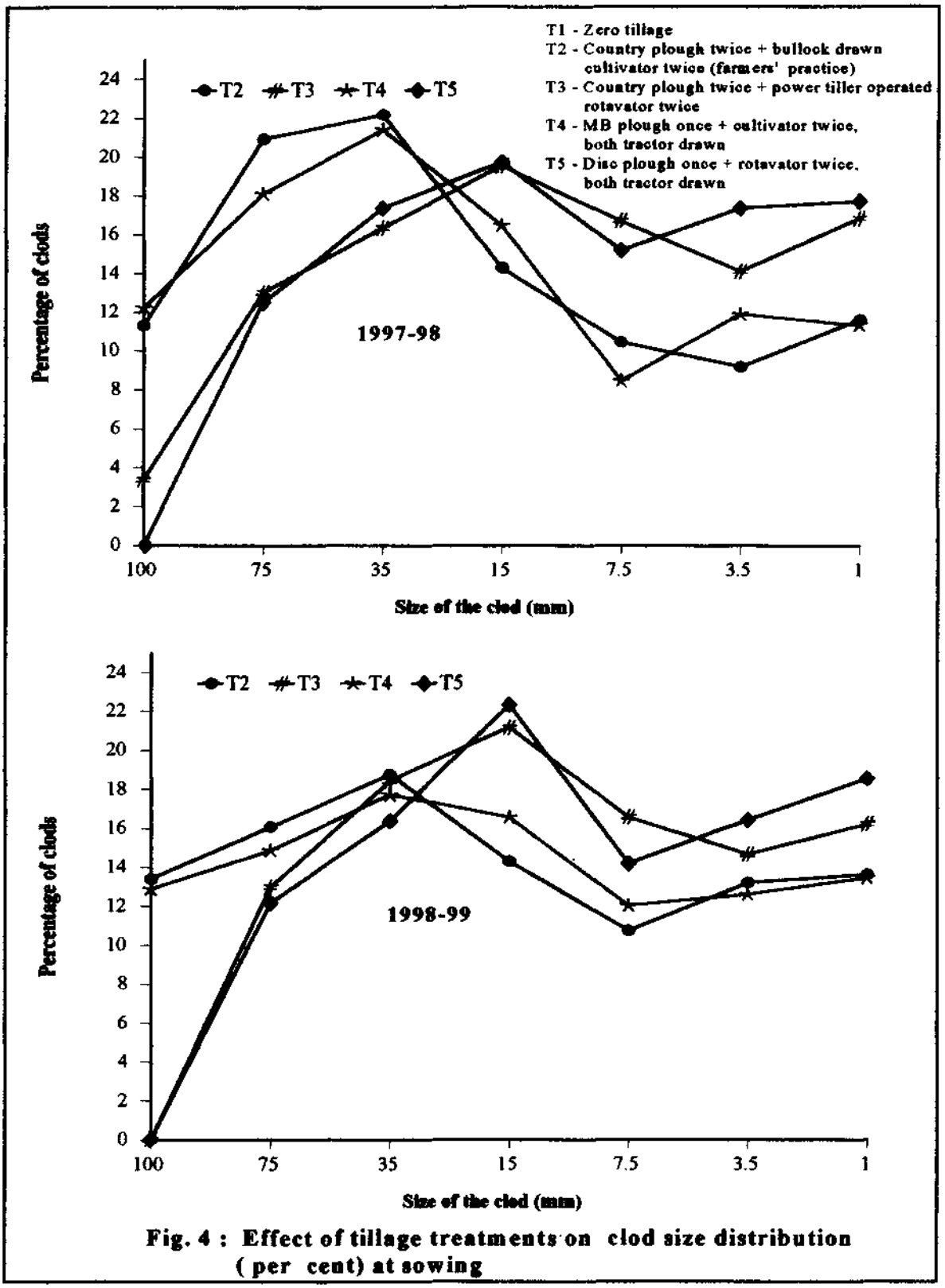


Fig. 4 : Effect of tillage treatments on clod size distribution (per cent) at sowing

a

b

2 T_1 (zero tillage)

(a) surface conditions of soil at sowing

(b) Crop at 30 DAS

a

b

3 T_2 (ploughing twice with country plough + twice with cultivator)

(a) surface condition of soil at sowing

(b) Crop at 30 DAS

a

b

4 T_3 (ploughing twice with country plough + twice with rotavator)

(a) Surface condition of soil at sowing

(b) Crop at 30 DAS

a

b

5 T_4 (ploughing twice with tractor drawn MB plough + twice with cultivator

(a) Surface condition of soil at sowing

(b) Crop at 45 DAS

a

b

6 T_5 (ploughing twice with tractor drawn disc plough + twice with rotavator)

(a) Surface condition of soil at sowing

(b) Crop at 30 DAS

plough and T_3 (secondary tillage with power tiller rotavator and primary shallow tillage with country plough) resulted in higher percentage of smaller aggregates (< 20 mm) and less percentage of larger aggregates (> 20 mm) in both the years of study. Other tillage treatments T_4 (mould board ploughing once + cultivator twice, both tractor drawn) and T_2 (country plough twice + bullock drawn cultivator twice) resulted in relatively more larger size clods (> 20 mm) and less of smaller size clods (< 20 mm). The mean weight diameter (MWD) of clods during first year of the study was lower (20.51 mm) in case of T_5 (secondary tillage with rotavator of primary tillage with tractor drawn disc plough) followed by T_3 (Secondary tillage with rotavator of primary tillage with country plough, 23.84 mm). Tillage was not that effective in T_2 and T_4 (secondary tillage with cultivator) as indicated by their mean weight diameter. The trend of variation was similar in both the years of study.

4.1.2 Mean weight diameter (MWD) of clods at 30 and 60 DAS of crop

The data on mean weight diameter (MWD) of dry soil clods at 30 and 60 DAS of crop are presented in Table 6 and depicted in Fig.5.

The data indicated that the mean MWD of clods in T_5 (14.72 mm and 10.95 mm at 30 and 60 DAS, respectively, in first year; and 12.78 mm and 8.71 mm at 30 and 60 DAS, respectively, in second year) and T_3 (15.40 mm and 12.46 mm at 30 mm and 60 DAS, respectively, in first year; and 13.43 mm and 9.72 mm at 30 and 60 DAS, respectively, in second year) was very much less compared to T_2 (25.55 mm and 17.48 mm at 30 and 60 DAS, respectively, in first year; and 22.03 mm and 15.57 mm at 30 and 60 DAS, respectively, in second year) and T_4 (22.87 mm and 15.80 mm at 30 and 60

Table 6: Effect of tillage treatments and soil moisture regimes on mean weight diameter (MWD) of dry clods in soil at 30 and 60 DAS

Tillage (T)	Mean weight diameter (mm)									
	30 DAS					60 DAS				
	Soil moisture regimes					Soil moisture regimes				
	M_1	M_2	M_3	M_4	Mean	M_1	M_2	M_3	M_4	Mean
					1997-98					
T_1	-	-	-	-	-	-	-	-	-	-
T_2	26.98	26.64	25.06	23.51	25.55	20.04	18.72	16.00	15.17	17.48
T_3	16.49	16.51	15.00	13.62	15.40	14.62	12.92	12.56	9.73	12.46
T_4	25.26	23.08	22.20	20.93	22.87	18.07	16.68	14.29	14.16	15.80
T_5	15.68	15.68	13.93	13.59	14.72	12.90	11.61	10.26	9.04	10.95
Mean	21.10	20.48	19.05	17.91		16.41	14.98	13.28	12.02	
					1998-99					
T_1	-	-	-	-	-	-	-	-	-	-
T_2	25.12	22.12	21.39	19.49	22.03	18.22	16.20	14.28	13.60	15.57
T_3	16.07	13.65	12.39	11.66	13.44	12.19	10.33	8.35	8.03	9.72
T_4	24.03	22.65	19.07	16.79	20.63	16.87	13.96	11.52	11.36	13.43
T_5	15.79	13.05	11.62	10.67	12.78	10.18	8.72	8.01	7.94	8.71
Mean	20.25	17.86	16.12	14.65		14.36	12.30	10.56	10.23	

T_1 : Zero tillage
T_2 : Country plough twice + bullock drawn cultivar twice
T_3 : Country plough twice + power tiller rotavator twice
T_4 : Mould board plough once + cultivator twice, both tractor darwn
T_5 : Disc plugh once + rotavator twice, both tractor darwn

M_1 : IW/CPE = 0.6
M_2 : IW/CPE = 0.8
M_3 : IW/CPE = 1.0
M_4 : IW/CPE = 1.2

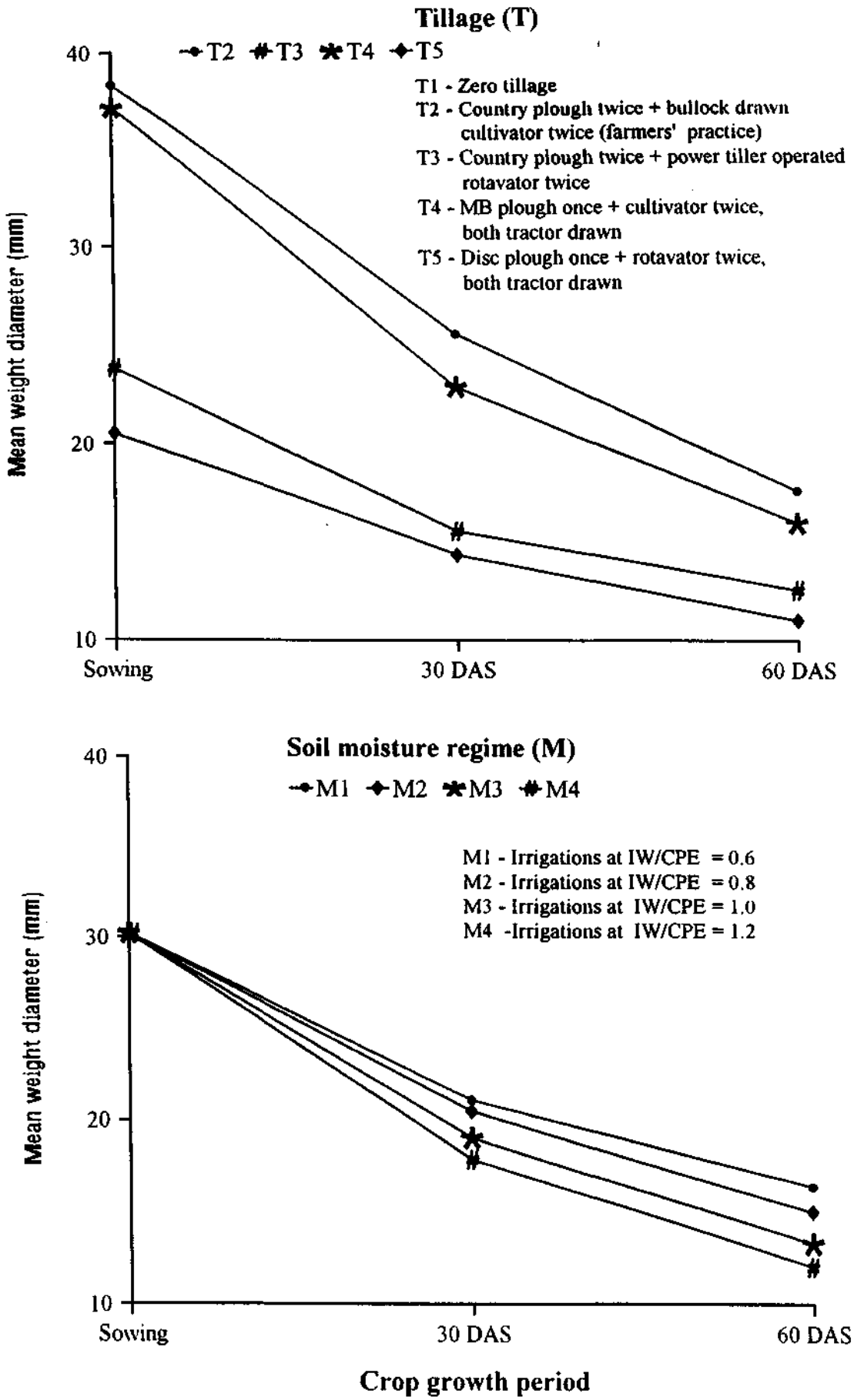


Fig. 5: Effect of tillage treatments and soil moisture regimes on mean weight diameter (MWD) of dry clods in soil, 1997-98

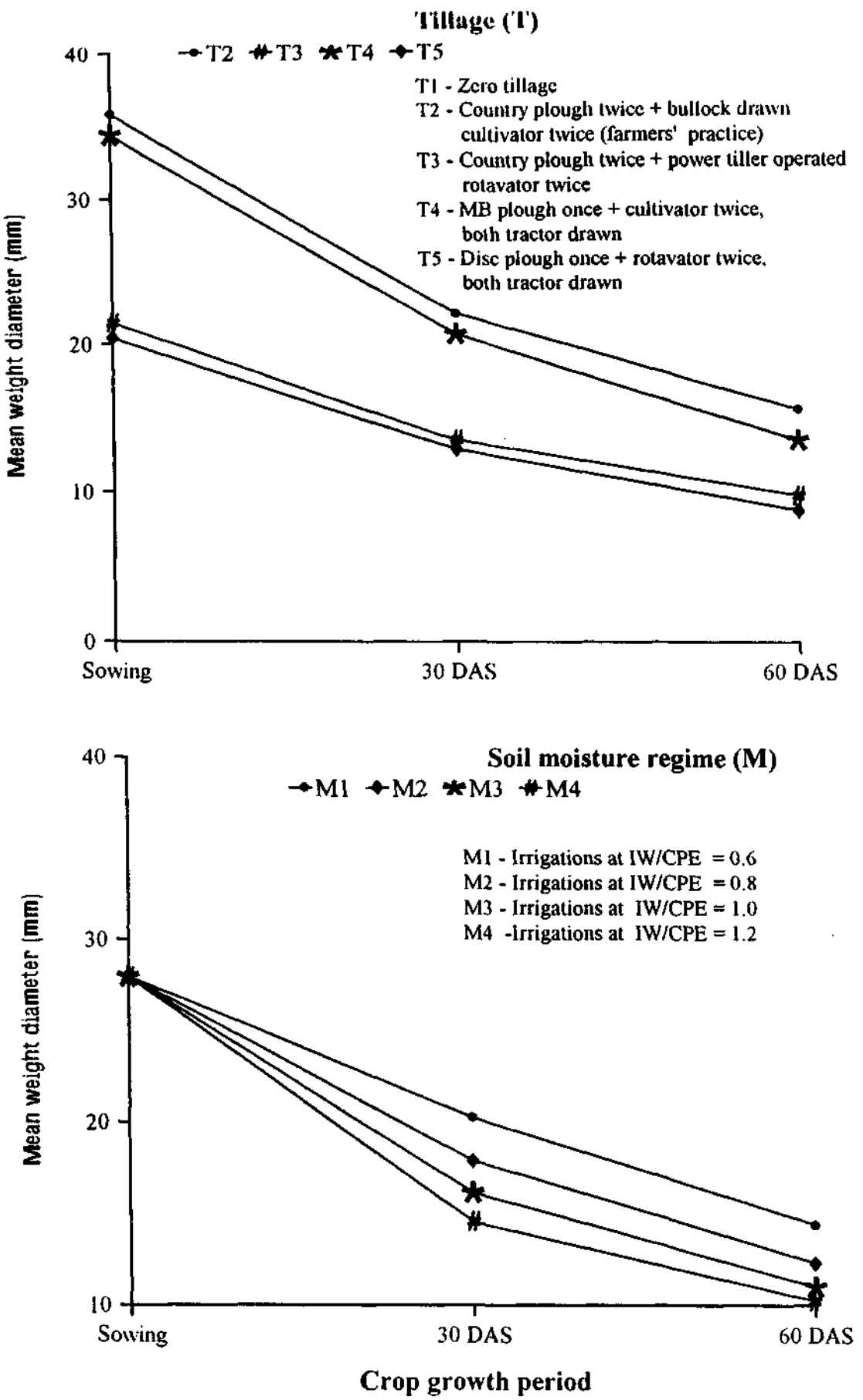


Fig. 6 : Effect of tillage treatments and soil moisture regimes on mean weight diameter (MWD) of dry clods in soil, 1998-99

DAS, respectively, in first year; 20.63 mm and 13.43 mm at 30 and 60 DAS, respectively, in second year) in both years of study. It was lowest in case of T_5 followed by T_3. Highest MWD was recorded in T_2 followed by T_4.

In general, the MWD of clods decreased from sowing time to 30 DAS and 60 DAS (Figs. 5). In all the tillage treatments the values of MWD at 60 DAS were nearly half of those at sowing time.

MWD was also affected by soil moisture regimes. MWD was highest (21.10 mm and 16.41 mm at 30 and 60 DAS, respectively, in 1997-98; 20.25 mm and 14.36 mm at 30 and 60 DAS, respectively, in 1998-99) in the treatment receiving irrigations at M_1 (IW/CPE 0.6) followed by M_2 (IW/CPE of 0.8), M_3 (IW/CPE = 1.0) and M_4 (IW/CPE = 1.2). Lowest MWD of clods was observed with M_4 (IW/CPE = 1.2) soil moisture regime (17.91 mm and 12.02 mm at 30 and 60 DAS, respectively, in 1997-98; 14.65 mm and 10.23 mm at 30 and 60 DAS, respectively in 1998-99).

The data also indicate that the decrease in MWD of clods was more with the increase in intensity of irrigations from M_1 to M_4. In case of T_2 and T_4, bigger size clods were produced due to tillage and the decrease was less in case of T_3 and T_5, where smaller clods were produced due to tillage. The same trend was noticed both at 30 and 60 DAS in both the years of study.

4.1.3 Effect of tillage treatments on depth of tillage

The data on depth of tillage are presented in Table 5. Tillage influenced the depth of tilth in both years.

The mean depth of tillage was highest (21.63 cm and 21.40 cm in 1997-98 and 1998-99, respectively) under T_5 treatments, (where tillage was done with tractor drawn disc plough + tractor drawn rotavator), closely followed T_4 (mould board plough once + cultivator twice, both tractor drawn (21.17 cm and 20.67 cm in 1997-98 and 1988-99, respectively)). The depth of tilth in both these treatments were much higher than the in the other two tillage treatments viz. Country plough twice + power tiller operated rotavator twice (11.0 cm in 1997-98 and 11.37 cm in 1998-99); and country plough twice + bullock drawn cultivator twice (11.07 cm in 1997-98 and 10.93 cm in 1998-99).

4.1.4 Bulk density

The data recorded on soil bulk density, measured at sowing, 30 and 60 DAS and at harvest of crop, in the three depths of soil i.e. 0-15, 15-30 and 30-45 cm, are presented in Table 7 and illustrated in Figs.7 and 8.

Tillage treatments significantly influenced the bulk density at 0-15 and 15-30 cm depths at sowing, and at all stages of observations in both the years. However, none of the tillage treatments could influence the bulk density at 30-45 cm depth.

Lowest mean bulk density was observed (1.29 and 1.35 Mg m^{-3}) at 0-15 and 15-30 cm respectively at sowing in first year) in T_5 (disc plough once + rotavator twice, both tractor drawn), followed by T_4 (MB plough once + cultivator twice, both tractor drawn) at all stages of crop growth. However, BD was at par in both these treatments. Highest bulk density was obtained in T_1 (zero tillage) treatment (1.45 and 1.54 Mg m^{-3} at 0-15 and 15-30 cm, respectively,

Table 7 : Effect of tillage treatments on soil bulk density at 0-15, 15-30 and 30-45 cm during crop growth period

	Bulk density (Mg m^{-3})							
	1997-'98				1998-'99			
	Crop growth period				Crop growth period			
	Sowing	30 DAS	60 DAS	Harvest	Sowing	30 DAS	60 DAS	Harvest
	0-15 cm							
Tillage (T)								
T_1	1.45	1.45	1.46	1.47	1.49	1.50	1.49	1.52
T_2	1.34	1.37	1.40	1.41	1.37	1.41	1.44	1.46
T_3	1.32	1.36	1.38	1.39	1.33	1.35	1.42	1.46
T_4	1.30	1.36	1.35	1.38	1.27	1.35	1.39	1.43
T_5	1.29	1.32	1.34	1.37	1.25	1.33	1.38	1.42
SEm±	0.014	0.020	0.011	0.007	0.018	0.017	0.012	0.011
CD(P=0.05)	0.032	0.047	0.032	0.018	0.042	0.040	0.031	0.025
	15-30 cm							
T_1	1.54	1.53	1.53	1.56	1.52	1.55	1.57	1.59
T_2	1.56	1.55	1.54	1.57	1.54	1.57	1.58	1.60
T_3	1.57	1.55	1.54	1.57	1.52	1.55	1.58	1.60
T_4	1.35	1.44	1.47	1.50	1.37	1.42	1.46	1.50
T_5	1.35	1.44	1.44	1.48	1.32	1.42	1.46	1.50
SEm±	0.007	0.026	0.020	0.026	0.015	0.012	0.018	0.012
CD(P=0.05)	0.019	0.060	0.046	0.060	0.035	0.028	0.041	0.028
	30-45 cm							
T_1	1.60	1.60	1.59	1.61	1.60	1.61	1.61	1.63
T_2	1.61	1.60	1.60	1.61	1.60	1.61	1.61	1.63
T_3	1.61	1.61	1.60	1.61	1.59	1.61	1.61	1.62
T_4	1.60	1.61	1.61	1.61	1.61	1.62	1.62	1.64
T_5	1.61	1.61	1.61	1.62	1.61	1.62	1.63	1.63
SEm±	0.008	0.006	0.018	0.017	0.012	0.010	0.011	0.010
CD(P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS

T_1 : Zero tillage
T_2 : Country plough twice + bullock drawn cultivar twice
T_3 : Country plough twice + power tiller rotavator twice
T_4 : Mould board plough once + cultivator twice, both tractor darwn
T_5 : Disc plough once + rotavator twice, both tractor darwn

T1 - Zero tillage
T2 - Country plough twice + bullock drawn cultivator twice (farmers' practice)
T3 - Country plough twice + power tiller operated rotavator twice
T4 - MB plough once + cultivator twice, both tractor drawn
T5 - Disc plough once + rotavator twice, both tractor drawn

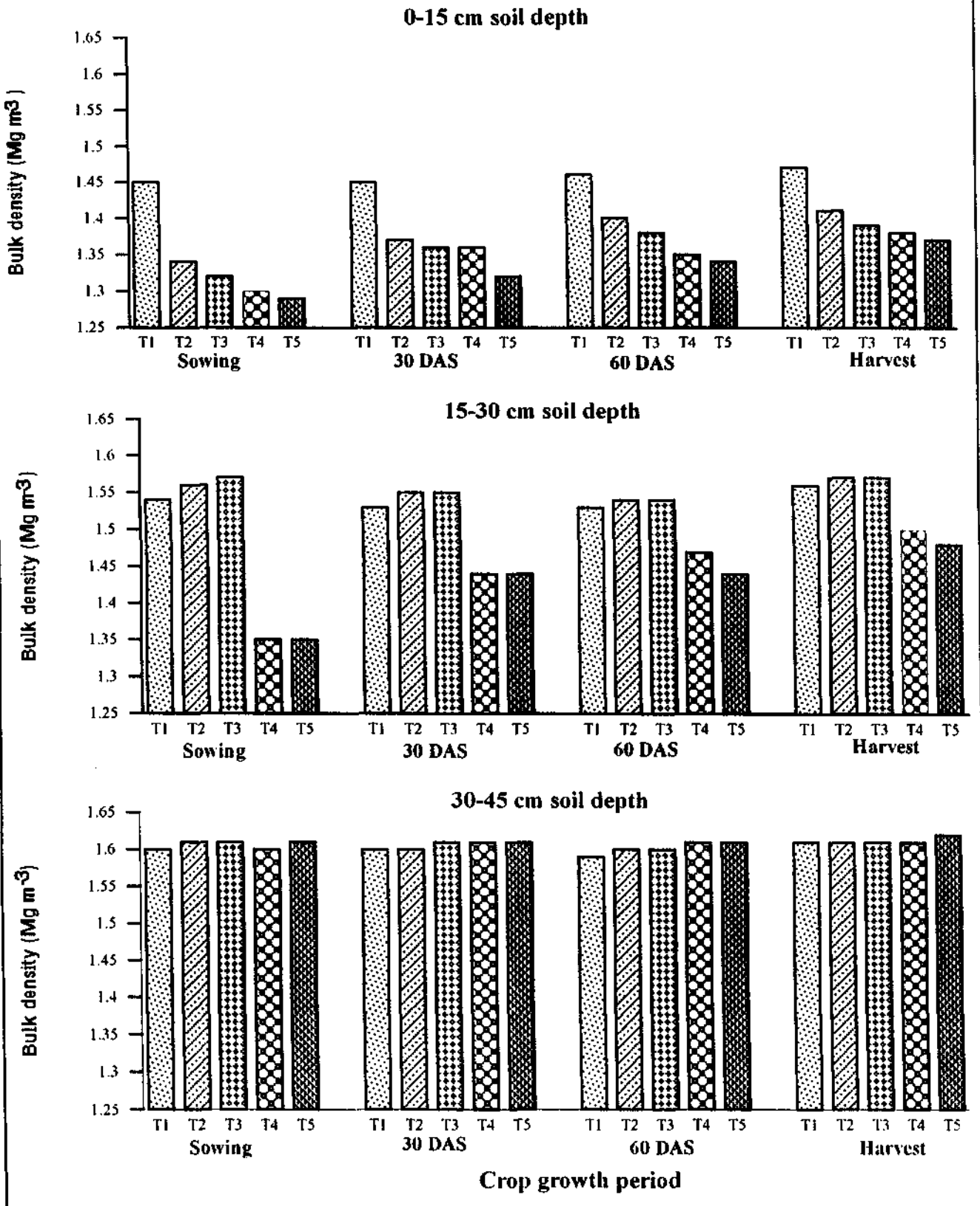


Fig. 7: Effect of tillage treatments on soil bulk density at different depths during crop growth period, 1997-98

T1 - Zero tillage
T2 - Country plough twice + bullock drawn cultivator twice (farmers' practice)
T3 - Country plough twice + power tiller operated rotavator twice
T4 - MB plough once + cultivator twice, both tractor drawn
T5 - Disc plough once + rotavator twice, both tractor drawn

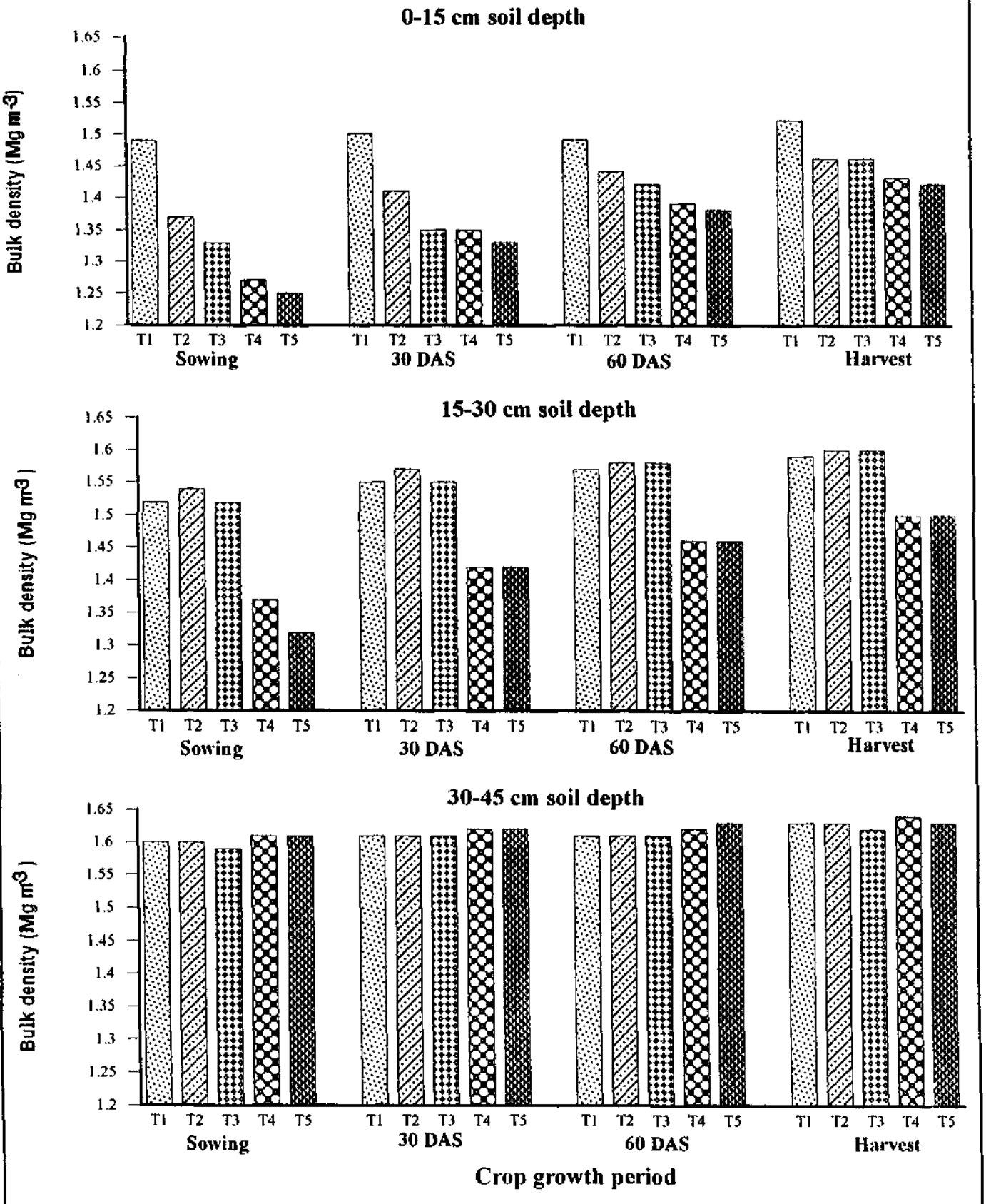


Fig. 8 : Effect of tillage treatments on soil bulk density at different depths during crop growth period, 1998-99

at sowing in first year), which was significantly higher compared to all other tillage treatments, and was followed by T_2 (country plough twice + cultivator twice) and T_3 (country plough twice + power tiller operated rotavator twice). Similar trend was observed at all the stages of crop growth in both the years of study.

However, mean bulk density at 15-30 cm soil depth was the lowest in T_5 closely followed T_4 which were statistically on par with each other, but was significantly lower than that of T_3, T_2 and T_1 treatments at all stages of observation.

The variations of bulk density due to interaction of soil moisture regimes with tillages were not significant at all times of sampling.

Critical observation of the data reveals that the bulk density of the soil in all the treatments increased with the increase in the age of crop.

4.1.5 Pore Space

The data on total pore space at different periods of crop growth as influenced by tillage practices are presented in Table 8 and illustrated in Figs. 9 and 10.

The data revealed that pore space was significantly influenced by only tillage. Soil moisture regimes and its interaction with tillage were not significant.

In the top soil layer (0-15 cm), T_5 (with tractor drawn disc plough and tractor drawn rotavator twice) resulted in maximum porosity (51.6 and 53.0 per cent in first and second years, respectively, at sowing); which is significantly

Table 8 : Effect of tillage treatments on total pore space of soil at 0-15, 15-30 and 30-45 cm oil depths during crop growth period

	Total pore space (%)							
	1997-'98				1998-'99			
	Crop growth period				Crop growth period			
	Sowing	30 DAS	60 DAS	Harvest	Sowing	30 DAS	60 DAS	Harvest
				0-15 cm				
Tillage (T)								
T_1	45.2	45.2	44.7	44.6	43.8	43.3	43.6	42.5
T_2	49.3	48.4	47.3	46.9	48.3	46.6	45.8	44.9
T_3	49.9	48.7	47.9	47.5	49.1	49.9	46.5	45.0
T_4	49.8	48.8	48.7	47.2	51.1	48.0	47.4	45.4
T_5	51.6	50.1	49.4	48.4	53.0	49.8	48.4	46.1
SEm±	0.11	0.45	0.25	0.16	0.33	0.33	0.24	0.13
CD(P=0.05)	0.25	1.05	0.57	0.37	0.80	0.76	0.55	0.30
				15-30 cm				
T_1	41.1	42.2	42.3	40.1	42.4	41.3	40.8	40.0
T_2	40.5	41.5	41.7	40.8	41.9	40.8	40.4	39.9
T_3	41.0	41.4	41.9	40.7	42.4	41.3	40.3	39.6
T_4	48.4	45.7	44.6	43.4	48.5	46.3	45.0	43.2
T_5	49.0	45.6	45.7	44.1	50.1	46.5	45.0	43.8
SEm±	0.08	0.74	0.48	0.56	0.59	0.28	0.67	0.47
CD(P=0.05)	0.20	1.71	1.11	1.30	1.47	0.64	1.54	1.08
				30-45 cm				
T_1	39.7	39.6	39.8	39.1	39.5	39.3	39.3	38.4
T_2	39.1	39.1	39.5	39.3	39.3	39.1	39.2	38.2
T_3	39.2	39.4	39.5	39.2	39.8	38.9	39.1	38.4
T_4	39.5	39.4	39.4	39.1	39.1	38.8	39.0	38.5
T_5	39.3	39.3	39.0	38.7	39.0	38.7	38.5	38.4
SEm±	0.76	0.73	0.68	0.78	0.33	0.31	0.28	0.26
CD(P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS

T_1 : Zero tillage
T_2 : Country plough twice + bullock drawn cultivar twice
T_3 : Country plough twice + power tiller rotavator twice
T_4 : Mould board plough once + cultivator twice, both tractor darwn
T_5 : Disc plough once + rotavator twice, both tractor darwn

T1 - Zero tillage
T2 - Country plough twice + bullock drawn cultivator twice (farmers' practice)
T3 - Country plough twice + power tiller operated rotavator twice
T4 - MB plough once + cultivator twice, both tractor drawn
T5 - Disc plough once + rotavator twice, both tractor drawn

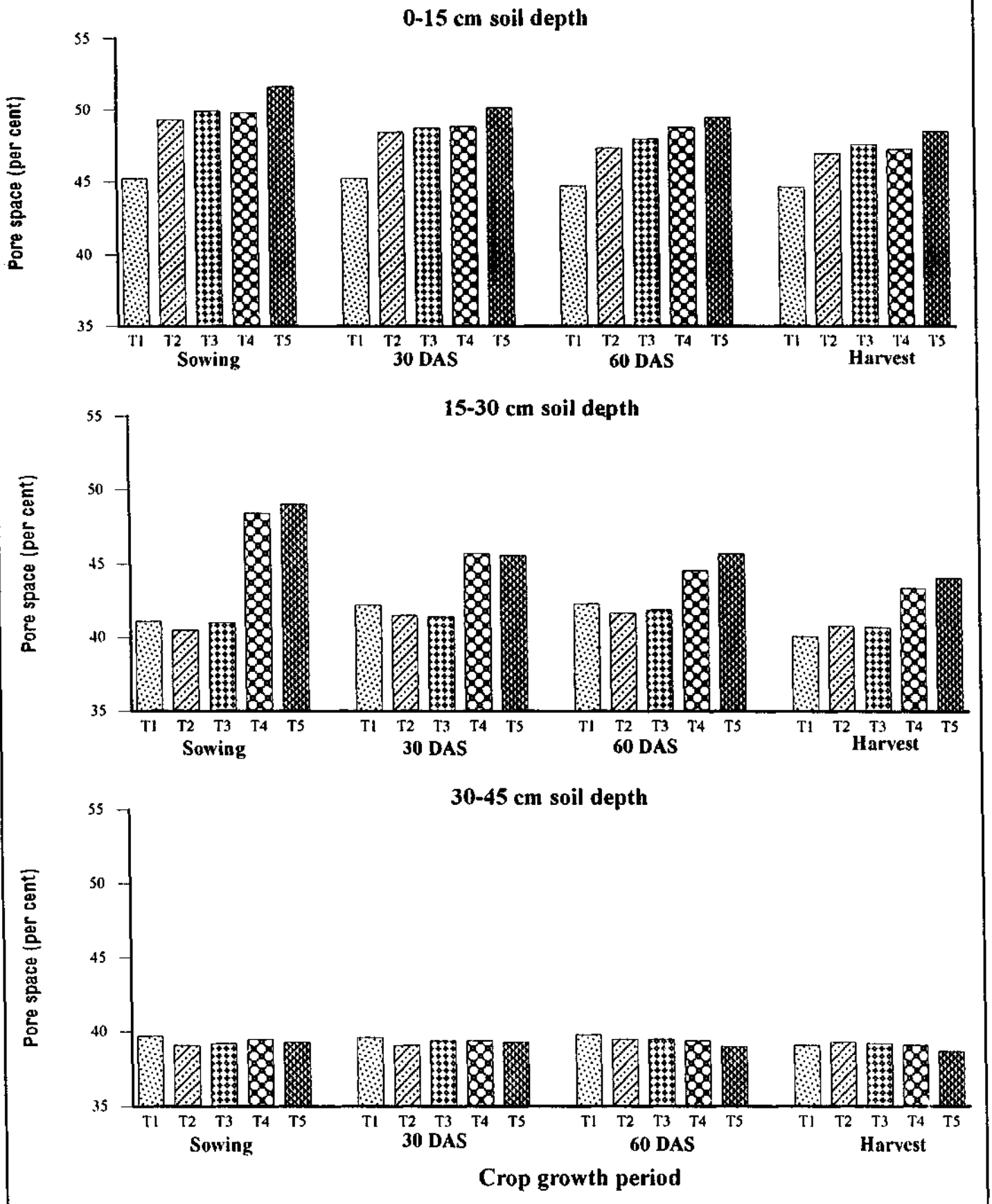


Fig.9 Effect of tillage treatments on total pore space of soil at different soils depths during crop growth period, 1997-98

T1 - Zero tillage
T2 - Country plough twice + bullock drawn cultivator twice (farmers' practice)
T3 - Country plough twice + power tiller operated rotavator twice
T4 - MB plough once + cultivator twice, both tractor drawn
T5 - Disc plough once + rotavator twice, both tractor drawn

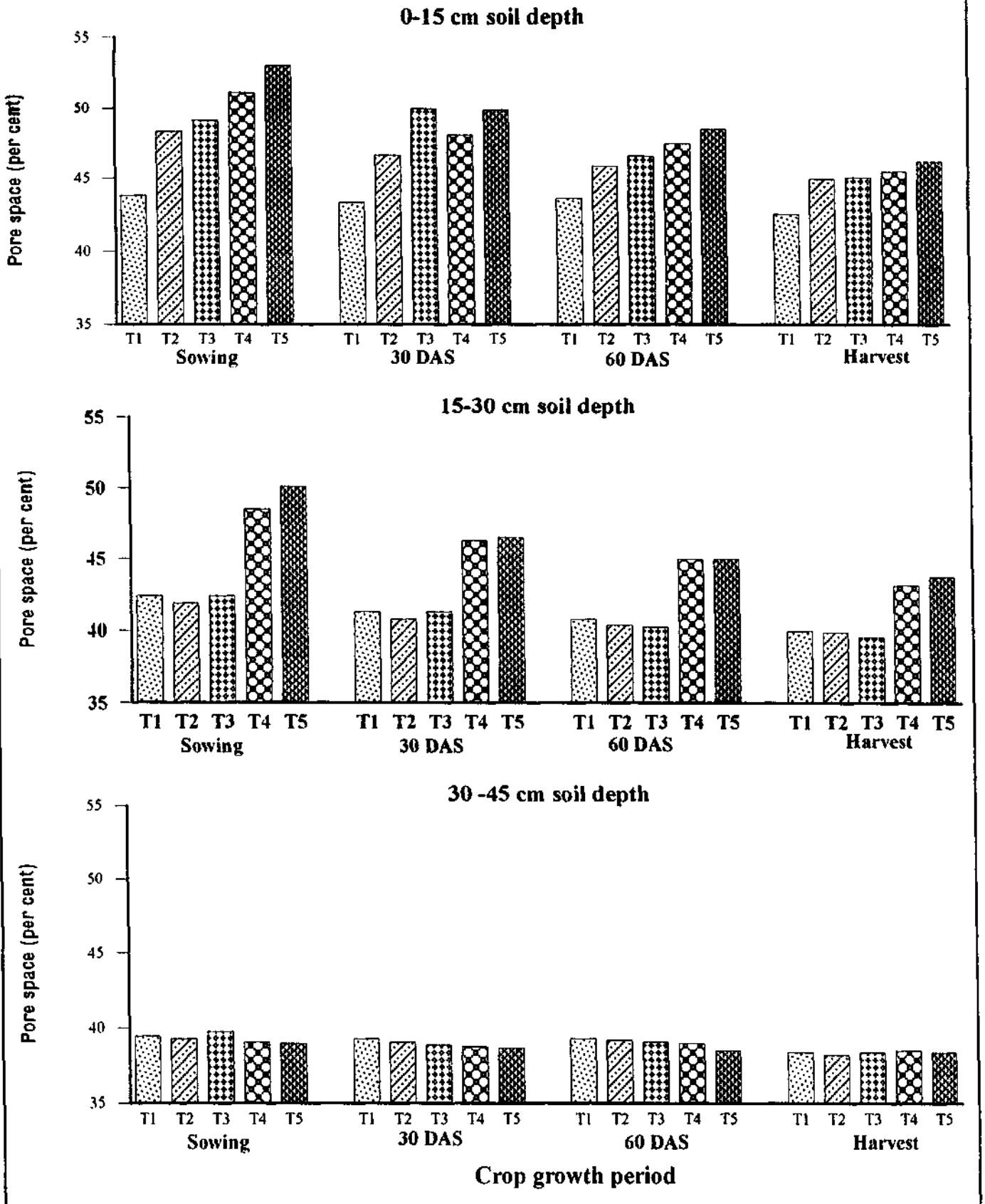


Fig. 10: Effect of tillage treatments on total pore space of soil at different soils depths during crop growth period, 1998-99

higher than that of T_4 (MB plough once + cultivator twice, both tractor drawn), T_3 (country plough once + power tiller operated rotavator twice), T_2 (country plough twice + bullock drawn cultivator twice) and T_1 (zero tillage) in the same order. Similar trend persisted throughout the crop growth period in both the years. Lowest pore space (45.2 and 43.8 % in first and second year, respectively, at sowing) was associated with T_1 (zero tillage) in 0-15 and 15-30 cm layers. Highest pore space was registered in T_5 (49.0 and 50.1 per cent in first and second years, respectively, at sowing), closely followed by T_4. T_5 and T_4 and were statistically at par with each other, and were significantly higher than that of T_3, T_2 and T_1. However, the difference in porosity at 15-30 cm layer in T_1 (zero tillage) and shallow tillage (T_2 & T_3) treatments were not significant. In the second soil layer (15-30 cm), pore space was not significantly altered with tillage treatments. The trends were similar in both the years of study.

Soil moisture regimes and their interaction with tillage were not significant in influencing the pore space at all times of observation.

Critical examination of the data reveals that the increase in pore space created by different tillage treatments gradually reduced by the time of crop harvest.

4.1.6 Infiltration rate

The data on final infiltration rate of soil measured at different stages of crop growth period are presented in Table 9 and depicted in Figs.11 and 12.

Infiltration rate of soil was significantly influenced by the tillage treatments all stages of observation. Infiltration rate was higher with (3.79, 3.38,

Table 9: Effect of tillage treatments and soil moisture regimes on infiltration rate of soil during crop growth period

	Infiltration rate (cm hr^{-1})							
	1997-'98				1998-'99			
	Crop growth period				Crop growth period			
	Sowing	30 DAS	60 DAS	Harvest	Sowing	30 DAS	60 DAS	Harvest
Tillage (T)								
T_1	1.05	1.13	1.14	1.18	1.34	1.79	1.51	1.25
T_2	2.22	2.02	2.06	1.90	2.40	2.39	2.31	2.00
T_3	2.32	2.16	2.12	1.90	2.90	2.60	2.41	2.12
T_4	3.70	3.25	2.67	2.49	4.12	3.37	3.02	2.81
T_5	3.79	3.38	2.74	2.51	4.25	3.48	3.14	2.90
SEm±	0.07	0.07	0.09	0.08	0.08	0.17	0.06	0.13
CD(P=0.05)	0.16	0.70	0.20	0.20	0.19	0.41	0.13	0.29
Soil moisture regime (M)								
M_1	2.62	2.56	2.32	2.11	2.98	2.90	2.61	2.30
M_2	2.62	2.41	2.18	2.00	2.99	2.69	2.56	2.28
M_3	2.60	2.30	2.10	1.95	3.02	2.67	2.40	2.20
M_4	2.60	2.28	1.98	1.92	3.02	2.64	2.33	2.07
SEm±	0.06	0.05	0.06	0.04	0.09	0.12	0.06	0.04
CD(P=0.05)	NS	0.13	0.14	0.10	NS	NS	0.14	0.13

T_1 : Zero tillage
T_2 : Country plough twice + bullock drawn cultivar twice
T_3 : Country plough twice + power tiller rotavator twice
T_4 : Mould board plough once + cultivator twice, both tractor darwn
T_5 : Disc plough once + rotavator twice, both tractor darwn

M_1 : IW/CPE = 0.6
M_2 : IW/CPE = 0.8
M_3 : IW/CPE = 1.0
M_4 : IW/CPE = 1.2

T1 - Zero tillage
T2 - Country plough twice + bullock drawn cultivator twice (farmers' practice)
T3 - Country plough twice + power tiller operated rotavator twice
T4 - MB plough once + cultivator twice, both tractor drawn
T5 - Disc plough once + rotavator twice, both tractor drawn

M1 - Irrigations at IW/CPE = 0.6
M2 - Irrigations at IW/CPE = 0.8
M3 - Irrigations at IW/CPE = 1.0
M4 -Irrigations at IW/CPE = 1.2

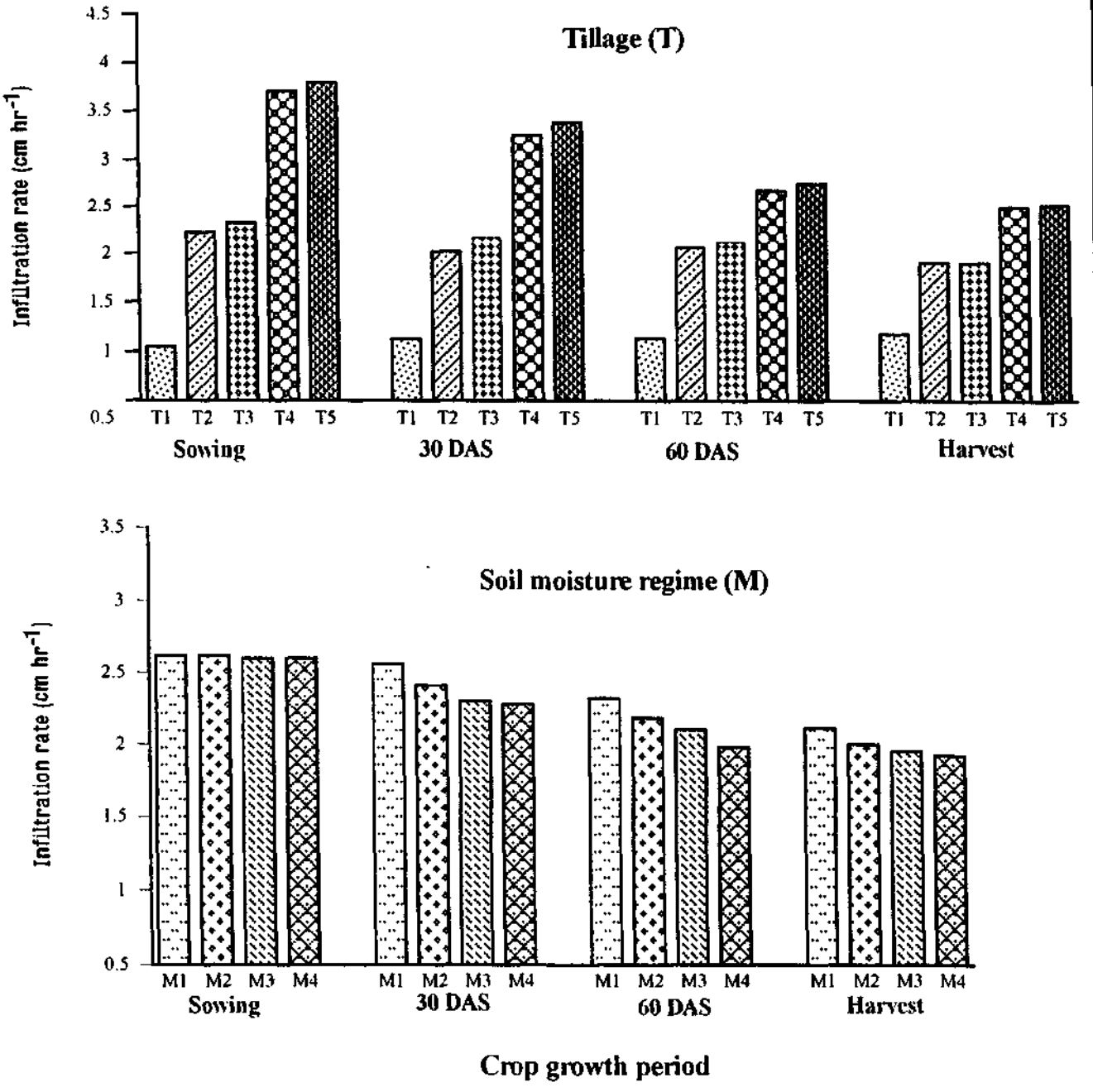


Fig.11 : Effect of tillage treatments and soil moisture regimes on infiltration rate of soil during crop growth period, 1997-98

T1 - Zero tillage
T2 - Country plough twice + bullock drawn cultivator twice (farmers' practice)
T3 - Country plough twice + power tiller operated rotavator twice
T4 - MB plough once + cultivator twice, both tractor drawn
T5 - Disc plough once + rotavator twice, both tractor drawn

M1 - Irrigations at IW/CPE = 0.6
M2 - Irrigations at IW/CPE = 0.8
M3 - Irrigations at IW/CPE = 1.0
M4 -Irrigations at IW/CPE = 1.2

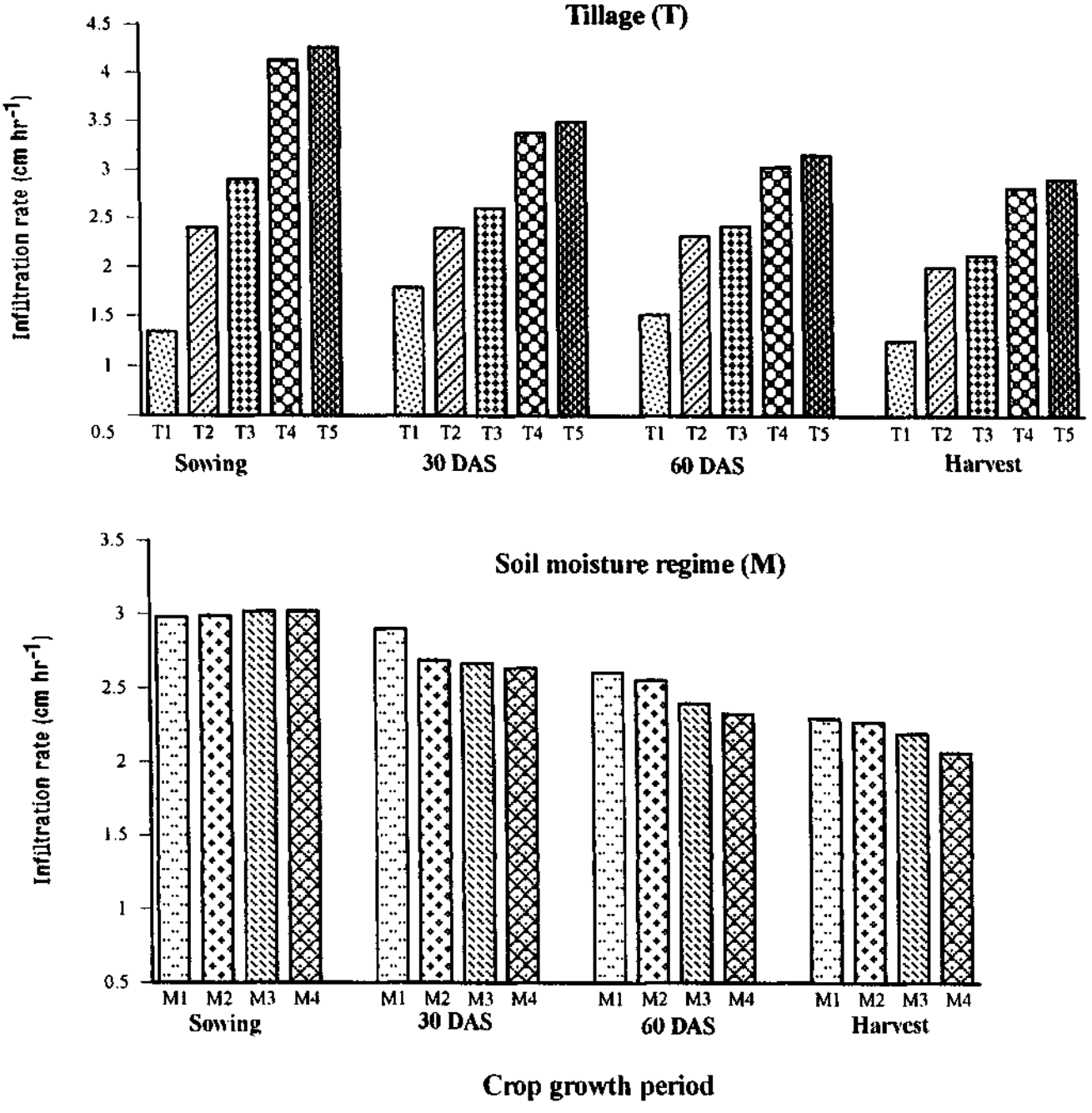


Fig. 12 : Effect of tillage treatments and soil moisture regimes on infiltration rate of soil during crop growth period, 1998-99

2.74 and 2.50 cm hr^{-1} at sowing, 30 DAS, 60 DAS and at harvest, respectively, in first year; 4.25, 3.48, 3.14 and 2.90 cm hr^{-1} at sowing, 30 DAS, 60 DAS and at harvest, respectively, in second year) with T_5 tillage treatment (disc plough once + rotavator twice, both tractor drawn) closely followed by T_4 (MB plough once + cultivator twice, both tractor drawn) both are at par and significantly higher compared to all other tillage practices. Lowest final infiltration rate 1.05, 1.13, 1.14 and 1.18 cm hr^{-1} was observed at sowing, 30 DAS, 60 DAS and harvest, respectively, in first year; 1.34, 1.79, 1.51 and 1.25 cm hr^{-1} at sowing, 30 DAS, 60 DAS and at harvest, respectively, in second year in T_1 (zero tillage) and was significantly lower than shallow tillage treatments (T_2 and T_3) and deep tillage treatments (T_4 and T_5).

