

**EVALUATION OF SOIL - WATER - PLANT AND ATMOSPHERIC PARAMETERS
IN RELATION TO FURROW, SPRINKLER AND DRIP IRRIGATION METHODS
FOR TOMATO (Lycopersicon esculentum, Mill.)**

By

JANARDAN RAJARAM KADAM

M. Sc. (Agrl.)

A Thesis submitted to the
MAHATMA PHULE AGRICULTURAL UNIVERSITY
RAHURI, DIST-Ahmednagar
Maharashtra State, (India)

in fulfilment of the requirements for the degree

of

Doctor of Philosophy (Agriculture)

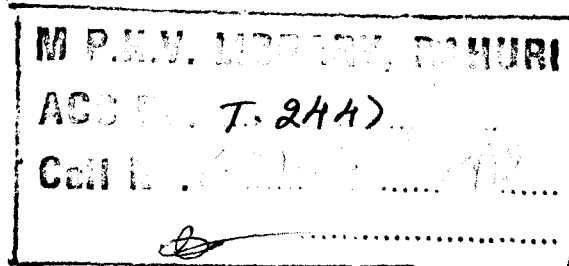
in

Soil Science



**DEPARTMENT OF AGRICULTURAL CHEMISTRY AND SOIL SCIENCE,
POST GRADUATE INSTITUTE,
MAHATMA PHULE AGRICULTURAL UNIVERSITY
RAHURI 413 722, DIST. AHMEDNAGAR**

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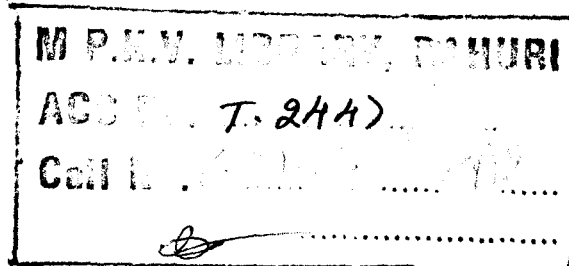
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1990



CANDIDATE DECLARATION.

I hereby declare that this thesis or part thereof has not been submitted by me or other person to any other University or Institute for a Degree or Diploma.

Rahuri.

Dated October 23, 1990


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CERTIFICATE

This is to certify that the thesis entitled "Evaluation of soil-water-plant and atmospheric parameters in relation to furrow, sprinkler and drip irrigation methods for tomato (Lycopersicon esculentum, Mill.)" inceptisols to the Faculty of Agriculture, Mahatma Phule Agricultural University, Rahuri, District Ahmednagar in fulfillment of the requirements for the degree of **DOCTOR OF PHILOSOPHY (AGRICULTURE)** in **SOIL SCIENCE** embodies the results of a piece of bonafide research work carried out by SHRI J. R. KADAM under my guidance and supervision. No part of the thesis has been submitted for any other degree or diploma.

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

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S. S. Magar,
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Associate Dean,
Post-Graduate Institute,
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CERTIFICATE

This is to certify that the thesis entitled "Evaluation of soil-water-plant and atmospheric parameters in relation to furrow, sprinkler and drip irrigation methods for tomato (Lycopersicon esculentum, Mill.)" in inceptisols submitted to the Mahatma Phule Agricultural University, Rahuri, District Ahmednagar in fulfillment of the requirements for the degree of **DOCTOR OF PHILOSOPHY (AGRICULTURE)** in **SOIL SCIENCE** embodies the results of a piece of bonafide research work carried out by SHRI J. R. KADAM under the guidance and supervision of Dr.S.S.Magar, Head, Interfaculty Department of Irrigation Water Management, Mahatma Phule Agricultural University, Rahuri. No part of the thesis has been submitted for any other degree or diploma.