Moisture supply to soil scheduled at M_4 (IW/CPE ratio of 1.2) recorded lowest infiltration rate (2.28, 1.98 and 1.92 cm hr^{-1} at 30 DAS, 60 DAS and at harvest, respectively, in first year; 2.64, 2.33 and 2.07 at 30, 60 DAS and at harvest, respectively, in second year followed by M_3 (IW/CPE ratio of 1.0) and both were on par and significantly lower compared to M_2 and M_1 (0.8 and 0.6 IW/CPE ratios) at all growth stages of crop except at sowing where soil moisture regimes does not differ significantly and hence were varying influence on infiltration rate in both years of study. Highest infiltration rate was obtained with driest soil moisture regimes (M_1) at all stages of crop growth in both years.

The interaction effects of tillage and soil moisture regimes were not significant on infiltration rate at all the stages studied.

4.1.7 Hydraulic conductivity

The data are furnished in Table 10 and depicted in Figs. 13 and 14.

Hydraulic conductivity of 0-15 and 15-30 cm soil layers varied significantly with tillage treatments at sowing, and at all the stages of crop growth period in both the years. Hydraulic conductivity of 30-45 cm depth, however, was not significantly influenced tillage at all crop growth stages.

The hydraulic conductivity of the soil was highest (5.16 and 4.04 cm hr^{-1} at 0-15 and 15-30 cm soil depths, respectively, at sowing in first year) in T_5 treatment (tractor drawn disc plough once + rotavator twice), which was significantly superior to other tillage treatments viz, T_4 (tractor drawn MB plough once + cultivator twice), T_3 (country plough twice + rotavator twice), T_2 (country plough twice + cultivator twice) and T_1 (zero tillage). Lowest hydraulic conductivity (0.78 and 0.64 at 0-15 and 15-30 cm soil depth, respectively, at sowing in first year) was observed with T_1 (zero tillage) treatment at both soil depths (0-15 and 15-30 cm) at all the stages of crop growth. However, at 15-30 cm soil depth the hydraulic conductivity of soil was at par in T_3, T_2 and T_1 tillage treatments and were significantly lower to that of T_5 and T_4 tillage treatments.

The hydraulic conductivity of deepest layer (30-45 cm) was not affected by either tillage or soil moisture regimes or their interactions

Soil moisture regimes and their interaction with tillage treatments did not influence the hydraulic conductivity.

Table 10 : Effect of tillage treatments on hydraulic conductivity of soil at 0-15, 15-30 and 30-45 cm depths during crop growth period

	Hydraulic conductivity (cm hr^{-1})							
	1997-'98				1998-'99			
	Crop growth period				Crop growth period			
	Sowing	30 DAS	60 DAS	Harvest	Sowing	30 DAS	60 DAS	Harvest
				0-15 cm				
Tillage (T)								
T_1	0.78	0.72	0.78	0.83	0.89	0.78	0.77	0.77
T_2	2.41	2.05	1.80	1.54	2.79	2.15	2.30	1.93
T_3	2.75	2.40	2.08	1.83	3.37	2.38	2.39	2.00
T_4	4.44	3.78	3.05	2.37	4.09	3.77	3.42	3.10
T_5	5.16	4.28	3.18	2.71	4.56	3.97	3.61	3.22
SEm±	0.102	0.130	0.100	0.160	0.280	0.100	0.140	0.110
CD(P=0.05)	0.240	0.300	0.210	0.420	0.560	0.230	0.260	0.290
				15-30 cm				
T_1	0.64	0.80	0.77	0.77	0.67	0.67	0.73	0.72
T_2	0.62	0.77	0.81	0.77	0.69	0.67	0.72	0.69
T_3	0.69	0.84	0.83	0.79	0.69	0.71	0.71	0.70
T_4	3.10	2.66	2.19	1.85	3.32	1.82	1.64	1.49
T_5	4.04	3.08	2.44	1.95	3.80	2.07	1.91	1.53
SEm±	0.060	0.054	0.062	0.051	0.044	0.068	0.060	0.040
CD(P=0.05)	0.180	0.17	0.140	0.108	0.150	0.160	0.150	0.100
				30-45 cm				
T_1	0.72	0.71	0.60	0.49	0.71	0.59	0.51	0.50
T_2	0.77	0.71	0.59	0.48	0.71	0.59	0.52	0.50
T_3	0.75	0.72	0.59	0.51	0.70	0.61	0.51	0.51
T_4	0.72	0.75	0.59	0.50	0.70	0.60	0.52	0.51
T_5	0.75	0.76	0.61	0.50	0.71	0.62	0.52	0.52
SEm±	0.016	0.019	0.007	0.008	0.016	0.014	0.013	0.015
CD(P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS

T_1 : Zero tillage
T_2 : Country plough twice + bullock drawn cultivar twice
T_3 : Country plough twice + power tiller rotavator twice
T_4 : Mould board plough once + cultivator twice, both tractor drawn
T_5 : Disc plough once + rotavator twice, both tractor drawn

T1 - Zero tillage
T2 - Country plough twice + bullock drawn cultivator twice (farmers' practice)
T3 - Country plough twice + power tiller operated rotavator twice
T4 - MB plough once + cultivator twice, both tractor drawn
T5 - Disc plough once + rotavator twice, both tractor drawn

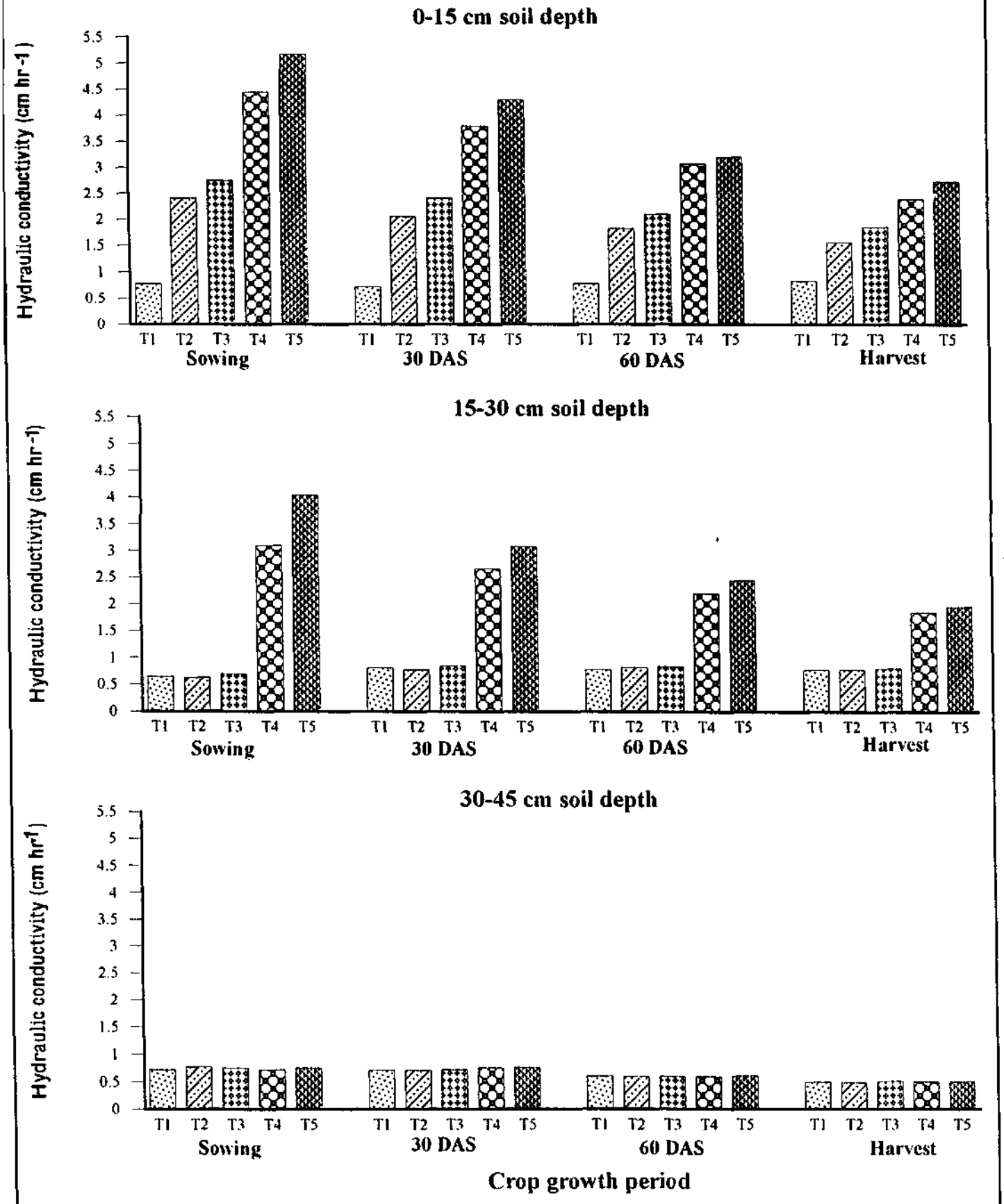


Fig. 13: Effect of tillage treatments on hydraulic conductivty of soil at different depths during crop growth period, 1997-98

T1 - Zero tillage
T2 - Country plough twice + bullock drawn cultivator twice (farmers' practice)
T3 - Country plough twice + power tiller operated rotavator twice
T4 - MB plough once + cultivator twice, both tractor drawn
T5 - Disc plough once + rotavator twice, both tractor drawn

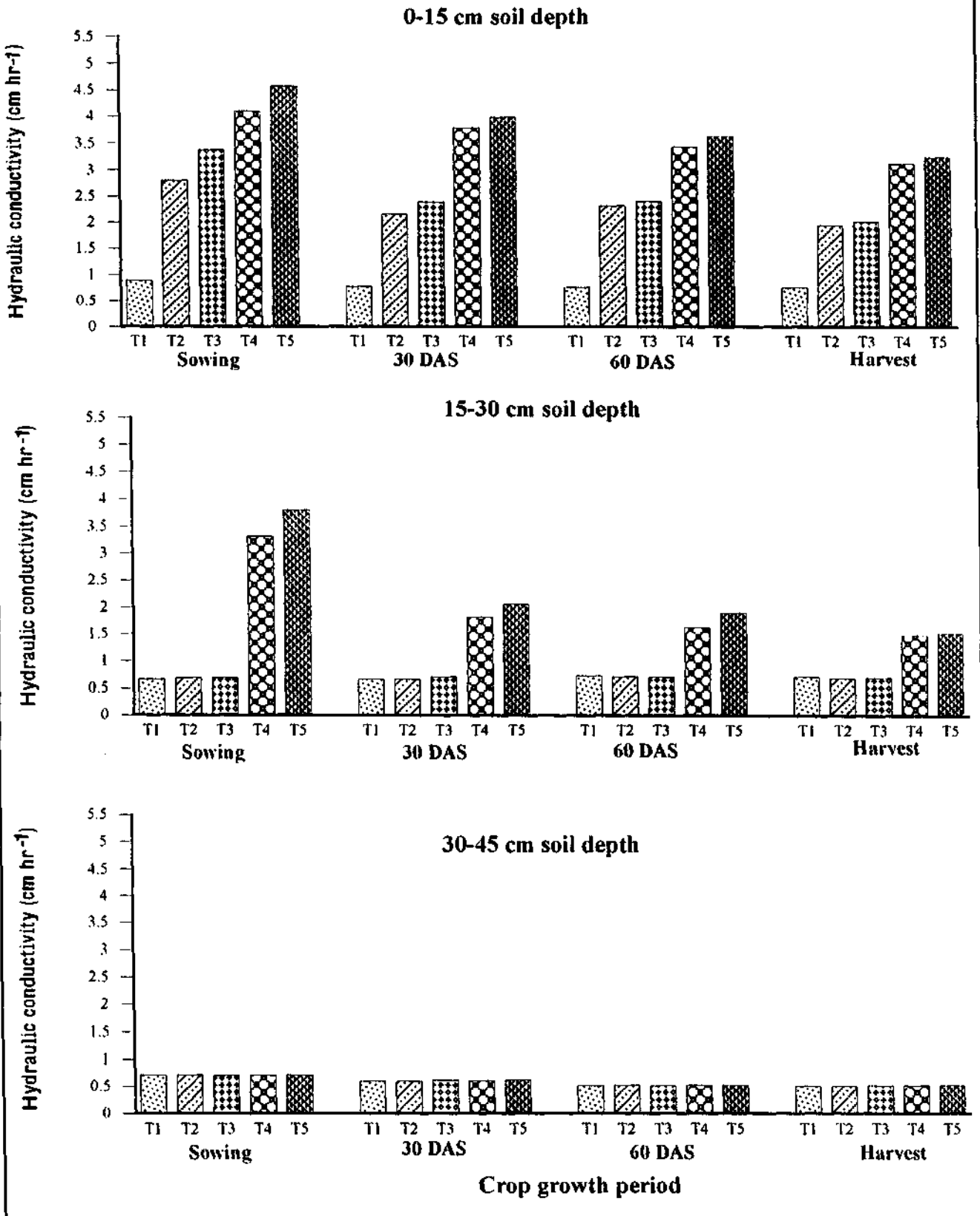


Fig. 14: Effect of tillage treatments on hydraulic conductivity of soil at different soils depths during crop growth period, 1998-99

4.1.8 Penetration resistance

The data are presented in Table 11 and illustrated in Figs. 15 and 16

Penetration resistance was significantly affected by tillage treatments at all stages of observation in both the years of study. Lowest penetration resistance was recorded with the tillage treatment T_5 (disc plough once + rotavator twice, both tractor drawn) which was on par with T_4 (MB plough once + cultivator twice, both tractor drawn) (33.4, 39.3 and 42.0 kg cm^{-2} at 10, 56 and 75 DAS, respectively, in first year, 30.1, 39.2 and 42.0 kg cm^{-2} at 10, 49 and 68 DAS, respectively, in second year) and both of these were significantly lower than in other tillage treatments viz., T_3 (country plough twice + power tiller operated rotavator twice), T_2 (country plough twice + bullock drawn cultivator twice) and T_1 (zero tillage). The highest penetration resistance 56.8, 63.3 and 60.8 kg cm^{-2} at 10, 56 and 75 DAS, respectively, in first year) was recorded in T_1 (zero tillage) at all the three stages of crop growth.

Soil moisture regimes also significantly influenced the penetration resistance. Lowest penetration resistance (43.7 and 45.8 kg cm^{-2} at 56 and 75 DAS in first year; 41.1 and 43.5 kg cm^{-2} at 49 and 68 DAS, respectively, in second year) was noticed with wettest soil moisture regime, M_4 (IW/CPE = 1.2) compared to other soil moisture regimes viz., M_3 (IW/CPE = 1.0), M_2 (IW/CPE= 0.8) and M_1 (IW/CPE = 0.6) at all the stages of crop growth except at 10 DAS, where it was not significant in both the years. Penetration resistance was the highest with dry soil moisture regime M_1 (IW/CPE = 0.6).

Table 11 : Effect of tillage tretments and soil moisture regimes on soil penetration resistance during crop growth period

	Soil penetration resistance (kg cm^{-2})					
	1997-'98			1998-'99		
	Crop growth period			Crop growth period		
	10 DAS	56 DAS	75 DAS	10 DAS	49 DAS	68 DAS
Tillage (T)						
T_1	56.8	63.3	60.8	47.3	54.6	55.9
T_2	44.9	50.1	49.7	39.9	45.8	47.4
T_3	40.8	46.1	47.6	37.6	45.4	47.6
T_4	35.0	40.7	43.0	31.1	41.1	41.9
T_5	33.4	39.3	42.0	30.1	39.2	42.0
SEm±	0.85	0.42	0.69	0.54	1.06	0.62
CD(P=0.05)	1.97	0.97	1.60	1.25	2.46	1.44
Soil moisture regime (M)						
M_1	43.1	51.5	53.6	37.8	48.6	49.0
M_2	42.2	50.0	52.1	38.4	47.2	50.6
M_3	40.6	46.5	47.1	36.2	43.8	44.6
M_4	41.6	43.7	45.8	36.3	41.1	43.5
SEm±	0.69	1.11	0.37	0.70	0.72	0.44
CD(P=0.05)	NS	2.73	0.79	NS	1.76	0.97

T_1 : Zero tillage
T_2 : Country plough twice + bullock drawn cultivar twice
T_3 : Country plough twice + power tiller rotavator twice
T_4 : Mould board plough once + cultivator twice, both tractor dawn
T_5 : Disc plough once + rotavator twice, both tractor dawn

M_1 : IW/CPE = 0.6
M_2 : IW/CPE = 0.8
M_3 : IW/CPE = 1.0
M_4 : IW/CPE = 1.2

T1 - Zero tillage
T2 - Country plough twice + bullock drawn cultivator twice (farmers' practice)
T3 - Country plough twice + power tiller operated rotavator twice
T4 - MB plough once + cultivator twice, both tractor drawn
T5 - Disc plough once + rotavator twice, both tractor drawn

M1 - Irrigations at IW/CPE = 0.6
M2 - Irrigations at IW/CPE = 0.8
M3 - Irrigations at IW/CPE = 1.0
M4 -Irrigations at IW/CPE = 1.2

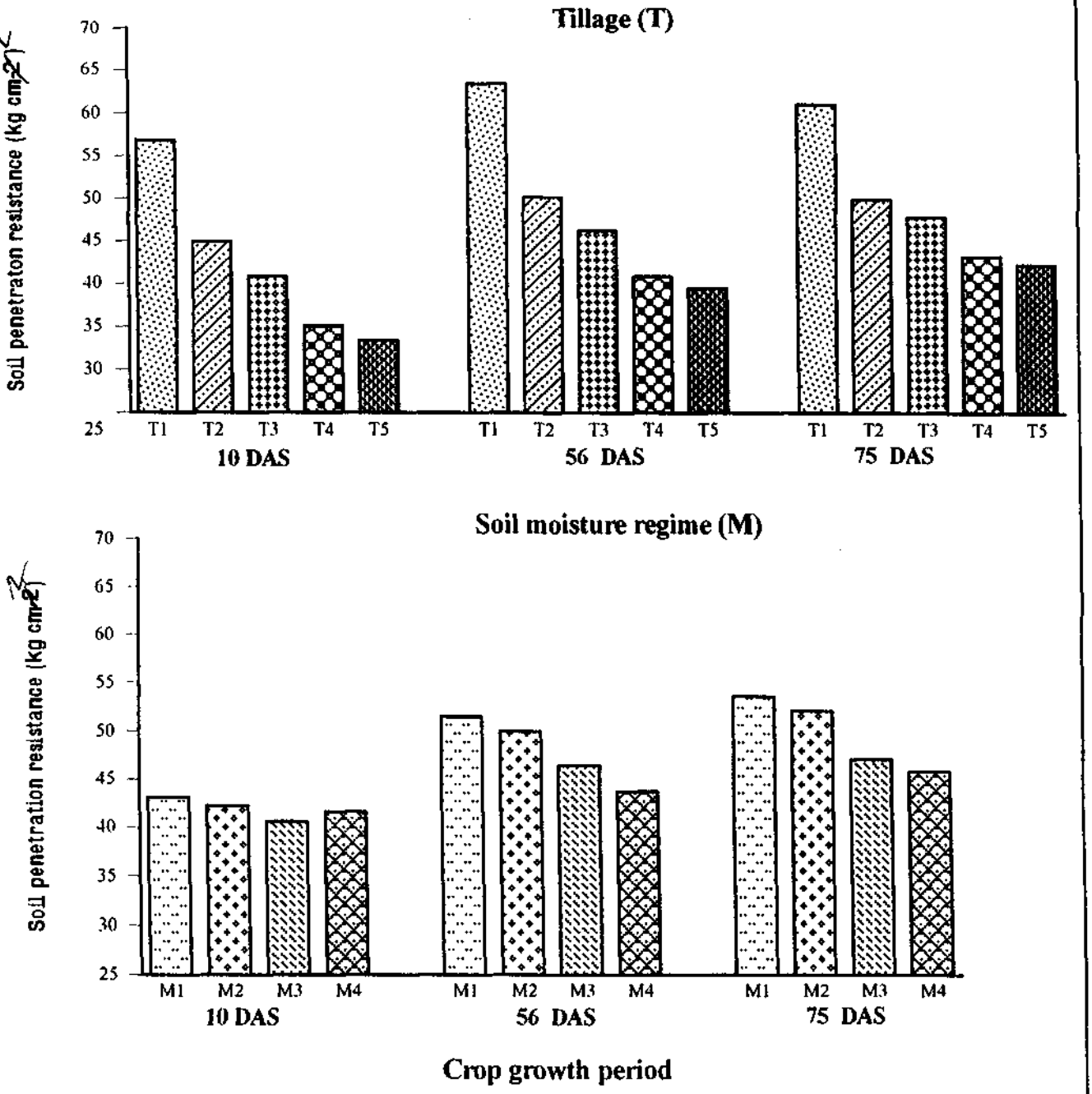


Fig. 15: Effect of tillage treatments and soil moisture regimes on soil penetration resistance during crop growth period, 1997-98

T1 - Zero tillage
T2 - Country plough twice + bullock drawn cultivator twice (farmers' practice)
T3 - Country plough twice + power tiller operated rotavator twice
T4 - MB plough once + cultivator twice, both tractor drawn
T5 - Disc plough once + ratavator twice, both tractor drawn

M1 - Irrigations at IW/CPE = 0.6
M2 - Irrigations at IW/CPE = 0.8
M3 - Irrigations at IW/CPE = 1.0
M4 -Irrigations at IW/CPE = 1.2

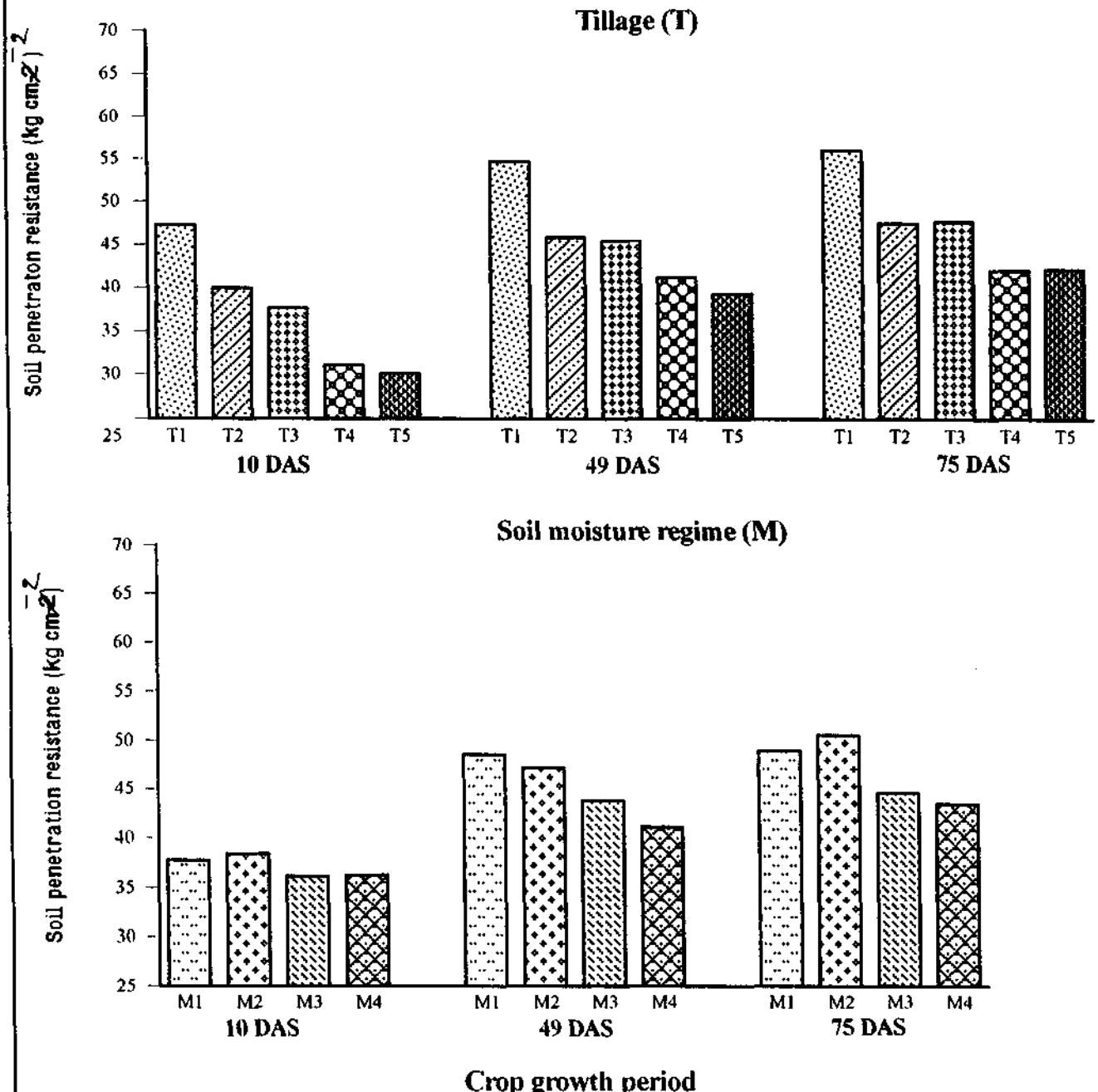


Fig.16: Effect of tillage treatments and soil moisture regimes on soil penetration resistance during crop growth period, 1998-99

Interactions between tillage and soil moisture regimes did not have significant influence on penetration resistance.

4.1.9 Soil temperature

The data presented in Table 12 and depicted in Figs. 17 and 18 show significant changes in soil temperature due to tillage at 5 cm depth of soil at all growth stages of the crop in both the years. However, the soil temperature at 15 cm soil depth does not differ significantly with tillage in both the years of study. Soil temperature was highest (29.87, 32.67 and 35.67°C at 10, 56 and 75 DAS, respectively, in first year; 30.87, 33.65 and 36.47 at 10, 49 and 68 DAS, respectively, in second year) with zero tillage treatment (T_1) and lowest soil temperature was observed in T_5 (disc plough once + rotavator twice, both tractor drawn), which was on par with T_4 (MB plough once + cultivator twice, both tractor drawn). Both T_5 and T_4 tillage treatments recorded significantly lower temperature compared to T_3 (country plough twice + bullock drawn cultivator twice), T_2 (country plough twice + cultivator twice) and T_1 (zero tillage) in all observations.

Soil moisture regimes also affected the soil temperature significantly at 5 cm depth at all crop growth stages in both the years except at 10 DAS. However, at 15 cm soil depth the changes in soil temperature due to moisture regimes was not significant. Lowest soil temperature was recorded at 5 cm depth in wettest soil moisture regime (M_4) (IW/CPE = 1.2) (27.26°C, 31.18°C and 34.00°C at 10, 56 and 75 DAS, respectively, in first year; 29.47°C, 31.50°C and 34.64°C at 10, 49 and 68 DAS, respectively, in second year) which were at par with M_3 (IW/CPE = 1.0). Soil temperature in (M_4 and M_3) moisture

Table 12 : Effect of tillage treatments and soil moisture regime on soil temperature at 5 and 15 cm soil depths during crop growth period

	Soil temperature (°C)					
	1997-'98			1998-'99		
	Crop growth period			Crop growth period		
	10 DAS	56 DAS	75 DAS	10 DAS	49 DAS	68 DAS
			5 cm depth			
Tillage (T)						
T_1	29.87	32.67	35.67	30.87	33.65	36.47
T_2	28.12	32.02	35.25	29.00	32.87	35.82
T_3	27.47	31.92	35.05	30.02	32.55	35.37
T_4	26.89	30.95	33.42	29.77	31.72	34.82
T_5	26.52	30.92	33.22	28.99	31.22	34.70
SEm±	0.42	0.43	0.32	0.52	0.52	0.49
CD(P=0.05)	1.29	1.00	0.72	1.24	1.20	1.03
Soil moisture regime (M)						
M_1	27.76	32.38	35.38	30.04	33.94	36.96
M_2	28.16	32.06	34.68	29.40	32.48	36.10
M_3	27.74	31.54	34.44	30.02	31.90	34.82
M_4	27.26	31.18	34.00	29.47	31.50	34.64
SEm±	0.27	0.32	0.29	0.46	0.25	0.41
CD(P=0.05)	NS	0.72	0.64	NS	0.81	0.96
			15 cm depth			
Tillage (T)						
T_1	25.87	27.12	30.20	27.30	30.05	32.61
T_2	25.25	26.57	29.74	26.47	29.37	31.90
T_3	25.00	26.50	29.50	26.72	29.08	32.10
T_4	24.80	25.77	28.37	26.62	29.52	30.65
T_5	24.85	25.60	28.90	26.35	29.19	30.35
SEm±	0.39	0.88	0.81	0.47	0.86	0.96
CD(P=0.05)	NS	NS	NS	NS	NS	NS
Soil moisture regime (M)						
M_1	25.26	26.54	29.60	27.02	30.97	31.94
M_2	25.44	26.68	29.71	26.70	29.77	31.78
M_3	24.88	25.94	29.14	26.64	28.64	31.21
M_4	25.03	26.10	28.91	26.42	28.39	31.16
SEm±	0.20	0.64	0.87	0.44	0.56	1.19
CD(P=0.05)	NS	NS	NS	NS	NS	NS

T_1 : Zero tillage
T_2 : Country plough twice + bullock drawn cultivar twice
T_3 : Country plough twice + power tiller rotavator twice
T_4 : Mould board plough once + cultivator twice, both tractor drawn
T_5 : Disc plough once + rotavator twice, both tractor drawn

M_1 : IW/CPE = 0.6
M_2 : IW/CPE = 0.8
M_3 : IW/CPE = 1.0
M_4 : IW/CPE = 1.2

T1 - Zero tillage
T2 - Country plough twice + bullock drawn cultivator twice (farmers' practice)
T3 - Country plough twice + power tiller operated rotavator twice
T4 - MB plough once + cultivator twice, both tractor drawn
T5 - Disc plough once + rotavator twice, both tractor drawn

M1 - Irrigations at IW/CPE = 0.6
M2 - Irrigations at IW/CPE = 0.8
M3 - Irrigations at IW/CPE = 1.0
M4 -Irrigations at IW/CPE = 1.2

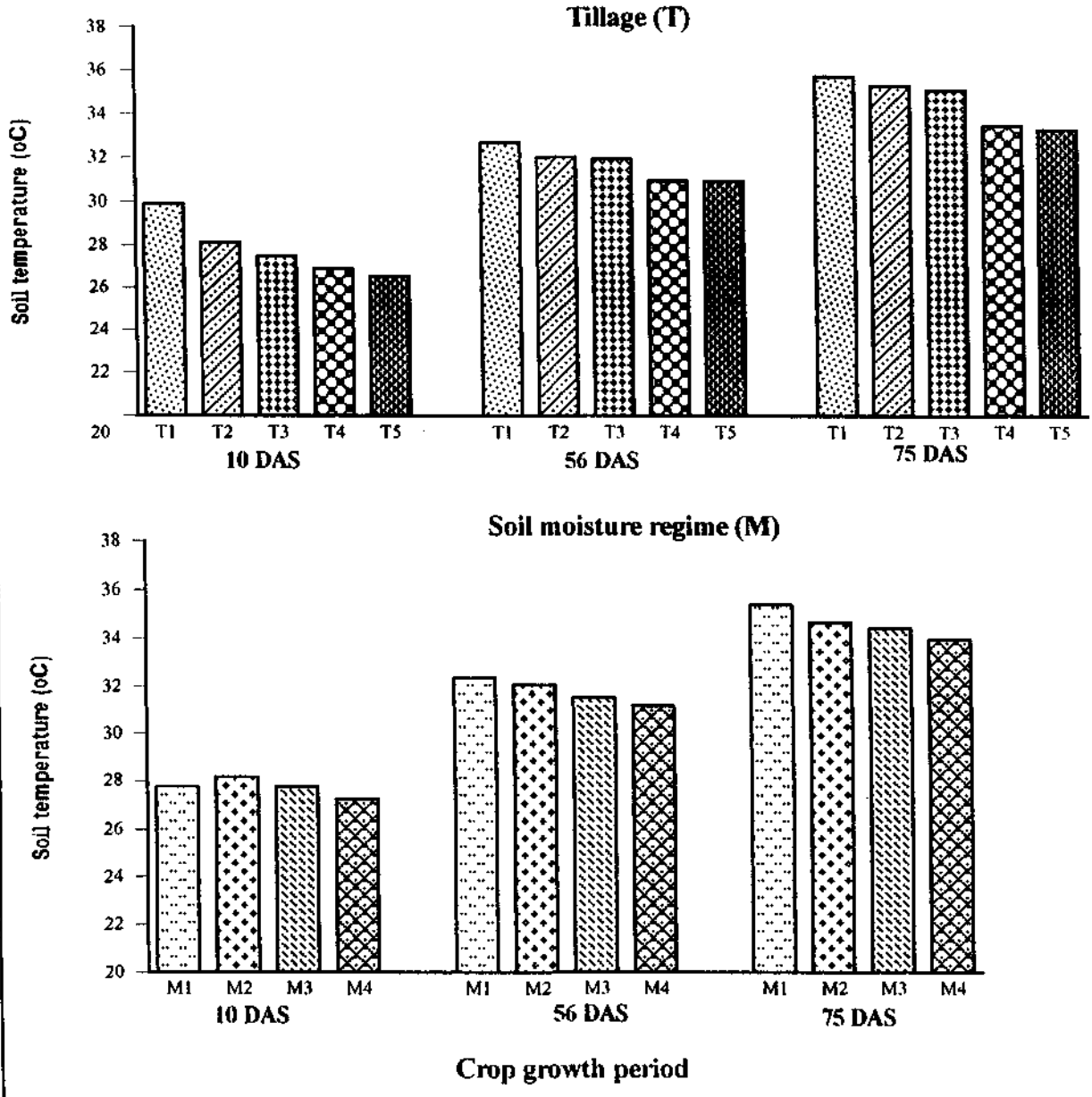


Fig. 17: Effect of tillage treatments and soil moisture regimes on soil temperature at 5 cm depth during crop growth period, 1997-98

T1 - Zero tillage
T2 - Country plough twice + bullock drawn cultivator twice (farmers' practice)
T3 - Country plough twice + power tiller operated rotavator twice
T4 - MB plough once + cultivator twice, both tractor drawn
T5 - Disc plough once + rotavator twice, both tractor drawn

M1 - Irrigations at IW/CPE = 0.6
M2 - Irrigations at IW/CPE = 0.8
M3 - Irrigations at IW/CPE = 1.0
M4 -Irrigations at IW/CPE = 1.2

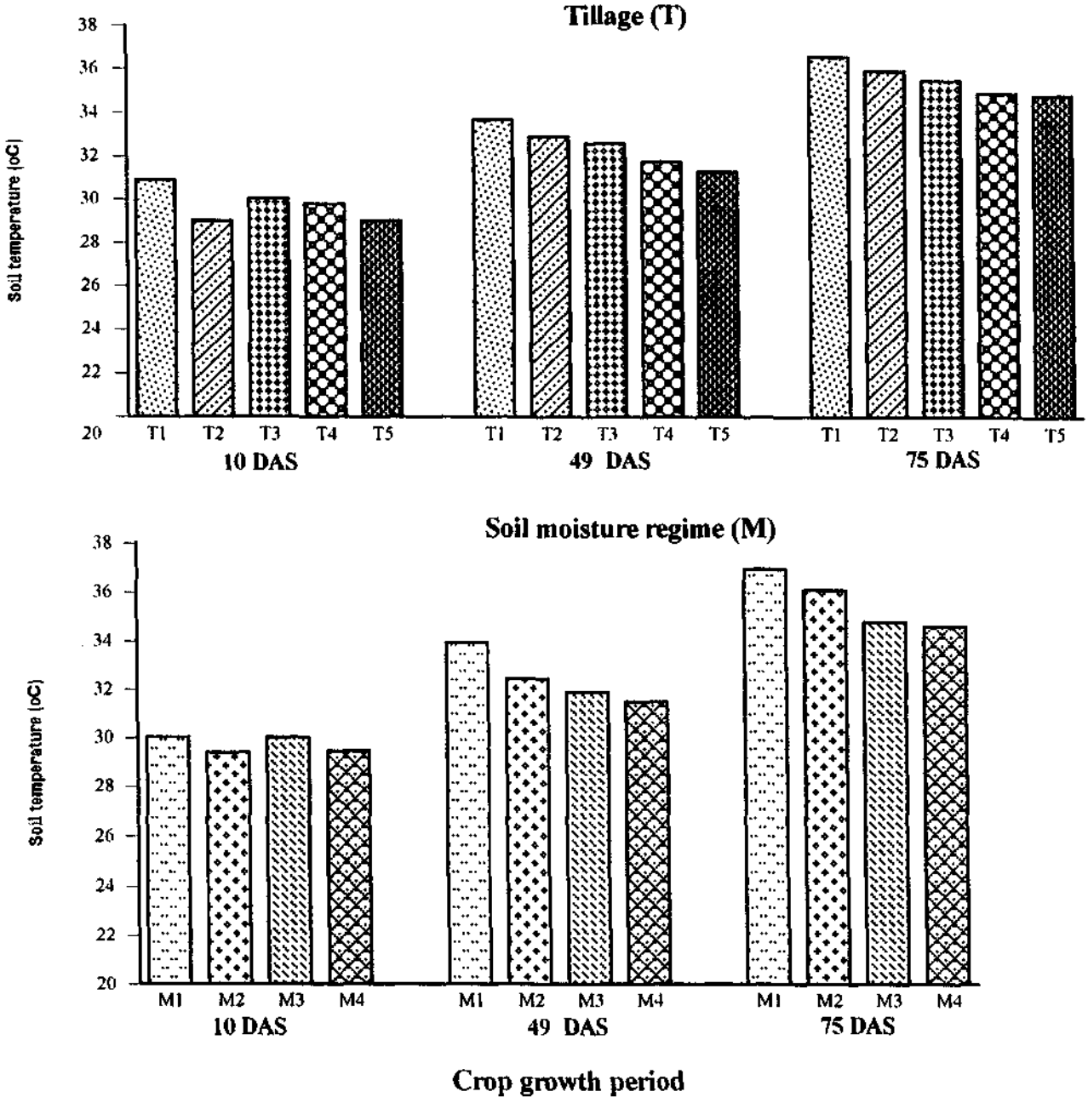


Fig. 18: Effect of tillage treatments and soil moisture regimes on soil temperature at 5 cm depth during crop growth period, 1998-99

regime treatments were significantly lower compared to those of M_1 (IW/CPE = 0.6) and M_2 (IW/CPE = 0.8) at 56 and 75 DAS in first year and 49 and 68 DAS in second year.

The interaction effects of tillage treatments and soil moisture regimes were not significant on soil temperature .

It was also observed that soil temperature in general increased from sowing to harvest irrespective of tillage and soil moisture regimes treatments.

Neither tillage treatments nor soil moisture regimes influenced soil temperature at 15 cm soil depth significantly.

4.2 EFFECT OF TILLAGE TREATMENTS AND SOIL MOISTURE REGIMES ON SEEDLING EMERGENCE

The data are presented in Table 13 and depicted in Fig. 19.

Significantly higher seedling emergence (73.62 and 77.06 per cent in first and second years, respectively) were recorded in T_5 plots (which received secondary tillage with rotavator following primary tillage with tractor drawn disc plough) and T_3 involving tillage with bullock drawn country plough (72.23 and 73.46 per cent in first and second years, respectively) compared to other tillage practices with cultivator or zero tillage in both the years of study. Seedling emergence was drastically reduced in zero tillage (T_1) (51.94 % in first year and 53.35 % in second year) in both the years of study.

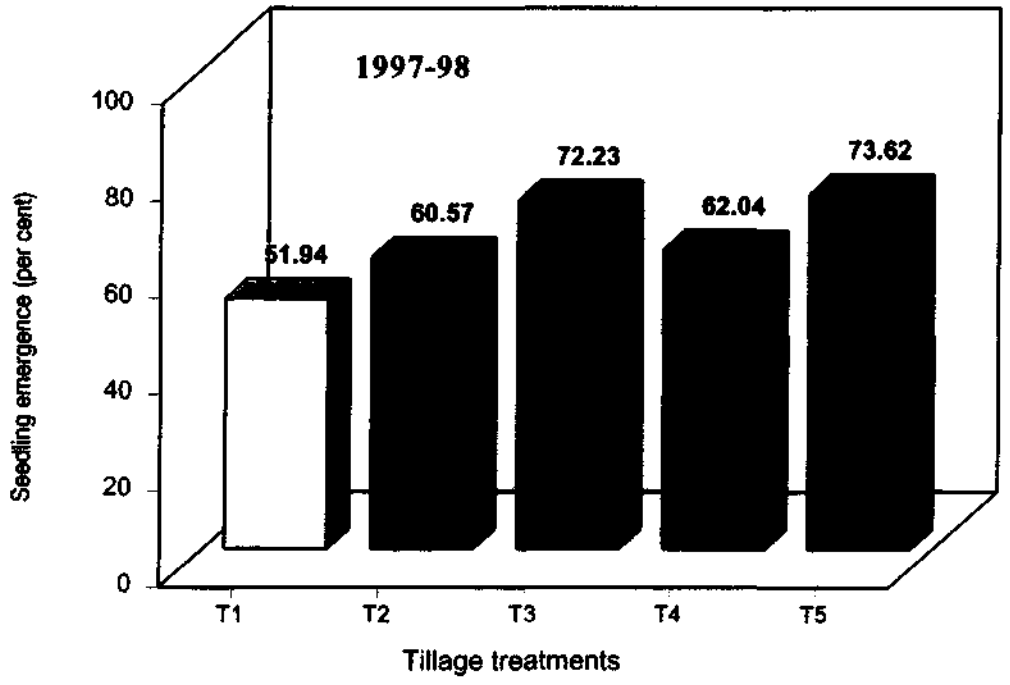
The effect of soil moisture regimes and their interaction was not significant on seedling emergence.

Table 13: Effect of tillage treatments on sunflower seedling emergence

Tillage (T)	Seedling emergence (per cent)	
	1997-98	1998-99
T_1	51.94	53.35
T_2	60.57	59.27
T_3	72.23	73.46
T_4	62.04	61.72
T_5	73.62	77.06
SEm±	2.12	1.96
CD (P=0.05)	4.88	4.52

T_1 : Zero tillage
T_2 : Country plough twice + bullock drawn cultivar twice
T_3 : Country plough twice + power tiller rotavator twice
T_4 : Mould board plough once + cultivator twice, both tractor darwn
T_5 : Disc plugh once + rotavator twice, both tractor darwn

T1 - Zero tillage
T2 - Country plough twice + bullock drawn cultivator twice (farmers' practice)
T3 - Country plough twice + power tiller operated rotavator twice
T4 - MB plough once + cultivator twice, both tractor drawn
T5 - Disc plough once + rotavator twice, both tractor drawn



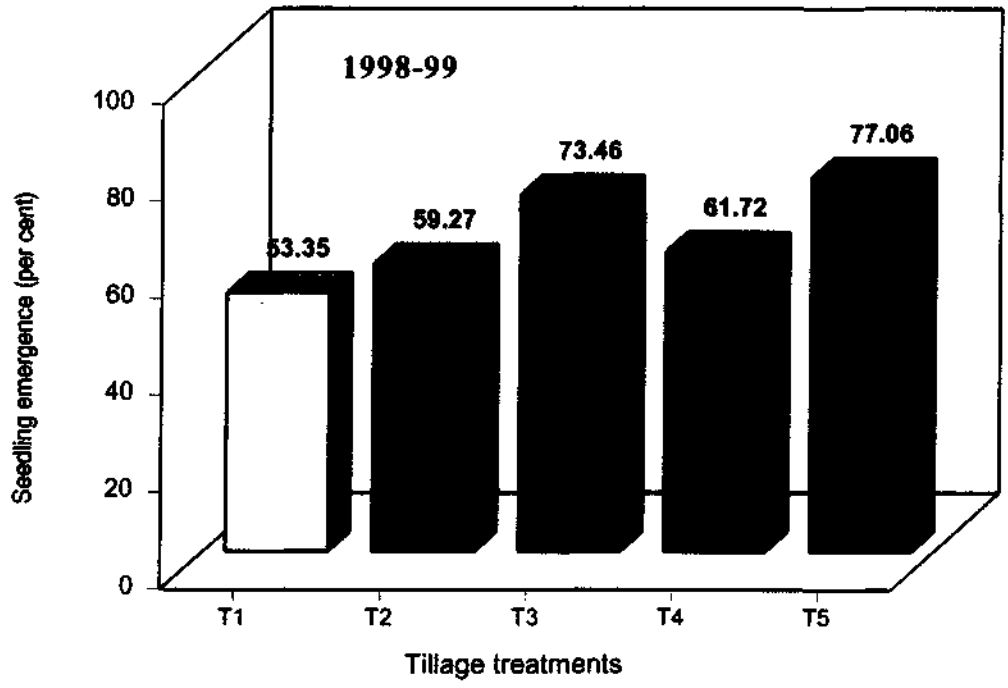


Fig. 19 : Effect of tillge treatments on seedling emergence (per cent) of sunflower

4.3 EFFECT OF TILLAGE TREATMENTS AND SOIL MOISTURE REGIMES ON PLANT GROWTH, YIELD ATTRIBUTES AND YIELD

4.3.1 Plant height

The data are presented in Table 14.