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(J. R. KADAM)

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Contents

CERTIFICATES :	1. Research Guide	ii
	2. Associate Dean, FGI, Rahuri	iii
ACKNOWLEDGEMENTS		iv
LIST OF TABLES		xii
LIST OF ILLUSTRATIONS		xv
LIST OF PLATES		xix
ABBREVIATIONS		xxi
ABSTRACT		xxii
1. INTRODUCTION		1
2. REVIEW OF LITERATURE		5
2.1. Soil-water-parameters		6
2.1.1. Soil-plant-atmosphere continuum (SPAC).....		6
2.1.2. Soil water flow parameters		7
2.1.2.1. Hydraulic conductivity		7
2.1.2.2. Soil water diffusivity		8
2.1.3. Dynamics of soil water transport		9
2.1.4. Soil water balance		10
2.1.5. Soil water modelling		11
2.2. Plant parameters and atmospheric effects		12
2.2.1. Soil water and leaf water potential		13
2.2.2. Soil temperature and leaf water potential.....		14
2.2.3. Atmospheric factors and leaf water potential.....		15
2.2.4. Effect of soil and aerial temperatures on crop growth		15

2.3. Plant response to soilwater and environment	16
2.3.1. Plant water deficit/	16
2.3.2. Water requirement/	18
2.3.2.1. Evapotranspiration	18
2.3.2.2. Reference evapotranspiration, E_{To}	19
2.3.2.3 Crop coefficients, K_c	20
2.4. Remote sensing technique	21
2.4.1. Crop stress measurements by infrared thermometry ..	21
2.4.2. Canopy temperatures and leaf water potential	22
2.4.3. Canopy temperatures and stress degree days	22
2.5. Water management techniques	23
2.5.1. Surface irrigation -furrow	23
2.5.2. Sprinkler irrigation	24
2.5.3. Drip irrigation	25
2.6. Crop response	26
2.6.1. Root development	26
2.6.2. Growth, quality and other characters of tomato	27
2.6.3. Yield of tomato	28
3 MATERIAL AND METHODS	31
3.1. Soils	31
3.1.1. Location description	31
3.1.2. Genesis and classification of black cotton soil ..	31
3.1.3. Profile characteristics of sawargaon series	32
3.1.4 Climate	32
3.2. Experimental details	35
3.2.1. Treatments	35

3.2.2. Experimental layout	35
3.2.3. Land preparation	44
3.2.4. Planning of irrigation treatments	44
3.2.4.1. Furrow irrigation	44
3.2.4.2. Sprinkler irrigation	48
3.2.4.3. Drip irrigation	48
3.2.5. Calibration of a drip irrigation system	50
3.2.6. Scheduling of irrigations and daily water application in drip system.....	53
3.2.7. Cultivation practices of tomato	53
3.3. Field observations and data collection	61
3.3.1. Soil moisture distribution and soil temperature ..	61
3.3.1.1 Measurement of soil matric potential.....	61
3.3.1.2 Wetting front.....	63
3.3.2 Hydraulic properties of soil	63
3.3.2.1. Hydraulic conductivity	63
3.3.2.2. Soil water diffusivity	64
3.4. Dynamics of physical properties	64
3.4.1. Bulk density	64
3.4.2. Soil moisture retention characteristics curve	64
3.5. Remote sensing technique.....	64
3.5.1. Crop canopy temperatures.....	64
3.5.2. Stress degree days.....	66
3.6. Plant parameters	66
3.6.1. Leaf area index	66
3.6.2. Leaf water potential	66

3.7. Biometric observation	68
3.7.1. Plant height	68
3.7.2. Number of branches per plant	68
3.7.3. Number of fruits per plant	68
3.7.4. Weight of individual fruit	68
3.7.5. Dry matter content per plant	68
3.7.6. 50 percent flowering	70
3.7.7. Total marketable yield of tomato fruits.....	70
3.7.8. Volume of individual fruit	70
3.7.9. Root study	70
3.8. Quality of tomato	72
3.8.1. Total soluble solids, juice per cent and pH	72
3.8.2. Total acidity	72
3.9. Consumptive use of water	72
3.10. Water use efficiency	74
3.11. Statistical analysis	74
4. RESULTS AND DISCUSSION	76
4.1 Soil moisture monitoring	76
4.1.1 Profile moisture distribution -Furrow irrigation...	76
4.1.2 Profile moisture distribution -Sprinkler irrigation	80
4.1.3 Profile moisture distribution - Drip irrigation	83
4.1.4 Moisture redistribution and wetting front	83
4.1.5 Advancement of wetting front under uniform frequency of water application	86
4.2 Pertinent soil properties	88
4.2.1. Soil-water properties	88
4.2.1.1 Hydraulic conductivity	88