Growth of the crop as indicated by plant height, was significantly influenced by the tillage treatments and soil moisture regimes at all stages of observation while interaction effects were significant only at later crop growth stages (60 DAS and at harvest).

Plant height was more in the tillage with tractor drawn MB plough once + cultivator twice (T_4) followed by tillage with tractor drawn disc plough once + rotavator twice (T_5), and these were at par with each other. These tillages were significantly superior to T_3 (country plough twice + power tiller operated rotavator twice), T_2 (country plough twice + bullock drawn cultivator twice) and T_1 (zero tillage). Plant height was low with zero tillage (T_1) throughout the crop growth period in both the years.

Moisture regime M_4 with more frequent irrigations (IW/CPE = 1.20) resulted in maximum plant height, which was at par with the M_3 (IW/CPE = 1.00) at all the stages of crop growth, and both the above treatments were significantly superior to the other two less frequent irrigated soils moisture regimes M_2 (IW/CPE = 0.80) and M_1 (IW/CPE = 0.60). The lowest plant height was recorded with M_1 at all stages of crop growth in both the years.

Table 14 : Effect of tillage treatments and soil moisture regimes on plant height during crop growth period

Tillage (T)	Plant height (cm)									
	1997-98					1998-99				
	Soil moisture regime (M)					Soil moisture regime (M)				
	M_1	M_2	M_3	M_4	Mean	M_1	M_2	M_3	M_4	Mean
					30 DAS					
T_1	20.2	21.0	20.9	21.0	20.8	19.7	18.5	18.9	20.2	19.3
T_2	21.3	21.9	22.5	22.3	22.0	20.6	21.6	20.9	21.5	21.1
T_3	22.0	21.8	23.1	23.7	22.6	20.5	21.3	22.0	23.5	21.8
T_4	23.3	24.5	24.9	25.5	24.5	21.0	21.7	24.4	24.9	23.0
T_5	23.5	24.2	24.5	25.0	24.3	23.2	23.9	24.8	25.5	24.3
Mean	22.0	22.7	23.2	23.5		21.0	21.4	22.2	23.1	
					60 DAS					
T_1	59.5	62.2	65.6	67.3	63.6	56.4	58.9	60.2	62.9	59.6
T_2	66.2	68.8	70.4	72.7	69.5	65.3	68.1	71.4	73.0	69.4
T_3	69.8	71.5	73.3	75.5	72.5	67.7	71.5	73.8	74.5	71.9
T_4	78.8	81.8	87.5	89.4	84.4	70.8	77.2	80.7	80.9	77.4
T_5	77.4	80.3	85.7	88.1	82.9	71.6	76.1	79.1	80.4	76.8
Mean	70.3	72.9	76.5	78.6		66.3	70.3	73.0	74.3	
					Harvest					
T_1	63.4	65.0	68.9	70.8	67.0	59.9	63.2	64.5	66.3	63.5
T_2	71.5	73.8	76.9	77.7	74.9	68.7	71.5	74.3	76.2	72.7
T_3	72.8	75.8	79.0	80.9	77.1	70.3	74.8	77.9	78.9	75.5
T_4	81.0	86.7	90.5	90.9	87.3	72.5	80.4	85.6	86.1	81.6
T_5	80.1	85.0	90.0	91.3	86.6	73.3	80.3	84.5	85.5	80.9
Mean	73.7	77.2	81.0	82.3		68.9	74.0	77.3	78.6	

	30 DAS	60 DAS	Harvest	30 DAS	60 DAS	Harvest
T						
SEm±	0.74	1.14	1.27	0.83	1.07	1.26
CD (P=0.05)	1.98	2.63	2.94	1.87	2.47	2.96
M						
SEm±	0.53	0.45	0.63	0.33	0.49	0.43
CD (P=0.05)	1.49	1.10	1.51	0.91	1.21	1.35
T at M						
SEm±	1.07	1.20	1.86	1.23	1.31	1.25
CD (P=0.05)	NS	5.30	7.06	NS	4.36	3.16
M at T						
SEm±	1.22	0.84	1.31	1.40	1.28	0.82
CD (P=0.05)	NS	2.35	4.12	NS	2.13	2.50

T_1 : Zero tillage
T_2 : Country plough twice + bullock drawn cultivar twice
T_3 : Country plough twice + power tiller rotavator twice
T_4 : Mould board plough once + cultivator twice, both tractor drawn
T_5 : Disc plough once + rotavator twice, both tractor drawn

M_1 : IW/CPE = 0.6
M_2 : IW/CPE = 0.8
M_3 : IW/CPE = 1.0
M_4 : IW/CPE = 1.2

Deep tillages coupled with high soil moisture regimes (IW/CPE ratios of 1.20 and 1.00) viz., treatments T_4M_4, T_4M_3, T_5M_4 and T_5M_3 resulted in significantly higher plant height compared to other treatment combinations. The lowest plant height was recorded with T_1 M_1 combination (zero tillage coupled with driest soil moisture regime).

4.3.2 Leaf area index (LAI)

Data presented in Table 15 and illustrated in Fig. 20.

Tillage and soil moisture regimes influenced the leaf area index significantly at all the stages of observation in both the years. However, their interaction affects were significant only at 60 DAS.

Tillage treatment T_5 (disc ploughing once + rotavator twice, both tractor drawn) recorded higher leaf area index and was significantly superior to the other tillage treatments at 60 DAS. At 30 DAS, T_3 (country plough once + power tiller operated rotavator twice) and T_5 (disc plough once + rotavator twice, both tractor drawn) were at par with each other and both recorded significantly higher LAI than the rest of the tillage treatments.

Maximum leaf area index was recorded in M_4 soil moisture regime (IW/CPE = 1.20) followed by M_3 (IW/CPE =1.0), which were at par with each other, and were significantly superior to the other two soil moisture regimes, M_2 (IW/CPE = 0.80) and M_1 (IW/CPE = 0.60). Minimum LAI was recorded with M_1 (IW/CPE = 0.60) at all growth stages in both the years of study.

Table 15 : Effect of tillage treatments and soil moisture regimes on leaf area index (LAI) of sunflower during crop growth period

Tillage (T)	Leaf area index (LAI)									
	1997-98					1998-99				
	Soil moisture regime (M)					Soil moisture regime (M)				
	M_1	M_2	M_3	M_4	Mean	M_1	M_2	M_3	M_4	Mean
					30 DAS					
T_1	0.72	0.70	0.75	0.80	0.74	0.69	0.73	0.70	0.74	0.71
T_2	0.85	0.91	0.95	1.00	0.93	0.73	0.78	0.82	0.85	0.79
T_3	1.20	1.24	1.25	1.33	1.27	1.05	1.12	1.20	1.25	1.15
T_4	0.95	1.10	1.06	1.10	1.05	0.89	0.94	1.00	1.05	0.97
T_5	1.28	1.35	1.44	1.40	1.37	1.12	1.10	1.25	1.28	1.19
Mean	1.00.	1.06	1.09	1.13		0.89	0.93	0.99	1.03	
					60 DAS					
T_1	1.58	1.70	1.87	1.96	1.78	1.52	1.68	1.83	1.94	1.74
T_2	1.80	2.03	2.30	2.24	2.09	1.70	2.00	2.24	2.36	2.07
T_3	1.94	2.35	2.78	2.95	2.50	1.91	2.20	2.63	2.71	2.36
T_4	2.05	2.69	3.01	3.23	2.74	1.97	2.48	2.93	3.03	2.60
T_5	2.27	2.96	3.38	3.46	3.02	2.25	2.77	3.12	3.29	2.86
Mean	1.93	2.35	2.67	2.77		1.87	2.23	2.55	2.67	
					Harvest					
T_1	0.45	0.52	0.60	0.63	0.55	0.40	0.47	0.53	0.59	0.50
T_2	0.50	0.57	0.63	0.65	0.59	0.46	0.50	0.56	0.61	0.53
T_3	0.60	0.65	0.69	0.72	0.66	0.51	0.58	0.63	0.67	0.60
T_4	0.52	0.59	0.65	0.65	0.60	0.50	0.56	0.59	0.62	0.57
T_5	0.62	0.70	0.77	0.80	0.72	0.56	0.61	0.69	0.72	0.64
Mean	0.54	0.61	0.65	0.69		0.49	0.54	0.60	0.64	

	30 DAS	60 DAS	Harvest	30 DAS	60 DAS	Harvest
T						
SEm±	0.06	0.07	0.03	0.05	0.11	0.02
CD (P=0.05)	0.15	0.17	0.07	0.12	0.26	0.04
M						
SEm±	0.02	0.09	0.02	0.02	0.09	0.01
CD (P=0.05)	0.03	0.21	0.05	0.05	0.18	0.04
T at M						
SEm±	0.08	0.11	0.04	0.07	0.12	0.02
CD (P=0.05)	NS	0.38	NS	NS	0.41	NS
M at T						
SEm±	0.07	0.12	0.05	0.04	0.12	0.03
CD (P=0.05)	NS	0.31	NS	NS	0.37	NS

T_1 : Zero tillage
T_2 : Country plough twice + bullock drawn cultivar twice
T_3 : Country plough twice + power tiller rotavator twice
T_4 : Mould board plough once + cultivator twice, both tractor drawn
T_5 : Disc plough once + rotavator twice, both tractor drawn

M_1 : IW/CPE = 0.6
M_2 : IW/CPE = 0.8
M_3 : IW/CPE = 1.0
M_4 : IW/CPE = 1.2

T1 - Zero tillage
T2 - Country plough twice + bullock drawn cultivator twice (farmers' practice)
T3 - Country plough twice + power tiller operated rotavator twice
T4 - MB plough once + cultivator twice, both tractor drawn
T5 - Disc plough once + rotavator twice, both tractor drawn

M1 - Irrigations at IW/CPE = 0.6
M2 - Irrigations at IW/CPE = 0.8
M3 - Irrigations at IW/CPE = 1.0
M4 -Irrigations at IW/CPE = 1.2

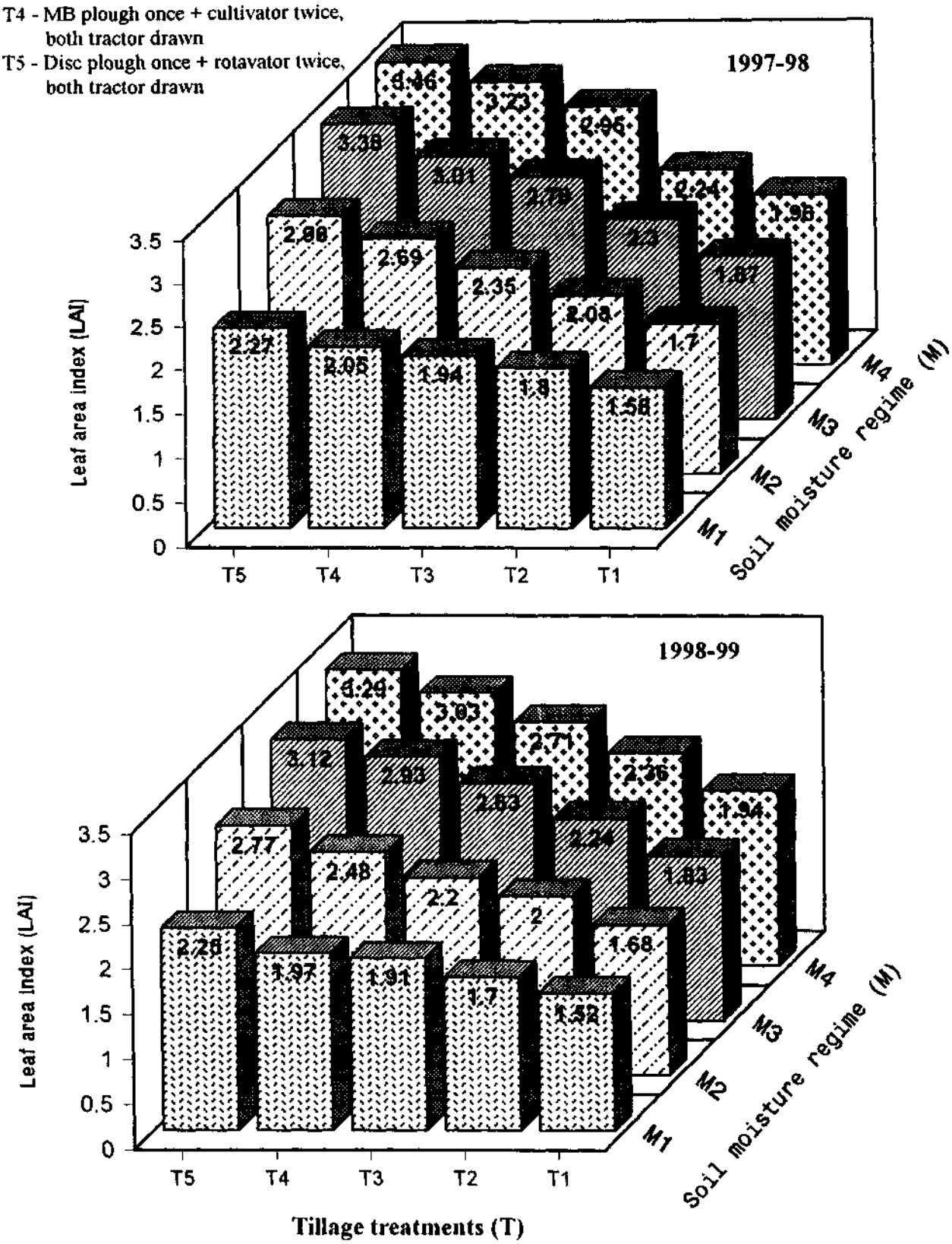


Fig.20 : Effect of tillage treatments and soil moisture regimes on leaf area index of sunflower at 60 DAS

Interaction effects of tillage and soil moisture regimes were significant at 60 DAS only LAI with T_5M_4 combination, was at par with combinations of T_5 M_3, T_4 M_4 and T_4 M_3, and was significantly superior to the rest of the treatment combinations. The minimum LAI was observed with T_1 M_1 combination (zero tillage and driest moisture regime).

4.3.3 Tap root length

Data are presented in Table 16 and depicted in Fig 21.

Deep tillage T_5 tractor drawn disc plough once and rotavator twice and T_4 (MB plough once + cultivator twice, both tractor drawn) resulted in longest tap root in both the years of study (22.13 and 23.12 cm in first and second years, respectively), which were at par with each other, and significantly superior to other tillage treatments. Shortest tap root was observed in T_1 (zero tillage) treatment (9.24 and 10.81 cm in first and second years, respectively) which was significantly lower than even the shallow tillage (T_2 and T_3) treatments.

Soil moisture regimes also significantly affected the tap root length. Highest length of tap root was observed in M_1 (IW/CPE ratio = 0.6) soil moisture regime followed by M_2 (IW/CPE = 0.8) and M_3 (IW/CPE = 1.0), which were at par with each other, but were significantly superior to M_4 (IW/CPE = 1.2) soil moisture regime. Interaction effect of tillage and soil moisture regimes were not significant on tap root length.

4.3.4 Root dry weight per plant

Data are presented in Table 17 and depicted in Figs. 22 and 23.

16

Table : Effect of tillage treatments and soil moisture regimes on tap root length at 60 DAS

Tillage (T)	Tap root length (cm)									
	1997-98					1998-99				
	Soil mositure regime (M)					Soil moisture regime (M)				
	M_1	M_2	M_3	M_4	Mean	M_1	M_2	M_3	M_4	Mean
T_1	8.84	9.35	9.69	9.10	9.24	10.18	11.65	11.21	10.48	10.81
T_2	13.33	14.74	14.50	14.10	14.17	15.08	14.96	14.50	13.66	14.50
T_3	16.40	15.23	15.37	14.25	14.90	15.68	14.88	13.18	14.21	13.98
T_4	23.67	22.28	21.33	20.49	21.94	24.18	23.67	22.48	20.95	22.81
T_5	23.33	22.51	21.60	21.08	22.13	23.41	23.08	23.66	22.33	23.12
Mean	17.11	16.82	16.50	15.80		17.71	17.65	17.00	16.10	

	1997-98	1998-99
T		
SEm±	0.70	0.59
CD (P=0.05)	1.63	1.37
M		
SEm±	0.28	0.37
CD (P=0.05)	0.64	0.90

T_1 : Zero tillage
T_2 : Country plough twice + bullock drawn cultivar twice
T_3 : Country plough twice + power tiller rotavator twice
T_4 : Mould board plough once + cultivator twice, both tractor drawn
T_5 : Disc plough once + rotavator twice, both tractor drawn

M_1 : IW/CPE = 0.6
M_2 : IW/CPE = 0.8
M_3 : IW/CPE = 1.0
M_4 : IW/CPE = 1.2

T1 - Zero tillage
T2 - Country plough twice + bullock drawn cultivator twice (farmers' practice)
T3 - Country plough twice + power tiller operated rotavator twice
T4 - MB plough once + cultivator twice, both tractor drawn
T5 - Disc plough once + rotavator twice, both tractor drawn

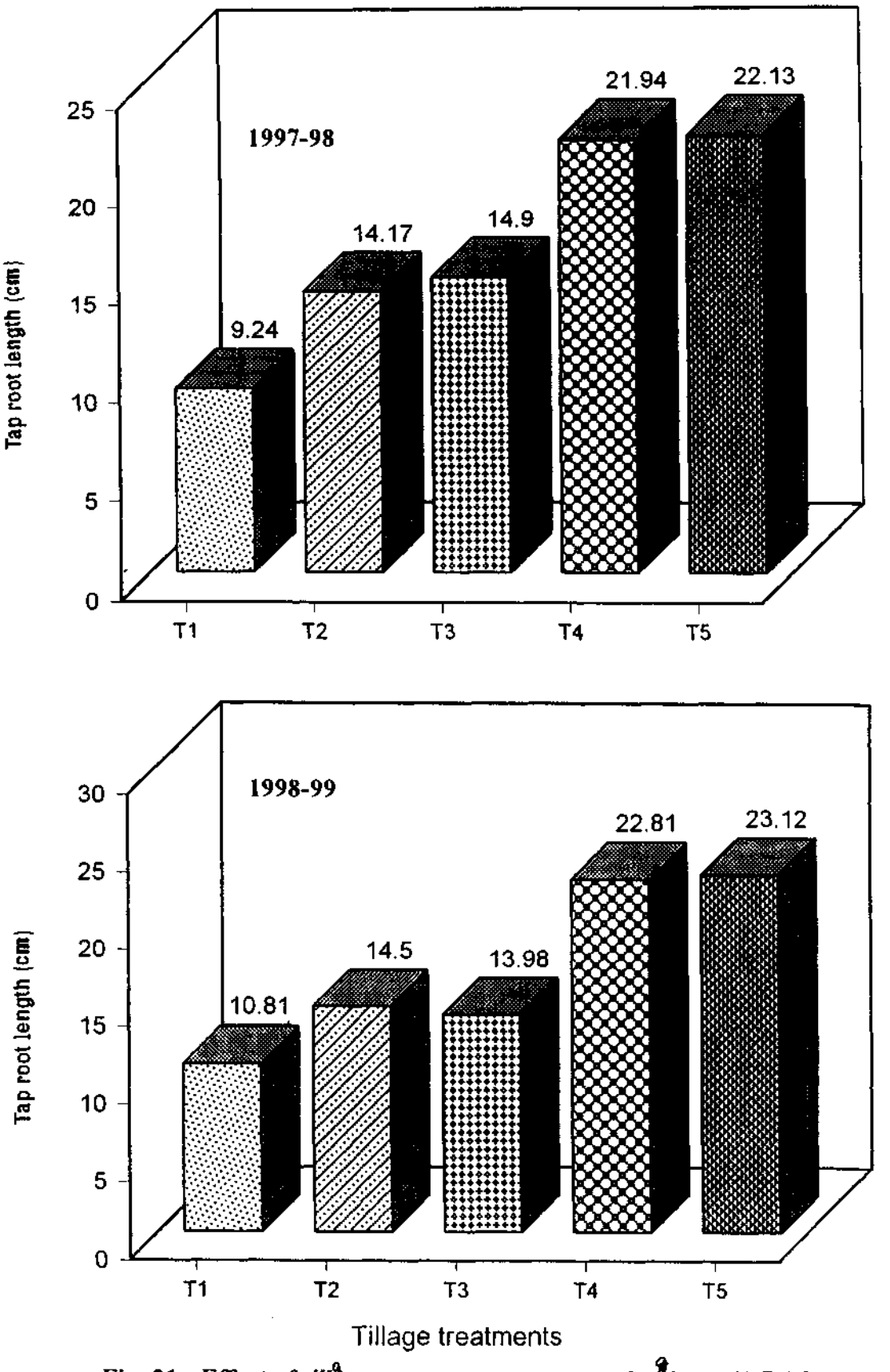


Fig. 21 : Effect of tillage treatments on tap root length at 60 DAS

Dry weight of roots increased progressively as the crop reached to maturity. Tillage treatments and soil moisture regimes and their interaction significantly influenced the root at 30 DAS.

Deep tillage treatments T_4 and T_5, involving mould board plough and disc plough, respectively, recorded higher root dry weight per plant at all growth stages, which were themselves at par but significantly superior to the shallow tillage treatments (T_3 country plough twice + power tiller operated rotavator twice), and T_2 country plough twice + bullock drawn cultivator twice) and zero tillage (T_1)). The root dry weight was the lowest in T_1 (zero tillage treatment) at all crop growth stages.

Root dry matter was the highest with M_4 soil moisture regime (1.2 IW/CPE ratio) followed by M_3 (IW/CPE ratio of 1.0) and both of these were significantly superior to other two soil moisture regimes (M_1 and M_2) at all crop growth observations in both the years. It was the lowest with M_1 (IW/CPE = 0.6) soil moisture regime at all stages of crop.

Deep and fine tillage combined with wettest soil moisture regime (T_5M_4) recorded highest root dry weight at all crop growth stages in both the years. However, at 60 DAS and at harvest, the above combination (T_5M_4) was closely followed by T_5 M_3 (disc plough once + rotavator twice, both tractor drawn and IW/CPE = 1.0), T_4 M_4 (MB plough once + cultivator twice, both tractor drawn and IW/CPE = 1.2) and T_4 M_3 (MB plough once + cultivator twice, both tractor drawn and IW/CPE = 1.0), which were at par with each other, but significantly

Table 17 : Effect of tillage and soil moisture regimes on root dry weight of sunflower during crop growth period

Tillage (T)	Root dry weight (g plant^{-1})									
	1997-98					1998-99				
	Soil moisture regime (M)					Soil moisture regime (M)				
	M_1	M_2	M_3	M_4	Mean	M_1	M_2	M_3	M_4	Mean
					30 DAS					
T_1	5.28	5.45	5.71	5.89	5.58	5.75	6.03	6.44	6.89	6.24
T_2	6.05	6.19	6.83	6.96	6.51	6.84	7.33	7.91	8.04	7.53
T_3	6.22	6.46	7.15	7.20	6.76	6.69	7.28	7.98	8.33	7.59
T_4	7.06	7.52	8.16	8.46	7.80	7.47	8.25	8.93	9.06	8.43
T_5	6.90	7.36	8.25	8.60	7.78	7.13	7.86	8.59	8.89	8.12
Mean	6.30	6.60	7.22	7.42		6.79	7.35	7.96	8.24	
					60 DAS					
T_1	19.21	21.78	25.67	27.08	23.43	18.41	20.16	22.98	22.76	21.08
T_2	24.37	27.64	30.33	30.75	28.27	24.76	26.22	29.92	28.96	27.42
T_3	23.83	27.25	29.75	31.33	28.04	24.98	26.84	29.58	29.38	27.69
T_4	34.37	37.88	40.40	41.67	38.58	29.65	31.87	33.68	33.21	32.10
T_5	35.58	36.50	45.37	44.28	38.92	29.25	30.33	33.08	34.81	31.85
Mean	27.47	30.21	33.10	35.05		25.41	27.08	29.85	29.75	
					Harvest					
T_1	30.73	32.66	36.50	39.15	34.77	32.35	34.80	38.60	39.48	36.31
T_2	40.45	42.82	49.28	52.93	46.37	42.33	45.61	49.86	48.43	46.48
T_3	39.66	43.35	51.30	52.55	46.71	41.98	44.25	49.25	51.96	46.86
T_4	53.23	59.48	64.57	66.75	61.16	52.87	56.48	61.65	63.55	58.64
T_5	54.18	58.25	65.81	65.05	60.82	53.25	55.93	62.41	63.98	58.90
Mean	44.25	47.31	53.49	54.89		44.56	47.36	52.35	53.48	

	30 DAS	60 DAS	Harvest	30 DAS	60 DAS	Harvest
T						
SEm±	0.22	1.06	0.88	0.37	0.97	0.56
CD (P=0.05)	0.51	2.45	2.03	0.86	2.24	1.29
M						
SEm±	0.17	0.68	0.88	0.25	0.49	0.41
CD (P=0.05)	0.42	2.29	2.23	0.58	1.20	1.27
T at M						
SEm±	0.29	1.37	0.92	0.54	1.21	1.14
CD (P=0.05)	NS	4.64	3.90	NS	3.82	2.27
M at T						
SEm±	0.22	1.06	0.89	0.65	1.50	1.37
CD (P=0.05)	NS	3.62	4.95	NS	2.02	2.18

T_1 : Zero tillage
T_2 : Country plough twice + bullock drawn cultivar twice
T_3 : Country plough twice + power tiller rotavator twice
T_4 : Mould board plough once + cultivator twice, both tractor drawn
T_5 : Disc plugh once + rotavator twice, both tractor drawn

M_1 : IW/CPE = 0.6
M_2 : IW/CPE = 0.8
M_3 : IW/CPE = 1.0
M_4 : IW/CPE = 1.2

T1 - Zero tillage
T2 - Country plough twice + bullock drawn cultivator twice (farmers' practice)
T3 - Country plough twice + power tiller operated rotavator twice
T4 - MB plough once + cultivator twice, both tractor drawn
T5 - Disc plough once + rotavator twice, both tractor drawn

M1 - Irrigations at IW/CPE = 0.6
M2 - Irrigations at IW/CPE = 0.8
M3 - Irrigations at IW/CPE = 1.0
M4 - Irrigations at IW/CPE = 1.2

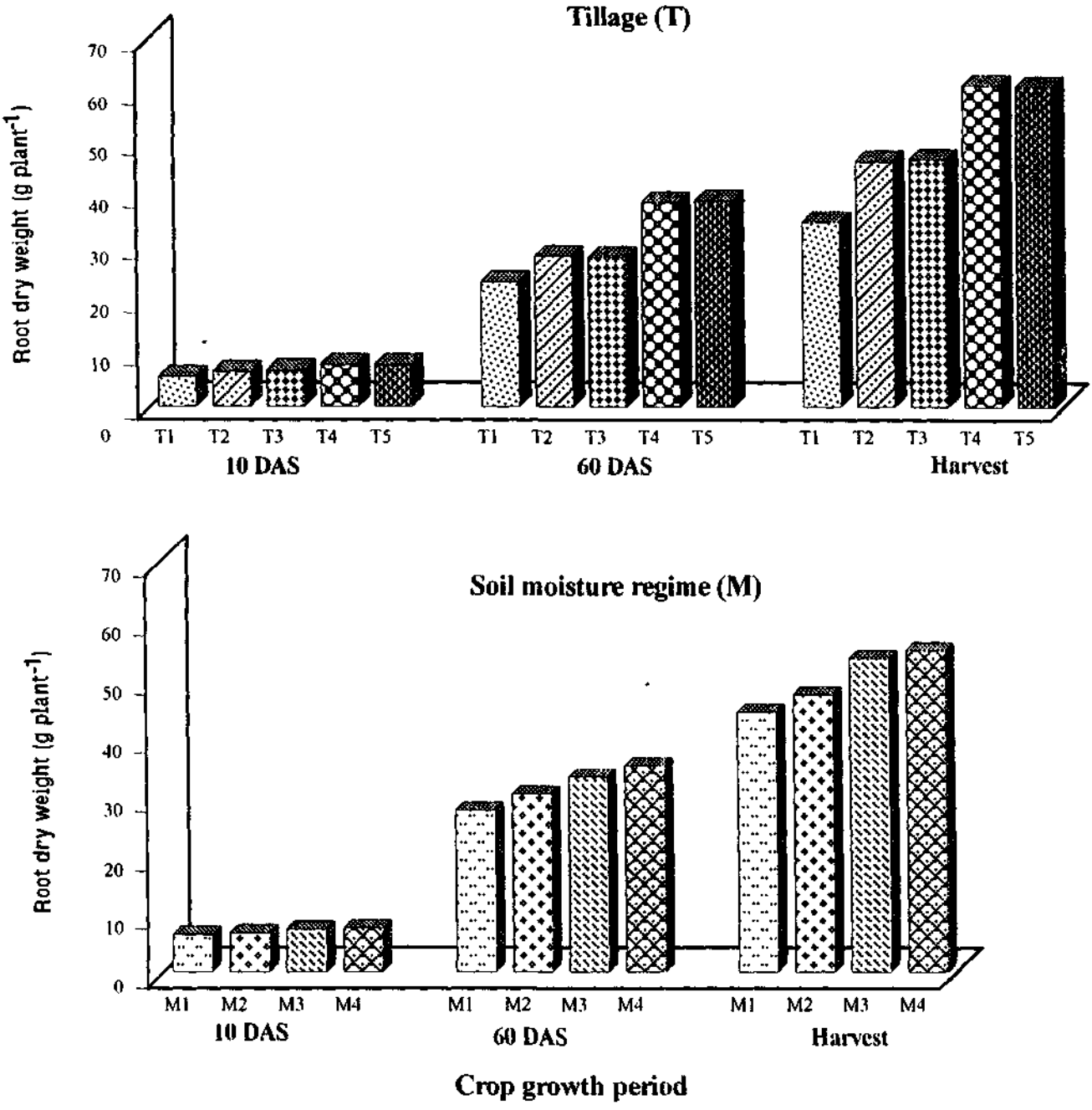


Fig.22: Effect of tillage treatments and soil moisture regimes on root dry weight of sunflower during crop growth period, 1997-98

T1 - Zero tillage
T2 - Country plough twice + bullock drawn cultivator twice (farmers' practice)
T3 - Country plough twice + power tiller operated rotavator twice
T4 - MB plough once + cultivator twice, both tractor drawn
T5 - Disc plough once + rotavator twice, both tractor drawn

M1 - Irrigations at IW/CPE = 0.6
M2 - Irrigations at IW/CPE = 0.8
M3 - Irrigations at IW/CPE = 1.0
M4 - Irrigations at IW/CPE = 1.2

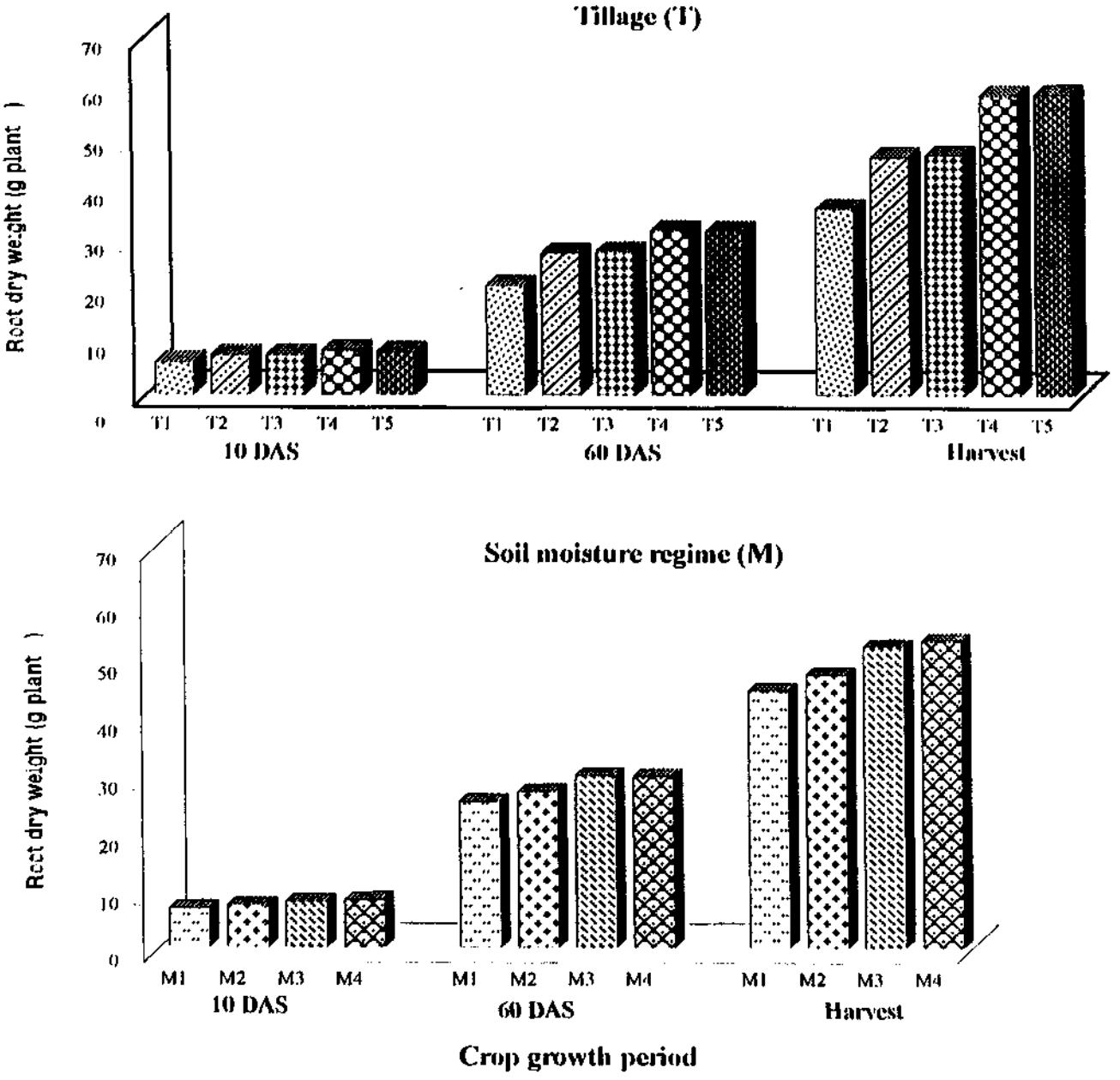


Fig. 23: Effect of tillage treatments and soil moisture regimes on root dry weight of sunflower during crop growth period, 1998-99

higher compared to rest of the combinations. Lowest root dry weight was obtained with T_1 M_1 (zero tillage and IW/CPE ratio of 0.60) combination.

4.3.5 Shoot dry matter accumulation

Data are furnished in Table 19 and depicted in Figs. 24 and 25.

Variations in shoot dry matter due to tillage treatments and soil moisture regimes and their interactions were significant at all the stages of sampling during both years of study.

At 30 DAS, tillage treatment T_5 (disc plough once + rotavator twice, both tractor drawn) recorded highest shoot dry matter accumulation (246 kg ha^{-1} in 1997-98 and 263 kg ha^{-1} in 1998-99) closely followed by T_3 (country plough twice + power tillers operated rotavator twice). Both these treatments (T_5 and T_3) were significantly superior to rest of the tillage treatments viz. T_4 (MB plough once + cultivator twice, both tractor drawn), T_2 (country plough twice + bullock drawn cultivator twice) and T_1 (zero tillage) in both years of study. Lowest dry matter content was obtained with T_1 (zero tillage) treatment in both years of study. Soil moisture regime M_4 (IW/CPE = 1.2) was found to be superior in shoot dry matter accumulation at 30 DAS (237 for 249 kg ha^{-1} in first and second years, respectively, which was significantly superior to other three moisture regimes. Minimum shoot dry matter was obtained with M_1 (IW/CPE 0.6) soil moisture regime.

At 60 DAS and at harvest, highest trends of variations due to tillage and soil moisture treatments were similar to those of 30 DAS. However, the differences got widered with advancement in the age of the crop.

Table 18 : Effect of tillage treatments and soil moisture regimes on shoot dry matter accumulation during crop growth period

Tillage (T)	Dry matter accumulation (kg ha^{-1})									
	1997-98					1998-99				
	Soil moisture regime (M)					Soil moisture regime (M)				
	M_1	M_2	M_3	M_4	Mean	M_1	M_2	M_3	M_4	Mean
					30 DAS					
T_1	152	164	176	190	171	161	176	192	206	184
T_2	180	199	211	221	203	186	210	211	225	208
T_3	199	227	240	264	232	218	235	255	280	247
T_4	191	210	228	239	217	195	210	229	245	220
T_5	219	241	254	271	246	241	254	270	288	263
Mean	189	208	222	237		200	217	231	249	
					60 DAS					
T_1	1009	1193	1368	1390	1240	968	1144	1334	1415	1215
T_2	1156	1447	1622	1698	1481	1165	1386	1559	1652	1440
T_3	1310	1612	1752	1797	1618	1263	1521	1737	1804	1581
T_4	1396	1714	1812	1835	1689	1421	1667	1843	1893	1706
T_5	1562	1785	1949	2026	1830	1564	1778	1904	1965	1803
Mean	1287	1550	1701	1749		1276	1499	1675	1746	
					Harvest					
T_1	1626	1952	2131	2178	1973	1536	1746	2040	2168	1872
T_2	1847	2280	2576	2664	2342	1802	2195	2490	2639	2281
T_3	2087	2580	2857	2952	2619	1993	2527	2862	3036	2604
T_4	2210	2706	3021	3154	2776	2253	2767	3052	3101	2793
T_5	2490	3079	3465	3545	3145	2493	2990	3287	3407	3044
Mean	2052	2522	2810	2899		2015	2445	2743	2870	

	30 DAS	60 DAS	Harvest	30 DAS	60 DAS	Harvest
T						
SEm±	3.45	39.12	72.50	5.03	31.50	50.50
CD (P=0.05)	10.23	93.20	169.30	12.45	76.20	110.70
M						
SEm±	2.72	30.90	60.20	3.89	35.80	42.60
CD (P=0.05)	6.68	76.60	132.10	9.10	81.70	97.90
T at M						
SEm±	5.72	56.20	91.90	7.91	49.40	61.38
CD (P=0.05)	19.53	176.40	272.17	26.78	154.90	171.40
M at T						
SEm±	8.15	70.40	100.50	6.21	58.10	71.50
CD (P=0.05)	25.70	203.20	312.48	21.70	174.00	231.60

T_1 : Zero tillage
T_2 : Country plough twice + bullock drawn cultivar twice
T_3 : Country plough twice + power tiller rotavator twice
T_4 : Mould board plough once + cultivator twice, both tractor drawn
T_5 : Disc plough once + rotavator twice, both tractor drawn

M_1 : IW/CPE = 0.6
M_2 : IW/CPE = 0.8
M_3 : IW/CPE = 1.0
M_4 : IW/CPE = 1.2

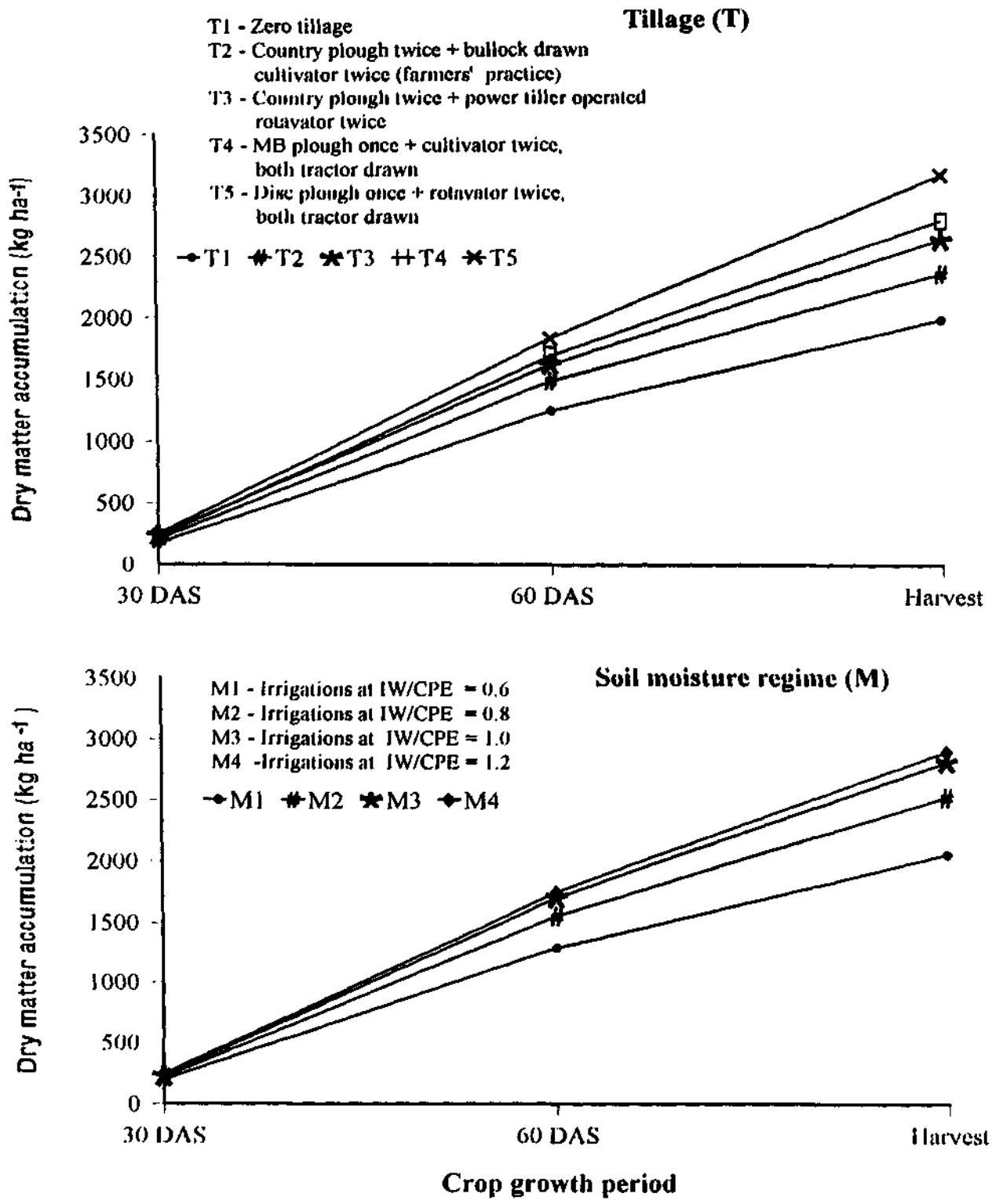


Fig. 24 : Effect of tillage treatments and soil moisture regimes on shoot dry matter accumulation during crop growth period, 1997-98

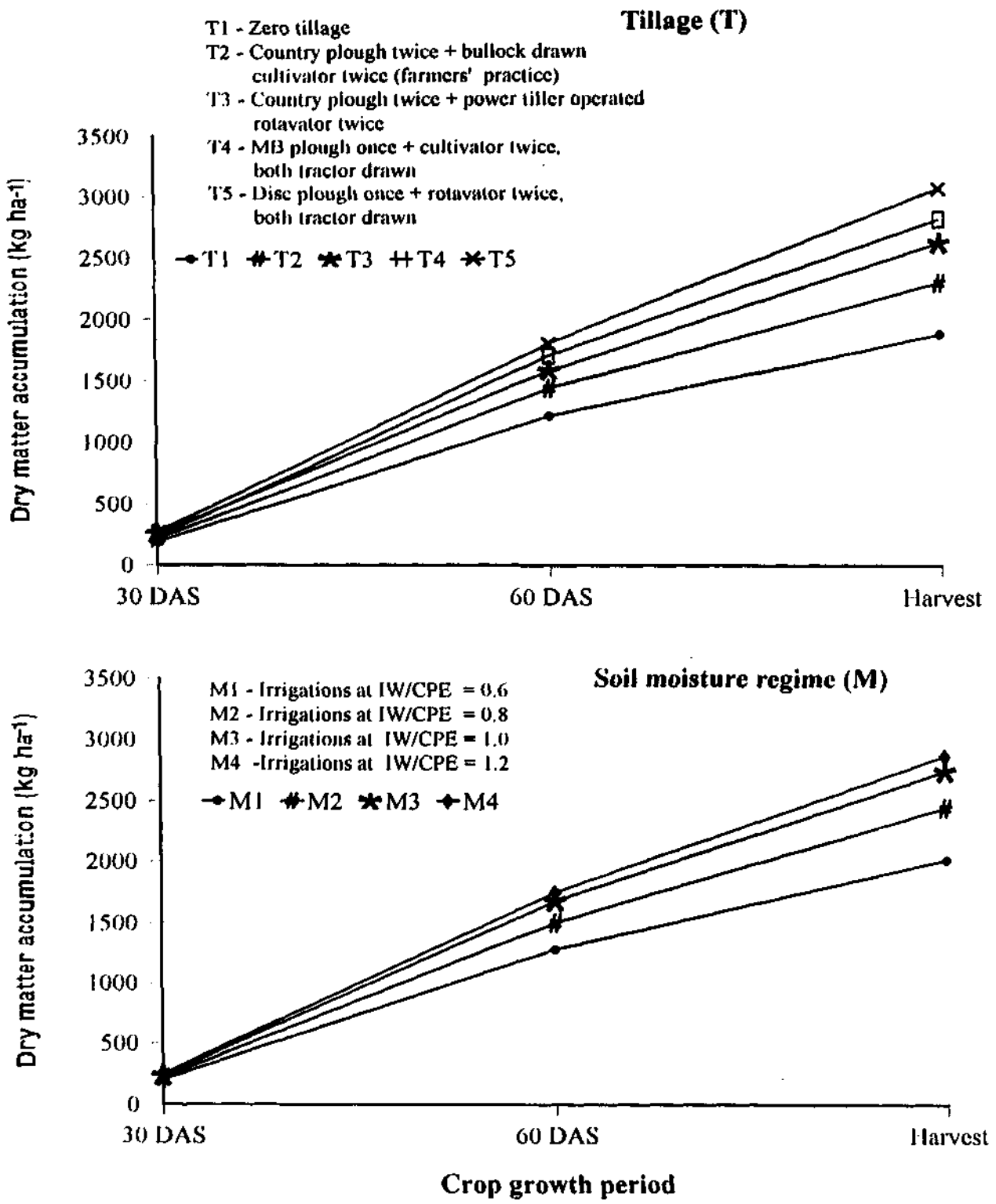


Fig. 25 : Effect of tillage treatments and soil moisture regimes on shoot dry matter accumulation during crop growth period, 1998-99

The interaction between tillage treatments and soil moisture regimes were significant on shoot dry matter accumulation. Shoot dry matter accumulation was highest in combinations of disc plough once + rotavator twice, both tractor drawn and IW/CPE = 1.2) and T_5 M_3 tractor drawn (disc plough once + rotavator twice, and IW/CPE = 1.0) treatment combinations, which did not differ significantly with each other, but were significantly superior to the rest of treatment combinations. Lowest dry matter production was recorded with T_1 M_1 combination (zero tillage and IW/CPE = 0.6).

However, at 30 DAS, T_5 M_4, T_5 M_3 and T_3 M_4 treatment combinations recorded higher shoot dry matter production, and were at par with each other, and were significantly superior to other treatment combinations.

4.3.6 Head diameter

Data are presented in Table 12 and illustrated in Fig. 26.

Deep tillage treatments (T_4 and T_5) produced bigger sized heads (16.44 and 16.14 cm for T_4 and T_5 in first year, ; 15.99 and 15.65 on for T_4 and T_5, respectively, in second year) compared to shallow tillage treatments T_3 (country ploughing twice + power tiller operated rotavator twice), T_2 (country ploughing twice + bullock drawn cultivator twice) and T_1 (zero tillage). The smallest head size was recorded with zero tillage (11.53 and 10.71 cm in the first and second years, respectively).

Wettest soil moisture regime M_4 (IW/CPE 1.20) resulted in largest head among the soil moisture regimes followed by M_3 (IW/CPE of 1.00), which were on par with each other and significantly superior to other two moisture regimes

Table 19 : Effect of tillage treatments and soil moisture regimes as sunflower head diameter at harvest

Tillage (T)	Head diameter (cm)									
	1997-98					1998-99				
	Soil moisture regimes					Soil moisture regimes				
	M_1	M_2	M_3	M_4	Mean	M_1	M_2	M_3	M_4	Mean
T_1	10.15	11.23	12.14	12.61	11.53	9.28	9.93	11.28	12.35	10.71
T_2	12.00	13.20	14.15	14.67	13.50	11.34	12.78	13.72	14.59	13.11
T_3	12.45	13.51	14.98	15.38	14.08	11.26	12.88	15.08	15.45	13.67
T_4	14.38	16.02	17.37	17.98	16.44	13.77	15.35	17.07	17.77	15.99
T_5	13.91	15.73	17.25	17.68	16.14	13.18	15.12	16.82	17.48	15.65
Mean	12.58	13.94	15.18	15.66		11.77	13.21	14.79	15.53	

	1997-98	1998-99
T		
SEm±	0.27	0.43
CD (P=0.05)	0.63	1.00
M		
SEm±	0.20	0.47
CD (P=0.05)	0.51	0.91
T at M		
SEm±	0.34	0.56
CD (P=0.05)	1.36	2.04
M at T		
SEm±	0.37	0.67
CD (P=0.05)	1.33	1.73

T_1 : Zero tillage
T_2 : Country plough twice + bullock drawn cultivar twice
T_3 : Country plough twice + power tiller rotavator twice
T_4 : Mould board plough once + cultivator twice, both tractor darwn
T_5 : Disc plugh once + rotavator twice, both tractor drawn

M_1 : IW/CPE = 0.6
M_2 : IW/CPE = 0.8
M_3 : IW/CPE = 1.0
M_4 : IW/CPE = 1.2

T1 - Zero tillage
T2 - Country plough twice + bullock drawn cultivator twice (farmers' practice)
T3 - Country plough twice + power tiller operated rotavator twice
T4 - MB plough once + cultivator twice, both tractor drawn
T5 - Disc plough once + rotavator twice, both tractor drawn

M1 - Irrigations at IW/CPE = 0.6
M2 - Irrigations at IW/CPE = 0.8
M3 - Irrigations at IW/CPE = 1.0
M4 -Irrigations at IW/CPE = 1.2

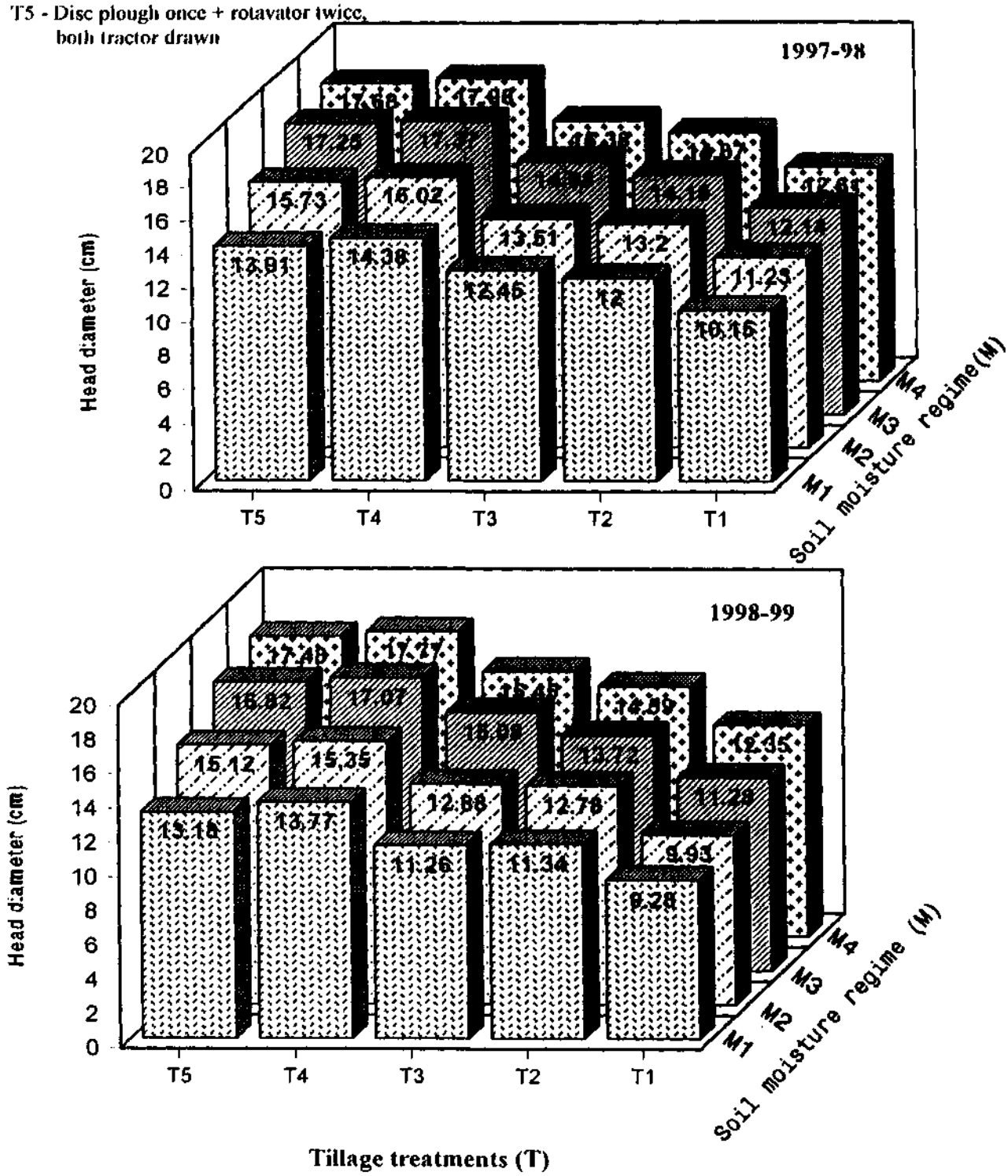


Fig. 26 : Effect of tillage treatments and soil moisture regimes on head diameter of sunflower

a

b

7 Effect of tillage treatment on crop growth

(a) T_1 : Zero tillage

(b) T_2 (Ploughing twice with country plough + cultivator)

a

b

8 Effect of tillage treatments as crop growth

(a) T_3 (ploughing twice with country plough + rotavator)

(b) T_5 (Plough twice with tractor drawn disc plough+ rotavator)

a

b

9 Effect of soil moisture regimes on
(a) Variation in crop growth under T_5
(b) Variation in head sizes under T_5

10 Effect of soil moisture regimes on variation in head size under T_4

viz., M_2 (IW/CPE = 0.8) and M_1 (IW/CPE = 0.6). The smallest head diameter was recorded with M_1 (IW/CPE = 0.6) soil moisture regime.

The interaction effect of tillage and soil moisture regime on head diameter of sunflower showed that the largest head was produced (17.68 and 17.48 cm in first and second years, respectively) with T_4 M_4 combination (MB plough once + cultivator twice, both tractor drawn and soil water supply at IW/CPE = 1.2), followed by T_5 M_4 (Disc plough once + rotavator twice, both tractor drawn and IW/CPE = 1.2), T_4 M_3 (MB plough once + cultivator twice, both tractor drawn and IW/CPE = 1.0) and T_5 M_3 (Disc plough once + rotavator twice, both tractor drawn and IW/CPE = 1.0), which were at par with each other and all these treatment combinations were superior to the rest of treatment combinations. The smallest head was produced in T_1 M_1 (zero tillage coupled with irrigation at IW/CPE ratio of 0.6) in both the years of investigation.

4.3.7 1000 seed weight

The data are presented in Table 20 and illustration in Fig. 27. Significant differences in 1000 seed weight due to tillage treatments, soil moisture regimes and their interaction were observed in both the years of study.

Deep tillage treatments T_5 and T_4 recorded higher 1000 seed weight (41.62 and 40.96 g in first year; 40.28 and 40.23 g in second year in T_5 and T_4 respectively), which were at par among themselves and significantly superior to the shallow (T_3 and T_2) and zero (T_1) tillage treatments. Zero tillage treatment resulted in the lower test weight in both the years of study (35.53 and 34.69 g in first and second years, respectively).

Table 20 : Effect of tillage treatments and soil moisture regimes as 1000 seed weight of sunflower

Tillage (T)	1000 seed weight (g)									
	1997-98					1998-99				
	Soil moisture regimes					Soil moisture regimes				
	M_1	M_2	M_3	M_4	Mean	M_1	M_2	M_3	M_4	Mean
T_1	32.05	34.47	36.16	39.45	35.53	31.12	33.98	35.98	37.68	34.69
T_2	32.96	35.86	38.44	41.57	37.21	34.16	36.76	37.84	39.24	36.99
T_3	33.50	36.18	39.75	42.28	37.93	34.98	37.23	38.88	41.06	38.04
T_4	36.84	39.26	43.00	44.76	40.96	36.37	40.30	41.27	42.97	40.23
T_5	37.76	40.35	43.89	44.50	41.62	37.70	39.65	41.56	42.22	40.28
Mean	34.62	37.22	40.25	42.51		34.87	37.58	39.10	40.63	

	1997-98	1998-99
T		
SEm±	0.65	0.47
CD (P=0.05)	1.50	1.09
M		
SEm±	0.34	0.40
CD (P=0.05)	0.95	1.21
T at M		
SEm±	0.77	0.89
CD (P=0.05)	3.62	2.65
M at T		
SEm±	0.46	0.92
CD (P=0.05)	1.77	2.38

T_1 : Zero tillage
T_2 : Country plough twice + bullock drawn cultivar twice
T_3 : Country plough twice + power tiller rotavator twice
T_4 : Mould board plough once + cultivator twice, both tractor drawn
T_5 : Disc plough once + rotavator twice, both tractor drawn

M_1 : IW/CPE = 0.6
M_2 : IW/CPE = 0.8
M_3 : IW/CPE = 1.0
M_4 : IW/CPE = 1.2

T1 - Zero tillage
T2 - Country plough twice + bullock drawn cultivator twice (farmers' practice)
T3 - Country plough twice + power tiller operated rotavator twice
T4 - MB plough once + cultivator twice, both tractor drawn
T5 - Disc plough once + rotavator twice, both tractor drawn

M1 - Irrigations at IW/CPE = 0.6
M2 - Irrigations at IW/CPE = 0.8
M3 - Irrigations at IW/CPE = 1.0
M4 -Irrigations at IW/CPE = 1.2

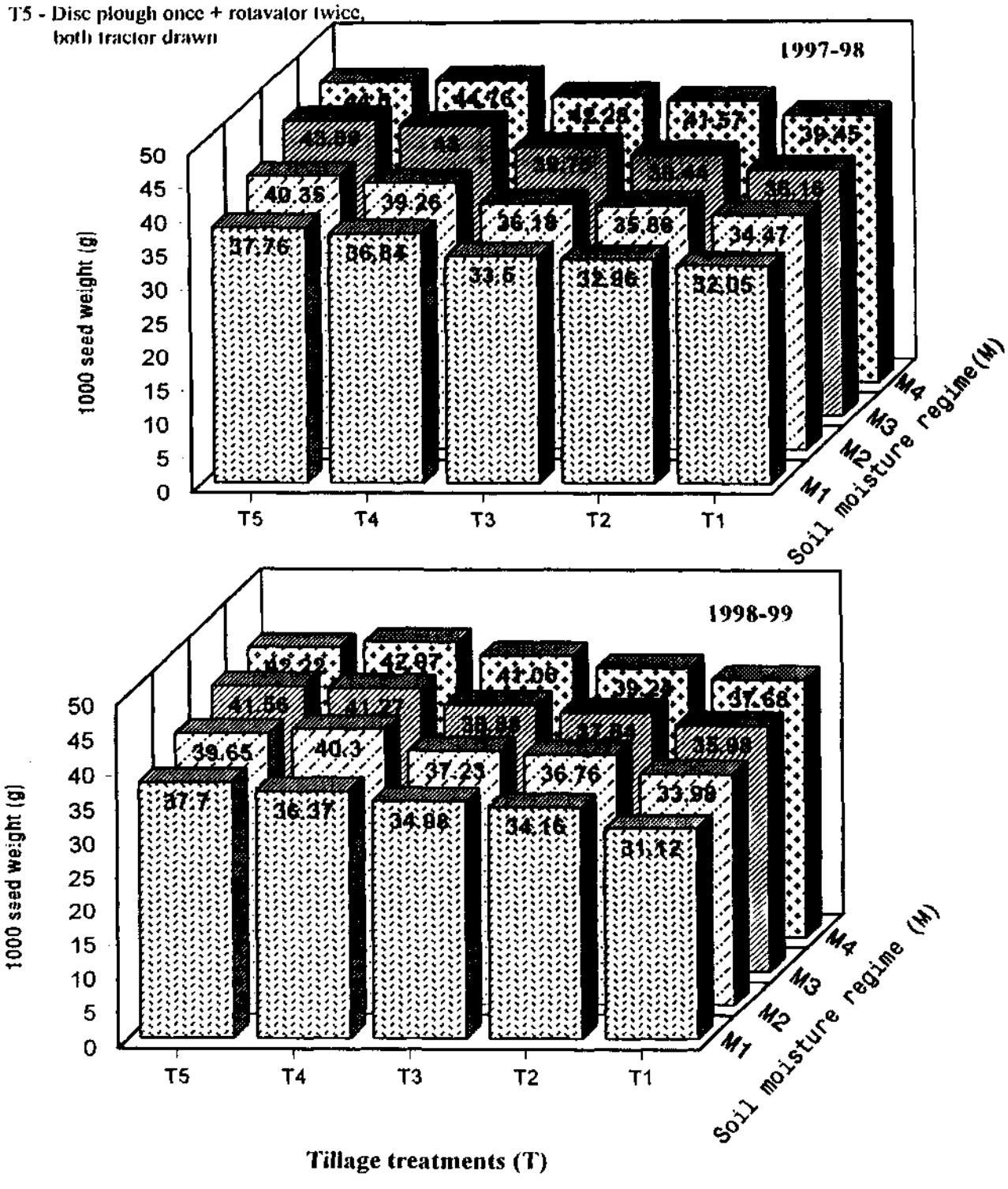


Fig. 27 : Effect of tillage treatments and soil moisture regimes on 1000 seed weight of sunflower

Among the soil moisture regimes, M_4 (IW/CPE = 1.2) recorded highest 1000 seed weight (42.51 and 40.63 g in first and second years of the study, respectively) followed by M_3 (IW/CPE = 1.0), which were at par with each other and are significantly superior to other two soil moisture regimes M_2 (IW/CPE = 0.8) and M_1 (IW/CPE = 0.6). The lowest 1000 seed weight was recorded with driest soil moisture regime M_1 (34.62 and 34.87 g in first and second years, respectively).

Interaction between tillages and soil moisture regimes were also significant. The highest test weight (44.76 and 42.97 g in 1997-98 and 1998-99, respectively) was recorded with T_4 M_4 combination followed by T_5 M_4, T_5 M_3 and T_4 M_3 combinations, which were statistically at par among themselves, and were significantly superior to other treatment combinations. The lowest 1000 test weight was recorded with T_1 M_1 combination (32.05 and 31.12 in first and second years, respectively).

4.3.8 Seed yield

Data are presented in Table 21 and depicted in Fig. 28.

Seed yield of sunflower deep tillage treatment (T_5 tractor drawn disc plough and rotavator treatment) was the highest (1357 and 1265 kg ha^{-1} in first and second year, respectively) and was significantly superior to other tillage treatments. Seed yield in other tillage treatments was decreasing significantly in the order of T_3. Among all the tillage treatments T_1 (zero tillage) recorded the lowest seed yield in both years of investigation (753 and 686 kg ha^{-1} in first and second years, respectively).

Table 21 : Effect of tillage treatments and soil moisture regimes on seed yield of sunflower

Tillage (T)	Seed yield (kg ha^{-1})									
	1997-98					1998-99				
	Soil moisture regime (M)					Soil moisture regime (M)				
	M_1	M_2	M_3	M_4	Mean	M_1	M_2	M_3	M_4	Mean
T_1	557	742	838	876	753	510	633	767	834	686
T_2	693	924	1097	1156	967	651	838	1004	1085	894
T_3	774	1036	1228	1305	1086	718	975	1158	1256	1022
T_4	881	1176	1315	1398	1192	851	1131	1285	1341	1152
T_5	996	1321	1528	1584	1357	944	1248	1392	1478	1265
Mean	780	1040	1201	1264		735	965	1121	1199	

	1997-98	1998-99
T		
SEm±	25.8	30.0
CD (P=0.05)	62.6	73.3
M		
SEm±	31.6	33.1
CD (P=0.05)	75.4	84.4
T at M		
SEm±	49.8	42.67
CD (P=0.05)	160.5	126.6
M at T		
SEm±	59.2	46.4
CD (P=0.05)	190.2	120.5

T_1 : Zero tillage
T_2 : Country plough twice + bullock drawn cultivar twice
T_3 : Country plough twice + power tiller rotavator twice
T_4 : Mould board plough once + cultivator twice, both tractor drawn
T_5 : Disc plough once + rotavator twice, both tractor drawn

M_1 : IW/CPE = 0.6
M_2 : IW/CPE = 0.8
M_3 : IW/CPE = 1.0
M_4 : IW/CPE = 1.2

T1 - Zero tillage
T2 - Country plough twice + bullock drawn cultivator twice (farmers' practice)
T3 - Country plough twice + power tiller operated rotavator twice
T4 - MB plough once + cultivator twice, both tractor drawn
T5 - Disc plough once + rotavator twice, both tractor drawn

M1 - Irrigations at IW/CPE = 0.6
M2 - Irrigations at IW/CPE = 0.8
M3 - Irrigations at IW/CPE = 1.0
M4 -Irrigations at IW/CPE = 1.2

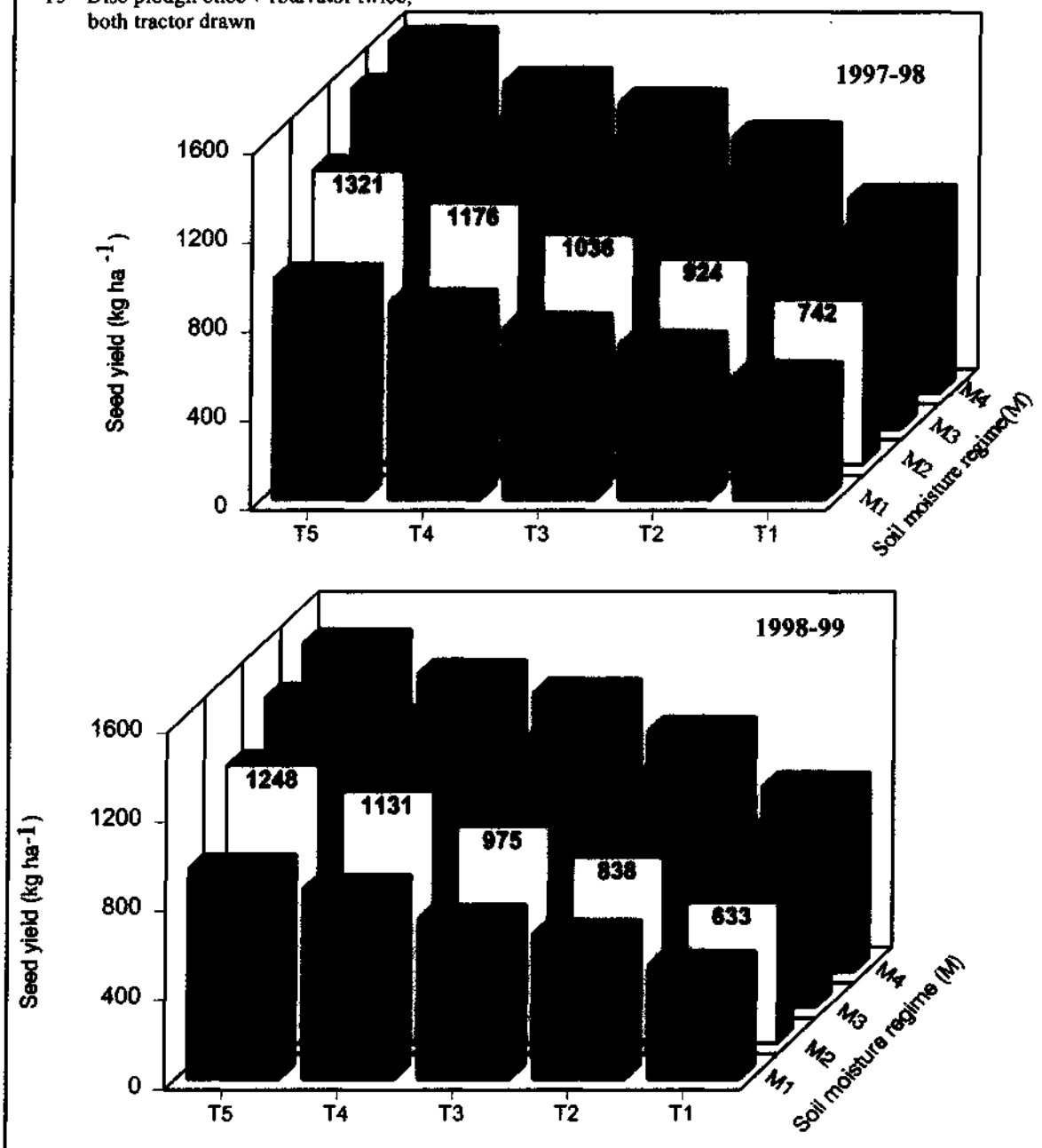


Fig. 28 : Effect of tillage treatments and soil moisture regimes on seed yield of sunflower

Wettest soil moisture regime, M_4 (irrigation scheduled at IW/CPE 1.2) recorded maximum seed yield (1264 and 1199 kg ha^{-1} in first and second year, respectively) which was closely followed by M_3 (IW/CPE = 1.0), but statistically on par with each other, and significantly higher compared to M_2 (IW/CPE = 0.8) and M_1 (IW/CPE = 0.6). Lowest seed yield was recorded in M_1 soil moisture regime (IW/CPE = 0.6) at 780 and 735 kg ha^{-1} in first and second year, respectively.

Interaction effects of tillage and soil moisture regimes on seed yield of sunflower indicated that maximum seed yield was obtained with T_5 M_4 (when tillage was done with tractor drawn disc plough once + rotavator twice and irrigations scheduled at IW/CPE 1.2) followed by T_5 M_3 combination (tractor drawn disc plough once + rotavator twice, both tractor drawn and moisture regime of IW/CPE = 1.0). These two combinations (T_5 M_4 and T_5 M_3) were statistically at par, but significantly superior to the rest of the treatment combinations. Lowest seed yield was noticed with T_1M_1 combination (zero tillage with moisture supply at IW/CPE ratio of 0.6) in both years of study.

The data (Table 21) further revealed that seed yield with T_5 M_2 combination was at par with these of T_3 M_4, T_4 M_3 and was much higher than T_2 M_4. The seed yield with T_4 M_2 was at par with these of T_3 M_3, T_2 M_4, but significantly higher than T_1 M_4. The yield with T_3 M_2 was at par with that of T_2 M_3 but significantly higher than T_1 M_4.

4.3.9 Harvest index

The data are presented in Table 22 and illustrated in Fig. 22.

Table 22 : Effect of tillage treatments and soil moisture regimes on harvest index (HI) of sunflower

Tillage (T)	Harvest index (%)									
	1997-98					1998-99				
	Soil moisture regimes					Soil moisture regimes				
	M_1	M_2	M_3	M_4	Mean	M_1	M_2	M_3	M_4	Mean
T_1	34.24	38.01	39.33	40.15	37.93	33.20	35.43	37.73	38.30	36.17
T_2	37.58	40.47	42.57	43.47	41.02	36..17	38.20	40.93	41.17	39.12
T_3	37.57	40.18	42.99	43.98	41.18	36.03	38.83	40.40	41.51	39.21
T_4	39.87	43.30	43.54	44.80	42.90	37.60	40.83	41.97	43.25	40.90
T_5	40.03	42.92	44.12	44.68	42.94	37.20	41.77	42.13	43.33	41.10
Mean	37.86	40.97	42.51	43.42		36.04	39.31	40.63	41.92	

	1997-98	1998-99
T		
SEm±	0.64	0.55
CD (P=0.05)	1.47	1.28
M		
SEm±	0.46	0.40
CD (P=0.05)	1.08	091

T_1 : Zero tillage
T_2 : Country plough twice + bullock drawn cultivar twice
T_3 : Country plough twice + power tiller rotavator twice
T_4 : Mould board plough once + cultivator twice, both tractor drawn
T_5 : Disc plough once – rotavator twice, both tractor drawn

M_1 : IW/CPE = 0.6
M_2 : IW/CPE = 0.8
M_3 : IW/CPE = 1.0
M_4 : IW/CPE = 1.2

T1 - Zero tillage
T2 - Country plough twice + bullock drawn cultivator twice (farmers' practice)
T3 - Country plough twice + power tiller operated rotavator twice
T4 - MB plough once + cultivator twice, both tractor drawn
T5 - Disc plough once + rotavator twice, both tractor drawn

M1 - Irrigations at IW/CPE = 0.6
M2 - Irrigations at IW/CPE = 0.8
M3 - Irrigations at IW/CPE = 1.0
M4 - Irrigations at IW/CPE = 1.2

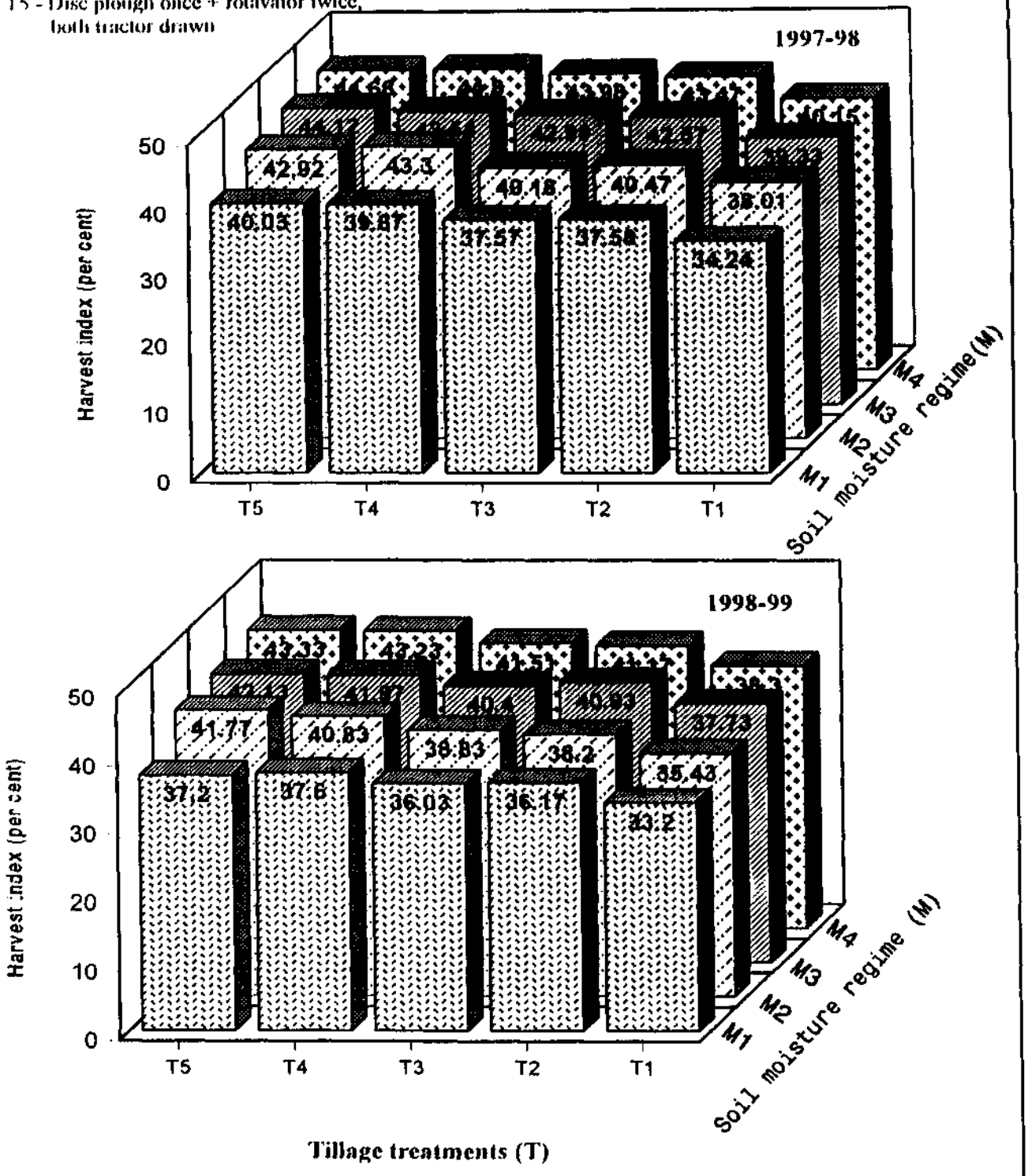


Fig. 29 : Effect of tillage treatments and soil moisture regimes on harvest index of sunflower

Tillage had positive and significant effect on harvest index. Highest harvest index was associated with T_5 (42.94 per cent in first year and 41.10 per cent in second year), followed by T_4 (42.90 per cent) in first year and 40.90% in second year). Which were at par with each other and significantly higher than other tillage treatments T_3 (41.18 in first year and 39.21 in second year), T_2 (41.02 % in first year and 39.12 % in second year) and T_1 (37.93 % in first year and 36.17 % in second year). Lowest harvest index was associated with zero tillage (T_1) in both the years.

Irrigation at IW/CPE ratio of 1.2 (M_4) recorded highest harvest index in both the years. In the first year (1997-98) of investigation, highest harvest index recorded in M_4 (IW/CPE = 1.2) and M_3 (IW/CPE = 1.0) which were at par with each other and both were significantly higher than M_2 (IW/CPE = 0.80) and M_1 (IW/CPE = 0.6), However, in the second year M_4 was significantly higher than M_3, M_2 and M_1 moisture regimes.

Interaction effects of tillage and soil moisture regimes were not significant on the harvest index in both the years of study.

4.3.10 Oil content

Data furnished in Table 23 and Fig. 30. The data indicated that tillage treatments, soil moisture regimes, as well as their interactions significantly influenced oil content.

Ploughing the field to deeper depths (T_5 and T_4) resulted in significantly higher oil content (41.69 and 41.60 per cent in first year 40.25 and 40.19 per cent in second year for T_5 and T_4, respectively). Both the above treatments

Table 23 : Effect of tillage treatments and soil moisture regimes on oil content of sunflower seed

Tillage	Oil content (%)									
	1997-98					1998-99				
	Soil moisture regimes					Soil moisture regimes				
	M_1	M_2	M_3	M_4	Mean	M_1	M_2	M_3	M_4	Mean
T_1	35.84	36.45	37.33	37.81	36.86	34.06	35.59	36.48	37.13	35.81
T_2	36.62	37.38	39.46	39.86	38.33	35.92	37.00	38.11	39.35	37.59
T_3	36.30	38.12	39.21	40.77	38.65	36.35	39.59	38.83	39.77	38.13
T_4	39.25	41.70	42.62	42.83	41.60	38.12	40.10	41.29	41.50	40.25
T_5	39.61	41.33	42.18	42.66	41.44	38.07	40.25	41.08	41.36	40.19
Mean	37.52	40.00	40.16	40.79		36.50	38.11	39.16	39.82	

	1997-98	1998-99
T		
SEm±	0.48	0.35
CD (P=0.05)	1.12	0.83
M		
SEm±	0.22	0.27
CD (P=0.05)	0.55	0.67
T at M		
SEm±	0.53	0.58
CD (P=0.05)	2.59	1.81
M at T		
SEm±	0.46	0.72
CD (P=0.05)	1.47	2.08

T_1 : Zero tillage
T_2 : Country plough twice + bullock drawn cultivar twice
T_3 : Country plough twice + power tiller rotavator twice
T_4 : Mould board plough once + cultivator twice, both tractor drawn
T_5 : Disc plough once + rotavator twice, both tractor drawn

M_1 : IW/CPE = 0.6
M_2 : IW/CPE = 0.8
M_3 : IW/CPE = 1.0
M_4 : IW/CPE = 1.2

T1 - Zero tillage
T2 - Country plough twice + bullock drawn cultivator twice (farmers' practice)
T3 - Country plough twice + power tiller operated rotavator twice
T4 - MB plough once + cultivator twice, both tractor drawn
T5 - Disc plough once + rotavator twice, both tractor drawn

M1 - Irrigations at IW/CPE = 0.6
M2 - Irrigations at IW/CPE = 0.8
M3 - Irrigations at IW/CPE = 1.0
M4 -Irrigations at IW/CPE = 1.2

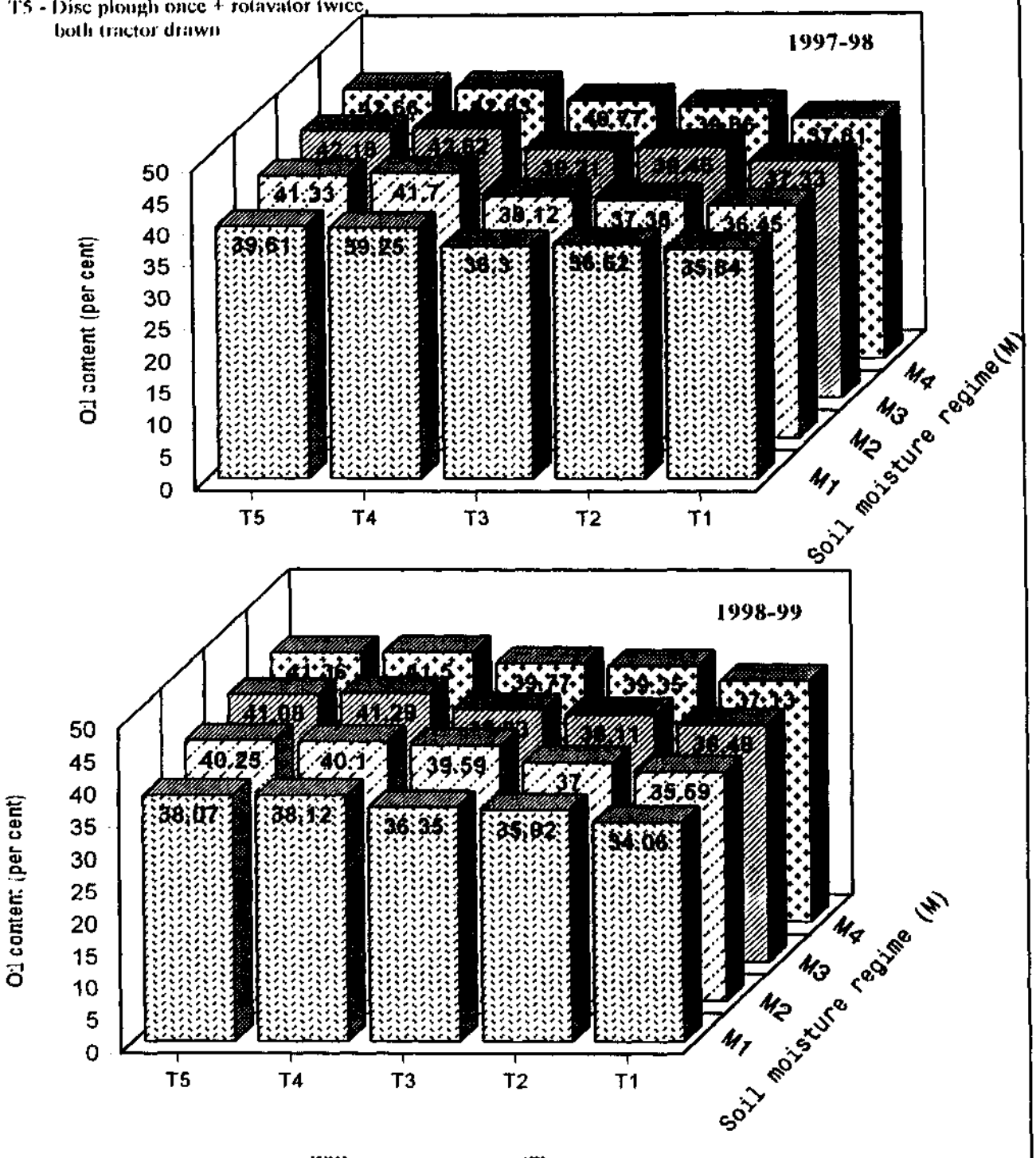


Fig. 30 : Effect of tillage treatments and soil moisture regimes on oil content of sunflower

were at par with each other but significantly superior as compared to other tillage treatments. Zero tillage (T_1) treatment recorded lowest oil content in both the years of study.

Scheduling of irrigations at shorter intervals (M_4) recorded higher oil content (40.79 and 39.82 per cent in first, and second years of study, respectively) closely followed by M_3 (IW/CPE = 1.0), which were on par and were significantly superior to other soil moisture regimes, M_2 (IW/CPE = 0.8) and M_1 (IW/CPE = 0.6). Driest soil moisture regime (M_1) (IW/CPE = 0.6) recorded lowest oil content in both the years.

The treatment combination of T_4 M_4 (tractor drawn MB plough once + cultivator twice, coupled with irrigation at IW/CPE 1.2) recorded highest oil content (42.83 per cent in first year and 41.50 per cent in second year) followed by T_5 M_4, T_4 M_3, T_5 M_3, T_4 M_2, T_5 M_2 and T_3 M_4 which were on par with each other but were significantly superior to other treatment combinations in both the years of study. T_1 M_1 combination (zero tillage and IW/CPE = 0.6) resulted in lowest oil content of 35.84 and 34.06 per cent in first and second years, respectively).

4.3.11 Oil yield

Data are presented in Table 24 and illustrated in Figure 31.

Tillage treatments, soil moisture regimes and their interaction effects significantly influenced the oil yield of sunflower. The oil yield obtained in different tillage treatments is in the order of T_5, > T_4, > T_3 > T_2 > T_1.

Table 24 : Effect of tillagae treatments and soil moisture regimes on oil yield of sunflower

Tillage (T)	Oil yield (kg ha^{-1})									
	1997-98					1998-99				
	Soil moisture regimes (M)					Soil moisture regimes (M)				
	M_1	M_2	M_3	M_4	Mean	M_1	M_2	M_3	M_4	Mean
T_1	200	270	312	331	278	174	225	280	309	247
T_2	254	345	433	460	373	234	310	389	428	340
T_3	281	395	494	532	426	261	366	449	499	394
T_4	346	490	561	597	499	323	453	531	556	466
T_5	394	532	650	676	566	359	504	570	611	511
Mean	295	407	492	519		270	372	444	481	

	1997-98	1998-99
T		
SEm±	13.88	11.78
CD (P=0.05)	32.02	27.16
M		
SEm±	12.16	15.12
CD (P=0.05)	30.34	39.17
T at M		
SEm±	17.45	17.45
CD (P=0.05)	58.17	50.05
M at T		
SEm±	19.88	21.22
CD (P=0.05)	78.57	61.80

T_1 : Zero tillage
T_2 : Country plough twice + bullock drawn cultivar twice
T_3 : Country plough twice + power tiller rotavator twice
T_4 : Mould board plough once + cultivator twice, both tractor dawn
T_5 : Disc plough once + rotavator twice, both tractor dawn

M_1 : IW/CPE = 0.6
M_2 : IW/CPE = 0.8
M_3 : IW/CPE = 1.0
M_4 : IW/CPE = 1.2

T1 - Zero tillage
T2 - Country plough twice + bullock drawn cultivator twice (farmers' practice)
T3 - Country plough twice + power tiller operated rotavator twice
T4 - MB plough once + cultivator twice, both tractor drawn
T5 - Disc plough once + ratavator twice, both tractor drawn

M1 - Irrigations at IW/CPE = 0.6
M2 - Irrigations at IW/CPE = 0.8
M3 - Irrigations at IW/CPE = 1.0
M4 -Irrigations at IW/CPE = 1.2

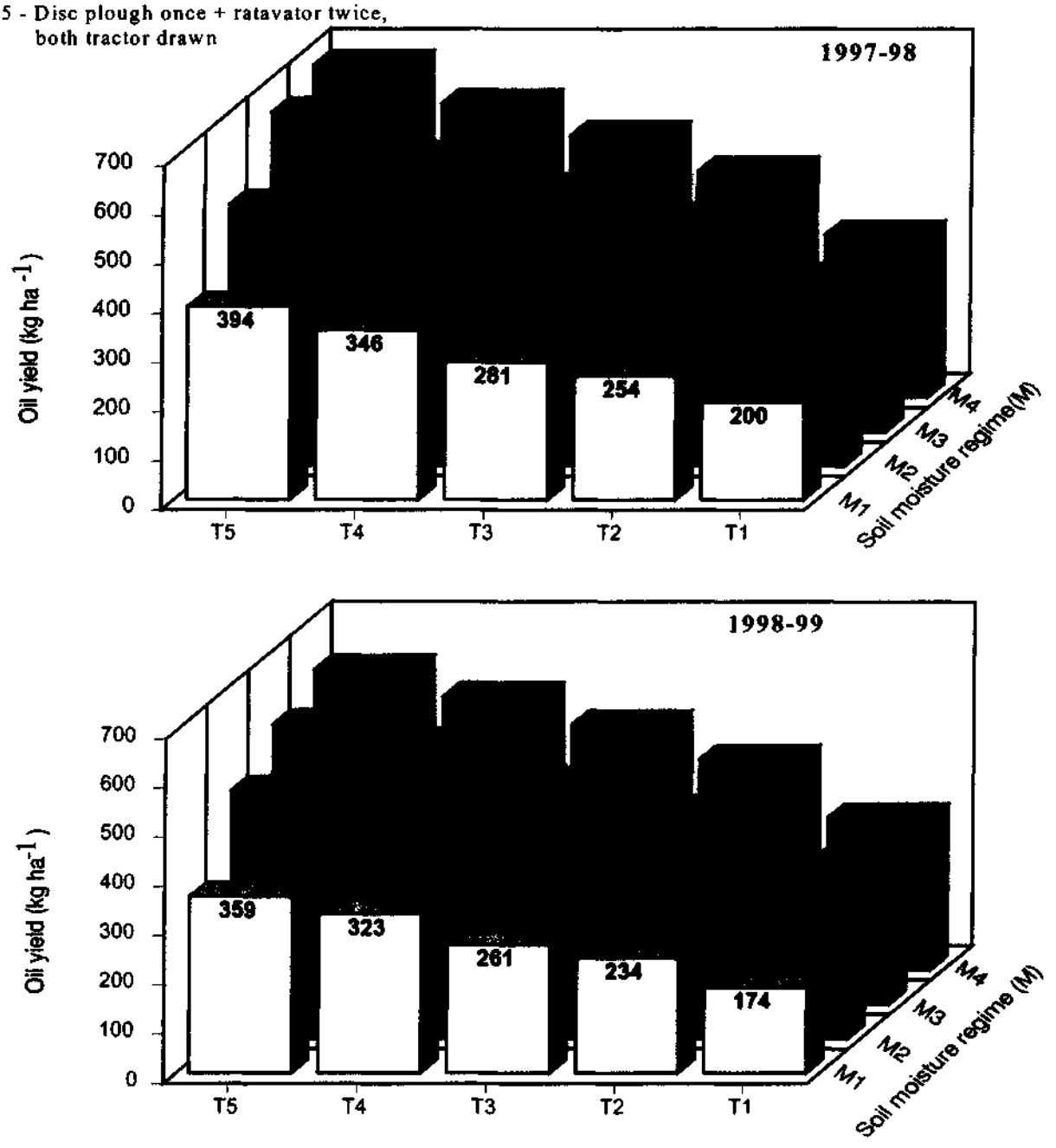


Fig. 31 : Effect of tillage treatments and soil moisture regimes on oil yield of sunflower

Oil yield increased with are increase in the frequency of irrigation. Irrigations given at IW/CPE = 1.2 (M_4) recorded highest oil yield (519 and 481 kg ha^{-1} in first and second year, respectively) closely followed by M_3 (IW/CPE = 1.0) yields 492 and 444 kg ha^{-1} in first and second years, respectively. Both were at par with each other and were significantly higher than M_2 (IW/CPE = 0.8) and M_1 (IW/CPE = 0.6). Lowest oil yield (295 and 270 kg ha^{-1} in first and second year, respectively) was observed when irrigation was given at IW/CPE = 0.6 (M_1).

The interaction effects indicated that deep fine tillage coupled with frequent irrigation (T_5M_4) resulted in highest oil yield (676 and 611 kg ha^{-1} in first year and second years, respectively) closely followed by deep fine tillage + next frequent water supply (T_5M_3). Both were at par with each other and were significantly superior to all other treatment combinations. Lowest oil yield (200 kg ha^{-1} in first year and 174 kg ha^{-1} in second year) was registered in zero tillage coupled with dry soil moisture regime (T_1M_1).

4.4 N, P, K CONTENT

The data are presented in Tables 25, 26 and 27.

4.4.1 Nitrogen content

Tillage treatments significantly influenced N content of the dry matter both in stalk at all stages and in seed at harvest. Highest nitrogen content was observed in T_5 (deep tillage with disc plough once + rotavator twice, both tractor drawn), which was on par with that of T_4 (deep ploughing with MB plough once + cultivator twice, both tractor drawn), T_3 (country plough twice + power

Table 25 : Effect of tillage treatments and soil moisture regimes on nitrogen content of sunflower at 30 and 60 DAS and at havest

	Nitrogen content (%)							
	1997-'98				1998-'99			
	30 DAS	60 DAS	At harvest		30 DAS	60 DAS	At harvest	
			Stalk	Seed			Stalk	Seed
Tillage (T)								
T_1	2.55	2.14	0.83	2.27	2.72	1.94	0.87	2.25
T_2	2.71	2.28	1.02	2.48	2.83	2.15	1.06	2.59
T_3	2.74	2.29	1.02	2.56	2.84	2.17	1.08	2.58
T_4	2.90	2.38	1.16	2.72	3.01	2.27	1.15	2.80
T_5	2.84	2.44	1.16	2.75	3.04	2.30	1.17	2.83
SEm±	0.07	0.10	0.04	0.07	0.10	0.13	0.05	0.18
CD(P=0.05)	0.17	0.23	0.09	0.16	0.22	0.31	0.12	0.31
Soil moisture regime (M)								
M_1	2.73	2.27	1.02	2.51	2.92	2.16	1.07	2.61
M_2	2.73	2.29	1.04	2.56	2.85	2.16	1.07	2.63
M_3	2.78	2.33	1.05	2.56	2.89	2.19	1.07	2.66
M_4	2.75	2.34	1.05	2.56	2.89	2.17	1.07	2.67
SEm±	0.06	0.09	0.05	0.05	0.05	0.07	0.06	0.06
CD(P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS

T_1 : Zero tillage
T_2 : Country plough twice + bullock drawn cultivar twice
T_3 : Country plough twice + power tiller rotavator twice
T_4 : Mould board plough once + cultivator twice, both tractor drawn
T_5 : Disc plough once + rotavator twice, both tractor drawn

M_1 : IW/CPE = 0.6
M_2 : IW/CPE = 0.8
M_3 : IW/CPE = 1.0
M_4 : IW/CPE = 1.2

tiller operated rotavator twice) and T_2 (country plough twice + bullock drawn cultivator twice). The trends of variation in N content were similar to that of dry matter at 30 and 60 DAS and N in the seed and stalk at harvest in both the years of study.

Soil moisture regimes individually and in combination with tillages did not significantly influence the nitrogen content of dry matter at all stages of observation.

4.4.2 Phosphorus content

The data presented in Table 26, it can be noticed that both tillage treatments and soil moisture regimes significantly influenced the phosphorus content at all stages of observation. However, the interaction effects of tillage and soil moisture regimes were found not significant on the phosphorus content.

Highest phosphorus content in the dry matter, stalk and seed was observed in T_5 plots (tractor drawn disc plough and rotavator tillage) followed by T_4 (MB plough + cultivator), T_3 (country plough twice + power tiller operated rotavator twice), T_2 (country plough twice + bullock drawn cultivator twice) and T_1 (zero tillage). The difference in phosphorus content due to tillage treatments in dry matter at 30 DAS, 60 DAS and both in stalk and seed was significant between deep tillage (T_4 and T_5) and zero tillage (T_1) treatments in the years of study.

Wettest soil moisture regime M_4 (IW/CPE = 1.2) recorded highest phosphorus content in dry matter through out the crop growth period followed by M_3. Both of these were on par with each other and significantly higher than

Table 26 : Effect of tillage treatments and soil moisture regimes on phosphorus content of sunflower at 30 and 60 DAS and at havest

	Phosphorus content (%)							
	1997-'98				1998-'99			
	30 DAS	60 DAS	At harvest		30 DAS	60 DAS	At harvest	
			Stalk	Seed			Stalk	Seed
Tillage (T)								
T_1	0.36	0.61	0.32	0.54	0.33	0.53	0.36	0.62
T_2	0.41	0.68	0.36	0.63	0.40	0.58	0.39	0.65
T_3	0.43	0.77	0.40	0.66	0.40	0.57	0.39	0.67
T_4	0.50	0.85	0.44	0.71	0.46	0.72	0.44	0.70
T_5	0.52	0.85	0.44	0.72	0.47	0.74	0.45	0.72
SEm±	0.024	0.011	0.012	0.018	0.041	0.013	0.029	0.022
CD(P=0.05)	0.068	0.026	0.028	0.042	0.098	0.031	0.068	0.050
Soil moisture regime (M)								
M_1	0.42	0.70	0.35	0.63	0.38	0.58	0.35	0.64
M_2	0.44	0.74	0.39	0.63	0.39	0.61	0.39	0.66
M_3	0.45	0.77	0.40	0.66	0.42	0.66	0.41	0.69
M_4	0.47	0.80	0.43	0.70	0.46	0.69	0.43	0.71
SEm±	0.014	0.017	0.024	0.011	0.020	0.018	0.028	0.018
CD(P=0.05)	0.033	0.044	0.059	0.026	0.051	0.048	0.066	0.043

T_1 : Zero tillage
T_2 : Country plough twice + bullock drawn cultivar twice
T_3 : Country plough twice + power tiller rotavator twice
T_4 : Mould board plough once + cultivator twice, both tractor dárwn
T_5 : Disc plúgh once + rotavator twice, both tractor dárwn

M_1 : IW/CPE = 0.6
M_2 : IW/CPE = 0.8
M_3 : IW/CPE = 1.0
M_4 : IW/CPE = 1.2

with other soil moisture regimes M_2 (IW/CPE = 0.8) and M_1 (IW/CPE = 0.6) in both the years of study in the same order.

The variations in P content due to interaction effects of tillage and soil moisture regimes were not significant.

4.4.3 Potassium content

Data in Table 27 revealed that potassium content in dry matter at 60 DAS and in seed was significantly influenced by tillage treatments. Soil moisture regimes and their interaction with tillages were not significant on K content in dry matter (30 and 60 DAS) and seed and stalk of sunflower in both the years of investigation.

Higher potassium content in dry matter at 30 DAS, 60 DAS and in both stalk and seed was registered with T_5 (deep tillage + rotavator treatment). However, the potassium contents as T_5 and T_4 were on par with each other but were significantly superior to T_3, T_2 and T_1 at 60 DAS, and in the seed in both the years. Tillage did not significantly influence the potassium content in dry matter at 30 DAS, and in the stalk at harvest.

Soil moisture regimes and their interaction with tillage did not significantly influence the K content in the dry matter (at all stages of observation.