4.2.1.2	Soil water diffusivity	90
4.2.2.	Physical properties	92
4.2.2.1	Bulk density	92
4.2.2.2	Soil moisture constants	94
4.2.2.3	Soil temperature	94
4.2.3.	Pertinent chemical properties	101
4.2.3.1	Soil pH	101
4.2.3.2	Electrical conductivity, EC	101
4.3	Water budgeting	104
4.3.1	Consumptive Use	104
4.3.2	Water use efficiency	108
4.4	Assessment of water stress by infrared thermometry	110
4.4.1	Mid-day crop canopy temperature	110
4.4.2	Air temperature	115
4.4.3	CATD	115
4.4.4	SDD	124
4.5	Leaf water potential	127
4.6	Crop growth models	132
4.6.1	CATD and LWP relationship	132
4.6.2	Soil water potential and leaf water potential	134
4.6.3	Stress-degree day consumptive use and yield of tomato	136
4.7	Crop-Growth-Yield	144
4.7.1	Plant growth parameters	144
4.7.1.1	Height of plant	144
4.7.1.2	Number of branches per plant	146
4.7.1.3	Leaf area per plant	146

4.7.1.4	Leaf area index	146
4.7.1.5	Dry matter content for plant	152
4.7.1.6	Number of days for 50 per cent flowering	152
4.7.1.7	Root and shoot biomass	156
4.7.2	Yield contributing parameters	158
4.7.2.1	Number of fruits	158
4.7.2.2	Weight of fruits	158
4.7.2.3	Volume of a individual fruit	161
4.7.3	Yield	161
4.7.4	Quality of tomato fruits	166
4.7.4.1	Juice and T.S.S.	166
4.7.4.2	Acidity and pH	168
4.8	Correlation	168
5	SUMMARY AND CONCLUSION	172
6	LITERATURE CITED	178
7	APPENDIX	203
8	VITA	205

=====

LIST OF TABLES

<u>Table</u>	<u>Title</u>	<u>Page</u>
3.1	The description of profile horizons of sawargoan series.	34
3.2	Methods used for determination of physical and chemical properties of soil.	39
3.3	Pertinent physical properties of the experimental soil.	40
3.4	Pertinent chemical properties of the experimental soil.	41
3.5	Quality of irrigation water used in the experiment.	42
3.6	Description of furrow, sprinkler and drip irrigation treatments of the field experiment.	43
3.7	Discharge through a 90° V-notch.	46
3.8	Components of sprinkler and drip irrigation system.	51
3.9	Crop coefficient factor for tomato.	50
3.10	Scheduling of irrigation to tomato under surface and sprinkler irrigation methods (1988-89).	55
3.11	Scheduling of irrigation to tomato under surface and sprinkler irrigation methods (1989-90).	56
3.12	Daily water requirement of tomato during the period of irrigation under drip method.	57
3.13	Schedule of cultural and other operations followed for tomato (cv. pusa early dwarf).	60
4.1	Soil moisture content before irrigation as influenced by irrigation treatments during crop growth period.	77
4.2	Details of soil moisture constants and other related physical properties in effective root zone.	97

- 4.3 Soil pH as influenced by different soil moisture regimes during crop growth. 102
- 4.4 Soil EC as influenced by different soil moisture regimes during crop growth. 103
- 4.5 Consumptive use, average daily consumptive use, total pan evaporation, average daily pan evaporation and average evaporation transpiration ratios in irrigation (1988-89). 106
- 4.6 Consumptive use, average daily consumptive use, total pan evaporation, average daily pan evaporation and average evaporation transpiration ratios in irrigation (1989-90). 107
- 4.7 Consumptive use efficiency and relative water saving under different irrigation treatments for both the years of investigation. 109
- 4.8 Crop canopy air temperature differences data in relation to soil moisture regimes created by different treatments during the crop growth period(1988-1989). 117
- 4.9 Crop canopy air temperature differences data in relation to soil moisture regimes created by different treatments during the crop growth period(1989-1990). 120
- 4.10 Crop canopy and air temperature differences ($T_c - T_a$) before irrigation under furrow and sprinkler irrigation methods of tomato (1988-89). 122
- 4.11 Crop canopy and air temperature differences ($T_c - T_a$) before irrigation under furrow and sprinkler irrigation methods of tomato (1989-90). 123