4.5 NUTRIENT (NPK) UPTAKE

4.5.1 Nitrogen uptake

Data are presented in Table 28.

Table 27 : Effect of tillage tretments and soil moisture regimes on potassium content of sunflower 30 and 60 DAS and at harvest

	Potassium content (%)							
	1997-'98				1998-'99			
	30 DAS	60 DAS	At harvest		30 DAS	60 DAS	At harvest	
			Stalk	Seed			Stalk	Seed
Tillage (T)								
T_1	2.68	2.84	2.54	1.05	2.80	2.69	2.42	1.00
T_2	2.72	3.02	2.56	1.12	2.83	2.81	2.57	1.11
T_3	2.74	3.01	2.57	1.15	2.86	2.83	2.56	1.14
T_4	2.72	3.14	2.57	1.23	3.04	2.97	2.58	1.23
T_5	2.74	3.14	2.57	1.25	2.97	2.97	2.64	1.25
SEm±	0.076	0.071	0.089	0.046	0.098	0.082	0.120	0.084
CD(P=0.05)	NS	0.168	NS	0.103	NS	0.180	NS	0.177
Soil moisture regime (M)								
M_1	2.71	3.03	2.55	1.13	2.88	2.83	2.52	1.13
M_2	2.72	3.01	2.55	1.16	2.88	2.84	2.54	1.13
M_3	2.72	3.03	2.58	1.18	2.89	2.86	2.58	1.16
M_4	2.72	3.05	2.56	1.17	2.93	2.89	2.59	1.67
SEm±	0.032	0.057	0.040	0.041	0.046	0.063	0.071	0.061
CD(P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS

T_1 : Zero tillage
T_2 : Country plough twice + bullock drawn cultivar twice
T_3 : Country plough twice + power tiller rotavator twice
T_4 : Mould board plough once + cultivator twice, both tractor drawn
T_5 : Disc plough once + rotavator twice, both tractor drawn

M_1 : IW/CPE = 0.6
M_2 : IW/CPE = 0.8
M_3 : IW/CPE = 1.0
M_4 : IW/CPE = 1.2

Nitrogen uptake was significantly influenced by tillage and soil moisture regimes at all growth stages of the crop. However, their interaction was significant only from 60 DAS.

It was significantly higher with deep tillage and fine tilth (T_5), compared to all other tillage treatments viz., T_4 (MB plough + cultivator, both tractor drawn), T_3 (country plough + power tiller rotavator); T_2 (country plough + cultivator, both bullock drawn) and T_1 (zero tillage). Lowest nitrogen uptake was registered with zero tillage (T_1) at all growth stages of plant in both the years of study.

Among soil moisture regimes, nitrogen uptake by the crop was highest in the plots where irrigations were given at IW/CPE of 1.2 (M_4) followed by IW/CPE of 1.0 (M_3). Both were at par with each other and significantly superior to IW/CPE of 0.8 and 0.6 at all crop growth stages. However, at 30 DAS the N uptake was significantly higher when irrigations were given at IW/CPE = 1.2 (M_4) compared to IW/CPE = 1.0 (M_3), 0.8 (M_2) and 0.6 (M_1) in both the years.

The data on the interaction effect of tillage and moisture regimes revealed that higher N-uptake was associated with the combination of deep fine tilth and frequent irrigations (T_5M_4) followed by deep fine tilth and irrigation at IW/CPE of next highest water 1.0 (T_5M_3), both of which were at par with each other but superior to all other treatment combinations. However, these interactions were not significant at 30 DAS. Zero tillage and driest moisture regime (T_1M_1) combination registered lowest nitrogen uptake by crop in both the years of study.

Table 29 : Effect of tillage treatments and soil moisture regimes on nitrogen uptake by sunflower at 30 and 60 DAS and at harvest

Tillage (T)	Nitrogen uptake (kg ha^{-1})									
	1997-98					1998-99				
	Soil moisture regime (M)					Soil moisture regime (M)				
	M_1	M_2	M_3	M_4	Mean	M_1	M_2	M_3	M_4	Mean
					30 DAS					
T_1	3.85	4.11	4.59	4.85	4.35	4.40	4.70	5.21	5.56	4.97
T_2	4.84	5.39	5.73	6.08	5.51	5.22	5.89	6.09	6.38	5.89
T_3	5.45	6.13	6.66	7.30	6.39	6.21	6.66	7.33	7.85	7.01
T_4	5.63	6.04	6.61	6.86	6.29	6.03	6.22	6.83	7.89	6.74
T_5	6.07	6.80	7.37	7.73	6.99	7.02	7.31	8.09	8.81	7.81
Mean	5.17	5.70	6.19	6.57		5.78	6.15	6.71	7.30	
					60 DAS					
T_1	20.99	25.27	30.08	30.31	26.66	19.09	22.31	26.29	27.61	28.83
T_2	25.76	32.54	37.39	39.55	33.81	25.50	29.21	34.48	35.68	31.22
T_3	28.82	36.75	40.77	42.16	37.13	27.22	34.84	37.88	39.86	34.95
T_4	32.91	40.84	43.11	44.41	40.32	32.23	37.41	41.78	42.11	38.38
T_5	39.00	42.67	45.50	50.20	44.34	36.47	40.82	45.12	46.58	42.25
Mean	24.50	35.61	39.37	41.32		28.10	32.92	37.11	38.37	
					Harvest					
T_1	20.9	26.9	30.2	31.7	27.4	21.2	24.7	29.7	32.2	27.0
T_2	27.9	37.0	42.1	44.6	38.1	29.0	35.7	42.3	45.0	38.0
T_3	31.5	40.6	46.4	50.5	42.3	32.3	41.9	48.3	52.0	43.6
T_4	37.8	48.4	53.2	58.9	50.0	39.9	50.5	56.2	58.4	51.2
T_5	45.3	56.5	63.9	66.1	57.7	43.9	56.0	62.3	64.2	56.6
Mean	32.7	41.9	47.4	50.8		33.3	41.7	47.8	50.3	

	30 DAS	60 DAS	Harvest	30 DAS	60 DAS	Harvest
T SEm±	0.15	1.06	1.33	0.17	1.35	0.98
CD (P=0.05)	0.38	2.43	3.27	0.40	3.12	2.35
M SEm±	0.12	0.89	0.85	0.12	0.77	0.79
CD (P=0.05)	0.28	2.18	2.18	0.29	1.88	1.93
T at M						
SEm ±	0.26	1.80	1.98	0.25	1.76	1.47
CD (P=0.05)	NS	3.26	5.07	NS	4.10	3.61
M at T						
SEm±	0.30	1.96	2.21	0.29	1.68	1.90
CD (P=0.05)	NS	3.84	3.05	NS	4.42	2.76

T_1 : Zero tillage
T_2 : Country plough twice + bullock drawn cultivar twice
T_3 : Country plough twice + power tiller rota[illegible]r twice
T_4 : Mould board plough once + cultivator tw[illegible], b[illegible] tractor darwn
T_5 : Disc plough once + rotavator twice both [illegible]ctor darwn

M_1 : IW/CPE = 0.6
M_2 : IW/CPE = 0.8
M_3 : IW/CPE = 1.0
M_4 : IW/CPE = 1.2

4.5.2 Phosphorus uptake

Data are presented in Table 29.

It is evident from the data that at all stages of crop growth, Phosphorus uptake was significantly influenced by tillage and soil moisture regimes. However, their interactions were significant from 60 DAS in both the years of study.

Among tillage treatments, T_5 (deep plough + rotavator) in general, resulted in highest phosphorus uptake, which was significantly higher compared to other tillage treatments throughout the crop growth period. The effect of tillage treatments T_3 and T_4 were on par with each other. Irrespective of the stage of crop growth, lowest phosphorus uptake was associated with zero tillage (T_1).

Among soil moisture regimes, irrigation given at IW/CPE of 1.2 (M_4) resulted in highest phosphorus uptake at all stages of sunflower followed by IW/CPE of 1.0. Both of these were significantly superior to M_2 IW/CPE = 0.8 and M_1 (IW/CPE = 0.6) in both years. Phosphorus uptake at 30 DAS was found significantly higher with M_4 (IW/CPE = 1.2) compared to M_3, M_2 and M_1. Lowest P uptake was associated with driest soil moisture regime (M_1).

Phosphorus uptake was also significantly influenced by the interaction of tillage and soil moisture regimes at 60 DAS and at harvest in both the years. It was highest with the tillage and moisture regime combination of T_5 M_4 followed by T_5 M_3, which were at par with each other but, significantly superior to other combinations at all stages of crop. Lowest phosphorus uptake was

Table 29 : Effect of tillage treatments and soil moisture regimes on phosphorus uptake by sunflower at 30 and 60 DAS and at harvest

Tillage (T)	Phosphorus uptake (kg ha^{-1})									
	1997-98					1998-99				
	Soil moisture regime (M)					Soil moisture regime (M)				
	M_1	M_2	M_3	M_4	Mean	M_1	M_2	M_3	M_4	Mean
					30 DAS					
T_1	0.52	0.56	0.65	0.68	0.60	0.51	0.54	0.67	0.76	0.62
T_2	0.70	0.83	0.84	0.95	0.83	0.67	0.80	0.86	0.95	0.82
T_3	0.81	0.97	1.03	1.08	0.98	0.75	0.92	1.03	1.09	0.95
T_4	0.91	1.03	1.16	1.18	1.07	0.81	0.94	1.07	1.13	0.99
T_5	1.09	1.25	1.31	1.38	1.26	1.05	1.09	1.24	1.33	1.18
Mean	0.81	0.93	1.00	1.05		0.76	0.86	0.98	1.05	
					60 DAS					
T_1	4.67	6.62	8.70	8.64	7.16	4.60	6.61	8.34	9.31	7.45
T_2	5.97	8.89	10.89	11.64	9.34	6.94	8.94	11.04	12.03	9.74
T_3	9.09	12.08	14.27	15.13	12.64	8.26	10.77	13.40	14.41	11.74
T_4	10.05	13.88	15.38	15.65	13.71	9.07	11.99	13.80	14.65	12.40
T_5	12.11	14.51	16.47	17.70	15.20	11.27	12.96	15.92	17.32	14.34
Mean	8.38	11.20	13.14	13.75		8.03	10.25	12.50	13.54	
					Harvest					
T_1	6.68	7.67	8.97	9.73	8.26	6.58	7.40	9.78	10.53	8.57
T_2	8.21	10.19	12.00	12.90	10.82	8.37	10.56	12.85	13.75	11.38
T_3	10.34	12.18	14.77	15.60	13.22	9.50	12.06	14.58	15.89	13.01
T_4	11.55	14.70	16.98	18.22	15.36	11.89	14.75	16.53	17.88	15.26
T_5	13.53	17.68	19.14	20.71	17.74	13.59	16.67	18.36	19.64	17.06
Mean	10.06	12.48	14.37	15.43		9.98	12.30	14.42	15.54	
	30 DAS	**60 DAS**	**Har-vest**			**30 DAS**	**60 DAS**	**Har-vest**		
T SEm±	0.043	0.53	0.35			0.032	0.78	0.30		
CD (P=0.05)	0.108	1.31	0.90			0.075	1.63	0.78		
M SEm±	0.023	0.33	0.20			0.015	0.46	0.19		
CD (P=0.05)	0.058	0.80	0.54			0.034	1.06	0.51		
T at M										
SEm ±	0.056	0.92	0.65			0.036	0.96	0.58		
CD (P=0.05)	NS	1.79	1.61			0.173	2.62	1.48		
M at T										
SEm±	0.060	0.60	0.56			0.032	0.78	0.66		
CD (P=0.05)	NS	1.46	1.24			0.090	2.18	0.90		

T_1 : Zero tillage
T_2 : Country plough twice + bul' ck wn cultivar twice
T_3 : Country plough twice + p r rotavator twice
T_4 : Mould board plough once + vator twice, both tractor drawn
T_5 : Disc plough once + rotavato e, both tractor drawn

M_1 : IW/CPE = 0.6
M_2 : IW/CPE = 0.8
M_3 : IW/CPE = 1.0
M_4 : IW/CPE = 1.2

associated with zero tillage coupled with driest soil moisture (T_1M_1) combination at all crop growth periods.

4.5.3 Potassium uptake

Data are presented in Table 30.

It is evident from the data that potassium uptake at all stages of observation was significantly influenced by the tillage treatments and soil moisture regimes. The interaction effects were significantly higher at 60 DAS and harvest.

Potassium uptake by the crop was significantly higher with deep tillage with fine seed bed (T_5) compared to all other treatments viz. deep coarse (T_4), shallow fine (T_3), shallow coarse (T_2) and zero tillage (T_1). Lowest potassium uptake was associated with zero tillage (T_1) treatment.

Wettest soil moisture regime, M_4 IW/CPE = 1.2) registered highest potassium uptake, which is significantly higher than M_3, M_2 and M_1 at all stages of observation.

Among interaction effects, significantly higher potassium uptake was recorded with deep fine seed bed (T_5M_4) coupled with irrigation at IW/CPE ratio of 1.2 compared to other combinations from 60 DAS. At 30 DAS, these effects were not significant. Lowest K uptake was associated with T_1M_1 (Zero tillage coupled with low water supply).

Table 30: Effect of tillage treatments and soil moisture regimes on potassium uptake by sunflower at 30 and 60 DAS and at harvest

Tillage (T)	Potassium uptake (kg ha^{-1})									
	1997-98					1998-99				
	Soil moisture regime (M)					Soil moisture regime (M)				
	M_1	M_2	M_3	M_4	Mean	M_1	M_2	M_3	M_4	Mean
					30 DAS					
T_1	4.11	4.37	4.79	4.97	4.56	4.19	4.68	5.28	5.70	4.96
T_2	4.94	5.43	5.66	6.06	5.52	5.22	5.95	5.93	6.27	5.84
T_3	5.38	6.12	6.61	7.31	6.36	6.29	6.68	7.34	8.08	7.10
T_4	5.23	5.79	6.17	6.59	5.94	6.07	6.51	6.98	7.83	6.85
T_5	5.51	6.54	7.07	7.83	6.72	7.23	7.85	8.45	8.89	8.11
Mean	5.04	5.65	6.06	6.55		5.80	6.34	6.80	7.35	
					60 DAS					
T_1	27.40	31.73	37.00	40.17	34.07	25.55	31.09	36.93	39.91	33.37
T_2	31.72	39.50	43.69	46.53	40.36	30.65	39.03	42.33	49.18	40.30
T_3	35.67	44.03	48.17	49.76	44.41	35.04	44.77	50.73	52.82	45.84
T_4	38.20	47.33	42.47	50.63	46.41	41.03	49.62	55.60	57.18	50.86
T_5	41.89	48.56	52.31	53.65	49.10	47.18	53.71	58.01	60.45	54.84
Mean	34.98	42.23	46.13	48.15		35.90	43.64	48.72	51.91	
					Harvest					
T_1	32.6	38.9	42.3	44.1	39.5	29.6	34.3	38.5	41.9	36.1
T_2	36.7	45.2	50.4	51.5	45.9	36.5	43.6	48.9	52.3	45.3
T_3	41.8	48.4	54.0	55.7	50.0	41.2	50.7	57.6	60.7	52.5
T_4	43.9	52.9	58.9	61.9	54.4	45.7	56.1	60.1	63.2	56.3
T_5	50.9	61.5	6.63	69.3	61.9	51.8	61.8	66.1	69.6	62.3
Mean	41.2	49.4	54.3	56.5		40.4	49.3	54.2	57.6	
	30 DAS	**60 DAS**	**Har-vest**			**30 DAS**	**60 DAS**	**Har-vest**		
T SEm±	0.23	0.97	1.04			0.15	1.13	0.76		
CD (P=0.05)	0.59	2.06	2.48			0.35	2.62	1.88		
M SEm±	0.16	0.75	0.66			0.08	1.24	0.55		
CD (P=0.05)	0.34	1.67	1.52			0.20	3.04	1.28		
T at M										
SEm ±	0.30	1.51	1.49			0.22	1.62	1.51		
CD (P=0.05)	NS	3.15	4.16.			NS	3.06	3.12		
M at T										
SEm±	0.38	1.20	1.74			0.25	1.93	1.81		
CD (P=0.05)	NS	1.92	3.22			NS	4.11	2.32		

T_1 : Zero tillage
T_2 : Country plough twice + bullock drawn cultivar twice
T_3 : Country plough twice + power tiller rotavator twice
T_4 : Mould board plough once + cultivator twice, both tractor drawn
T_5 : Disc plugh once + rotavator twice, both tractor drawn

M_1 : IW/CPE = 0.6
M_2 : IW/CPE = 0.8
M_3 : IW/CPE = 1.0
M_4 : IW/CPE = 1.2

4.6 SOIL WATER STUDIES

4.6.1 Seasonal water use

Seasonal water use by sunflower under different tillage and soil moisture regimes was assessed in the form of crop water use (Crop ETa). The data are presented in Tables 31 and 32 and depicted in Figure 32.

The crop ETa varied with tillage and soil moisture regimes at all stages of observation. Highest mean crop ETa was registered with T_5, involving deep and finer tilth (386.3 in first year and 445.75 mm in second year) followed by T_4, T_3, T_2 and T_1 in both the years of study. The lowest crop ETa was recorded with T_1 (330.60 mm in first year and 375.89 mm in the second year).

Among soil moisture regimes, the crop ETa was highest (437.9 mm in first year and 503.4 mm in second year) with irrigation at IW/CPE of 1.2 (M_4), which was superior to all other soil moisture regimes. Lowest crop ETa was found with driest soil moisture regime i.e. M_1 (259.58 mm in first year and 318.4 mm in second year).

4.6.2 Crop ETa rate

The data on crop ETa rate (which indicate's rate of soil drying (mm day^{-1}), as influenced by tillage and soil moisture regimes are presented in the Tables 33 and 34 and Illustrated in Figure 33.

In general, ETa rate was low at initial stages of the crop growth. It progressively increased with crop age reaching a maximum level and again reduced towards the end of the growing period. The highest ETa rate was

Table 31 : Effect of tillage treatments and soil moisture regimes on crop ETa at different irrigation cycles, 1997-98

Treatment	IW/CPE ratio	Crop ETa (mm)										
		0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9 (Harvest)	10 (Cumulative)
T_1 M_1	0.6	34.77	41.64	49.24	58.55						56.36	240.56
T_1 M_2	0.8	28.41	34.26	41.45	48.45	55.01	54.74				41.65	304.10
T_1 M_3	1.0	26.97	31.16	37.33	43.46	51.33	53.46	54.98	49.24		24.50	372.42
T_1 M_4	1.2	23.32	28.45	34.12	41.70	48.15	52.62	53.24	45.31	40.50	38.10	405.41
T_2 M_1	0.6	33.94	42.47	52.84	61.75						58.12	249.19
T_2 M_2	0.8	29.55	35.45	42.28	51.80	57.79	56.25				47.72	320.79
T_2 M_3	1.0	27.15	32.59	39.75	46.29	53.95	56.28	58.50	50.70		25.17	390.38
T_2 M_4	1.2	23.75	28.69	35.40	43.68	50.85	56.70	58.35	49.90	43.15	38.94	429.41
T_3 M_1	0.6	32.34	44.58	55.60	64.31						61.96	258.79
T_3 M_2	0.8	29.84	35.74	44.92	53.25	62.05	58.75				48.36	332.81
T_3 M_3	1.0	26.31	33.28	41.87	50.87	60.47	61.73	61.15	53.35		27.80	416.80
T_3 M_4	1.2	22.31	29.40	37.18	45.35	53.32	61.20	60.50	51.60	44.44	40.89	446.19
T_4 M_1	0.6	33.65	42.90	54.30	68.75						65.70	270.31
T_4 M_2	0.8	29.65	35.82	45.96	56.15	66.66	63.35				52.85	350.44
T_4 M_3	1.0	27.75	32.71	41.56	50.24	62.86	63.10	65.49	55.27		27.25	426.28
T_4 M_4	1.2	23.27	28.35	35.91	44.88	55.33	64.80	61.33	52.18	43.85	39.50	449.67
T_5 M_1	0.6	32.88	45.36	57.21	70.05						68.62	278.54
T_5 M_2	0.8	28.33	37.32	49.21	59.75	69.10	66.64				55.50	367.85
T_5 M_3	1.0	25.94	33.24	42.60	52.15	64.77	66.50	67.84	57.49		29.33	439.84
T_5 M_4	1.2	22.25	29.79	38.46	46.51	54.25	63.29	62.61	54.77	45.34	41.65	458.91

T_1 : Zero tillage
T_2 : Country plough twice + bullock drawn cultivar twice
T_3 : Country plough twice + power tiller rotavator twice
T_4 : Mould board plough once + cultivator twice, both tractor drawn
T_5 : Disc plough once + rotavator twice, both tractor drawn

M_1 : IW/CPE = 0.6
M_2 : IW/CPE = 0.8
M_3 : IW/CPE = 1.0
M_4 : IW/CPE = 1.2

Table 32 : Effect of tillage treatments and soil moisture regimes on crop ETa at different irrigation cycles, 1998-99

Treatment	Crop ETa (mm)											Cumulative
	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	10 Harvest	
T_1 M_1	33.25	39.40	47.29	55.78	59.38							47.54	282.69
T_1 M_2	29.26	33.11	40.67	47.02	51.33	53.48	50.93					30.43	336.29
T_1 M_3	25.48	29.30	36.23	43.29	50.29	53.79	51.44	48.95	42.99			30.50	412.76
T_1 M_4	23.90	26.19	32.85	38.13	44.96	49.86	51.32	48.27	46.66	43.83	37.80	29.10	471.84
T_2 M_1	35.25	43.73	53.63	60.84	61.91							49.24	306.10
T_2 M_2	29.83	35.21	44.01	53.06	56.25	58.23	53.10					32.79	362.51
T_2 M_3	26.04	31.74	39.49	47.86	54.62	56.50	54.72	51.82	44.21			31.15	438.15
T_2 M_4	23.69	28.77	34.29	40.08	47.50	52.24	53.40	50.84	47.08	44.41	39.31	29.88	491.29
T_3 M_1	34.83	45.82	55.96	64.29	64.92							50.85	320.21
T_3 M_2	29.56	37.28	47.78	55.28	59.44	61.04	55.09					33.25	378.69
T_3 M_3	25.96	32.94	41.45	50.31	56.66	59.43	57.04	55.34	47.78			32.30	459.21
T_3 M_4	23.86	29.31	35.25	42.61	49.27	53.63	55.10	51.94	48.15	45.99	40.88	30.70	506.80
T_4 M_1	35.86	46.48	60.90	69.41	70.74							51.59	334.98
T_4 M_2	29.66	38.74	47.41	57.00	63.08	64.35	60.89					33.63	394.76
T_4 M_3	25.55	33.58	42.14	52.86	59.50	63.00	60.38	58.59	49.83			31.33	476.78
T_4 M_4	23.38	29.00	35.27	42.72	50.69	55.63	57.63	53.51	49.75	47.32	42.03	29.48	516.41
T_5 M_1	35.96	48.35	63.64	72.19	74.13							54.48	348.15
T_5 M_2	30.47	40.41	50.14	59.65	65.67	68.51	61.78					33.93	410.63
T_5 M_3	25.31	34.33	44.64	54.34	62.34	65.53	62.96	60.95	50.91			32.07	493.17
T_5 M_4	23.88	30.02	36.88	43.21	51.48	57.03	59.56	55.40	50.11	48.76	43.60	30.54	530.57

T_1 : Zero tillage
T_2 : Country plough twice + bullock drawn cultivar twice
T_3 : Country plough twice + power tiller rotavator twice
T_4 : Mould board plough once + cultivator twice, both tractor drawn
T_5 : Disc plough once + rotavator twice, both tractor drawn

M_1 : IW/CPE = 0.6
M_2 : IW/CPE = 0.8
M_3 : IW/CPE = 1.0
M_4 : IW/CPE = 1.2

T1 - Zero tillage
T2 - Country plough twice + bullock drawn cultivator twice (farmers' practice)
T3 - Country plough twice + power tiller operated rotavator twice
T4 - MB plough once + cultivator twice, both tractor drawn
T5 - Disc plough once + rotavator twice, both tractor drawn

M1 - Irrigations at IW/CPE = 0.6
M2 - Irrigations at IW/CPE = 0.8
M3 - Irrigations at IW/CPE = 1.0
M4 -Irrigations at IW/CPE = 1.2

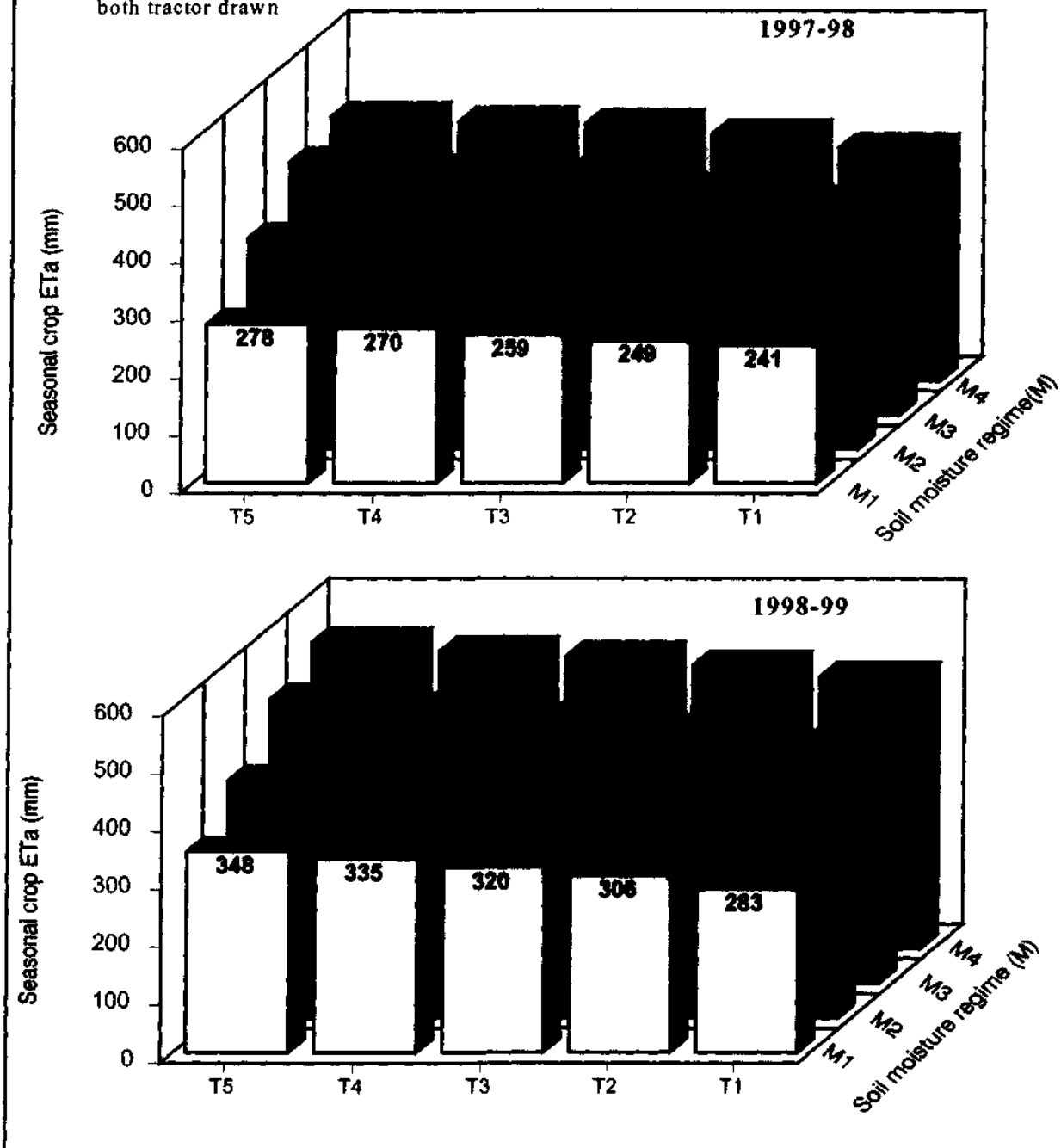


Fig. 32 : Effect of tillage treatments and soil moisture regimes on seasonal crop ETa of sunflower

Table 33: Effect of tillage treatments and soil moisture regimes on crop ETa rate at different irrigation cycles, 1997-98

Treatment	IW/CPE ratio	Crop ETa rate (mm day^{-1})									
		0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9 harvest
T_1 M_1	0.6	1.51	2.31	3.28	4.50						3.76
T_1 M_2	0.8	1.58	2.28	3.45	4.40	5.50	6.08				4.63
T_1 M_3	1.0	1.93	2.83	3.39	4.83	5.70	6.68	7.85	7.03		4.08
T_1 M_4	1.2	1.94	2.58	3.41	5.21	6.02	7.52	7.61	7.55	6.75	4.23
T_2 M_1	0.6	1.48	2.36	3.52	4.75						3.87
T_2 M_2	0.8	1.64	2.36	3.52	4.71	5.78	6.25				5.30
T_2 M_3	1.0	1.94	2.96	3.61	5.14	5.99	7.03	8.36	7.24		4.19
T_2 M_4	1.2	1.98	2.61	3.54	5.46	6.36	8.10	8.34	8.32	7.19	4.33
T_3 M_1	0.6	1.41	2.48	3.71	4.95						4.13
T_3 M_2	0.8	1.66	2.38	3.74	4.84	6.20	6.53				5.36
T_3 M_3	1.0	1.88	3.02	3.81	5.65	6.72	7.72	8.74	7.62		4.63
T_3 M_4	1.2	1.86	2.67	3.72	5.67	6.66	8.74	8.64	8.60	7.41	4.54
T_4 M_1	0.6	1.46	2.38	3.62	5.29						4.38
T_4 M_2	0.8	1.65	2.39	3.83	5.10	6.67	6.04				5.87
T_4 M_3	1.0	1.98	2.97	3.78	5.58	6.98	7.89	9.35	7.89		4.62
T_4 M_4	1.2	1.94	2.58	3.59	5.61	6.92	9.26	8.76	8.70	7.31	4.39
T_5 M_1	0.6	1.43	2.52	3.81	5.39						4.57
T_5 M_2	0.8	1.57	2.38	4.10	5.43	6.91	6.77				5.94
T_5 M_3	1.0	1.85	3.02	3.87	5.79	7.20	8.31	9.69	8.21		4.89
T_5 M_4	1.2	1.85	2.71	3.85	5.81	6.98	9.04	8.94	9.13	7.56	4.63

T_1 : Zero tillage
T_2 : Country plough twice + bullock drawn cultivar twice
T_3 : Country plough twice + power tiller rotavator twice
T_4 : Mould board plough once + cultivator twice, both tractor darwn
T_5 : Disc plugh once + rotavator twice, both tractor darwn

M_1 : IW/CPE = 0.6
M_2 : IW/CPE = 0.8
M_3 : IW/CPE = 1.0
M_4 : IW/CPE = 1.2

Table 34: Effect of tillage treatments and soil moisture regimes on crop ETa rate at different irrigation cycles, 1998-99

Treatment	IW/CPE ratio	Crop ETa rate (mm)											
		0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11 Harvest
T_1 M_1	0.6	1.85	2.46	3.15	4.29	4.95							4.74
T_1 M_2	0.8	2.09	2.55	3.39	4.70	5.13	5.94	6.37					3.80
T_1 M_3	1.0	2.32	2.93	3.62	4.81	6.29	6.72	7.35	6.99	6.14			5.08
T_1 M_4	1.2	2.39	3.27	4.10	4.77	5.62	7.12	7.33	8.04	7.77	7.30	6.30	5.82
T_2 M_1	0.6	1.96	2.73	3.57	4.68	5.16							4.92
T_2 M_2	0.8	2.13	2.71	3.67	5.31	5.63	6.47	6.44					4.10
T_2 T_3	1.0	2.37	3.17	3.95	5.32	6.83	7.06	7.82	7.40	6.31			5.19
T_2 T_4	1.2	2.37	3.59	4.28	5.01	5.93	7.46	7.63	8.47	7.85	7.40	6.55	5.98
T_3 M_1	0.6	1.99	2.86	3.86	4.99	5.41							5.08
T_3 M_2	0.8	2.11	2.87	3.98	5.52	5.94	6.78	6.88					4.16
T_3 M_3	1.0	2.36	3.29	4.14	5.59	7.08	7.43	8.15	7.90	6.82			5.38
T_3 M_4	1.2	2.39	3.66	4.41	5.33	6.15	7.66	7.87	8.66	8.02	7.66	6.81	6.14
T_4 M_1	0.6	1.99	2.90	4.06	5.34	5.89							5.45
T_4 M_2	0.8	2.12	2.98	3.95	5.70	6.31	7.15	7.61					4.20
T_4 M_3	1.0	2.32	3.36	4.10	5.87	7.44	7.87	8.63	8.37	7.12			5.22
T_4 M_4	1.2	2.34	3.62	4.41	5.34	6.34	7.95	8.23	8.92	8.29	7.88	7.00	5.90
T_5 M_1	0.6	2.00	3.07	4.24	5.55	6.18							5.45
T_5 M_2	0.8	2.18	3.11	4.18	5.96	6.56	7.61	7.72					4.24
T_5 M_3	1.0	2.30	3.43	4.46	6.04	7.79	8.19	8.99	8.77	7.28			5.34
T_5 M_4	1.2	2.39	3.75	4.61	5.40	6.43	8.15	8.51	9.25	8.35	8.13	7.23	6.11

T_1 : Zero tillage
T_2 : Country plough twice + bullock drawn cultivar twice
T_3 : Country plough twice + power tiller rotavator twice
T_4 : Mould board plough once + cultivator twice, both tractor drawn
T_5 : Disc plough once + rotavator twice, both tractor drawn

M_1 : IW/CPE = 0.6
M_2 : IW/CPE = 0.8
M_3 : IW/CPE = 1.0
M_4 : IW/CPE = 1.2

M1 - Irrigations at IW/CPE = 0.6
M2 - Irrigations at IW/CPE = 0.8
M3 - Irrigations at IW/CPE = 1.0
M4 -Irrigations at IW/CPE = 1.2

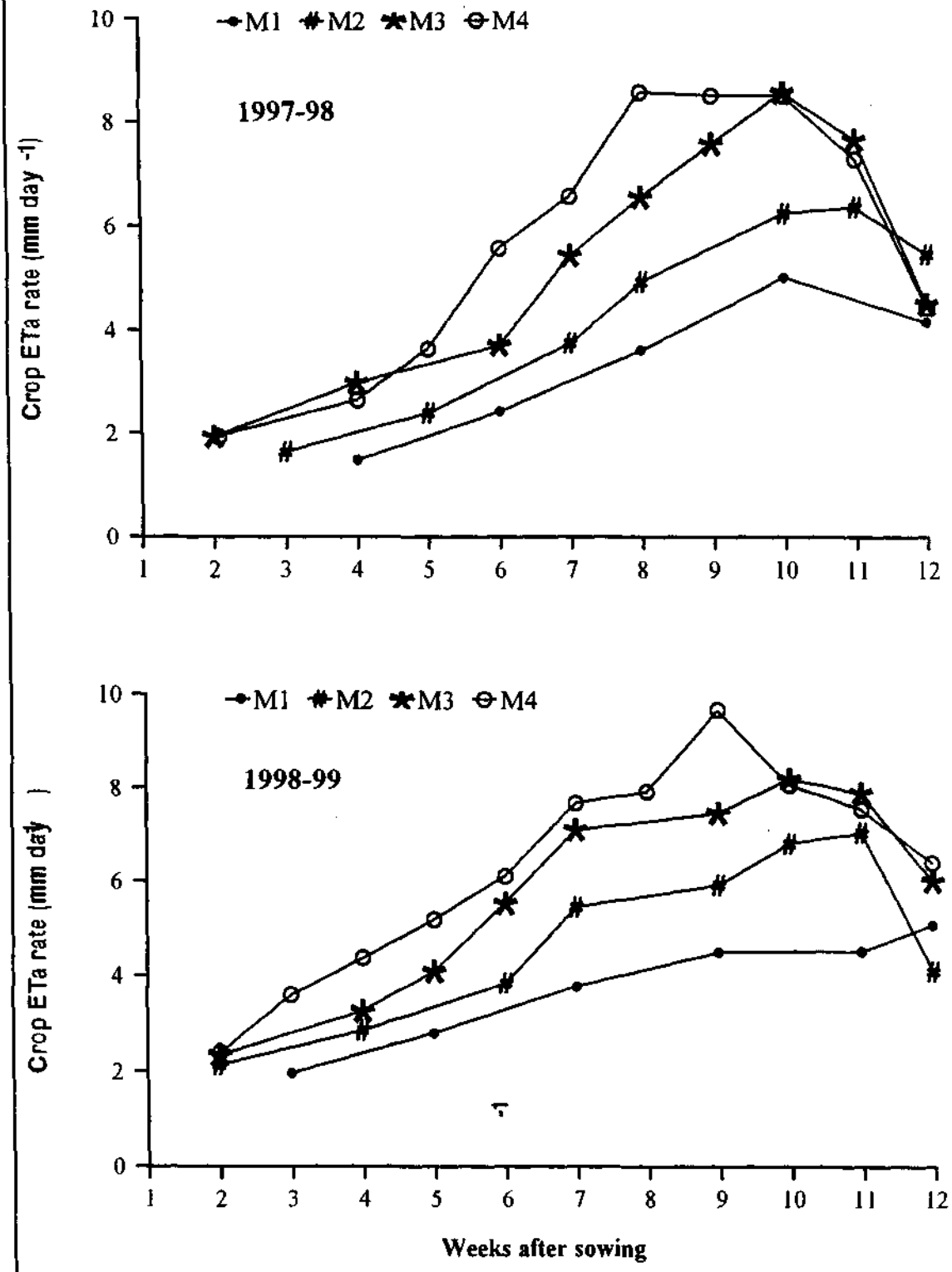


Fig. 33 : Effect of soil moisture regimes on crop ETa rate at diffrent irrigation cycles during crop growth period

registered with deep fine tillage (T_5) treatment compared to T_4 (MB plough once + cultivator twice, both tractor drawn), T_3 (country plough twice + power tiller operated rotavator twice), T_2 (country plough twice + bullock drawn cultivator twice) and T_1 (zero tillage). The lowest ETa rate was associated with zero tillage (T_1) in both the years of study.

Wettest soil moisture regime M_4 (irrigation at IW/CPE = 1.2) resulted in highest ETa rate compared to all other moisture regimes. The ETa rate progressively decreased with decrease in irrigation with IW/CPE ratio from 1.2 to 0.6.

4.6.3 Soil moisture extraction pattern

Data are presented in Figures 34 and 35.

In general, soil moisture extraction was highest from surface layer (0-15 cm) in all the treatments followed by 15-30 and 30-45 cm soil depths in both the years. In zero tillage (T_1), soil moisture extraction (per cent of total) was highest in 0-15 cm layer closely followed by shallow tillage (T_2 and T_3). On the other hand, in case of deep tillage treatments (T_5 and T_4) resulted in higher moisture extraction from deeper soil depths (15-30 and 30-45 cm) compared to shallow (T_3 and T_2) and zero (T_1) tillage treatments. The trends were similar in both the years.

Irrespective of tillage treatments soil moisture extraction from the top soil layer (0-15 cm) increased with an increase in frequency of irrigation. It was observed that with decrease in frequency of irrigation, relatively more moisture was extracted from deeper soil layers (15-30 and 30-45 cm). In M_4

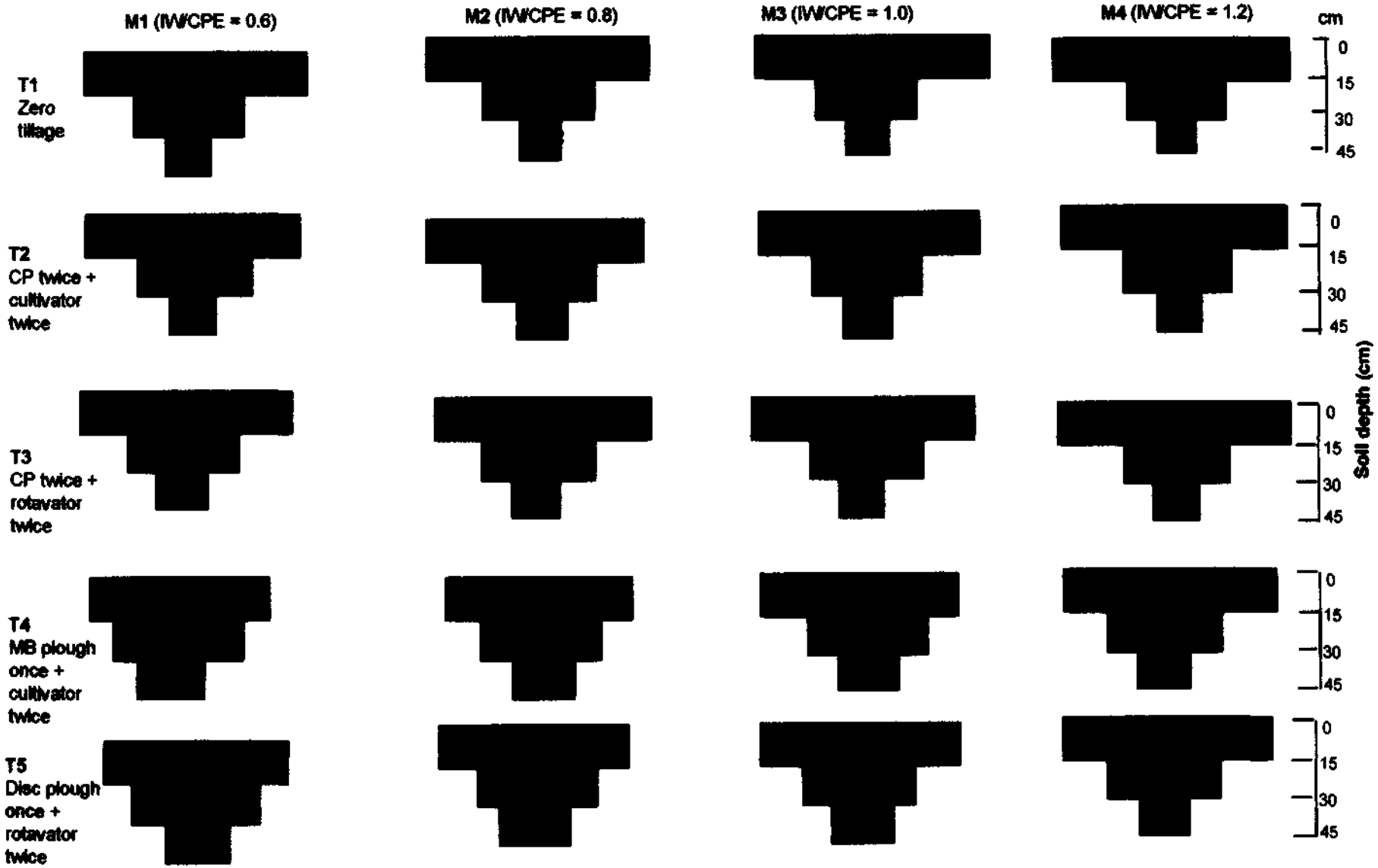


Fig. 34: Effect of tillage treatments and soil moisture regimes on soil moisture extraction pattern, 1997-98

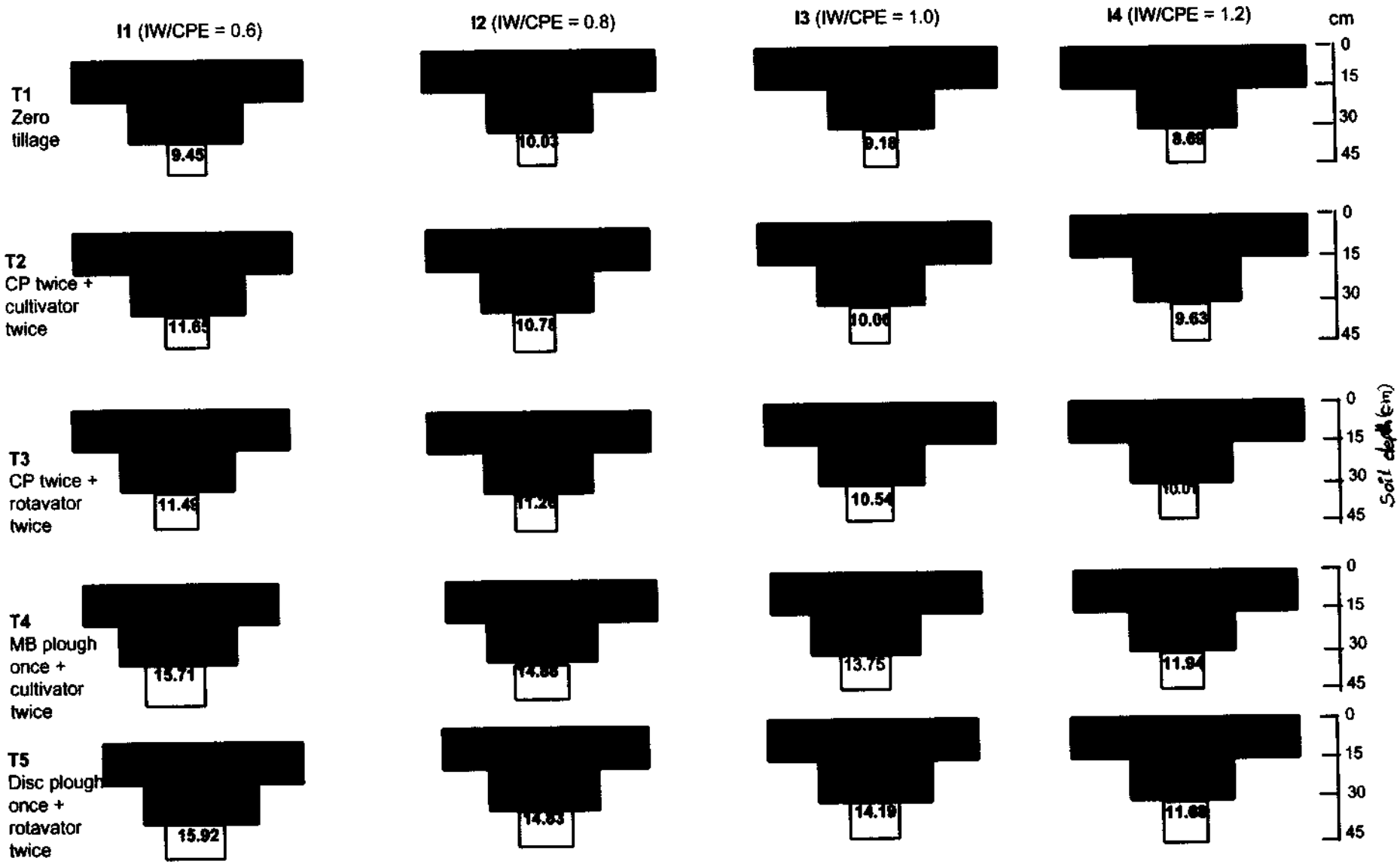


Fig. 35: Effect of tillage treatments and soil moisture regimes on soil moisture extraction pattern, 1998-99

(IW/CPE = 1.2) soil moisture extraction was more from the top layer (0-15 cm) and less from the layers below (15-30 and 30-45 cm) compared to M_3, M_2 and M_1. Moisture extraction was relatively low from the top layer (0-15 cm) and high from the lower layers (15-30 and 30 - 45 cms) when irrigations were given at 0.6 IW/CPE ratio. The same trend was noticed in the second year.

4.6.4 Water use efficiency (WUE)

Data on the effect of tillage and soil moisture regimes on water use efficiency by sunflower are presented in Table 35 and depicted in Fig. 36.

Deep and fine tilth (T_5) recorded highest water use efficiency (3.53 kg ha mm^{-1} in first year and 2.83 kg ha mm^{-1} in second year) which was superior to other tillage treatments in both years of study. Lowest WUE was associated with zero tillage (2.30 kg m^{-1} in first year and 1.82 kg mm^{-1} in second year).

Among the soil moisture regimes, irrigations given at IW/CPE of 0.8 (M_2) resulted in highest WUE in both the years of study. However, in the first year, it was significantly higher than M_4 (IW/CPE = 0.6), M_3 (IW/CPE = 1.0) and M_5 (IW/CPE = 1.2), while in the second year M_2 (IW/CPE = 0.8) and M_3 (IW/CPE = 1.0) were at par with each other but were significantly superior compared to M_4 and M_1. Among all the soil moisture regimes lowest WUE was associated with M_4 in the first year and with M_1 in the second year.

Interaction effects of tillage and soil moisture regimes were not significant on WUE in both the years of study.