4.12	Summation of stress - degree -day as influenced by different soil moisture regimes during crop growth period.	126
4.13	Leaf water potential of a tomato as influenced by furrow and sprinkler irrigation methods.	128
4.14	Leaf water potential of a tomato as influenced by different soil moisture regimes under drip irrigation method.	129
4.15	Different mathematical equations of different variables	141
4.16	Different mathematical equations based on the yield contributing and quality parameters.	142
4.17	Leaf area of tomato as influenced by different soil moisture regimes during crop growth. (1988-89)	148
4.18	Leaf area of tomato as influenced by different soil moisture regimes during crop growth. (1989-90)	149
4.19	Days for 50 per cent flowering of tomato crop as influenced by different soil moisture regimes.	155
4.20	Root, shoot weight and there ratio as influenced by different soil moisture regimes after harvest of the tomato crop.	157
4.21	Yield of a tomato as influenced by different soil moisture regimes (t/ha).	164
4.22	Juice percentage and TSS (brix) of tomato as influenced by different soil moisture regimes.	167
4.23	Total acidity and pH of tomato juice as influenced by different soil moisture regimes.	169
4.24	Correlations with different variables.	170

LIST OF ILLUSTRATIONS

<u>Fig. No.</u>	<u>Title</u>	<u>Page No.</u>
3.1	Map of India showing locations and geographical positions.	33
3.2	Maximum and minimum temperature and relative humidity during crop growth period. (1988-89)	36
3.3	Maximum and minimum temperature and relative humidity during crop growth period. (1989-90)	37
3.4	Particle size ditribution of soils.	38
3.5	Experimental layout showing position of furrow sprinkler and drip irrigation treatments.	45
3.6	Crop coefficent values as influenced by critical growth stages of tomato crop.	52
3.7	Calibration of discharge through emitter as a function of pressure.	54
3.8	Soil moisture retention characteristics for different soil layers.	65
4.1	Soil water content in a profile under furrow irrigation during crops growth. (1988-89)	78
4.2	Soil water content in a profile under furrow irrigation during crop growth.(1989-90)	79
4.3	Soil water content in profile under sprinkler irrigation during crop growth. (1988-89)	81
4.4	Soil water content in a profile under sprinkler irrigation during crop growth. (1989-90)	82

4.5	Soil water content in a profile under drip irrigation during crop growth.	84
4.6	Volumetric water content as function of depth just below the emitter.	85
4.7	Advancement of wetting front from the point source (emitter) after 72 and 144 hrs.	87
4.8	Hydraulic conductivity as a function of water content in different depth intervals of black soil.	89
4.9	Soil water diffusivity versus moisture content in different depth intervals of black soil.	91
4.10	Bulk density as a function of depth.	93
4.11	Soil temperature in relation to different soil moisture regimes under furrow and sprinkler irrigation during crop growth. (1988-89)	95
4.12	Soil temperature in relation to different soil moisture regimes under furrow and sprinkler irrigation during crop growth. (1989-90)	96
4.13	Soil temperature in relation to different soil moisture regimes under drip irrigation during crop growth period.	98
4.14	Crop canopy temperature in relation to different soil moisture regimes under furrow and sprinkler irrigation during crop growth. (1988-89)	111
4.15	Crop canopy temperature in relation to different soil moisture regimes under furrow and sprinkler irrigation during crop growth. (1989-90)	112