Table 35 : Effect of tillage treatments and soil moisture regimes on water use efficiency (WUE) of sunflower

Tillage (T)	Water use efficiency (kg ha^{-1} mm^{-1})									
	1997-98					1998-99				
	Soil moisture regimes					Soil moisture regimes				
	M_1	M_2	M_3	M_4	Mean	M_1	M_2	M_3	M_4	Mean
T_1	2.30	2.44	2.30	2.16	2.30	1.79	1.88	1.85	1.77	1.82
T_2	2.78	2.88	2.80	2.69	2.79	2.12	2.31	2.30	2.21	2.23
T_3	2.99	3.11	2.94	2.90	2.98	2.24	2.57	2.51	2.47	2.45
T_4	3.25	3.36	3.08	3.01	3.17	2.53	2.85	2.69	2.59	2.67
T_5	3.57	3.64	3.47	3.44	3.53	2.70	3.04	2.80	2.78	2.83
Mean	2.98	3.09	2.92	2.84		2.28	2.53	2.43	2.36	

	1997-98	1998-99
T		
SEm±	0.08	0.08
CD (P=0.05)	0.19	0.17
M		
SEm±	0.04	0.05
CD (P=0.05)	0.09	0.13

T_1 : Zero tillage
T_2 : Country plough twice + bullock drawn cultivar twice
T_3 : Country plough twice + power tiller rotavator twice
T_4 : Mould board plough once + cultivator twice, both tractor drawn
T_5 : Disc plough once + rotavator twice, both tractor drawn

M_1 : IW/CPE = 0.6
M_2 : IW/CPE = 0.8
M_3 : IW/CPE = 1.0
M_4 : IW/CPE = 1.2

T1 - Zero tillage
T2 - Country plough twice + bullock drawn cultivator twice (farmers' practice)
T3 - Country plough twice + power tiller operated rotavator twice
T4 - MB plough once + cultivator twice, both tractor drawn
T5 - Disc plough once + rotavator twice, both tractor drawn

M1 - Irrigations at IW/CPE = 0.6
M2 - Irrigations at IW/CPE = 0.8
M3 - Irrigations at IW/CPE = 1.0
M4 -Irrigations at IW/CPE = 1.2

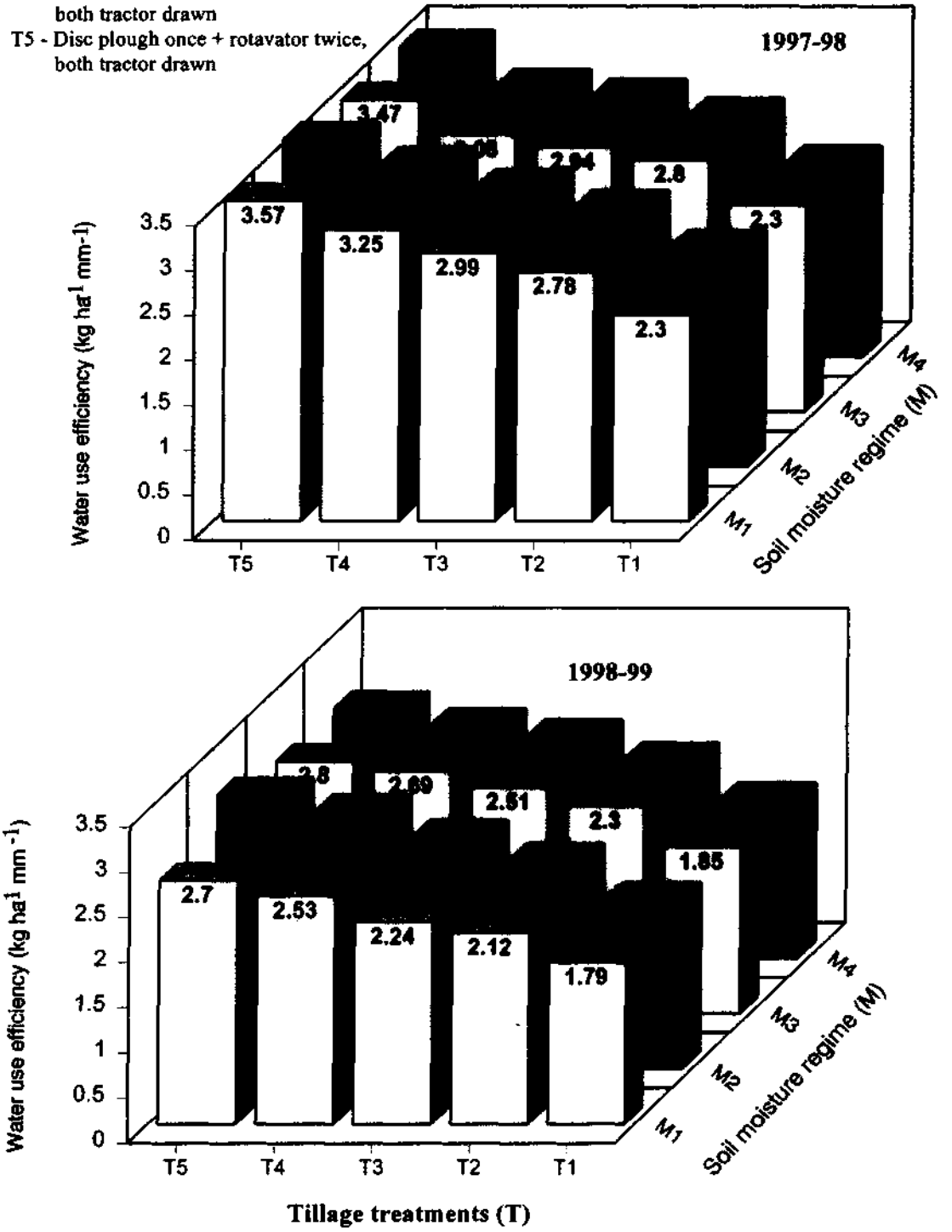


Fig. 36 : Effect of tillage treatments and soil moisture regimes on water use efficiency of sunflower

4.7 PLANT-WATER RELATIONS

Plant water relations were studied by measuring plant water stress parameters viz., relative leaf water content, leaf water potential, leaf diffusion resistance, transpiration rate and leaf temperature. These characteristics were measured one day before irrigation, approximately to 30, 45, 60 and 75 DAS in both the years of study.

4.7.1 Relative leaf water content (per cent)

The data are presented in Table 36 and depicted in Fig. 37 and 38.

In general, the relative leaf water content of sunflower was highest at 30 DAS, and then decreased with an increase in crop age and registered the lowest values at 75 DAS. Crop in deep tillage treatments (T_4 and T_5) registered significantly higher values, as compared to shallow tillage (T_3 and T_2) and zero (T_1) tillage at all stages of observation. However, at 30 DAS T_5 (Disc plough once + rotavator twice, both tractor drawn) and T_4 (mould board plough once + cultivator twice, both tractor drawn) were on par with each other, but were superior to T_3 (country plough twice + power tiller operated rotavator twice) and T_2 (country plough once + bullock drawn cultivator twice) and T_1 (zero tillage) in both the years. Lowest leaf water content was recorded in T_1 (zero tillage treatment) at all stages of observation.

Wettest soil moisture regime M_4 (IW/CPE = 1.2) resulted in highest relative leaf water content at all growth stages followed by M_3 (IW/CPE = 1.0), which were on par with each other but significantly superior to other soil moisture

Table 36 : Effect of tillage treatments and soil moisture regimes on relative leaf water content of sunflower at different growth periods

	Relative water content (%)							
	1997-'98				1998-'99			
	Crop growth period				Crop growth period			
	30 DAS	45 DAS	60 DAS	75 DAS	30 DAS	45 DAS	60 DAS	75 DAS
Tillage (T)								
T_1	84.44	81.64	78.28	70.19	83.21	80.33	75.53	71.00
T_2	86.24	82.61	79.58	70.97	84.70	81.69	76.44	72.11
T_3	86.10	82.80	79.56	70.76	85.86	81.97	76.66	72.22
T_4	87.46	84.86	81.70	73.09	86.17	84.42	78.85	74.21
T_5	87.82	84.86	81.67	72.93	86.44	84.83	78.73	74.81
SEm±	1.21	0.62	0.89	0.66	0.90	0.57	0.43	0.54
CD(P=0.05)	2.79	1.49	1.92	1.53	2.15	1.26	1.00	1.38
Soil moisture regime (M)								
M_1	83.81	77.45	76.77	68.64	82.20	76.93	71.39	69.50
M_2	84.33	81.54	78.23	69.96	83.92	81.33	76.89	71.20
M_3	87.93	86.84	82.51	73.88	86.79	85.46	80.06	74.98
M_4	89.59	87.50	83.73	74.09	88.20	86.69	80.78	75.95
SEm±	0.61	0.42	0.69	0.44	0.56	0.33	0.34	0.48
CD(P=0.05)	1.43	0.97	1.42	0.98	1.37	0.80	0.83	1.22

T_1 : Zero tillage
T_2 : Country plough twice + bullock drawn cultivar twice
T_3 : Country plough twice + power tiller rotavator twice
T_4 : Mould board plough once + cultivator twice, both tractor drawn
T_5 : Disc plough once + rotavator twice, both tractor drawn

M_1 : IW/CPE = 0.6
M_2 : IW/CPE = 0.8
M_3 : IW/CPE = 1.0
M_4 : IW/CPE = 1.2

T1 - Zero tillage
T2 - Country plough twice + bullock drawn cultivator twice (farmers' practice)
T3 - Country plough twice + power tiller operated rotavator twice
T4 - MB plough once + cultivator twice, both tractor drawn
T5 - Disc plough once + rotavator twice, both tractor drawn

M1 - Irrigations at IW/CPE = 0.6
M2 - Irrigations at IW/CPE = 0.8
M3 - Irrigations at IW/CPE = 1.0
M4 - Irrigations at IW/CPE = 1.2

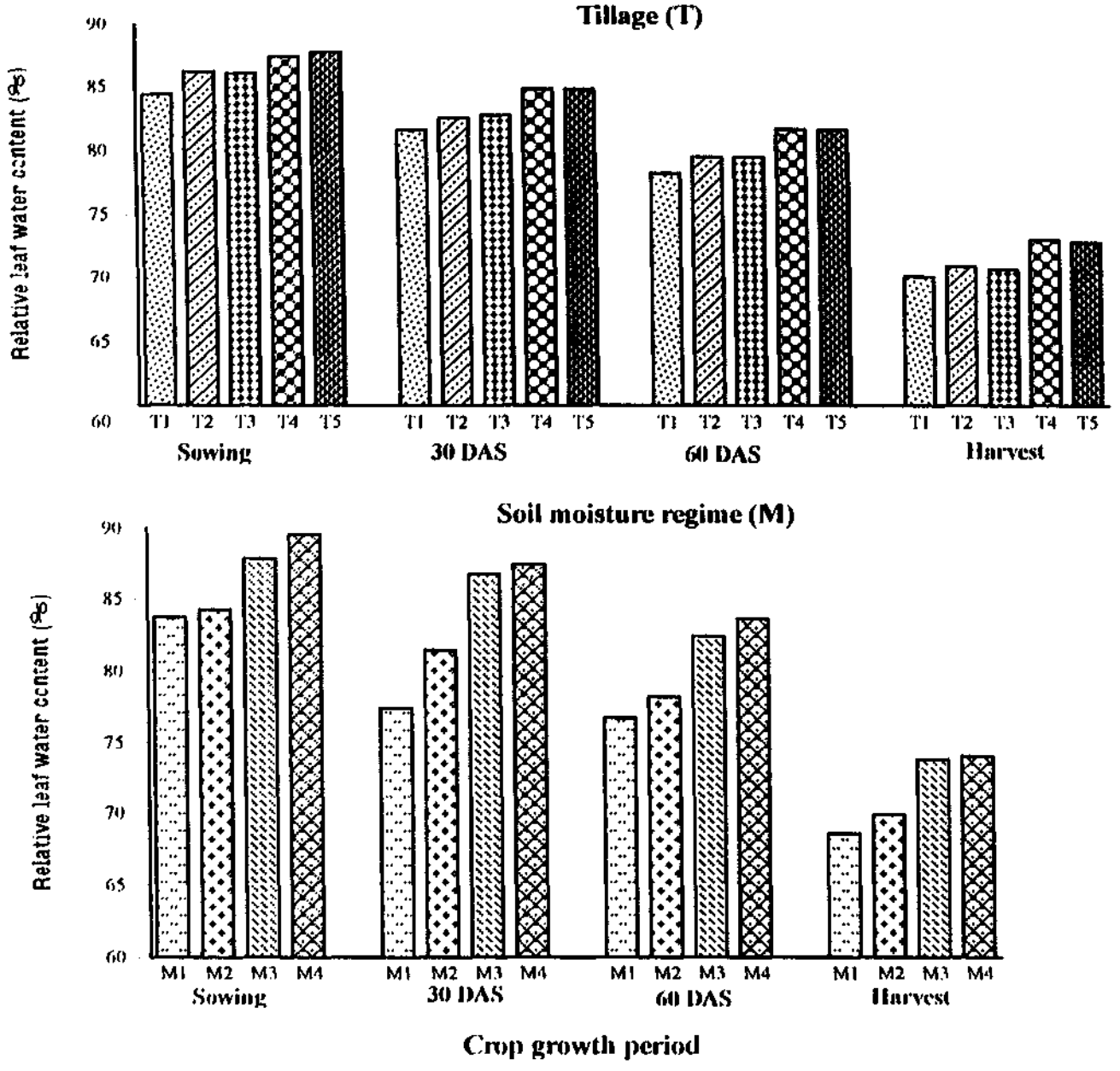


Fig. 37: Effect of tillage treatments and soil moisture regimes on relative leaf water content of sunflower during crop growth period, 1997-98

T1 - Zero tillage
T2 - Country plough twice + bullock drawn cultivator twice (farmers' practice)
T3 - Country plough twice + power tiller operated rotavator twice
T4 - MB plough once + cultivator twice, both tractor drawn
T5 - Disc plough once + ratavator twice, both tractor drawn

M1 - Irrigations at IW/CPE = 0.6
M2 - Irrigations at IW/CPE = 0.8
M3 - Irrigations at IW/CPE = 1.0
M4 - Irrigations at IW/CPE = 1.2

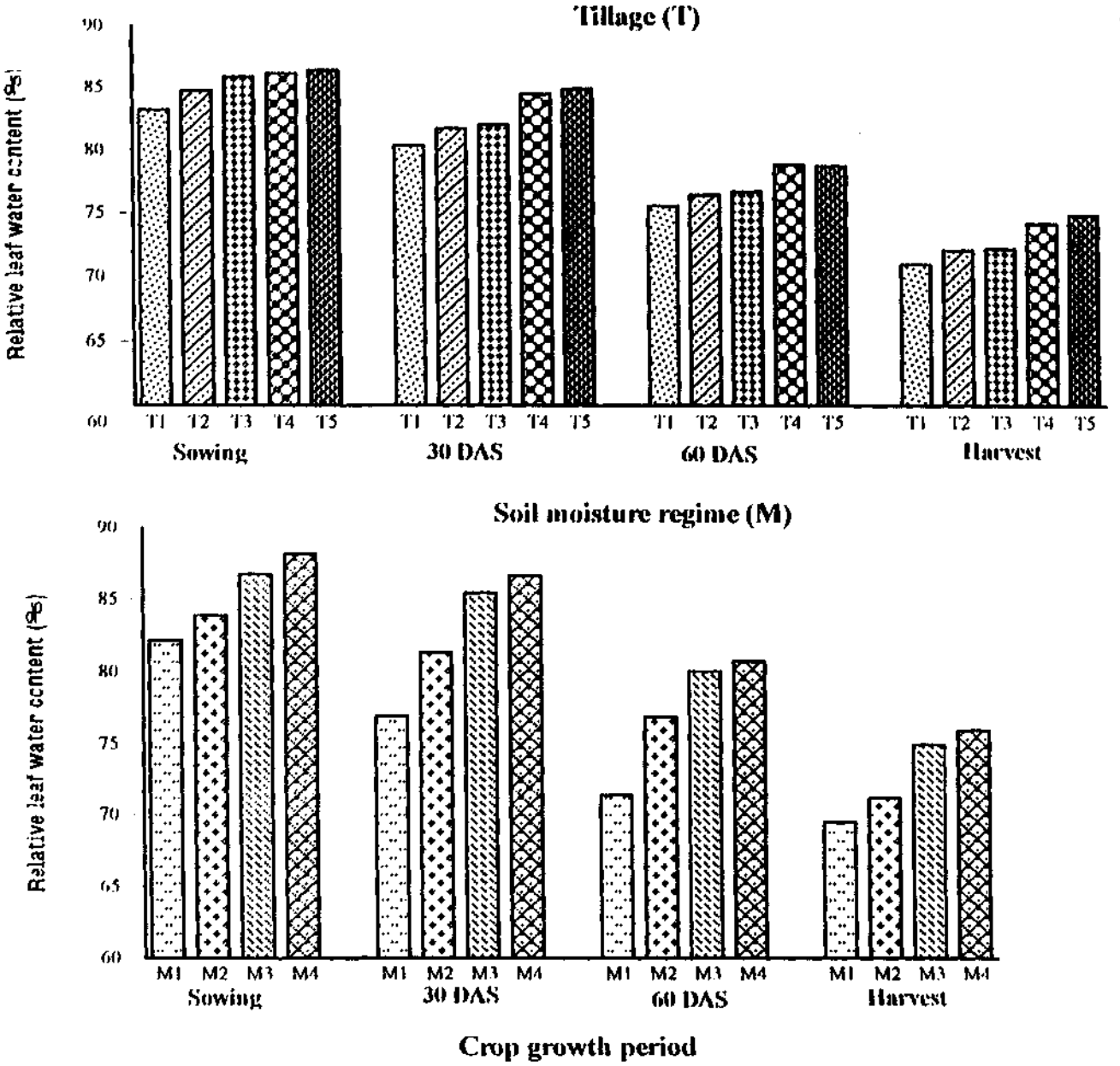


Fig. 38 : Effect of tillage treatments and soil moisture regimes on relative leaf water content of sunflower during crop growth period, 1998-99

regimes. Lowest relative water content was found in M_1 soil moisture regime at all stages of crop in both the years.

Interaction effect of tillage and soil moisture regimes were not significant.

4.7.2 Leaf water potential

The data are presented in Table 37 and depicted in Figs 39 and 40.

In general, the leaf water potential was higher in the early stages of the crop, and decreased with increasing age of the crop.

Lowest leaf water potential was recorded with zero tillage (T_1) at all growth stages of crop in both the years. Leaf water potential in zero tillage plots (T_1) was significantly lower at compared to that of deep tillage treatments (T_4 and T_5) in both the years of study. However, at 30 DAS, tillage had no significant effect on leaf water potential. Leaf water potential was highest in deep tillage with finer seed bed (T_5) at all stages of crop growth in both the years of study.

Crop growth with wettest soil moisture regime (M_4) showed highest leaf water potential, which was significantly superior to all other soil moisture regimes viz., M_3 (IW/CPE = 1.0), M_2 (IW/CPE = 0.8) and M_1 (IW/CPE = 0.6) at all stages of crop growth in both the years of study. Lowest leaf water potential was registered in driest soil moisture regime in all observations.

The interaction effects of tillage and soil moisture regimes were not significant on the leaf water potential at all the stages of observation.

Table 37 : Effect of tillage tretments and soil moisture regimes on leaf water potential of sunflower during crop growth period

	Leaf water potential (bars)							
	1997-'98				1998-'99			
	Crop growth period				Crop growth period			
	30 DAS	45 DAS	60 DAS	75 DAS	30 DAS	45 DAS	60 DAS	75 DAS
Tillage (T)								
T_1	-12.04	-14.97	-16.64	-19.67	-12.37	-15.60	-16.70	-20.07
T_2	-11.55	-14.37	-15.98	-18.92	-11.97	-14.47	-16.35	-19.05
T_3	-11.25	-14.40	-16.00	-18.65	-11.70	-14.52	-16.02	-18.95
T_4	-10.82	-13.32	-15.00	-17.87	-10.90	-13.57	-15.65	-18.47
T_5	-10.72	-13.15	-14.72	-17.77	-10.77	-13.55	-15.42	-18.20
SEm+	0.44	0.67	0.55	0.70	0.45	0.51	0.43	0.45
CD(P=0.05)	NS	1.47	1.27	1.58	NS	1.18	0.99	1.14
Soil moisture regime (M)								
M_1	-12.54	-15.52	-17.28	-20.06	-12.98	-16.2	-17.88	-20.60
M_2	-11.84	-14.36	-15.82	-20.18	-12.00	-14.98	-16.16	-19.28
M_3	-10.86	-13.72	-15.24	-18.20	-11.00	-14.02	-15.28	-18.40
M_4	-9.90	-12.68	-14.25	-16.68	-10.08	-12.12	-14.30	-17.52
SEm+	0.32	0.48	0.35	0.41	0.49	0.37	0.47	0.32
CD(P=0.05)	0.78	0.87	0.85	1.00	0.90	0.79	1.14	0.78

T_1 : Zero tillage
T_2 : Country plough twice + bullock drawn cultivar twice
T_3 : Country plough twice + power tiller rotavator twice
T_4 : Mould board plough once + cultivator twice, both tractor drawn
T_5 : Disc plough once + rotavator twice, both tractor drawn

M_1 : IW/CPE = 0.6
M_2 : IW/CPE = 0.8
M_3 : IW/CPE = 1.0
M_4 : IW/CPE = 1.2

T1 - Zero tillage
T2 - Country plough twice + bullock drawn cultivator twice (farmers' practice)
T3 - Country plough twice + power tiller operated rotavator twice
T4 - M3 plough once + cultivator twice, both tractor drawn
T5 - Disc plough once + rotavator twice, both tractor drawn

M1 - Irrigations at IW/CPE = 0.6
M2 - Irrigations at IW/CPE = 0.8
M3 - Irrigations at IW/CPE = 1.0
M4 -Irrigations at IW/CPE = 1.2

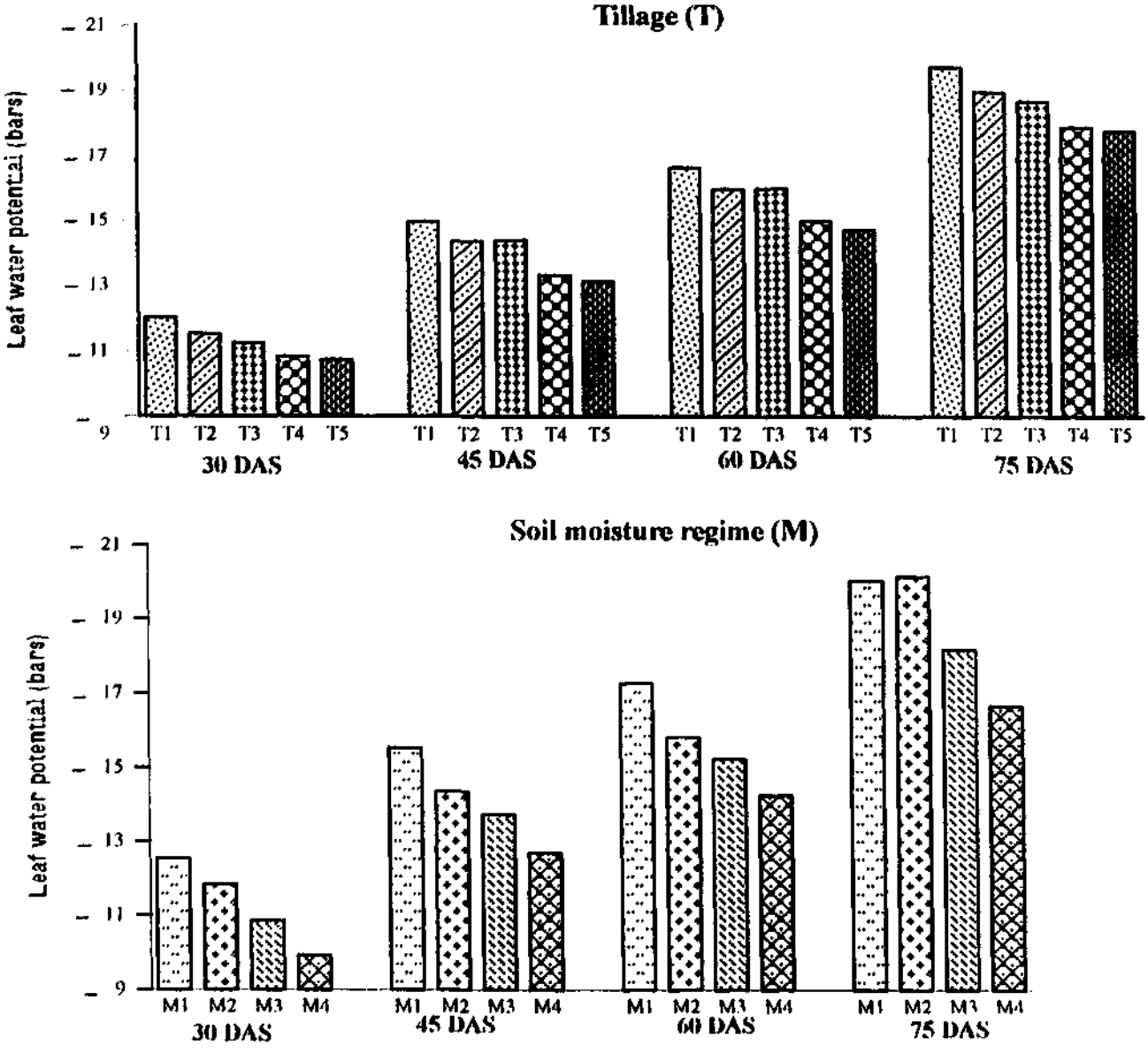


Fig. 39: Effect of tillage treatments and soil moisture regimes on leaf water potential of sunflower during crop growth period, 1997-98

T1 - Zero tillage
T2 - Country plough twice + bullock drawn cultivator twice (farmers' practice)
T3 - Country plough twice + power tiller operated rotavator twice
T4 - MB plough once + cultivator twice, both tractor drawn
T5 - Disc plough once + rotavator twice, both tractor drawn

M1 - Irrigations at IW/CPE = 0.6
M2 - Irrigations at IW/CPE = 0.8
M3 - Irrigations at IW/CPE = 1.0
M4 -Irrigations at IW/CPE = 1.2

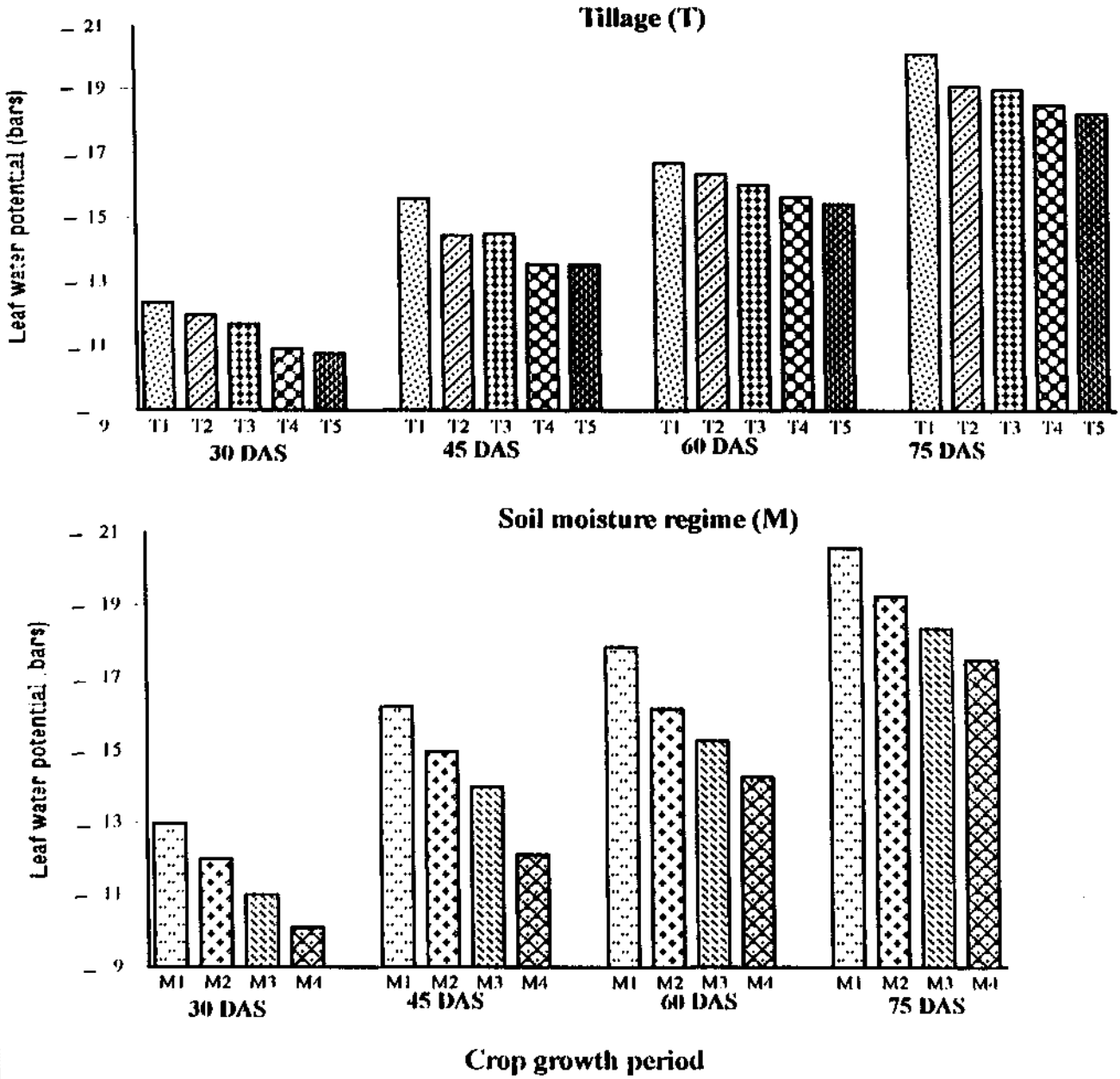


Fig. 40 : Effect of tillage treatments and soil moisture regimes on leaf water potential of sunflower during crop growth period, 1998-99

4.7.3 Leaf diffusion resistance

The data are presented in Table 38.

In general, leaf diffusion resistance in all the treatment combinations was low at early stages of crop, but increased with crop age reaching the highest values at 75 DAS.

Lowest leaf diffusion resistance was registered in T_5 plots (disc plough once + rotavator twice, both tractor drawn) followed by T_4 (MB plough once + cultivator twice, both tractor drawn). Both of these treatments (T_5 and T_4) were on par and significantly lower than other tillage treatments viz., T_3 (country ploughing twice + power tiller operated rotavator twice), T_2 (country ploughing twice + bullock drawn cultivator twice) and T_1 (zero tillage) at all stages of crop growth in both the years. Higher leaf diffusion resistance was associated with zero tillage (T_1) treatment at all stages of crop growth in both the years of study.

Wettest soil moisture regime M_4 (IW/CPE = 1.2) registered lowest leaf diffusion resistance values, which was significantly lower than in other moisture regimes. Highest leaf diffusion resistance values were noticed with driest soil moisture regime (M_1).

Interaction effects of tillage and soil moisture regimes were not significant on leaf diffusion resistance.

Table 38 : Effect of tillage tretments and soil moisture regimes on leaf diffusion resistance at different of sunflower growth periods

	Diffusive resistance (Sm^{-1})							
	1997-'98				1998-'99			
	Crop growth period				Crop growth period			
	30 DAS	45 DAS	60 DAS	75 DAS	30 DAS	45 DAS	60 DAS	75 DAS
Tillage (T)								
T_1	47.81	63.27	67.70	74.23	51.44	61.91	70.50	77.92
T_2	46.27	60.21	65.77	74.32	49.62	59.80	68.63	76.71
T_3	45.85	59.71	64.95	73.25	49.25	60.17	68.29	75.82
T_4	43.88	56.39	62.13	69.96	46.58	56.16	65.23	72.46
T_5	43.56	55.97	61.85	69.45	46.35	56.24	64.98	72.03
SEm+	0.51	0.96	0.83	0.69	0.64	0.62	1.28	1.10
CD(P=0.05)	1.19	2.25	1.90	1.60	1.48	1.48	2.96	2.53
Soil moisture regime (M)								
M_1	51.25	70.20	73.83	82.04	55.47	70.49	78.21	83.65
M_2	47.03	63.62	67.96	74.99	49.52	62.19	69.89	78.88
M_3	43.46	53.03	60.26	67.14	47.64	55.21	62.81	69.80
M_4	40.00	49.66	55.87	64.29	41.96	47.53	59.13	67.51
SEm+	0.38	0.47	0.60	0.53	0.42	0.30	0.72	0.73
CD(P=0.05)	0.85	1.16	1.21	1.17	1.02	0.73	1.55	1.68

T_1 : Zero tillage
T_2 : Country plough twice + bullock drawn cultivar twice
T_3 : Country plough twice + power tiller rotavator twice
T_4 : Mould board plough once + cultivator twice, both tractor drawn
T_5 : Disc plough once + rotavator twice, both tractor drawn

M_1 : IW/CPE = 0.6
M_2 : IW/CPE = 0.8
M_3 : IW/CPE = 1.0
M_4 : IW/CPE = 1.2

4.7.4 Transpiration rate

The data are furnished in Table 39. Transpiration rate was high at initial stages of growth and reduced towards harvest.

Tillage with tractor draw disc plough once + rotavator twice (T_5 recorded highest transpiration rate, closely followed by tillage with at tractor drawn and mould board plough + cultivator twice (T_4). Both the above tillages (T_5 and T_4) were significantly superior compared to other treatments. Lowest transpiration rate was observed in zero tillage (T_1) treatment.

Wettest soil moisture regime (M_4), where irrigation scheduled at IW/CPE= 1.2 registered highest transpiration rate, which is significantly higher compared to other three soil moisture regimes viz., M_3 (IW/CPE = 1.0), M_2 (IW/CPE = 0.8) and M_1 (IW/CPE = 0.6). Lowest transpiration was recorded in driest soil moisture regime (M_1), wherein, irrigation given at IW/CPE = 0.6.

Interaction effects of tillage and soil moisture regimes were not significant in affecting transpiration rates.

4.7.5 Leaf temperature

The data are presented in the Table 40.

Lowest leaf temperature was observed in T_5 plots (disc plough once + rotavator twice, both tractor drawn), which was on par with that of T_4 plots (mould board plough once + cultivator twice, both tractor drawn). Both these tillage treatments recorded significantly low leaf temperature values than that of T_1 (zero tillage) in all observations. However, the leaf temperatures recorded

Table 39 : Effect of tillage tretments and soil moisture regime on transpiration rate of sunflower at different growth periods

	Transpiration rate (μg H_2O cm^{-2} S^{-1})							
	1997-'98				1998-'99			
	Crop growth period				Crop growth period			
	30 DAS	45 DAS	60 DAS	75 DAS	30 DAS	45 DAS	60 DAS	75 DAS
Tillage (T)								
T_1	17.95	15.31	13.32	10.64	19.23	16.75	14.26	12.61
T_2	18.37	17.04	14.49	11.60	19.61	18.41	15.68	12.41
T_3	19.19	17.25	15.08	11.72	20.05	18.14	15.07	12.07
T_4	20.95	19.21	16.64	13.74	21.99	20.02	16.55	14.33
T_5	20.95	19.23	16.59	13.78	22.24	20.23	16.23	14.24
SEm+	0.55	0.56	0.99	0.60	0.37	0.68	0.83	0.84
CD(P=0.05)	1.48	1.30	2.29	1.46	0.85	1.57	1.78	1.87
Soil moisture regime (M)								
M_1	17.22	14.06	12.62	9.42	18.15	15.75	13.79	10.31
M_2	18.36	16.32	14.12	11.66	20.44	17.66	15.78	11.59
M_3	20.62	18.75	16.11	13.91	21.14	20.47	16.44	13.58
M_4	21.84	21.01	18.05	14.20	22.98	22.16	17.82	15.19
SEm+	0.41	0.35	0.55	0.43	0.24	0.27	0.53	0.42
CD(P=0.05)	0.94	0.86	1.34	1.05	0.60	0.67	1.30	1.04

T_1 : Zero tillage
T_2 : Country plough twice + bullock drawn cultivar twice
T_3 : Country plough twice + power tiller rotavator twice
T_4 : Mould board plough once + cultivator twice, both tractor drawn
T_5 : Disc plough once + rotavator twice, both tractor drawn

M_1 : IW/CPE = 0.6
M_2 : IW/CPE = 0.8
M_3 : IW/CPE = 1.0
M_4 : IW/CPE = 1.2

Table 40 : Effect of tillage tretments and soil moisture regime on leaf temperature of sunflower during crop growth period

	Leaf temperature (°C)							
	1997-'98				1998-'99			
	Crop growth period				Crop growth period			
	30 DAS	45 DAS	60 DAS	75 DAS	30 DAS	45 DAS	60 DAS	75 DAS
Tillage (T)								
T_1	26.82	27.15	28.20	28.58	27.60	28.37	28.82	29.25
T_2	25.72	26.22	27.70	28.27	26.72	26.95	28.05	28.73
T_3	25.82	26.17	27.52	27.67	26.69	26.92	28.27	28.42
T_4	24.85	25.87	26.75	27.07	25.80	26.17	27.47	27.72
T_5	24.65	25.07	26.37	26.85	25.66	26.33	27.32	27.59
SEm±	0.53	0.57	0.68	0.48	0.69	0.66	0.39	0.63
CD(P=0.05)	1.23	1.49	1.35	1.21	1.59	1.67	0.96	1.36
Soil moisture regime (M)								
M_1	27.80	28.30	29.56	29.96	28.37	29.82	30.16	30.64
M_2	26.16	26.58	28.06	28.36	26.69	26.72	28.50	29.28
M_3	25.20	25.44	26.30	27.53	25.47	26.01	27.40	27.42
M_4	22.28	23.44	24.38	24.96	24.44	24.50	25.86	25.60
SEm±	0.32	0.33	0.32	0.39	0.36	0.22	0.35	0.44
CD (P=0.05)	0.78	0.74	0.77	0.95	0.86	0.53	0.87	1.07

T_1 : Zero tillage
T_2 : Country plough twice + bullock drawn cultivar twice
T_3 : Country plough twice + power tiller rotavator twice
T_4 : Mould board plough once + cultivator twice, both tractor darwn
T_5 : Disc plugh once + rotavator twice, both tractor darwn

M_1 : IW/CPE = 0.6
M_2 : IW/CPE = 0.8
M_3 : IW/CPE = 1.0
M_4 : IW/CPE = 1.2

from shallow tilled plots (T_2 and T_3) ranged between zero tillage and deep tillage treatments. Highest leaf temperature was recorded with T_1 (zero tillage) at all stages of crop growth in both the years of study.

Crop grown under wettest soil moisture regime (M_4) recorded lowest leaf temperature, which was significantly lower compared to that under any other soil moisture regime i.e., M_3, M_2 and M_1 at all crop growth stages in both the years. Highest leaf temperature was observed with driest soil moisture regime in both the years of study.

Leaf temperatures were not influenced by the interaction tillage practices and soil moisture regimes in both the years of investigation.

DISCUSSION

CHAPTER V

DISCUSSION

Effects of different tillage treatments and soil moisture regimes on soil properties, crop growth and yield of sunflower, grown after *kharif* rice, were studied. The effects on soil properties were assessed in terms of size distribution and mean weight diameter of clods, bulk density, porosity, hydraulic conductivity in 0-15, 15-30 and 30-45 cm depth; and penetration resistance and infiltration rate of surface layer (0-15 cm). The effect of the treatments on crop growth were assessed in terms of seedling emergence, plant growth, leaf area index, root growth, dry matter accumulation, head size, 1000 seed weight, oil content, yield (both seed and oil yield) and harvest index. Soil water studies were made in terms of water use (crop evaportanspiration i.e., ETa, day^{-1}), soil moisture extraction pattern, and water use efficiency.

The trends of variations noticed (presented in chapter IV) have been discussed in this chapter in the light of available literature. In doing so, only major trends have been discussed instead of the individual variations.

5.1 EFFECT OF TILLAGE TREATMENTS AND SOIL MOISTURE REGIMES ON SOIL PHYSICAL PROPERTIES

5.1.1 Clod size distribution and mean weight diameter (MWD) of clods at sowing

The different tillage treatments adopted, brought appreciable variations in size distribution and mean weight diameter of dry clods (Table 5 and Fig.4).

The higher percentage of smaller size clods (20 mm) with T_5 tractor drawn (disc plough + rotavator) and T_3 (country plough + rotavator) indicated the creation of fine seed bed (Fig.4). In T_2 (country plough + cultivator) and T_4 (tractor drawn MB plough + cultivator), however, large sized clods were relatively higher over smaller clods and were not conducive for seed-soil contact, which had adverse effect on seedling emergence (Table 5). In zero tillage (T_1) treatment, soil was hard and compact. Hence, clod size distribution could not be studied.

Higher percentage of smaller size clods (20 mm) in T_5 and T_3 was due to more vigorous and more inversion type of tillage with rotavator. In case of T_2 and T_4, however, the bigger size clods (20 mm) might be due to less vigorous and less inversion type of tillage given. Similar observations were reported by Khan (1984) and Singa Rao *et al.* (1995) with rotary tillage.

A critical examination of the data further revealed gradual decline in mean weight diameter (MWD) as the age of the crop advanced, a manifestation of gradual compaction and less smaller clods. It was considerably low with T_5 and T_3 tillage treatments as they produced relatively more smaller clods, which provided conducive seed bed with fine tilth for sunflower seed after submergence in *kharif* rice. Similar trends of results were also reported by Prasadini *et al.* (1993) and Mandhar (1989).

5.1.2 Clod size distribution and mean weight diameter (MWD) at 30 DAS and 60 DAS

The close perusal of data (Table 6 and Fig. 5) revealed reduction in MWD with an increase in crop duration, irrespective of the treatment, suggesting continuous break down of larger size clods following various agronomic practices during crop growth period. However, the extent of break down varied with frequency of irrigations given (moisture regimes). The reduction in MWD from sowing to 30 DAS was much higher than reduction rate from 30 to 60 DAS.

Lesser MWD was noticed in the plots where rotavator was used for secondary tillage (T_5 and T_3). Rotavator breaks the bigger clods and results in higher proportion of smaller size clods (20 mm). In case of T_2 and T_4, wherein secondary tillage was done with cultivator, (primary tillage was carriedout either with tractor drawn disc plough (T_4) or with bullock drawn country plough (T_2)), larger size clods (20 mm) dominated the resultant tilth. The trends were similar throughout the crop growth period in both the years of study.

Soil moisture regimes, created by application of irrigations based on IW/CPE ratio, reduced the size of the dry clods during the crop growth period. Lowest dry clod size was observed with soil moisture regimes created by giving irrigations at IW/CPE ratio of 1.2, i.e., M_4 followed by M_3 (IW/CPE = 1.0), M_2 (IW/CPE = 0.8) and M_1 (IW/CPE = 0.6). This could be attributed to breakdown of larger size clods and corresponding increase in proportion of smaller size clods with increasing frequency of irrigations.

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When a dry soil clod is wetted by irrigating the field, a rapid absorption of water causes unequal swelling throughout the clod mass, producing fractures along cleavage planes resulting in break down of clods (Ghildyal and Tripathi, 1987). With increase in number of irrigations the break down of bigger clods into smaller ones occur.

5.1.3 Depth of tillage

The depth of tillage depends on the type of primary tillage implement used. The mean depth of ploughing (Table 5) was higher (21.63 cm) when primary tillage was done with tractor drawn disc plough (T_5) and tractor drawn mould board plough (T_4). It was less in case of country plough (T_3 and T_1). However, secondary tillage implements have no effect on depth of tillage. The high revolutions per minute (rpm) of disc. due to high power (tractor) used in T_5 resulted in cutting of soil to deeper depths. High drought power of tractor with MB plough also resulted in deeper depths of ploughing. Depth of tillage has its influence on other soil physical properties like water storage, bulk density, porosity and on the root penetration and extraction of moisture and nutrients from a greater soil volume. These results are in agreement with the results obtained by Rautaray (1983) and AICRP on SPCIP (1986-87).

5.1.4 Bulk density and porosity

Considerable variations in soil bulk density and porosity (Tables 7 & 8) were observed with tillage practices and depth of sampling. Bulk density depends on the looseness of the soil created, in the present study, by the tillage. Irrespective of stage of crop growth and tillage treatment, bulk density (and also

pore space) was relatively higher in sub soil i.e., 15-30 cm and 30-45 cm and low in surface soil i.e. 0-15 cm and vice versa. In zero tillage treatment as the soil was not disturbed, and remained compact, recorded relatively higher bulk density and low pore space compared to other treatments. In the sub surface 15-30 cm layer relatives low bulk density and higher porosity were associated with deep tillage treatments (T_5 and T_4) compared to shallow tillage (T_3 and T_2) and zero tillage (T_1). This is because of the fact that the plots under T_5 and T_4 were ploughed to deeper depths with tractor drawn disc plough and tractor drawn mould board plough, respectively. However, in the lower layer (30-45 cm), soil bulk density was not affected any one of the five tillage practices, because the depth of tillage was only upto 21.63 cm in even deep tillage plots.

Among tilled plots, relatively lower bulk density and higher porosity values were associated with deep tillage treatments (T_5 and T_4) than shallow tillage treatments (T_3 and T_2). However, T_5 (secondary tillage with rotavator) recorded relatively low bulk density and high porosity than T_4 (secondary tillage with cultivator) and T_3 (secondary tillage with rotavator) than T_2 (secondary tillage with cultivator). This might be due to vigorous and more inversion type of tillage in T_5 and T_3, which pulvarised and loosened the soil to a greater extent, and increased the porosity, and thereby appreciably reduced the bulk density. In the second layer also, significantly lower bulk density values were observed with deep tillage treatments (T_5 and T_4) compared to shallow tillage (T_3 and T_2) and zero tillage (T_1). In zero tillage the soil is hard and compact and therefore recorded high bulk density. These finding are in agreement with

those of Bhushan *et al.* (1973); Rautaray (1983); Khan (1984); Choudhary *et al.* (1985) and AICRP on SPCIP (1986-87).

It is interesting to note that there was considerable difference in the bulk density of soil due to different tillage treatments in surface and middle layers soon after imposition of tillage., but later the differences diminished towards harvest stage of the crop obviously due to consolidation of soil particles. This is in accordance with the finding of Awadhwal and Thierstein (1984), Gajri *et al.* (1997) and Meharban Singh and Choudhary (1998).

Soil moisture regimes and their interactions with tillage did not significantly influence the soil bulk density and porosity. However, a slightly high bulk density and low porosity values were noticed with increase in frequency of irrigation during crop growth period (Table 7 and 8). This might be due to the number of wetting and drying cycles as a consequence of irrigations that led to break down of clods and consolidation of soil.

5.1.5 Infiltration rate

In general, the steady state infiltration rates (Table 9 and Figs. 11 & 12) of water into the soil were higher at the time of sowing and gradually reduced with crop growing period (Table 9). Among tillage treatments, highest infiltration rate was associated with deep tillage plots (T_5 and T_4) followed by shallow tillage + power tillage operated rotavator, (T_3), shallow tillage + bullock drawn cultivator (T_2). This was due to ploughing of soil to deeper depths in T_5 and T_4 resulting in loosening the sub soil hard layers created during the previous puddled crop. Zero tillage (T_1) plots are hard and compact with high bulk

density (Table 7) and low pore space (Table 8) and hence lowest infiltration rate was observed. Bulk density and infiltration rate were negatively correlated at both 30 and 60 DAS (r = -0.951 at 30 DAS and -0.960 at 60 DAS). The results are in conformity with those of Vittal *et al.* (1983), Khan (1984) and Aggarwal *et al.* (1997).

Soil moisture regimes also influenced the infiltration rate from 60 DAS of the crop. Lower infiltration rate was observed with M_4 soil moisture regime, in which irrigations were given at IW/CPE = 1.2, while higher infiltration rate was associated with less soil moisture regime (IW/CPE = 0.6). This might be due to variation in bulk density of soil brought by variations in the soil moisture regimes.

5.1.6 Hydraulic conductivity

Irrespective of the tillage, surface (0-15 cm) and sub surface (15-30 cm) layers of the soil registered higher hydraulic conductivity (Table 10 and Figs. 13 & 14) at sowing and gradually decreased towards the end of the growing period except in zero tillage (T_1), where in the hydraulic conductivity values are more or less similar through out the crop growth season.

Deep tillage treatments (T_5 and T_4) recorded higher hydraulic conductivity in surface (0-15 cm) and sub surface (15-30 cm) compared to shallow tillage (T_3 and T_2) and zero tillage (T_1). This appears to be due to ploughing upto deeper depths (21 cm) in case of T_5 and T_4, which loosened the soil and increased the porosity up to deeper depths. Between deep tillage treatments, disc ploughing + rotavator treatment (T_5) registered higher hydraulic conductivity than

MB plough + cultivator treatment (T_4). This difference could be attributed to less bulk density and higher porosity of soil in T_5 than T_4 (Table 10). It is known fact that the saturated hydraulic conductivity of soil increases with decrease in bulk density and increase in porosity of soil. BD and HC were negatively correlated with each other at 30 and 60 DAS (r =-0.951 and-0.988, respectively). The same condition was observed with T_3 and T_2 in surface soil (0-15 cm) where in tilth in T_3 was more pulvarised to fine tilth. However, the hydraulic conductivity in zero tillage was very low compared to any of the tillage treatments which could be attributed to the continuation of hard compact soil formed after *kharif* rice in the preceding season, not being disturbed at all. The findings are in accordance with these of Paul, (1970), Pratibha (1992) and Aggarwal *et al.* (1997).

The hydraulic conductivity values in the bottom layer (30-45 cm depth) were not altered with tillage practices due to the fact that the soil in the bottom layer was not disturbed with any of the tillage implements used in the study.

5.1.7 Penetration resistance

The effect of various tillage practices and soil moisture regimes on soil penetration resistance during crop growing period of sunflower is shown in Table 11 and Figs. 15 and 16. At 10 DAS, penetration resistance values were measured before imposition of the soil moisture regimes and hence, only reflected the tillage effects. It was observed that penetration resistance was significantly higher under zero tillage plots (T_1) compared to all other tilled plots. Soil penetration resistance varies mainly with bulk density and soil moisture content. Among tillage treatments, the resistance offered by the soil was significantly low in the

plots which received tractor drawn disc plough + rotavator (T_5) and tractor drawn MB plough + cultivator (T_4) compared to country plough twice + power tiller operated rotavator twice (T_3) and country plough twice + bullock drawn cultivator twice (T_2). There was positive correlation between bulk density and penetration resistance ($r = 0.782$ at 30 DAS and 0.566 at 60 DAS).

Soil moisture regimes also influenced the penetration resistance in the soil to conepenetrometer. At 56 DAS in first year and 49 DAS in second year, the penetration resistance was measured in all the plots just before giving irrigation, which coincided with cumulative pan evaporation at 300 mm in all the treatments. It was found that lower penetration resistance values were associated with wettest soil moisture regime (M) and higher with driest soil moisture regime (M_1). Penetration resistance was positively correlated with soil moisture tension at 60 DAS ($r = 0.739$).