4.16	Crop canopy temp in relation to different soil moisture under drip irrigation during crop growth.	114
4.17	Summation of stress degree day as influenced by different soil moisture regimes.	125
4.18	Canopy air temperature differences vs-leaf water potential of tomato.	133
4.19	Leaf water potential of tomato vs soil water potential.	135
4.20	Soil moisture use and summation of stress degree days for tomato crop.	137
4.21	Yield of tomato (t/ha) vs summation of stress degree days.	138
4.22	Relationship of available soil moisture in the root zone and leaf water potential of tomato.	140
4.23	Height of a plant as influenced by different soil moisture regimes.	145
4.24	Number of branches per plant as influenced by different soil moisture regimes.	147
4.25	Leaf area index of tomato plant as influenced by different soil moisture regimes. (1988-89)	150
4.26	Leaf area index of tomato plant as influenced by different soil moisture regimes. (1989-90)	151
4.27	Dry matter accumulation of a plant as influenced by different soil moisture regimes. (1988-89)	153
4.28	Dry matter accumulation of a plant as influenced by different soil moisture regimes. (1989-90)	154
4.29	Number of fruits per plants as influenced by different soil moisture regimes.	159

4.30	Weight of individual fruits as influenced by different irrigation methods.	160
4.31	Volume of a individual fruits as influenced by different irrigation treatments.	162
4.32	Yield of a tomato as influenced by different soils moisture regimes.	165

LIST OF PLATES

<u>Plate NO.</u>	<u>Title</u>	<u>Page</u>
1	'V' notch for measurement of irrigation water under furrow irrigation.	47
2	Syphon tubes for measurement of irrigation water under furrow irrigation.	47
3	Pictorial view of sprinkler irrigation.	49
4	Use of microtube supplying irrigation water for four plants under drip irrigation.	49
5	Recording of soil temperature by digital soil temperature indicator.	62
6	Monitoring of soil moisture by tensiometer under drip irrigation.	62
7	Recording of crop canopy temperature with the help of infrared thermometer.	67
8	Measurement of leaf water potential with the help of HP-115 microprocessor.	69
9	Vegetative growth of tomato crop indicating the plant height	69
10	Vegetative growth of tomato under 50 mm CPE (IF) 50 under furrow irrigation.	71
11	Vegetative growth of tomato under 50 mm CPE (IS) 50 under sprinkler irrigation.	71
12	Vegetative growth of tomato under alternate day drip irrigation.	71

13	Root growth of tomato under furrow irrigation.	73
14	Root growth of tomato under sprinkler irrigation.	73
15	Root growth of tomato under drip irrigation.	73



List of symbols

C_p	volumetric heat capacity of soil, cal cm ⁻³ °C ⁻¹
D	thermal diffusivity, cm ² sec ⁻¹
D_θ	moisture diffusivity of soil, cm ² sec ⁻¹
E	rate of evaporation, cm sec ⁻¹
ΣE	cumulative evaporation, cm day ⁻¹
RH	relative humidity
K_θ	unsaturated hydraulic conductivity, cm day ⁻¹
T_a	air temperature at screen height, °C
T_s	soil temperature at $Z = -30$ cm
t	time, sec
Z	vertical co-ordinate, positive upwards, cm
r	temperature coefficient of surface tension of water, °C ⁻¹
θ	soil moisture content, g g ⁻¹
θ_v	volumetric moisture content (cm ³ of water cm ⁻³ of soil)
λ	thermal conductivity, cal cm sec ⁻¹ °C ⁻¹
λ_a	thermal conductivity of dry air, cal cm sec ⁻¹ °C ⁻¹
Ψ_s	soil water potential -MPa,
Ψ_L	leaf water potential, -MPa.

A B S T R A C T

Evaluation of soil water plant and atmospheric parameters in relation to furrow , sprinkler and drip irrigation methods for tomato (Lycopersicon esculentum , Mill) in neptisols.

By

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Science.