Mechanical impedance of soil is a function of both bulk density and soil moisture content. Higher penetration resistance in untilled plots could be attributed to their high bulk density. Choudhary *et al.* (1985) and Gajri *et al.* (1997) reported similar relation between bulk density and penetration resistance under different tillage practices. A lower resistance to penetration under disc plough (T_5) and MB plough (T_4) treatments indicated their beneficial effects in keeping the seed bed comparatively loose for longer duration and to deeper soil depths.

Reduction in penetration resistance with increase in water application ($M_1 > M_2 > M_3 > M_4$ (in decreasing order) may be attributed to relatively higher moisture content in the soil under M_4.

5.1.8 Soil temperature

The soil temperature measured at 9.30 AM during crop growth period (Table 12 and Figs. 17 and 18) indicated that soil temperature at 5 cm depth was altered by both tillage and soil moisture regimes in both the years of study. However, the sub-surface soil temperature was not altered appreciably with tillage or soil moisture regimes or due to their interaction effects.

At 5 cm depth irrespective of duration of crop and soil moisture regimes, highest soil temperature was recorded with zero tillage (T_1) which might be due to high bulk density, low porosity, leads to low moisture content with zero tillage (T_1) and resulting in quick transfer of heat. On the other hand, tilled plots created more porosity thereby reducing the soil contact and also increasing water retention capacity of soil. Lowest soil temperature was recorded with T_5 (tractor drawn disc plough + rotavator twice), which could be attributed to low bulk density, high porosity and high moisture content. Soil temperature was positively correlated with soil moisture tension at 60 DAS ($r = 0.805$). The variations in soil temperature relatively reduced towards the crop harvesting stage due to consolidation of soil during crop growth period reduced tillage effects.

5.2 EFFECT OF TILLAGE TREATMENTS ON SEEDLING EMERGENCE

Seedling emergence (Table 13 and Fig. 19) was influenced significantly by the tillage practices only. Among different tillages adopted, T_5 and T_3, where secondary tillage was done with rotavator (either tractor drawn or power tiller operated), recorded significantly higher seedling emergence (75 %). This might be due to favourable seed bed created in T_5 and T_3 which is evident from the reductions in MWD of dry clods. More of smaller size clods (20 mm dia), less bulk density (Table 7), less penetration resistance (Table 11) and high moisture content (Appendix Va) increased seed germination and seedling emergence (Table 13). Seedling emergence was negatively correlated with MWD ($r = -0.961$), penetration resistance ($r = -0.311$) and soil moisture tension ($r = -0.868$). The seed-soil contact in these treatments have been appreciably better, facilitated better germination. In case of T_2 and T_4, involving secondary tillage with cultivator (either bullock or tractor drawn), the seed bed was relatively less favourable, which is evident from higher mean weight diameter of clods (plots under T_2 and T_4 were visibly more cloddy than the other tillage treatments, shown in plates 3 and 5). In addition, high bulk density and low moisture content in T_2 and T_4 appear to have adversely affected the germination and emergence of seedlings.

Increased seedling emergence with decreased clod size and mean weight diameter (MWD) was reported by Bhushan *et al.* (1973) in case of wheat; and Khan and De Datta (1983), and Singa Rao *et al.* (1995) in case of groundnut.

In zero tillage (T_1) lowest emergence was observed compared to any of the tillage treatments. This could be attributed to high bulk density of the soil (very narrow seed line opened about 2 cm depth to facilitate sowing) (Table 7), which offered high resistance to the growing radicle to emergence from the soil.

These findings are in accordance wither Omer and Elamin (1997) on sorghum crop.

5.2.1 Relation between seedling emergence (per cent) and tillage induced soil physical properties at sowing

Step down multilinear functions (MLR) were worked out between seedling emergence and tillage induced soil physical edaphic properties at sowing viz., MWD (mm), bulk density, penetration resistance and soil moisture tension). The step down MLR function resulted in the identification of only one significant contributory physical edaphic property i.e., mean weight diameter (MWD) of dry clods influencing the seedling emergence. The relationship is presented in the model along with figure 41. The model with figure explained variation in seedling emergence to an extent of 92.6 per cent with change in mean weight diameter of dry clods at sowing. The R^2 value was highly significant ($P = 0.01$). The value of the regression coefficient (b) was also highly significant ($P = 0.01$) and negatively affected the yield. The magnitude of re- inforcent in seed yield varied with the magnitude of regression coefficient (b), which inturn was a function of unit measured as mean weight diameter of dry soil clods.

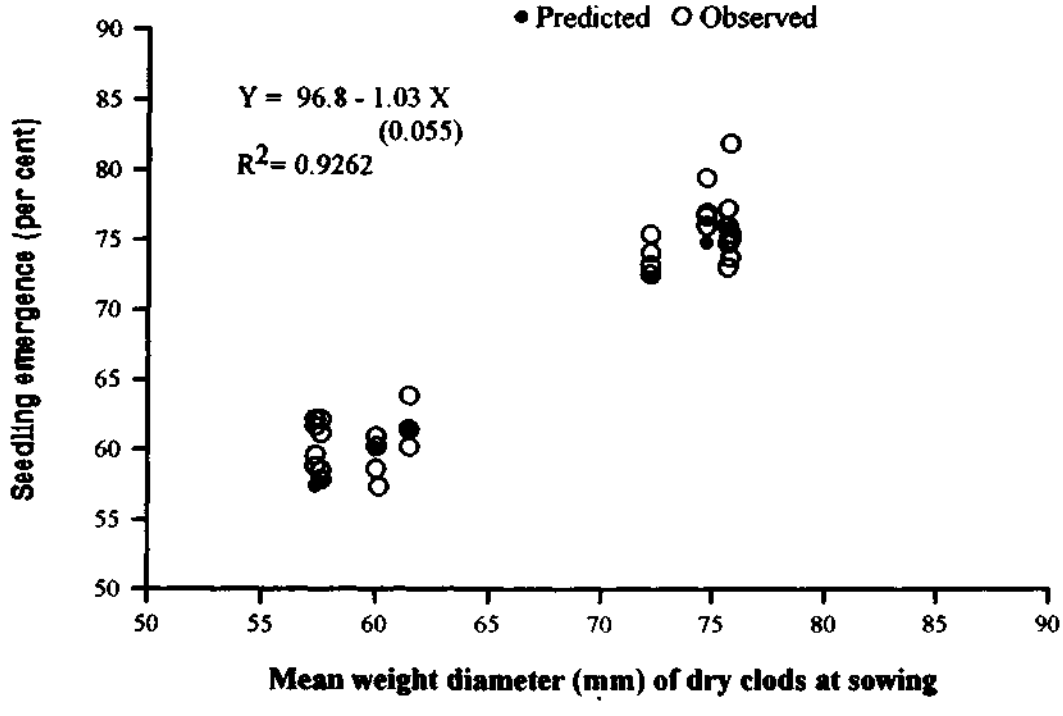

Fig. 41 : Variation of observed seedling emergence over predicted seedling emergence by MLR

Table 41 : Correlation matrix of seedling emergence percentage and tillage induced physical edaphic properties at sowing

	X_1	X_2	X_3	X_4	Y
X_1	1.000	0.334	0.406	0.900	-0.961
X_2	0.334	1.000	0.805	0.489	-0.292
X_3	0.406	0.805	1.000	0.458	-0.311
X_4	0.900	0.489	0.458	1.000	-0.868
Y	-0.961	-0.292	-0.311	-0.868	1.000

r(P = 0.05) = 0.349
r(P = 0. 01) = 0.449

X_1 = Mean weight diameter of dry clods (mm)
X_2 = Bulk density (Mg m^{-3})
X_3 = Penetration resistance (kg cm^{-2})
X_4 = Soil moisture tension (bars)
Y = Seedling emergence (per cent)

The MWD of dry clods negatively correlated with the seedling emergence indicating that finer tilth leads to better germination and seedling emergence.

$$Y = 96.8 - 1.03\ x$$
$$(0.055)$$

$R^2 = 0.926$

Y = Seedling emergence (per cent)

where x = mean weight diameter of dry clods at sowing.

5.3 EFFECT OF TILLAGE TREATMENTS AND SOIL MOISTURE REGIMES ON PLANT GROWTH, YIELD ATTRIBUTES AND YIELD OF SUNFLOWER

5.3.1 Plant height

Tillage treatments and soil moisture regimes significantly influenced the plant height (Table 14). Deep tilled plots (T_5 and T_4) registered taller plants compared to shallow tilled plots (T_3 and T_2) and zero tillage (T_1) plots. Ploughing the soil to deeper depths resulted lossening the soil to greater depths, creating low bulk density and low resistance for root penetration, faclitating root proliferation into deeper depths. The plants in these treatments, hence, could extract more water and nutrients from deeper depths of soil leading to better growth, as indicated by its height. In case of T_2 and T_3, depth of tillage was shallow (11 cm) and hence restricted the root growth leading to poor growth and less plant height.

In zero tillage the soil was hard and compact with higher bulk density and penetration resistance. Hence root growth was shallow, leading to very poor growth and shorter plants. Similar results were reported by Pratibha (1992) in

case of sunflower, Gill *et al.* (1996) in case of maize; and Salih *et al.* (1998) in case of cotton.

Irrigations given at IW/CPE = 1.2 (M_4) and IW/CPE = 1.0 (M_3) produced taller plants compared to those in the plots receiving irrigations at IW/CPE = 0.8 (M_2) and 0.6 (M_1). This could be mainly due to sufficient moisture being available through out the crop period with practically no moisture stress in these treatments in M_4 and M_3 compared to M_2 and M_1. In case of M_2 and M_1, the soil water potential was relatively less and the plants have experienced certain amount of stress each time before the irrigation was given (Appendix Va & b). Lesser soil moisture resulted in high soil strength, which affects the plant growth indirectly. Similar observations were made by Patel and Singh (1981) and Vivek and Chakor (1992).

Interaction of tillage with soil moisture regimes indicated significantly taller plant height with T_4 M_4, T_4 M_3, T_5 M_4 and T_5 M_3, which were at par and significantly superior to other treatment combinations (Table 14). These combinations having deep tillage with better seed bed and better soil moisture regimes. Combined favourable effects of better tilth created in T_4 and T_5 coupled with favourable soil moisture regimes in M_4 and M_3 increased the plant height at all stages of crop growth, except at 30 DAS, where the interaction effects was not significant and the gap between the first irrigation and observation time was small and no significant interaction could be obtained with the short period. Shortest plants were observed in T_1 M_1 combinations because of hard and compact soil condition (high soil strength) coupled with moisture stress conditions.

5.3.2 Leaf area index

Tillage, soil moisture regimes and their interactions affected the leaf area index of sunflower (Table 15 and Fig. 20). At 60 DAS, higher leaf area index (LAI) resulted when the soil was tilled to deeper depths and made to fine tilth (T_5) compared to deep coarse tilth (T_4), shallow but fine tilth (T_3), shallow coarse tilth (T_2) and zero tillage (T_1). Finer tilth coupled with deep ploughing (T_5) resulted in higher plant population (Table 13) and higher plant growth (Table 18) producing high leaf area index. However, in deep and coarse tilled (T_4) plots though plant growth was appreciably high, leaf area index was significantly lesser than T_5 due to low plant population (Table 13). Leaf area index in T_3 and T_2 was still lesser due to restricted plant growth because of hard compact subsurface layer (Table 7). The leaf area index was lowest in zero tillage (T_1) where the surface soil itself was much compact and hard, hence restricted plant growth. Similar results were reported in case of mungbean (IRRI, 1984), groundnut (Khan, 1984) and Wheat (Gill *et al.*, 1996).

Irrigation given at shorter intervals and at relatively higher soil water regimes (M_4 and M_3), resulted in higher leaf area index compared to irrigations at longer intervals and lesser soil water regimes. The availability of moisture to the plants at all the stages of crop growth, as indicated by relative leaf water content and leaf water potential (Tables 36 and 37), resulted in the production of larger leaves, there by high LAI in M_4 and M_3 treatments. Irrigations scheduled at longer intervals (M_2 and M_1) resulted in significantly lower LAI at all the stages of crop growth because of prevalence of moisture stress conditions. The results

are in confirmation with those of Roller and Pierse (1975), Vivek and Chakor (1992) and Tomar *et al.* (1997).

At harvest, the leaf area index was very low irrespective of treatment. This might be due to the gradual fall of leaves till the crop harvest.

5.3.3 Root growth

The root growth of sunflower, interms of tap root length at 60 DAS (Table 16 and Fig. 21) and dry root weight at different stages (Table 17 and Fig. 22 and 23) of crop was significantly influenced by both tillage and soil moisture regimes. However, the interaction effects were confined only to root dry weight at 60 DAS and at harvest.

Significantly longest roots were associated with deep tillage (T_5 and T_4) compared to shallow tillage (T_3 and T_2) and zero tillage (T_1). Ploughing to deeper depth in T_5 (tractor drawn disc plough (21 cm)) and T_4 (tractor drawn MB plough (21 cm)) reduced soil bulk density (Table 7) and penetration (Table 11) upto deeper soil depths, apparently have facilitated the sunflower crop to extend its root system to deeper layers. In zero tillage, the soil was hard massive and compact and hence the root penetration appears to have been restricted to shallow soil depth. Hundel and De Datta (1984); Sharma *et al.* (1988) and Kumar (1991) reported similar results. However, the tap root length in wettest soil moisture regime (irrigations at IW/CPE = 1.2) was significantly low compared to other soil moisture regimes (M_3). This could be attributed to availability of sufficient moisture in the surface soil layers itself in frequently irrigated soil

(M_4). In case of less soil moisture regimes involving higher moisture depletion roots grew into deeper depths in research of moisture leading to longer root length.

Root dry weight measured at different growth stages (Table 17), was significantly influenced by both tillage and soil moisture regimes and their interactions at all stages of observation except at 30 DAS. Significantly higher root dry weight in general, was obtained with deep tillage treatments (T_5 and T_4) followed by shallow tillage (T_3 and T_2). Lowest root dry weight was noticed in zero tillage (T_1) at all stages of sampling. Significant differences in root dry weight between deep tillage plots (T_5 and T_4) and shallow tillage plots (T_3 and T_2) could be attributed to low bulk density and low penetration resistance even at deeper soil depths in deep tillage plots (T_5 and T_4) leading to higher proliferation and deeper penetration of tap root

Deep and finely tilled plots, involving tractor drawn disc plough and rotavator (T_5), characterized by smaller clods (20 mm) and low mean weight diameter of dry clods, with low soil bulk density, low penetration resistance and high moisture availability inturn had apparently favoured better growth, more proliferation and ramification of root system. Similar observations were reported earlier by Sharma *et al.* (1988) and Kumar (1991).

Hard and massive soil structure in zero tillage plots limited the growth of the root system.

5.3.4 Shoot dry matter accumulation

Tillage practices and soil moisture regimes significantly influenced the dry matter production (Table 18 and Fig. 24, 25). At 60 DAS and at harvest, interaction effects were significant in shoot dry matter production.

Deep and finely tilled (T_5) plots recorded significantly higher dry matter accumulation compared to other tillage treatments. This could be attributed to higher seedling emergence (Table 13), better crop stand with deep tillage, which lead to favourable soil physical environment. More over, after seedling emergence, low penetration resistance in the deeper soil depths in T_5 and T_4 treatment encouraged extensive root growth which resulted in better plant growth and dry matter production. Variations in shoot dry matter accumulation with in deep (T_5 and T_4) and shallow (T_3 and T_2) tillage treatments, appears to be is due to finer tilth in T_5 and T_3, which resulted in higher seedling emergence, high plant stand and more proliferation of roots, leading to more dry matter accumulation compared to coarse tillage treatments viz., T_4 and T_2. In zero tillage (T_1), hard, massive and compact soil structure restricted the root growth leading to less utilization of soil water and nutrients and resulting in lowest dry matter production. Rautaray (1983) reported that the tillage systems, involving combination of MB plough once and disc harrow twice, resulted in faster plant growth of sorghum. Awadhwal and Thierstein (1984) observed that total dry matter of sorghum and pearl millet were marginally higher in tillage treatments wherein bed splitting followed by two strip ploughings was done with mould board plough. Vijayakumar (1991) also observed higher dry matter accumulation of groundnut with MB plough + rotavator treatment.

Increase in soil moisture regime from IW/CPE 0.6 to 1.2 significantly increased the dry matter accumulation at 60 DAS and at harvest. This could be attributed to lower soil moisture stress prevailing before next irrigation in the plots irrigated with IW/CPE ratio of 1.2 and 1.0. There was higher soil water potential resulting in higher leaf water potential. On the other hand in M_2 (IW/CPE = 0.8) and M_1 (IW/CPE = 0.6) moisture regimes, growing plants experienced relatively higher soil water stress and low leaf water potential before next irrigations. Taller plants and higher LAI due to availability of soil moisture through out the crop growth period in M_4 and M_3 resulted in highest dry matter production. Vivek and Charkar (1992), Kumar *et al.* (1991) also reported similar results with regard to dry matter production.

The interaction effects of tillage and soil moisture regimes significantly affected the dry matter production, appears largely to be due to high seedling emergence and relatively high growth at initial stages of crop in deep and fine tillage coupled with higher water supply (M_4 and M_3). This could be due to creation of favourable soil physical conditions as reflected in low bulk density, low penetration resistance, low mean weight diameter and high soil moisture content in deep and fine tillage, where benefits persisted through out the crop period. Irrigations at shorter intervals (M_4) appears to have resulted in significantly higher dry matter production as in T_5 M_4 and T_5 M_3 compared to other tillage and soil moisture regime combinations. Crop in T_1 M_1 i.e., zero tillage coupled with driest soil moisture regime, encouraged unfavourable soil physical conditions as well as soil moisture, leading to lowest dry matter production.

5.3.5 Yield attributes (Head diameter and 1000 seed weight)

Yield attributes viz., head diameter and 1000 seed weight of sunflower (Tables 19 and 20, Fig. 26 and 27) were significantly influenced by different tillage practices and soil moisture regimes and their interactions.

Larger heads and higher test weight were observed to be associated with deep tillage with disc plough and finer tilth (T_5) which was closely followed by deep tillage with MB plough + cultivator (T_4), which were at par and both were significantly higher to shallow tillage (T_3 and T_2) and zero tillage treatments (T_1). These could be attributed to better soil physical conditions viz., low bulk density, low penetration resistance and high moisture content, associated with deeper depths in former treatments, which in turn encouraged more extensive root growth favouring better absorption of plant nutrients and moisture from greater volume of soil and increased plant growth. The increased plant growth observed above was also probably due to the production of more photosynthetates derived from high leaf area index and efficient translocation of these photosynthetates resulting in lesser heads and effective seed filling. Poor soil physical conditions (hard and massive structure) in zero tillage apparently have restricted, the root and shoot growth, leading to smaller heads and low test weight. The results are in accordance with those of Gupta and Gupta (1986) and Pratibha (1991).

Scheduling irrigation at closer intervals (M_4 and M_3) resulted in larger head diameter and 1000 seed weight, compared to irrigation at longer intervals (M_1 and M_2). This may be due to sufficient soil moisture being available to the growing plant and higher leaf water potential (Table 37) before successive irrigation was given. This appears to have led to efficient translocation of photosynthesis

from source to sink. The diameter of the head and 1000 seed weight in M_1 (IW/CPE = 0.6) was less because of prevalence of more stress conditions throughout crop growth period. These trends are in accordance with those reported by Pal and Yadav (1974) and Singh *et al.* (1995).

Interaction effects of tillage and soil moisture regimes influenced the head size and 1000 seed weight of sunflower. Deep tillage (T_5 and T_4) coupled with frequent irrigation (M_4 and M_3) produced larger heads and higher 1000 seed weight. This could be attributed to adequate moisture supply coupled with existence of favourable soil physical conditions like low bulk density, low penetration resistance up to deeper depths and higher soil moisture throughout, the crop growth and resulted in increased leaf area there by larger head size and proper filling of the seeds. Small head size and low 1000 seed weight in zero tillage combined with relatively dry soil moisture regime might be due to un favourable soil physical conditions during plant growth period.

5.3.6 Seed yield

Seed yield of sunflower was significantly influenced by tillage and soil moisture regimes and their interaction (Table 21 and Fig. 28).

The mean seed yield was highest with disc plough + rotavator twice (T_5), which was significantly higher than that of MB plough + cultivator (T_4), country plough + power tiller drawn rotavator (T_3), country plough + bullock drawn cultivator (T_2), and zero tillage (T_1) in descending order. The difference between T_3 and T_4 was not significant.

The highest seed yield with T_5 could be attributed to prevalence of ideal soil physical conditions viz., low MWD of dry clods, low bulk density, low penetration resistance and high moisture content which had favourably affected seedling emergence (Table 13), root growth and proliferation (Table 17), high leaf area index (Table 15) and overall growth of the plant as indicated by dry matter (Table 18). Earlier reports also indicated similar results on crops like groundnut (Khan, 1984), AICRP on SPCIP, Hyderabad Centre, (1986-87). T_4 (MB plough once + cultivator twice, both tractor drawn) was the next best tillage followed by T_3 (country plough twice + PT rotavator twice). Though the plant population was relatively higher in T_3 (due to finer tilth), favourable soil physical conditions upto deeper depths were better created in T_4 than in T_3, which resulted in significantly larger heads and high 1000 seed weight in T_4 as compared to T_3.

Between shallow tillage treatments (farmers' practices (T_2) and modified farmers' practice (T_3), T_3 recorded significantly higher seed yield than T_2 (farmers' practice). This appears to be due to relatively low bulk density, smaller MWD and higher moisture content leading to higher seedling emergence and higher plant population in T_3 compared to T_2. Even after seedling emergence, finer tilth in T_3 has encouraged good proliferation of roots, leading to enhanced plant growth and in higher seed yield compared to T_2. The same relations also appear like high bulk density which have contribution to lower yields in zero tillage (T_1).

The mean seed yield with wettest soil moisture regime M_4 (IW/CPE = 1.2) was the highest (1231 kg ha^{-1}), which was at par with that of

M_3 (1161 kg ha^{-1}), both of which were significantly superior to M_1 (1002 kg ha^{-1}) and M_2 (757 kg ha^{-1}). The significantly higher seed yields in M_4 and M_3 might be due to prevalence of more favourable moisture regime through out the crop growth (as indicated by RWC, leaf water potential, diffusion resistance, transpiration rate (Tables 36 to 40) leading to efficient production and translocation of photosynthetates. Non significant variation in yield in M_3 and M_4 moisture regime indicates that irrigations scheduling at IW/CPE ratio 1.0 is adequate for optimum yields of sunflower in late *rabi* sunflower. Similar results were also reported by Bhan and Khan (1980); Cox and Jolliff (1986); Hedge and Havanagi (1989); Human *et al.* (1990), Ventanna *et al.* (1994) and Bharambe *et al.* (1997).

A critical examination of interaction data (Table 21) clearly indicated that deep and effective tilth could reduce the water requirement of sunflower crop. The yield in T_5 M_2 was at par with that of T_3 M_4, which results in a saving of three irrigations (180 mm) in the first year and four irrigations (240 mm) in the second year (Table 4) with deep tillage compared to shallow tillage. Seed yield in T_5M_2 was at par with that of T_4 M_3, and the yield differences between T_3 M_2 and T_2 M_3 were not significant, which suggests that fine seed bed preparation using rotavator leads to saving of two irrigations (120 mm irrigation water) over farmer's practice (coarse secondary tillage). The data on sunflower seed yield (Table 21) has clearly established the superiority of deep fine tillage.

5.3.6.1 Relation between seed yield and tillage induced soil physical properties

Multi linear functions (step down) were worked out between seed yield of sunflower and various tillage induced soil physical properties viz., mean weight

diameter of dry clods, bulk density, penetration resistance, soil moisture tension and soil temperature. The step down multilinear function resulted in identification of four significantly contributing tillage induced soil edaphic properties viz., MWD of dry clods, penetration resistance, soil moisture tension and soil temperature. This model could explain 93 per cent variation in the seed yield. Likewise, the values of regression co-efficients (h) were highly significant (P =0.01) and negatively correlated with the seed yield.

The magnitude of reinforcement in seed yield varied with the magnitude of 'b' co-efficient, which inturn was a function of unit measurement of a given soil physical property.

Multiple regression (step down) between seed yield and tillage induced soil physical properties (MWD, BD, PR, soil temperature and moisture tension) which resulted in model could explain seed yield of sunflower grown after rice in sandy clay loam soil in Southern Telangana zone is determined by tillage induced soil physical properties viz., MWD (b=3.79); penetration resistance (b = 4.32), soil temperature (b = 20.84) and soil moisture tension (b = 7.1), R^2 = 0.932. This indicates the necessity to have deep fine tilth to ensure better seed yield of sunflower.

Further, the correlation studies between tillage induced soil physical properties and the seed yield indicated significant positive association among themselves and all of them were negatively correlated with the yield.

X1 = Mean weight diamter of clods at 60 DAS (mm)
X2 = Penetration resistance of soil at 60 DAS (kg cm^{-1})
X3 = Soil temperaure (oC centigrade)
X4 = Soil moisture tension (bars)
Y = Seed yield (kg ha^{-1})

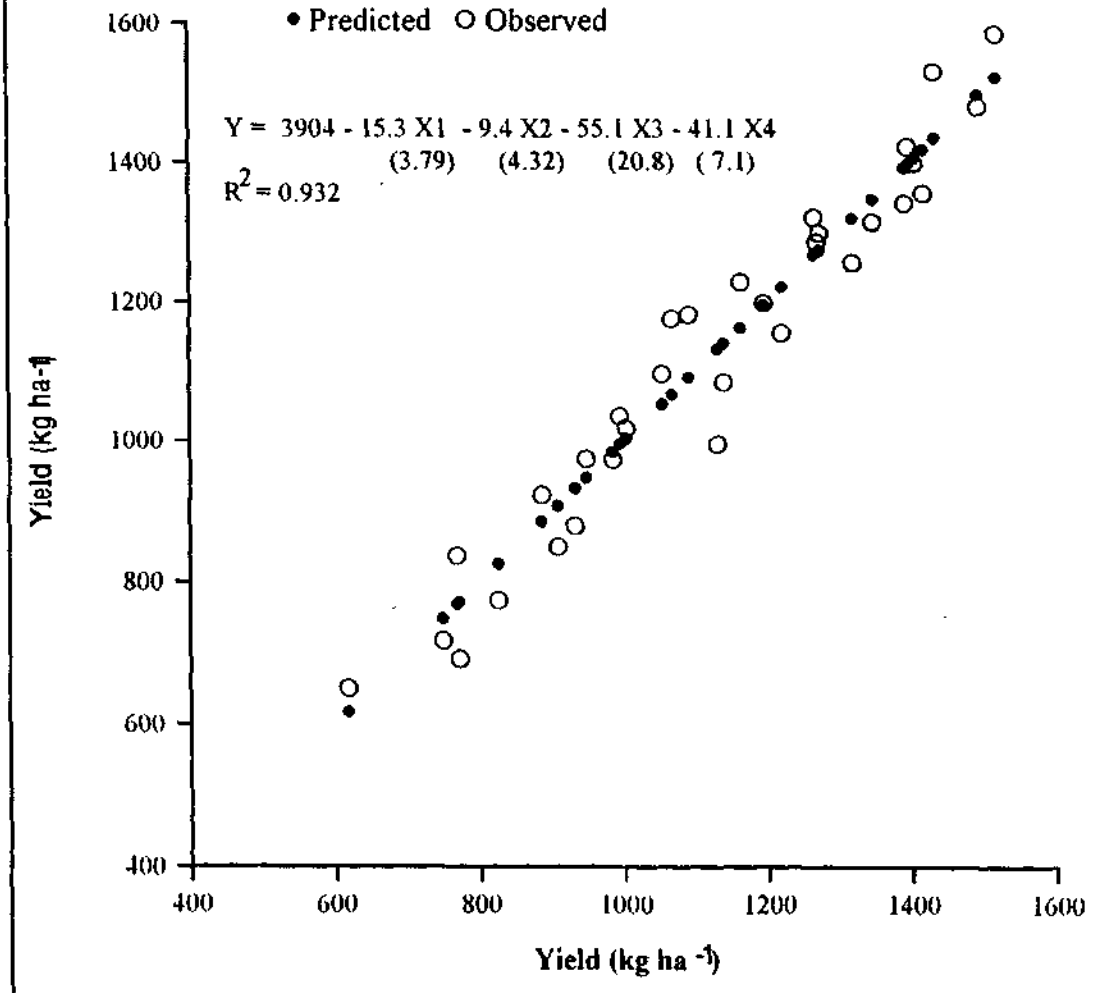

Fig. 42 : Variation of observed seed yield over predicted yield by MLR

Table 42: Correlation matrix for sunflower seed yield and tillage induced physical edaphic properties at 60 DAS

	X_1	X_2	X_3	X_4	X_5	Y
X_1	1.000	0.262	0.650	0.451	0.412	-0.667
X_2	0.263	1.000	0.566	0.507	0.357	-0.472
X_3	0.650	0.566	1.000	0.739	0.699	-0.846
X_4	0.451	0.507	0.739	1.000	0.805	-0.860
X_5	0.412	0.356	0.699	0.805	1.000	-0.890
Y	-0.667	-0.472	-0.846	-0.860	-0.890	1.000

r(P = 0.05) = 0.349
r(P = 0. 01) = 0.449

X_1 = Mean weight diameter of dry clods (mm) at 60 DAS
X_2 = Bulk density (Mg m^{-3}) soil at 60 DAS
X_3 = Penetration resistance (kg cm^{-2}) at 60 DAS
X_4 = Soil moisture tension (bars) at 60 DAS
X_5 = Soil temperature (^{0}C) at 60 DAS
Y = Seed yield (kg ha^{-1})

Table 37 : Correlation matrix for yield and yield components

	X_1	X_2	X_3	X_4	Y
X_1	1.000	0.456	0.463	0.460	0.471
X_2	0.456	1.000	0.926	0.949	0.958
X_3	0.463	0.926	1.000	0.977	0.977
X_4	0.462	0.949	0.977	1.000	0.997
Y	0.471	0.958	0.977	0.997	1.000

r(P = 0.05) = 0.444
r(P = 0.01) = 0.561

X_1 = Head diameter (cm)
X_2 = 1000 seed weight (g)
X_3 = Leaf area index at 60 DAS
X_4 = Dry mater accumulation at harvest (kg ha^{-1})
Y = Yield (kg ha^{-1})

$$Y = 3904.5 - 15.29\ X_1 - 9.40\ X_2 - 55.14\ X_3 - 41.15\ X_4$$
$$\qquad\qquad (3.79) \qquad (4.32) \qquad (20.84) \qquad (7.08)$$

$R^2 = 0.932$

Where,

Y = Seed yield (kg ha^{-1})

X_1 Mean weight diameter of dry clods at 60 DAS

X_2 Penetration resistance of soil at 60 DAS

X_3 Soil temperature at 60 DAS

X_4 Soil moisture potential at 60 DAS from 0-15 cm soil layer.

(figures in brackets indicate SE of b).

5.3.6.2 Yield-water relation

The empirical estimates for the relationship between sunflower seed yield and crop water use (seasonal evapotranspiration), as expressed by linear water production function, are shown in Figs. 43 and 44. The seasonal water production function, as expressed by linear model under different tillages, performed well for seed yield. The model explained more than 94 per cent variation in the seed yield with the values of coefficient of determination (R^2) being 0.941, 0.951, 0.981, 0.960, 0.975 for T_1, T_2, T_3, T_4 and T_5, respectively, 0.983, 0.966, 0.971, 0.977 for M_1, M_2, M_3 and M_4 respectively. This can be explained that the seed yield of sunflower is responding to both intensity of tillage (finer tilth). Total water inputs was linear under the present experimental conditions.

5.3.7 Harvest index

Increased harvest index with increase in intensity of tillage from T_1 to T_5 (Table 22 and Figure 29) is attributed to favourable soil physical condition

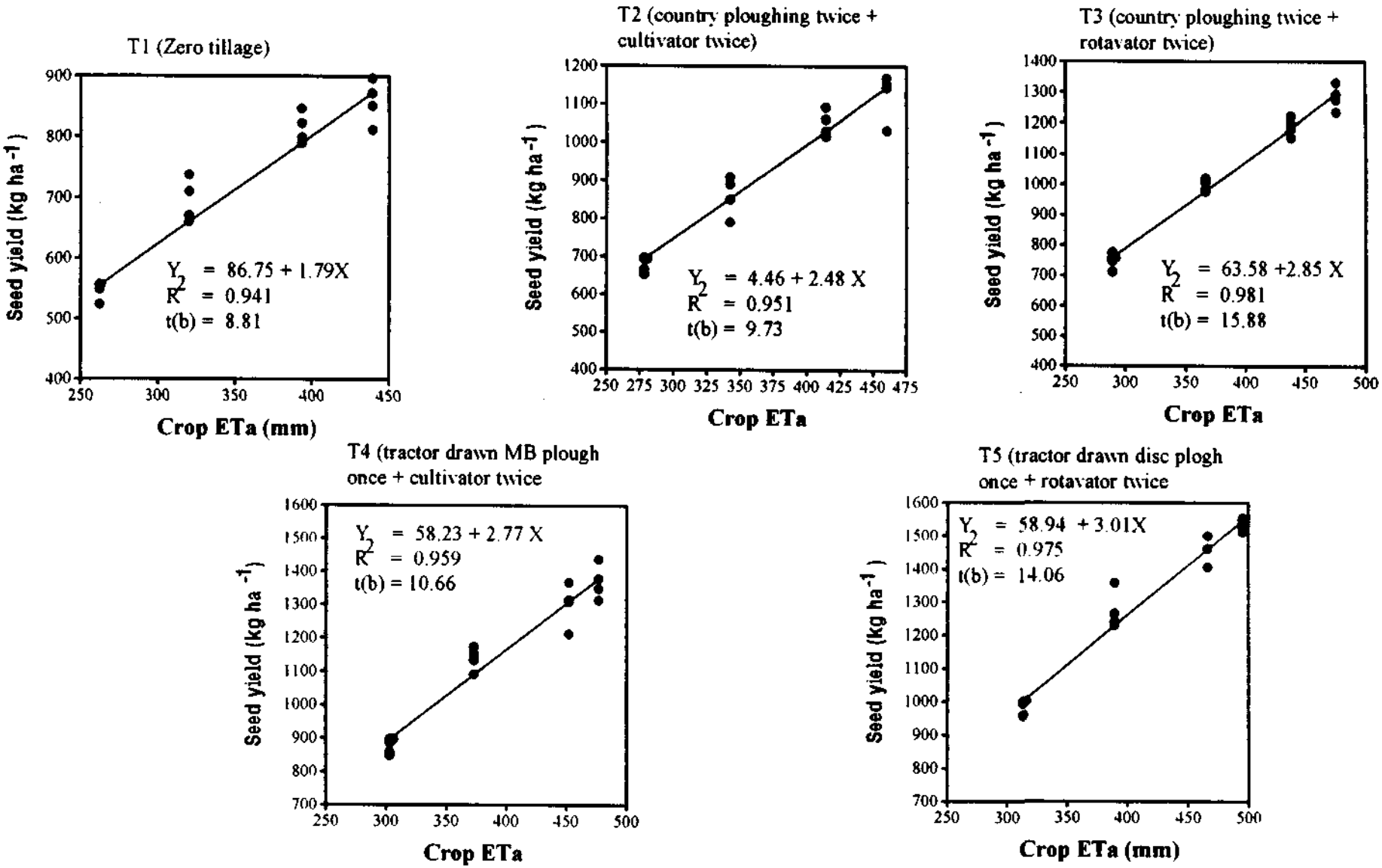

Fig. 43 : Yield- water relations under different tillage treatments

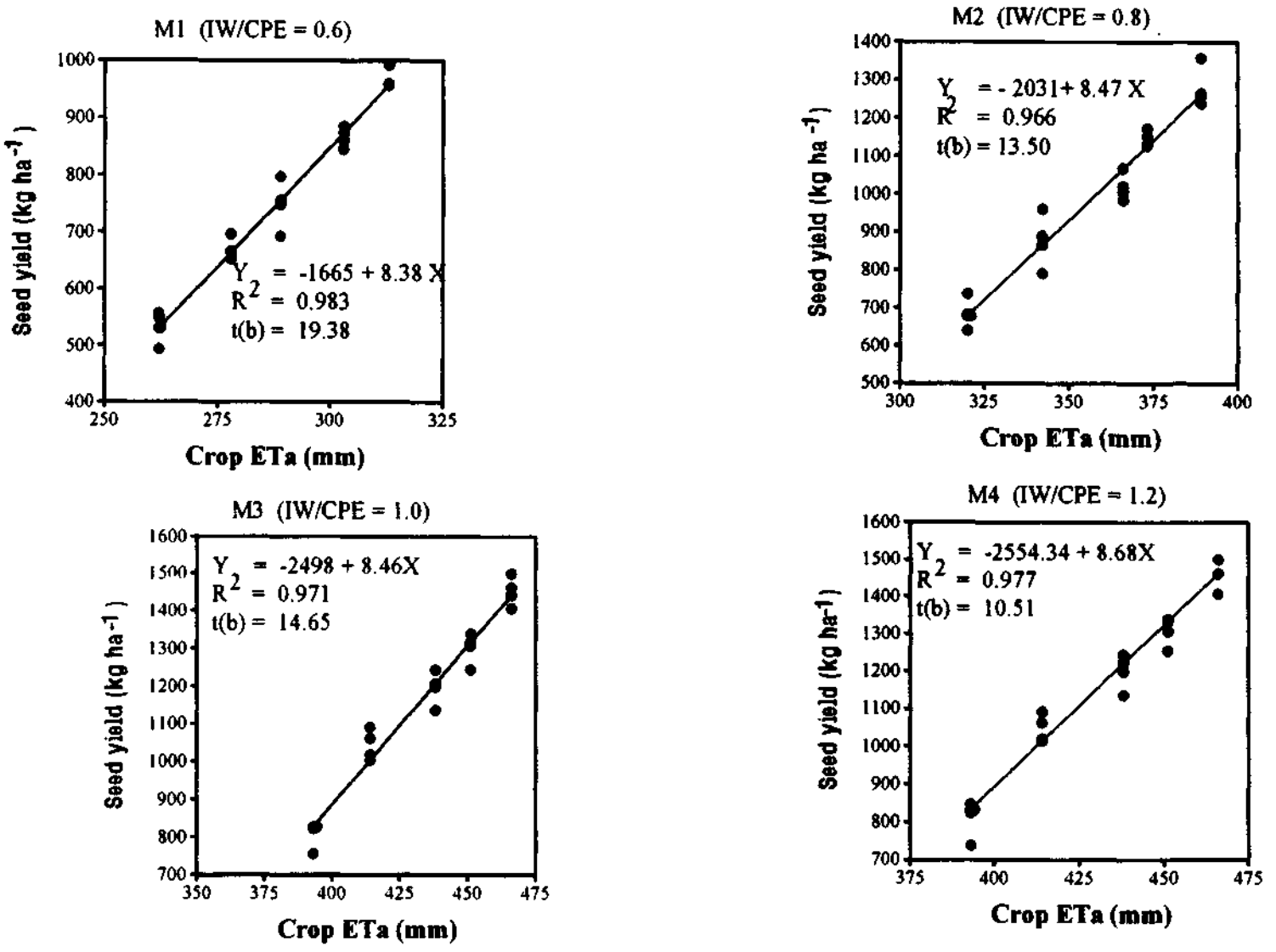

Fig. 44 : Yield-water relations under different soil moisture regimes

viz., deeper depth of tillage, low mean weight diameter of dry clods, low bulk density and low penetration resistance, created with increase in tillage intensity especially in deep and fine tilled plots (T_5) encouraged more exhaustic root growth favouring better absorption of water and plant nutrients. The increased absorption of soil water and plant nutrients led to higher production of photosynthates and their efficient translocation in to final sink (seeds) resulted in effective seed filling, thereby high 1000 seed weight and harvest index. The results also emphasised the importance of adequate water supply throughout the crop growth period by creating soil moisture regime of IW/CPE = 1.0 or 1.2 (the effect of soil moisture regimes M_4 and M_3 on harvest index were on par) coupled with deep fine tillage made efficient translocation of photosynthates in to seed resulted in highest harvest index in T_5M_4, T_5M_3, T_4M_4 and T_5M_3.

5.3.8 Oil content

Oil content in sunflower seeds was significantly influenced by tillage and soil moisture regimes (Table 23 and Fig. 30). Deep tillage (T_5 and T_4) recorded significantly higher oil content compared to shallow tillage (T_3 and T_2) and zero tillage (T_1). Persistence of favourable soil physical conditions in T_5 and T_4, throughout crop growth appear to have resulted in better root and shoot growth, and conversion of photosynthates to quality seed during later periods of growing season. Similar observations were also reported by Pratibha (1992).

Giving irrigations at IW/CPE = 1.2 (M_4) and 1.0 (M_2) resulted in significantly higher oil content compared to irrigations at IW/CPE ratio of 0.8 (M_2) and 0.6 (M_1) (Table 23), the reasons were already explained. The results

are in accordance with those of Karani (1977), Kumar (1991), Babu *et al.* (1993) and Bharanbe *et al.* (1997).

5.3.9 Oil yield

The variation in sunflower oil yield under different tillage and soil moisture regime combinations are mainly attributed to variation in yield levels and oil content. Deep fine tillage treatment (T_5) and irrigation at IW/CPE = 1.2 (M4) or IW/CPE = 1.0 (M_3) individually and combindly recorded highest oil content which could be due to favourable soil physical conditions and adequate moisture supply, which resulted in higher seedling emergence percentage, water and nutrient absorption from larger soil volume, enhanced crop growth, and effective translocation of photosynthates in to seeds and reflected in higher seed yield and oil content. Lowest oil yield in zero tillage (T_1) dry moisture regime (M_1) individually and combindly have uncongenial conditions for plant growth, there by produced lowest seed yield and oil content which lead to lowest oil yield.

5.4 NUTRIENT (N, P AND K) CONTENT

Among the nutrients studied (N, P and K) (Tables 25, 26 and 27), nitrogen and potassium contents were influenced by tillage treatments. Phosphorus content was significantly influenced by both tillage and soil moisture regimes in dry matter at 30 and 60 DAS and at harvest (stalk and seed).

Crop with deeper tillage (T_5 and T_4) accumulated higher N, P and K than with shallow tillage. This could be attributed to better soil physical environment in terms of low bulk density, low penetration resistance and high moisture content

with deep tillage compared to shallow tillage (T_3, T_2 and T_1) created, which was already discussed earlier in this chapter.

Reports of Wiersum (1962); Cornforth (1968); Voorhees *et al.* (1971), Broadford (1980) and Misra *et al.* (1988) lend support to the present findings.

Higher phosphorus content (Table 26) in the plant in frequently irrigated plots (M_4 and M_3) could be attributed to higher diffusion of phosphorus to plant roots in the soil leading to higher uptake in these treatments owing to prevalence of relatively thick water films favouring more diffusion of phosphorus towards the roots.

Relatively lesser contents of N and P in stalk at harvest and the corresponding increase of N and P in seed could be attributed to the translocation of these nutrients from vegetative parts to fruiting organs. These observation are in agreement with the findings of Surajbhan (1977), Patel and Singh (1981) and Jain and Dixit (1987).

5.5 NUTRIENT (N, P AND K) UPTAKE

Tillage and soil moisture regimes and their interactions were found to have significant influences on N, P and K uptake (Table 28, 29 and 30). Among the tillage treatments, highest uptake of nutrients by the crop in T_5, might be due to better crop growth coupled with higher mobility of nutrients leading to higher nutrient absorption form larger soil volume. It could also be due to higher dry matter production in this treatment. The findings of Wiersum (1962); Cornforth (1968) and Voorhees *et al.* (1971) lend support to the present findings.

Soil moisture regimes M_4 and M_3 recorded higher nutrient uptake compared to M_2 and M_1 (Tables 28, 29 and 30). This might be due to more solubility and increased mobility of nutrients, which facilitated higher absorption by crop plants and also more dry matter accumulation. Similar findings were supported by Kharwara and Bindra 1992; Nagavani 1995 and Susheel Kumar *et al.*, 1995.

Among interactions, combination of deep and fine tillage with frequent irrigations given at IW/CPE = 1.2 treatment (T_5 M_4) was found to be superior in nutrient (N, P and K) uptake compared to other combinations. This could be attributed to the combined favourable effects of these treatments are crop growth.

5.6 SOIL-WATER STUDIES

5.6.1 Seasonal water use

The seasonal crop ETa (Tables 31 and 32 and Fig. 32) in T_5 was greater than in other tillage treatments. This could be due to prevalence of relatively favourable soil physical conditions even at deeper depths in the soils which facilitated higher root growth, dry matter and leaf area index, in addition to favourable leaf water potential (Tables 37). Lowest ETa values were observed in zero tillage treatment (T_1). Arora *et al.* (1991) and Gill *et al.* (1996) also reported higher water use by wheat and maize crops with deep tillage.

Among soil moisture regimes, the seasonal ETa in wettest soil moisture regime (M_4), where irrigations were given at 1.2 IW/CPE ratio, was more compared to other treatments (Tables 31 and 32). This could be due to availability of adequate soil moisture being available through out the crop growth. In addition,

the LAI was also more in this treatment. However, not much difference in water use was observed between M_4 and M_3 in both the years of study. These observations are in accordance with Patel and Singh (1981), Tripathi and Sawhney (1989) and Singh *et al.* (1997).

The seed yield significantly correlated with water use. A linear model of water production functions was tested. Both the models were developed under different tillage and moisture regimes, and these suggest that yield had direct relation with water use. From zero tillage (T_1) to intensive tillage (T_5), Crop water use increased (Tables 31 and 32), and this could be attributed to high water storage in soil profile, and favourable soil physical conditions created with increase in intensity of tillage.

The water use rate i.e. ETa day^{-1} in general increased with increase in age of crop (Table 33 and 34) and decrease by the time of harvest. These results are in conformity with those of Danial Hillel (1999) who concluded that the reduction in water uptake by roots by the time of harvest is due to senescence.

5.6.2 Soil moisture extraction pattern

Among tillage treatments deep tillage treatments (T_5 and T_4) registered higher proportions of moisture extraction from lower depths of soil i.e., 15-30 cm and 30-45 cm (Figs 34 and 35). This might be attributed to creation of favourable soil physical environment (low bulk density, low penetration resistance and high available water content in soil profile) for plant growth even in deeper layers allowing better root penetration and proliferation. These roots extracted relatively higher soil moisture from deeper depths compared to shallow

tillage (T_3 and T_2) and zero tillage (T_1) treatments. On the other hand in zero tillage (T_1) treatment, more soil moisture was extracted only from top layer i.e. 0-15 cm depth, which could be attributed to hard compact nature of the soil at the lower depths, which restricted the root growth and soil moisture extraction. Arora *et al.* (1991), Gill *et al.* (1996) and Meharban Singh and Choudhary (1998) also reported similar observations with deep tillage treatments.

In frequently irrigated soil moisture regime (M_4) the extraction of water was relatively more from shallow soil depths. However, in treatments where irrigation was given at longer interval (M_1 and M_2), soil moisture extraction was relatively higher from deeper layers. As the water application decreased with decrease in IW/CPE, the moisture extraction was relatively more from lower depths indicating that zone of root activity moved to deeper soil layers under these conditions. Daniel Hillet (1999); and Hegde and Hawanagi (1989) stated that under field conditions, where soil moisture was uniform and adequate, it is possible to divide the extraction pattern in to two distinct layers, an *upper layer* in which the root density was greatest and nearly uniform hence water extraction was also more and uniform, and a *lower layer* in which the roots were relatively sparse and hence the rate of water depletion was low as long as the water content of *upper layer* was fairly high. These observations corroborate well with the findings in the present study with sunflower.

5.6.3 Water use efficiency

In general, bulk of the water uptake by the plant are from top (0-25 cm) layer only. Daniel Hillel (1999) stated that as a rough approximation, it is possible to divide the rooting systems in to two layers; an *upper layer*, in which root density

is greater, and a *lower layer*, in which the roots are relatively sparce and in which the rate of water depletion is slow as long as the water content of the *upper layer* is fairly high. The results of present investigation are in accordance with the same.

Among the tillage treatments, the WUE was in the order of $T_5 > T_4 > T_3 > T_2 > T_1$ and its difference between any two of the treatments was significant and WUE depends on two things i.e. the yield and the crop ETa. The seed yield was highest in T_5 followed by T_4, T_3, T_2 and T_1 and the crop ETa was also in same order but the decrease was not at that magnitude resulting in higher WUE. Lowest water use efficiency was observed with zero tillage. The mean crop growth in terms of dry matter and yield were found lowest in zero tillage treatment. In general, the WUE was higher with deep tillage treatment (T_5 and T_4) compared to shallow (T_3 and T_2) and zero tillage treatment (T_1). Similar observation was also made by Masand *et al.* (1993 and 1994), Gill *et al.* (1996) and Salih *et al.* (1998).

The water use efficiency (Table 35 and Fig. 36) was found to be highest with M_2, where irrigations were given at IW/CPE = 0.8. Either decreased or increased water application resulted in decreased water use efficiency.

Between M_4 and M_3, the yield was not appreciably altered but the water use, ETa, was high in M_4 compared to M_3 leading to excess water supply in case of M_4. Similar (non significant) yield in case of M_4 and M_3 suggests preference for irrigation scheduling at IW/CPE ratio of 1.0 over 1.2, which resulted in a saving of one irrigation (60 mm irrigation water) in first year and two irrigation (120 mm irrigation water) in second year.

Critical examination of the data on further reveals that even under low water supply conditions (M_1 and M_2), WUE in T_5 and T_4 was found appreciably higher compared to that in T_3, T_2. This could be due to creation of tillage induced favourable soil physical conditions (viz., depth of tillages, low bulk density, low penetration resistance, high moisture storage capacity) leading to efficient utilisation of irrigation water through extensive root system (Table 17). On the other hand, WUE of T_3, T_2 and T_1 under M_2 and M_3 are almost similar thereby indicating the response of sunflower to water supply under shallow and zero tillage conditions. However, deep tillage treatments did not respond much to increased water supply i.e. M_3 and M_4.

5.7 Plant water relations

Plant water relations viz. relative leaf water content, leaf water potential, leaf diffusive resistance, transpiration rate and leaf temperature, measured at different stages crop growth were significantly affected by tillage and soil water regimes (Tables 36, 37, 38, 39 and 40). The crop in T_5 (tractor drawn disc plough + rotavator) and T_4 (tractor drawn MB plough + cultivator) maintained higher relative leaf water content, leaf water diffusion resistance and leaf temperature in comparision to T_3, T_2 and T_1. This might be attributed to higher soil water potential and deep and extensive roots of crop plants, which resulted in high absorption of soil water. Similarly, the crop in plots which received irrigation at IW/CPE = 1.2 (M_4) recorded higher relative leaf water content, leaf water potential and lower leaf diffusion resistance, and leaf temperature compared to the same under M_3, M_2 and M_1.

The relative leaf water content, leaf water potential, leaf diffusion resistance, transpiration rate and leaf temperature are the indicators of the leaf the evaporative demand of the atmosphere and the amount of water absorbed by the plant roots. Thus the crop plants in deep tillage (T_5 and T_4) and in frequently irrigating soil moisture regime (M_4 and M_3) treatments extracted adequate water and perform better.

In contrast, shallow (T_3 and T_2) and zero tillage (T_1) treatments, owing to limited root system leading to low extraction of soil water under reduced water supply (M_1 and M_2) treatments, had less water supply (indicated by soil moisture content and potential in Appendix Vb) resulted in decreased water flow to the crop plants. These two situations, consequently lead to reduction in water content of plant, as indicated by relative water content and leaf water potential, affecting the opening and closing to stomata and high resistance for stomatal conductance of water vapour diffusion, leading to reduced transpiration rate and organ (plant parts) development as evident from various growth and yield attributes in these treatments. Similar trends were also reported by Hsiao (1973), Cox and Boersma (1967), Tomar and Gildyal (1973). Sandhu and Hortan (1977), Varshney (1980) and Hsio *et al.* (1980).

In general, the temperature of a leaf or canopy is less than the surrounding ambient temperature under adequate and is able to meet the evaporation demand of the atmosphere. But when the water absorption by the root lags behind the plant transpiration requirements due to limited root system or decreased soil moisture content, the stomata start closing and there is a rise in leaf or canopy temperature, as evident in shallow (T_3 and T_4) and zero tillage (T_1),

Table 38 : Correlation matrix for yield and plant water stress parameters at 45 DAS

	X_1	X_2	X_3	X_4	X_5	Y
X_1	1.000	0.966	0.904	-0.931	-0.945	0.892
X_2	0.966	1.000	0.959	-0.966	-0.970	0.904
X_3	0.904	0.959	1.000	-0.970	-0.950	0.850
X_4	-0.931	-0.966	-0.970	1.000	0.953	-0.850
X_5	-0.945	-0.970	-0.950	0.953	1.000	-0.901
Y	0.892	0.904	0.850	-0.836	-0.901	1.000

r(P = 0.05) = 0.444
r(P = 0.01) = 0.561

X_1 = Leaf water potential (bars)
X_2 = Transpiration rate (μg H_2O cm^{-2} S^{-1})
X_3 = Relative leaf water content (per cent)
X_4 = Leaf diffusion resistance (S m^{-1})
X_5 = Leaf temperature (^oC)
Y = yield (kg ha^{-1})

tillage treatments (Table 39) and dry soil moisture regimes (M_1 and M_2) in comparision to deep tillage treatments (T_5 and T_4) and wet soil moisture regimes (M_4 and M_3), respectively.

Thus, it can be inferred that the variation in plant water status parameters in different tillage treatments and soil moisture regimes were primarly due to their close relationship in soil plant atmosphere continuum (SPAC).

5.7.1 Relationship between the seed yield and plant water - stress parameters

Simple correlation matrix functions were worked out between the seed yield and various plant water-stress parameters viz. leaf water potential, relative leaf water content, leaf difference resistance, transpiration rate and leaf diffusion. The results (Tables 36 to 40) indicated significant association among themselves and all of them were significantly correlated with the seed yield of sunflower. Leaf water potential, transpiration rate and relative leaf water content were positively correlated while leaf diffusion resistance and leaf temperature were negatively correlated with seed yield of sunflower.

5.8 RESULTS OF PRACTICAL UTILITY

1. The optimum tilth of seed bed in rice based cropping system could be defined in terms of mean weight diameter (MWD) of dry clods.
2. The optimum tilth in sandy clay loam soils is about 20 mm of dry clod mean weight diameter.
3. The optimum tilth could be obtained by using rotavator either of tractor drawn or power tiller drawn.

4. The depth of tillage for sunflower grown after puddled rice is about 21 cm, which could be achieved by tractor drawn disc plough or tractor drawn mould board plough.

5. The optimum moisture regime for better yield of sunflower by giving irrigations at IW/CPE ratio of 1.0.

6. There will be a saving of 180 - 240 mm irrigation water by providing deep tillage (21 cm) compare to shallow tillage (11 cm) maintaining yield levels at optimum level.

5.9 FUTURE LINES OF WORK SUGGESTED

1. The optimum physical edaphic environment required for upland crops in terms of the mean weight diameter of the clods and depth of tillage need to be worked out for different crops to increase the yield levels in different soil types.

2. The achievement of such tilth condition using different tillage implements may be specified.

3. Tillage operations influences the water and nutrient use efficiency by the crops. The interactive effect of tillage with irrigation water and fertilizer levels needs to be worked out for different upland crops in rice based cropping system.

SUMMARY

CHAPTER VI

SUMMARY

In order to develop suitable soil management practices for alleviating soil physical constraints and efficient utilization of irrigation water for sustainable higher productivity of upland crops like sunflower grown after puddled transplanted rice in rice-based cropping systems, present investigation entitled "Effect of tillage induced soil physical properties and soil moisture regimes on performance of sunflower (*Helianthus annuus* L.) in rice-based cropping system" was under taken with field experiments in sandy clay loam soils of Rajendranagar during *late rabi* 1997-98 and 1998-99. The experiments were conducted with combinations of five tillage treatments, viz., T_1 : zero tillage (seed line tillage only); T_2 : ploughing twice with country plough + twice with bullock drawn cultivator; T_3 : ploughing twice with country plough + twice with power tiller rotavator; T_4 : ploughing once with MB plough + twice with cultivator, both tractor drawn, T_5 : ploughing once with disc plough + twice with rotavator, both tractor drawn and four soil moisture regimes, viz., M_1 : irrigations at IW/CPE = 0.6; M_2 : irrigations at IW/CPE = 0.8; M_3 : irrigations at IW/CPE = 1.0 and M_4 : irrigations at IW/CPE = 1.2). The treatments were replicated thrice in strip plot design. Sunflower var. Morden was chosen for the study.

Tillage induced soil physical properties were studied in terms of mean weight diameter of dry soil clods (MWD), bulk density, total pore space, penetration resistance, hydraulic conductivity, infiltration rate, soil moisture content and soil temperature. The effects of these tillage induced physical edaphic factors and soil moisture regimes, individually and combine were studied on sunflower crop in

terms of seedling emergence, dry matter accumulation, root growth, leaf area index, head size, 1000 seed weight, seed yield, oil content and oil yield. In addition, nutrient (N, P and K) content in plant and their uptake at different crop growth periods were also studied. Total soil water use (seasonal crop ETa), soil moisture extraction pattern and water use efficiency of sunflower were also assessed under different tillage and soil moisture regimes to find the impact of the treatments on water use parameters. Plant water stress parameters like relative leaf water content and leaf water potential at different periods of crop growth were also studied. The trends of variations in the data and the findings more are more or less similar in both the years of study. These are briefly summerised as under.

1. Tillage with tractor drawn disc plough + rotavator (T_5) and tractor drawn MB plough + cultivator (T_4) resulted in deep ploughing of the soil upto about 21 cm compared to only 11 cm depth with country ploughing (T_3 and T_2).

2. Different tillage treatments adopted resulted in wide variation in the mean weight diameter of dry soil clods. Secondary tillage with rotavator irrespective of primary tillage, produced smaller size clods (MWD = 20 mm) compared cultivator (MWD = 37.5 mm). The mean weight diameter of the clods decreased with an increase in the days after sowing. Further, the decrease was more in case of frequently irrigated soil moisture regimes (M_4 and M_3) as compared to less frequently irrigated soil moisture regimes (M_1 and M_2).

3. Soil bulk density, porespace, hydraulic conductivity, infiltration rate, penetration resistance and soil temperature were influenced by different tillage systems. Deep tillage treatment (T_5 and T_4) resulted in low bulk density and penetration resistance, and higher pore space, hydraulic conductivity and infiltration rate. In zero tillage, the soil was hard and compact, and recorded high bulk density and penetration resistance, low pore space, hydraulic conductivity and infiltration rate. When tillage was done with tractor drawn implements (T_4 and T_5), favourable changes in the physical properties were brought about to a deeper depth compared to bullock drawn implements or power tiller operated rotavator.

4. Soil moisture regimes influenced the penetration resistance, soil temperature and infiltration rate from 30 DAS to harvest. Penetration resistance, soil temperature and infiltration rate were lower in case of wet soil moisture regime M_4 (IW/CPE = 1.2).

5. Tillage induced soil physical properties affected the seedling emergence, crop growth and yield. Finer seed bed preparation (< 20 mm MWD of dry clods) with rotavator (T_5 and T_3) resulted in significantly higher seedling emergence than with coarse seed bed plots viz. T_2 and T_4 (MWD 37.5 mm). The data on seedling emergence showed clear dependence of seedling emergence on tillage practices. Seedling emergence favoured by the soil physical environment viz., low MWD, low bulk density and low moisture tension. Highly significant negative correlation (r = -0.961) was observed between seedling emergence and mean weight diameter of dry soil clods and linear model fitted well.

5. Better plant stand and taller plants in T_5 (tractor drawn disc plough + rotavator) produced higher LAI, dry matter accumulation, deeper and prolific root system and bigger heads compared to other tillage practices. Next best was T_4 (tractor drawn MB plough + cultivator) where, though plant growth (as indicated by root weight, plant height, head size and test weight) was at par with T_5, low plant stand in T_4 tillage treatment, significantly reduced the seed yield compared to T_5 indicating that the crop stand and is very important in deciding the yield of sunflower in rice based cropping system. The growth and yield of crop in T_3 (country plough twice + power tiller rotavator twice) was significantly superior to T_2 (farmers' practice). Crop growth and yield were the lowest treatments of zero tillage there by indicating the necessity to have tillage before sowing the upland crops following submerged rice.

7. Soil moisture regimes created, based on IW/CPE, significantly influenced the crop growth and yield. Plant height, leaf area index, root growth and shoot dry matter accumulation were increased with an increase in IW/CPE from 0.6 to 1.2. However, the growth, yield parameters and yield (seed and oil) did not significantly differ between M_4 and M_3.

8. Deep tillage treatments (T_5 and T_4) maintained highest relative leaf water content, leaf water potential and transpiration rate and lower leaf diffusion resistance and leaf temperature by extracting more soil moisture from deeper layers, while reverse was true in case of shallow and zero tillage treatments. Wettest soil moisture regime (M_4) maintained highest relative leaf water content, leaf water potential, transpiration rate and least leaf diffusion resistance and leaf temperature, while the trend was reversed

in case of driest soil moisture regime (IW/CPE = 0.6). Water use, growth and yield of sunflower also correlated well with the plant water stress parameters.

9. Highest yield (both seed 1531 kg ha^{-1} and oil yield 537 kg ha^{-1}) was obtained with T_5M_4 which was at par with T_5M_3 suggesting that a saving in irrigation water could be effective with fine and deep tillage. The lowest seed (533 kg ha^{-1}) and oil (187 kg ha^{-1}) yield was observed in T_1M_1. Creation of deep and fine seed bed could reduce the water requirement of sunflower crop grown after puddled rice in rice-based cropping system. The yield in T_5M_2 was on par with that of T_3M_4, hence there was a saving of three irrigations (180 mm) in first year and four irrigations (240 mm) in second year with deep tillage over shallow tillage. The yield in T_5 M_2 was at par with that of T_4M_3 and the yield difference between T_3M_2 and T_2M_3 was not significant, which indicates the importance of fine seed bed preparation. Using rotavator (T_3) for secondary tillage resulted in saving of two irrigations (120 mm irrigation water) over farmers practice (secondary tillage with bullock drawn cultivator).

10. Irrigations scheduled at IW/CPE = 1.0 produced yield (both seed 1460 kg ha^{-1} and oil yield 467 kg ha^{-1}) on par with that of IW/CPE = 1.2 (1531 kg ha^{-1} and 500 kg ha^{-1}, seed and oil yields, respectively) indicating that irrigation scheduling at 1.0 IW/CPE to sunflower grown in sandy clay loam soils of Southern Telangana region of Andhra Pradesh is optimum.

11. Creation of deep fine tilth (T_5) and wet soil moisture regime (M_4) individually and combine recorded significantly high total N, P and K

uptake. The uptake of nutrients reflected more of the changes in dry matter accumulation than their contents in plant samples due to different treatments.

12. Tillage with tractor drawn disc plough + rotavator (T_5) and irrigations scheduled at IW/CPE = 1.2 individually and together registered higher seasonal water use (crop ETa) compared to other individual and combined effects of tillage and soil moisture regimes. Water use efficiency of sunflower was the highest in T_5 (deep and fine tillage) followed by T_4 (deep and course tillage), low in T_3 (shallow fine) and T_2 (shallow course) and lowest in case of T_1 (zero tillage). Irrigations scheduled at IW/CPE = 0.8 registered higher WUE compared to other moisture regimes, but the yield (both seed and oil) increased with an increase in intensity of irrigations.

13. Soil moisture extraction (per cent extraction of total) from lower soil depth (15-30 and 30-45 cm) was relatively higher in deep tillage treatments (T_5 and T_4) and lower in case of shallow tillage (T_3 and T_2), and lowest in zero tillage (T_1). Irrespective of tillages, increase in intensity of irrigations resulted in decreased moisture extraction from deeper layers. This infers that under deep tillage (especially deep and fine) favourable soil physical conditions viz., low MWD, low bulk density, low penetration resistance, more ploughing depth and high moisture availability resulted in higher soil moisture extraction, high water use and there by higher growth and yield of crop, which intern result in high water use efficiency.

14. Multiple regression functions (step down) were developed for seedling emergence with tillage induced soil physical properties and for seed yield

with tillage induced soil physical properties. These regression functions indicated that clod size distribution (mean weight diameter of dry clods) is the major determinant of tillage induced edaphic factor for seedling emergence. Mean weight diameter of dry clods, soil penetration resistance, soil moisture tension and soil temperature were the major tillage induced soil properties influencing the seed yield of sunflower grown after rice in rice based cropping system and could account for more than 94 per cent of the variation.

15. Taking the soil physical properties, yield (both seed and oil) in the rotavator tillage succeeding tractor drawn disc plough once (T_5) was found to be the best tillage practice for getting higher yield of sunflower when grown after rice in rice based cropping system. Next best tillage were T_4 (tractor drawn MB plough once + cultivator twice). On the other hand, simple modification to farmers' practice by running power tiller rotavator as secondary tillage instead of bullock drawn cultivator also improved the crop yield significantly and for high water use efficiency.

16. Finally, application of irrigations at IW/CPE = 1.0 in combination with T_5 (tractor drawn disc plough + rotavator) or T_4 (tractor drawn MB plough + cultivator) was recommended for getting maximum returns from sunflower grown after rice in rice based cropping system.

17. It is also suggested that under water shortage conditions, specially well water irrigating conditions in Southern Telangana region deep tillage with tractor drawn disc plough or tractor drawn MB plough be done as primary tillage to reduce the number of irrigations for efficient utilization of irrigation water.

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* Originals not seen

The pattern of `Literature cited' presented above is in accordance with the `Guidelines' for thesis presentation for Acharya N G Ranga Agricultural University, Hyderabad.

APPENDICES

Appendix Ia

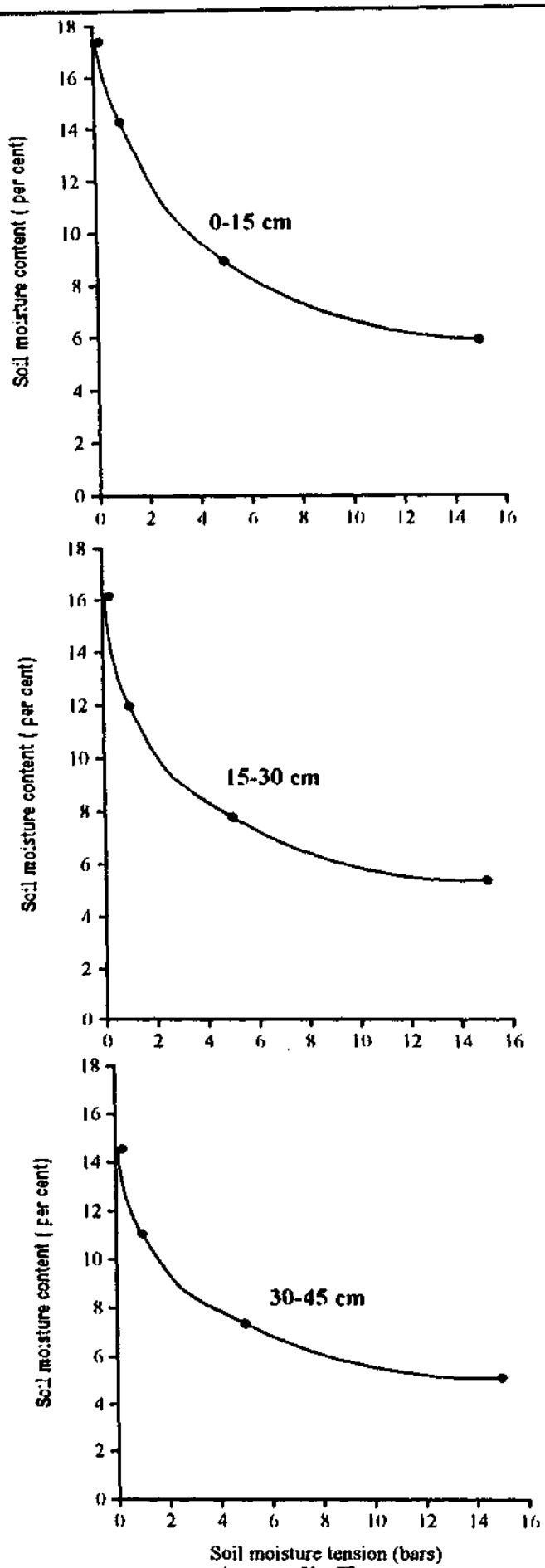
Meteorological data during crop growth period (weekly means) during late *rabi* 1998-99

Standard week	Dates	Temperature (°C)		R.H (%)		Rainfall (mm)	Sunshine (Hrs)	Wind speed (km/hr)	Evaporation (mm)	No. of rainy days	Mean temperature day^{-1} °C
		Max.	Min.	I	II						
7	12-2-99 to 18-2-99	31.7	15.2	85	28	0.0	10.2	3.5	4.9	0	23.5
8	19-2-99 to 25-2-99	33.2	14.6	79	23	0.0	10.5	2.9	5.6	0	23.9
9	26-2-99 to 4-3-99	34.7	15.9	77	24	0.0	10.4	2.9	5.9	0	25.3
10	5-3-99 to 11-3-99	36.0	17.4	66	21	0.0	10.5	2.5	4.5	0	26.7
11	12-3-99 to 18-3-99	36.0	19.4	72	25	0.0	10.2	2.9	6.4	0	27.7
12	19-3-99 to 25-3-99	36.9	23.2	72	32	0.0	7.7	2.1	5.3	0	30.1
13	26-3-99 to 1-4-99	38.2	17.9	61	16	0.0	10.7	2.6	6.6	0	28.1
14	2-4-99 to 8-4-99	38.7	20.0	66	18	0.0	10.5	2.5	7.2	0	29.3
15	9-4-99 to 15-4-99	40.7	24.3	54	15	0.0	9.9	3.3	8.6	0	32.5
16	16-4-99 to 22-4-99	39.3	20.3	54	17	0.0	8.8	2.5	7.7	0	29.8
17	23-4-99 to 29-4-99	40.0	26.7	58	26	0.0	8.4	3.1	9.1	0	33.4
18	30-4-99 to 8-5-99	41.3	27.0	52	27	0.8	10.0	4.4	8.8	2	34.2

Appendix Ib

Meteorological data during crop growth period (weekly means) during late *rabi* 1997-98

Standard week	Dates	Temperature (°C)		R.H (%)		Rainfall (mm)	Sunshine (Hrs)	Wind speed (km/hr)	Evaporation (mm)	No. of rainy days	Mean temperature day^{-1} °C
		Max.	Min.	I	II						
3	15-1-98 to 21-1-98	32.1	17.1	88	39	0.0	8.8	2.5	4.2	0	24.6
4	22-1-98 to 28-1-98	31.5	19.8	84	42	0.0	9.0	3.3	4.3	0	25.6
5	29-1-99 to 4-2-99	31.5	18.0	89	40	0.0	9.0	2.3	4.7	0	24.7
6	5-2-99 to 11-2-99	31.4	18.2	82	36	0.8	9.0	3.4	4.6	0	24.8
7	12-2-99 to 18-2-99	31.9	15.8	76	30	0.0	10.6	2.4	5.6	0	23.9
8	19-2-99 to 25-2-99	34.3	16.9	71	26	0.0	10.9	1.7	6.5	0	25.6
9	26-2-99 to 4-3-99	35.3	20.6	78	30	0.2	10.1	2.9	6.7	0	28.0
10	5-3-99 to 11-3-99	35.5	20.9	67	37	0.0	9.2	2.5	6.6	0	28.2
11	12-3-99 to 18-3-99	35.3	21.1	63	31	0.0	9.5	4.3	7.8	0	28.2
12	19-3-99 to 25-3-99	37.8	21.7	71	28	0.0	9.3	2.7	8.1	0	29.8
13	26-3-99 to 1-4-99	36.6	21.9	77	27	0.0	9.2	3.3	8.1	0	29.3
14	2-4-99 to 6-4-99	38.1	22.0	66	26	0.0	9.5	2.9	8.6	0	30.0



Appendix II

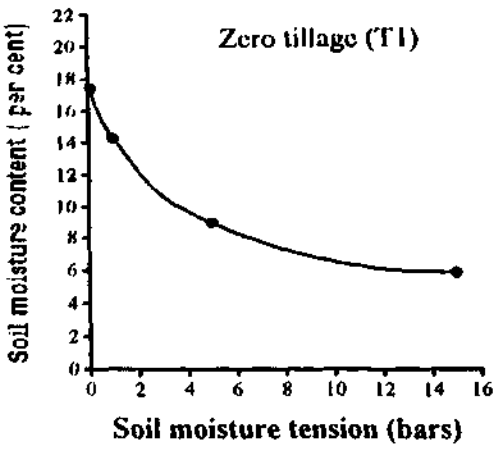
Soil moisture characteristic curves at different soil depths of experimental site

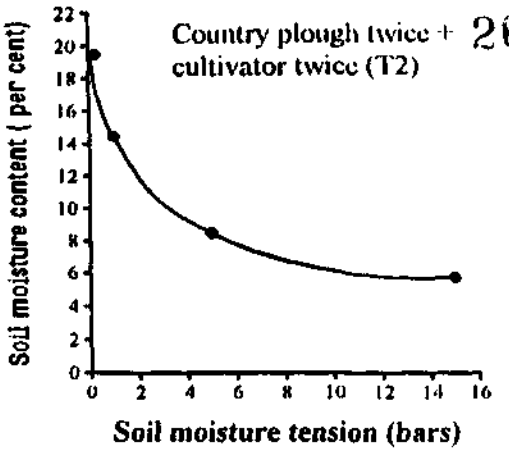
Appendix IIIa

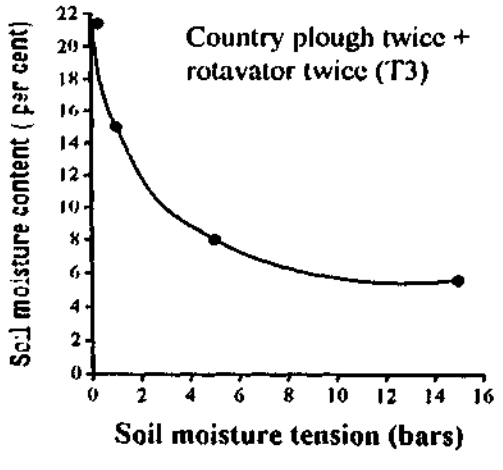
Effect of tillage treatments on moisture retension characteristics 0-15, 15-30 and 30-45 cm depth treatment

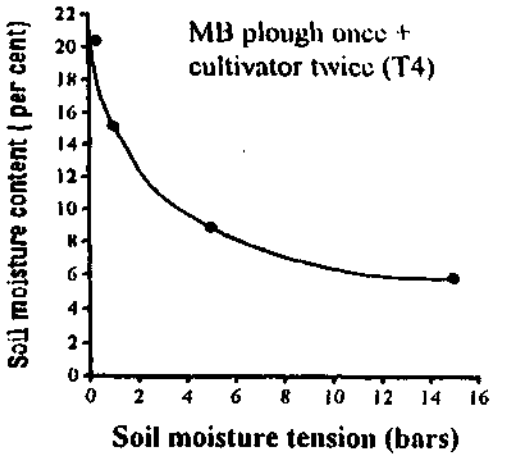
Tillage treatment	Soil depth	Soil moisture (%)				BD ($Mg\ m^{-3}$)	Avl moisture
		0.1	1.0	5.0	15.0		
T_1	0-15	17.39	14.25	8.92	5.86	1.44	2.49
	15-30	16.15	11.95	7.77	5.40	1.55	2.51
	30-45	14.55	11.05	7.33	5.12	1.59	2.25
						Total	7.25
T_2	0-15	19.46	14.44	8.45	5.70	1.36	2.81
	15-30	16.32	12.14	7.55	5.61	1.54	2.47
	30-45	14.44	11.54	7.17	5.24	1.59	2.17
						Total	7.45
T_3	0-15	21.38	14.96	8.00	5.58	1.37	3.25
	15-30	16.50	12.25	7.85	5.64	1.53	2.49
	30-45	14.66	11.25	7.00	5.35	1.59	2.22
						Total	7.96
T_4	0-15	20.37	15.14	8.88	5.80	1.36	2.97
	15-30	18.91	13.55	8.00	5.39	1.40	2.84
	30-45	14.61	11.44	7.35	5.23	1.60	2.25
						Total	8.06
T_5	0-15	21.53	15.33	9.21	5.65	1.35	3.22
	15-30	19.36	13.76	8.27	5.25	1.39	2.94
	30-45	14.50	11.75	7.22	5.16	1.60	2.24
						Total	8.40

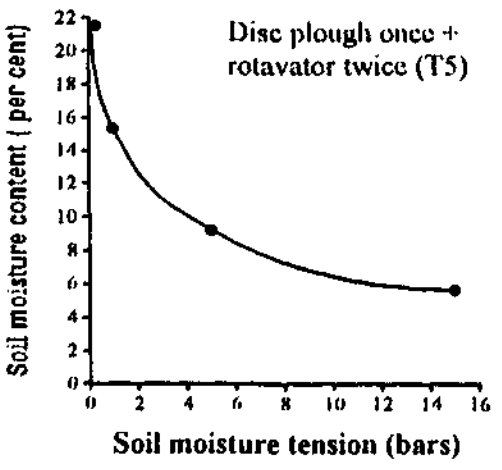
T_1 : Zero tillage
T_2 : Country plough twice + bullock drawn cultivar twice
T_3 : Country plough twice + power tiller rotavator twice
T_4 : Mould board plough once + cultivator twice, both tractor drawn
T_5 : Disc plough once + rotavator twice, both tractor drawn











Appendix IIIb

Effect of tillage treatments on soil moisture (per cent) retension characteristic curves in 0 to 15 cm soil layer at 30 DAS

Appendix IVa

Effect of tillage treatments and soil moisture regimes on soil clod size distribution and mean weight diameter (MWD) during crop growth period 1997-'98

	Clod size (mm)							MWD
	>100	50-100	20-50	10-20	5-10	2-5	< 2	(mm)
				30 DAS				
T_2 M_1	6.98	11.44	20.94	15.38	11.66	15.41	19.06	26.98
T_2 M_2	5.83	12.18	21.68	16.14	10.22	15.33	18.00	26.64
T_2 M_3	6.14	10.78	17.96	18.53	10.84	16.21	19.52	25.06
T_2 M_4	4.35	11.54	16.13	19.08	13.65	16.33	19.87	23.51
T_3 M_1	-	8.00	15.18	19.56	16.13	15.99	24.14	16.49
T_3 M_2	-	8.78	13.96	17.48	18.19	15.47	26.12	16.51
T_3 M_3	-	6.47	14.33	18.21	16.84	16.80	27.35	15.00
T_3 M_4	-	5.35	11.76	20.48	17.33	19.27	25.81	13.62
T_4 M_1	7.22	10.00	17.18	18.55	12.33	12.19	19.53	25.26
T_4 M_2	4.45	12.22	14.72	17.76	11.68	15.16	20.01	23.08
T_4 M_3	4.21	10.67	14.51	19.35	13.75	15.66	21.54	22.20
T_4 M_4	3.10	10.42	15.07	18.35	13.60	16.18	22.42	20.93
T_5 M_1	-	6.83	15.26	19.84	14.44	19.26	27.37	15.68
T_5 M_2	-	6.16	16.48	20.21	15.33	17.96	23.88	15.68
T_5 M_3	-	4.74	13.96	20.75	17.28	17.62	25.65	13.93
T_5 M_4	-	5.21	12.57	17.44	19.87	18.25	26.66	13.59
				60 DAS				
T_2 M_1	3.31	8.42	15.88	16.66	18.88	16.21	21.34	20.04
T_2 M_2	1.93	8.35	16.76	16.00	17.35	14.93	21.71	18.72
T_2 M_3	-	7.34	14.55	19.89	18.18	16.96	23.05	16.00
T_2 M_4	-	6.00	15.33	20.14	16.36	17.55	24.72	15.17
T_3 M_1	-	6.45	13.68	16.44	17.45	19.94	26.04	14.62
T_3 M_2	-	3.96	14.26	14.82	20.14	20.33	26.49	12.92
T_3 M_3	-	4.82	11.65	14.13	18.62	22.45	28.33	12.56
T_3 M_4	-	-	12.87	16.22	19.26	21.67	29.98	9.73
T_4 M_1	4.19	6.13	12.48	16.26	18.87	18.41	23.66	18.07
T_4 M_2	1.35	6.68	11.98	16.42	19.68	18.66	25.18	16.68
T_4 M_3	-	7.25	11.22	14.33	20.31	20.47	26.42	14.29
T_4 M_4	-	7.79	9.85	14.05	19.28	22.36	26.67	14.16
T_5 M_1	-	4.14	13.28	16.38	19.17	20.64	26.39	12.90
T_5 M_2	-	2.33	12.88	17.86	18.42	21.33	27.18	11.61
T_5 M_3	-	-	13.52	18.75	19.66	19.18	28.89	10.26
T_5 M_4	-	-	12.46	17.15	19.71	20.64	30.04	9.04

T_1 : Zero tillage
T_2 : Country plough twice + bullock drawn cultivar twice
T_3 : Country plough twice + power tiller rotavator twice
T_4 : Mould board plough once + cultivator twice, both tractor drawn
T_5 : Disc plough once + rotavator twice, both tractor drawn

M_1 : IW/CPE = 0.6
M_2 : IW/CPE = 0.8
M_3 : IW/CPE = 1.0
M_4 : IW/CPE = 1.2

Appendix IVb

Effect of tillage treatments and soil moisture regimes on soil clod size distribution and mean weight diameter (MWD) during crop growth period 1998-'99

	Clod size (mm)							MWD (mm)
	>100	50-100	20-50	10-20	5-10	2-5	< 2	
				30 DAS				
T_2 M_1	5.14	12.83	17.57	15.33	12.48	16.55	20.10	25.12
T_2 M_2	2.78	11.18	18.69	16.28	13.13	16.33	21.61	22.12
T_2 M_3	3.20	10.70	16.45	15.05	14.73	17.19	72.68	21.39
T_2 M_4	2.00	10.00	14.94	16.50	15.56	17.89	23.11	19.49
T_3 M_1	-	7.28	15.64	17.33	19.86	16.41	23.48	16.07
T_3 M_2	-	5.33	12.94	15.94	20.28	20.35	25.16	13.65
T_3 M_3	-	2.94	14.28	16.33	19.67	22.45	24.33	12.39
T_3 M_4	-	3.18	11.64	16.18	19.28	23.09	26.65	11.66
T_4 M_1	5.42	11.26	17.33	12.48	17.58	14.64	21.59	24.03
T_4 M_2	2.91	12.48	14.94	11.21	19.36	16.16	22.94	22.65
T_4 M_3	1.08	11.97	13.34	10.14	22.56	19.19	21.76	19.07
T_4 M_4	-	10.25	13.00	11.74	21.24	20.45	23.29	16.79
T_5 M_1	-	7.92	14.36	15.63	17.37	19.45	25.22	15.79
T_5 M_2	-	5.00	12.01	16.34	17.96	21.38	27.31	13.05
T_5 M_3	-	2.74	12.72	15.96	18.34	23.68	26.56	11.62
T_5 M_4	-	1.06	13.34	16.24	18.94	22.83	27.56	10.67
				60 DAS				
T_2 M_1	2.33	8.04	14.38	16.66	16.76	17.37	24.46	18.22
T_2 M_2	1.10	6.94	14.94	17.58	15.58	16.97	26.91	16.20
T_2 M_3	-	6.00	13.67	15.75	19.44	18.72	26.42	14.28
T_2 M_4	-	5.13	14.10	14.35	18.92	19.08	28.42	13.60
T_3 M_1	-	4.39	11.74	13.38	18.22	23.64	28.63	12.19
T_3 M_2	-	1.78	12.64	11.28	18.71	25.46	30.13	10.33
T_3 M_3	-	-	9.80	12.55	20.31	24.91	32.43	8.35
T_3 M_4	-	-	9.20	11.58	19.71	26.53	32.98	8.03
T_4 M_1	1.02	9.16	13.26	12.34	17.28	20.13	26.81	16.87
T_4 M_2	-	6.93	11.62	13.18	18.43	22.43	27.41	13.96
T_4 M_3	-	4.86	9.14	11.61	21.18	24.33	28.88	11.52
T_4 M_4	-	4.18	8.86	13.78	20.94	26.86	27.38	11.36
T_5 M_1	-	2.04	10.34	15.27	16.93	24.68	30.74	10.18
T_5 M_2	-	-	10.94	13.67	17.41	25.41	32.58	8.72
T_5 M_3	-	-	9.60	11.33	17.80	26.72	34.55	8.01
T_5 M_4	-	-	9.18	11.74	18.38	25.17	35.33	7.94

T_1 : Zero tillage
T_2 : Country plough twice + bullock drawn cultivar twice
T_3 : Country plough twice + power tiller rotavator twice
T_4 : Mould board plough once + cultivator twice, both tractor drawn
T_5 : Disc plough once + rotavator twice, both tractor drawn

M_1 : IW/CPE = 0.6
M_2 : IW/CPE = 0.8
M_3 : IW/CPE = 1.0
M_4 : IW/CPE = 1.2

Effect of tillage treatments and soil moisture regimes on soil moisture content (per cent) at 0-15 soil layer during crop growth period

	Soil moisture content (per cent)									
	1997-98					1998-99				
	10 DAS	30 DAS	45 DAS	60 DAS	75 DAS	12 DAS	30 DAS	45 DAS	60 DAS	75 DAS
T_1 M_1	8.90	6.07	5.73	5.57	6.13	8.91	5.75	5.54	5.40	5.63
T_1 M_2	8.90	6.72	6.55	6.15	6.72	8.91	5.81	5.68	5.60	5.96
T_1 M_3	8.90	7.31	6.98	6.60	7.54	8.91	6.52	6.29	6.05	6.40
T_1 M_4	8.90	7.77	7.24	7.05	8.01	8.91	7.23	6.89	6.58	6.93
T_2 M_1	10.28	6.43	6.01	5.63	6.50	9.97	5.88	5.46	5.32	5.81
T_2 M_2	10.28	7.02	6.88	6.22	7.20	9.97	6.23	5.81	5.60	6.04
T_2 M_3	10.28	7.93	7.58	6.79	8.03	9.97	6.83	6.67	6.40	6.64
T_2 M_4	10.28	8.51	8.00	7.53	8.55	9.97	7.61	7.33	7.30	7.40
T_3 M_1	11.55	6.55	6.35	5.95	6.40	11.41	6.21	5.88	5.58	6.00
T_3 M_2	11.55	8.57	6.98	6.30	7.05	11.41	6.86	6.57	6.29	6.54
T_3 M_3	11.55	8.38	7.80	6.83	8.43	11.41	7.55	7.00	7.10	7.33
T_3 M_4	11.55	8.80	8.47	7.78	8.93	11.41	8.01	7.55	7.55	7.64
T_4 M_1	11.11	7.64	6.98	6.20	7.10	10.94	7.11	6.33	6.25	6.44
T_4 M_2	11.11	8.23	8.05	7.01	7.94	10.94	7.55	7.10	6.85	7.21
T_4 M_3	11.11	8.68	8.66	7.86	8.59	10.94	8.03	7.70	7.55	7.72
T_4 M_4	11.11	9.86	9.18	8.48	9.25	10.94	9.10	8.63	8.50	8.80
T_5 M_1	12.39	7.90	7.33	6.66	7.54	12.08	7.30	6.60	6.45	6.68
T_5 M_2	12.36	8.60	8.49	7.59	8.30	12.08	7.96	7.42	7.25	7.40
T_5 M_3	12.36	8.96	8.88	8.32	8.75	12.08	8.55	8.16	7.98	8.20
T_5 M_4	12.36	10.08	9.61	8.94	9.31	12.08	9.42	9.06	8.61	9.15

T_1 : Zero tillage
T_2 : Country plough twice + bullock drawn cultivar twice
T_3 : Country plough twice + power tiller rotavator twice
T_4 : Mould board plough once + cultivator twice, both tractor drawn
T_5 : Disc plough once + rotavator twice, both tractor drawn

M_1 : IW/CPE = 0.6
M_2 : IW/CPE = 0.8
M_3 : IW/CPE = 1.0
M_4 : IW/CPE = 1.2

Appendix V b

Effect of tillage treatments and soil moisture regimes on soil moisture potential (bars) at 0-15 cm soil layer during crop growth period

	Soil moisture potential (bars)									
	1997-98					1998-99				
	10 DAS	30 DAS	45 DAS	60 DAS	75 DAS	12 DAS	30 DAS	45 DAS	60 DAS	75 DAS
T_1 M_1	-5.0	-12.6	-13.4	-14.1	-12.2	-5.0	-13.6	-14.2	-15.1	-13.0
T_1 M_2	-5.0	-9.8	-10.5	-11.7	-10.2	-5.0	-13.0	-13.8	-14.2	-12.8
T_1 M_3	-5.0	-8.0	-8.8	-10.1	-7.6	-5.0	-10.6	-11.2	-12.6	-10.8
T_1 M_4	-5.0	-6.6	-8.0	-8.9	-6.8	-5.0	-8.0	-9.0	-10.2	-9.1
T_2 M_1	-3.8	-9.0	-10.0	-11.4	-9.0	-3.6	-10.4	-11.8	-12.5	-10.9
T_2 M_2	-3.8	-7.6	-8.0	-9.4	-7.2	-3.6	-9.6	-10.2	-11.2	-10.0
T_2 M_3	-3.8	-5.8	-6.4	-8.0	-5.7	-3.6	-8.0	-8.3	-8.9	-8.6
T_2 M_4	-3.8	-4.9	-5.8	6.4	-4.8	-3.6	-6.4	-7.2	-7.8	-6.7
T_3 M_1	-3.0	-9.6	-11.0	-12.0	-10.4	-2.9	-11.0	-12.5	-13.8	-12.0
T_3 M_2	-3.0	-7.0	-7.6	-10.2	-7.6	-2.9	-8.6	-9.6	-10.8	-9.6
T_3 M_3	-3.0	-5.0	-5.5	-8.4	-4.9	-2.9	-7.0	-8.0	-8.2	-6.9
T_3 M_4	-3.0	-4.4	-4.8	-5.7	-4.5	-2.9	-5.2	-6.4	-6.4	-6.0
T_4 M_1	-3.4	-7.5	-9.1	-12.0	-9.0	-3.4	-9.0	-11.3	-11.5	-11.0
T_4 M_2	-3.4	-5.8	-6.6	-9.1	-6.6	-3.4	-7.5	-9.0	-9.8	-8.6
T_4 M_3	-3.4	-5.0	-5.4	-6.6	-5.3	-3.4	-6.5	-7.4	-7.5	-7.3
T_4 M_4	-3.4	-3.9	-4.4	-5.0	-4.6	-3.4	-4.6	-5.2	-5.4	-5.1
T_5 M_1	-2.8	-7.2	-8.6	-10.4	-8.1	-2.2	-8.8	-10.6	-11.2	-10.3
T_5 M_2	-2.8	-5.8	-6.1	-7.8	-6.3	-2.2	-7.1	-8.4	-9.1	-8.2
T_5 M_3	-2.8	-5.1	-5.4	-6.4	-5.5	-2.2	-6.0	-6.7	-7.2	-6.6
T_5 M_4	-2.8	-4.0	-4.5	-5.1	-4.7	-2.2	-4.7	-5.1	-5.6	-5.0

T_1 : Zero tillage
T_2 : Country plough twice + bullock drawn cultivar twice
T_3 : Country plough twice + power tiller rotavator twice
T_4 : Mould board plough once + cultivator twice, both tractor drawn
T_5 : Disc plough once + rotavator twice, both tractor drawn

M_1 : IW/CPE = 0.6
M_2 : IW/CPE = 0.8
M_3 : IW/CPE = 1.0
M_4 : IW/CPE = 1.2

Effect of tillage treatments and soil moisture regimes on nitrogen uptake by stalk and seed of sunflower at harvest

Tillage (T)	Nitrogen uptake (kg ha^{-1})									
	1998-99					1997-98				
	Soil moisture regime (M)					Soil moisture regime (M)				
	M_1	M_2	M_3	M_4	Mean	M_1	M_2	M_3	M_4	Mean
					Stalk					
T_1	8.65	10.05	10.86	11.77	10.33	9.11	9.60	10.97	11.78	10.37
T_2	11.19	13.82	15.39	15.68	14.02	12.18	14.28	15.87	16.70	14.76
T_3	12.98	15.31	16.92	17.88	15.77	14.03	16.26	18.13	19.56	16.99
T_4	14.05	16.19	17.88	19.22	16.83	16.30	19.32	19.92	20.59	19.03
T_5	17.78	20.23	21.85	22.33	20.56	17.36	20.79	22.42	23.66	20.94
Mean	12.93	15.12	16.58	17.58		13.79	16.05	17.46	18.46	
					Seed					
T_1	12.29	16.90	19.31	19.98	17.12	12.07	15.13	18.74	20.43	16.59
T_2	16.71	22.15	27.74	28.89	23.87	16.83	21.42	26.47	28.26	23.25
T_3	18.51	25.31	30.69	31.91	26.60	18.28	25.58	30.16	32.40	26.60
T_4	23.77	30.72	35.72	36.66	31.75	23.64	31.13	36.26	37.80	32.71
T_5	27.55	35.32	41.21	42.75	36.70	26.52	35.21	39.85	42.04	35.90
Mean	19.77	26.08	30.93	32.04		19.47	25.69	30.30	32.18	
			Stalk	Seed				Stalk	Seed	
T SEm±			0.64	1.04				0.81	1.06	
CD (P=0.05)			1.43	2.31				1.82	2.21	
M SEm±			0.46	0.67				0.43	0.79	
CD (P=0.05)			1.13	1.48				1.08	1.86	
T at M										
SEm ±			0.81	1.31				1.33	1.34	
CD (P=0.05)			1.62	3.21				2.75	3.28	
M at T										
SEm±			0.74	1.08				0.98	1.07	
CD (P=0.05)			1.31	2.77				2.26	3.24	

T_1 : Zero tillage
T_2 : Country plough twice + bullock drawn cultivar twice
T_3 : Country plough twice + power tiller rotavator twice
T_4 : Mould board plough once + cultivator twice, both tractor drawn
T_5 : Disc plough once + rotavator twice, both tractor drawn

M_1 : IW/CPE = 0.6
M_2 : IW/CPE = 0.8
M_3 : IW/CPE = 1.0
M_4 : IW/CPE = 1.2

Appendix VIb

Effect of tillage treatments and soil moisture regimes on phosphorus uptake by stalk and seed of sunflower at harvest

Tillage	Phosphorus uptake (kg ha^{-1})									
	1997-98					1998-99				
	Soil moisture regime (M)					Soil moisture regime (M)				
	M_1	M_2	M_3	M_4	Mean	M_1	M_2	M_3	M_4	Mean
					Stalk					
T_1	3.64	3.75	4.22	4.65	4.06	3.57	3.56	4.80	4.95	4.22
T_2	3.85	4.47	5.32	4.97	4.66	4.36	5.28	6.02	6.05	5.43
T_3	5.24	5.55	6.23	6.70	5.92	4.97	5.72	6.52	7.13	6.10
T_4	5.21	6.15	6.50	7.78	6.41	6.18	6.98	7.99	8.31	7.36
T_5	6.27	7.91	8.33	8.82	7.83	7.01	7.84	8.64	9.86	8.34
Mean	4.84	5.57	6.12	6.57		5.22	5.87	6.79	7.26	
					Seed					
T_1	3.04	3.92	4.75	5.08	4.20	3.00	3.84	4.98	5.62	4.36
T_2	4.35	5.72	7.12	7.52	6.18	4.00	5.28	6.82	7.69	5.95
T_3	5.10	6.62	8.21	8.94	7.22	5.52	6.34	8.06	8.76	7.16
T_4	6.34	8.55	9.48	10.44	8.70	5.73	7.77	9.24	9.53	8.07
T_5	7.27	9.77	10.80	11.88	9.93	6.57	8.82	10.12	10.96	9.11
Mean	5.22	6.92	8.07	8.77		4.96	6.41	7.84	8.52	
			Stalk	**Seed**				**Stalk**	**Seed**	
T SEm±			0.24	0.29				0.49	0.36	
CD (P 0.05)			0.63	0.78				1.13	0.84	
M SEm±			0.18	0.34				0.39	0.31	
CD (P=0.05)			0.48	0.88				0.85	0.79	
T at M										
SEm ±			0.35	0.41				0.64	0.28	
CD (P=0.05)			0.78	1.22				1.46	0.95	
M at T										
SEm±			0.34	0.58				0.89	0.29	
CD (P=0.05)			1.13	2.10				1.94	1.18	

T_1 : *Zero tillage*
T_2 : Country plough twice + bullock drawn cultivar twice
T_3 : Country plough twice + power tiller rotavator twice
T_4 : Mould board plough once + cultivator twice, both tractor drawn
T_5 : Disc plugh once + rotavator twice, both tractor drawn

M_1 : IW/CPE = 0.6
M_2 : IW/CPE = 0.8
M_3 : IW/CPE = 1.0
M_4 : IW/CPE = 1.2

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Appendix VIc

Effect of tillage treatments and soil moisture regimes on potassium uptake by stalk and seed of sunflower at harvest

Tillage (T)	Potassium uptake (kg ha^{-1})									
	1997-98					1998-99				
	Soil moisture regimes (M)					Soil moisture regimes (M)				
	M_1	M_2	M_3	M_4	Mean	M_1	M_2	M_3	M_4	Mean
					Stalk					
T_1	27.21	30.21	32.84	34.86	31.28	24.63	26.13	30.85	33.21	28.70
T_2	29.07	34.70	38.17	39.53	35.36	29.22	34.82	38.25	40.25	35.63
T_3	32.90	36.21	39.85	40.88	37.46	32.51	40.34	44.96	46.17	40.99
T_4	33.28	38.53	42.55	43.29	39.41	35.58	42.21	44.01	46.26	42.02
T_5	36.70	43.05	47.42	48.80	44.00	39.72	46.75	50.57	51.16	47.05
Mean	31.83	36.54	40.17	41.37		32.33	38.05	41.73	43.41	
					Seed					
T_1	5.45	7.63	8.49	9.20	7.69	5.00	6.17	7.69	8.77	6.91
T_2	7.62	10.49	12.25	13.93	11.07	7.16	8.97	11.70	13.14	10.23
T_3	8.89	12.24	14.15	15.86	12.78	8.68	11.40	13.10	14.58	11.94
T_4	10.65	14.46	16.28	17.65	14.76	9.99	13.89	16.05	17.41	14.58
T_5	12.25	16.48	19.86	20.48	17.26	12.08	15.08	17.58	19.00	16.18
Mean	8.97	12.26	14.20	15.42		8.58	11.10	13.22	14.92	
			Stalk	Seed				Stalk	Seed	
T SEm±			0.76	0.56				0.79	0.32	
CD (P=0.05)			1.81	1.34				1.86	0.81	
M SEm±			0.70	0.36				0.59	0.36	
CD (P=0.05)			1.57	0.88				1.45	0.90	
T at M										
SEm ±			1.31	0.68				1.54	0.86	
CD (P=0.05)			1.93	1.71				2.97	1.83	
M at T										
SEm±			1.73	0.61				1.71	0.92	
CD (P=0.05)			3.06	2.41				3.37	2.25	

T_1 : Zero tillage
T_2 : Country plough twice + bullock drawn cultivar twice
T_3 : Country plough twice + power tiller rotavator twice
T_4 : Mould board plough once + cultivator twice, both tractor drawn
T_5 : Disc plough once + rotavator twice, both tractor drawn

M_1 : IW/CPE = 0.6
M_2 : IW/CPE = 0.8
M_3 : IW/CPE = 1.0
M_4 : IW/CPE = 1.2