A field experiment was conducted at Mahatma Phule Agricultural University, Rahuri on clay, (BD 1.21 g cm⁻³ , ASM 125 mm in effective root zone of 60 cm, F.C. 34.7 per cent, FWP 18.5 per cent) medium black soil (neptisol) with an object to evaluate the SPAC relationship and use the said information for scheduling irrigation. The pertinent properties of black soil related to soil water and its dynamics and soil temperature as well as determination of canopy environment such as CATD and SDD and LWP were the major components. Evaluation of periodical dry matter accumulation estimation of crop response to variable water quantities, time and depth of irrigation, the yield and yield contributing parameters were correlated with each other.

The soil moisture content in four layers were monitored before each irrigation under furrow and sprinkler. However, it was monitored at 30 days interval under drip system. The available soil moisture

had gone below MAD under IF and IS treatments. The wetting front under drip irrigation was more or less semi-elliptical in shape with maximum diameter of 57 cm. The unsaturated hydraulic conductivity and soil water diffusivity exhibited exponential relationship with volumetric water content. Number of irrigations under furrow and sprinkler irrigation treatments was 8,6 and 4 for 50, 75 and 100 mm CPE respectively and 120, 60 and 40 in case of ID₁, ID₂ and ID₃ treatments respectively under drip irrigation.

The total pan evaporation was 401 and 461 mm during the crop growth period for the years 1988-89 and 1989-90 respectively. The maximum CU of 395 mm was recorded under IF₅₀ treatments. It was followed by 375 and 355 mm under IF₇₅ and IF₁₀₀ treatments respectively. It was 285, 270 and 265 mm under IS₅₀, IS₇₅ and IS₁₀₀ in case of sprinkler irrigation treatments respectively. The consumptive use in case of drip was 155 mm. The CU values were 2.5 and 2.0 times more in furrow and sprinkler irrigation treatments respectively compared to drip. The water use efficiency values were highest (29.0 and 29.4 Kg/ha-mm) in case of drip irrigation. The saving of water under drip irrigation was 58.1 and 44.6 per cent compared to furrow and sprinkler irrigation methods respectively.

The CATD difference was very large in case of drip irrigation ranging from -3.1 to -4.5 C. Similar trends were observed with SDD values. Leaf water potential values decreased to -1.57 and -1.54 M Pa under IF₁₀₀ and IS₁₀₀ respectively. The Leaf water potential values decreased with the advancement of plant growth. The yield contributing parameters were higher under drip irrigation than furrow

and sprinkler irrigations. Amongst the different treatments the highest yield of 43.3 t/ha was obtained under drip irrigation when water was applied on alternate day.

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Chapter Opener Page

1. INTRODUCTION

1. INTRODUCTION

Water loss from the plant foliage depends entirely on atmospheric conditions whereas water absorption by roots depend on soil water content and its potential. An understanding of the relationship between plant water and the dynamics of water in the Soil Atmosphere-Continuum (SPAC) is important in improving water use efficiency of crops. In order to predict leaf water status, it is necessary to have information simultaneously on both the soil water potential and atmospheric conditions. The water potential of plant foliage is the link between the soil-water-reservoir of high potential and the atmospheric sink with low potential. The interaction of growing plant with the imposed environment is complex and leaf water potential is influenced by the number of soil and environmental factors, such as air and soil temperatures, soil water availability, etc. Relating plant stress development to different variables of prevailing soil and atmospheric environment, help in deciding scheduling of irrigations based on plant water stress criteria.

Leaf temperature gives an indirect measurement of how well plants are growing and the effect of root (soil) temperatures on leaf temperature. Infrared thermometry (IR) is a reliable technique for the determination of plant temperature which has long been recognised as an indicator of water stress. Temperature depression for the given conditions is mostly proportional to the transpiration rate.

It is also an established fact that the continued transpiration results in soil water depletion which results in a decrease in transpiration rate and an increase in canopy temperature. Accurate

monitoring of the differences between leaf (or canopy) temperature and air temperature (ΔT) has been used to indicate plant water stress. If ΔT is related specifically to a change in plant water potential, it may be used by an indicator of plant water status. Similarly canopy temperature (T_c) data need to be correlated with the soil moisture status to ascertain the suitability of remotely sensed canopy temperature data for irrigation scheduling and yield prediction. Hand-held IR thermometry is an application of remote sensing technology, that is potentially useful in irrigation scheduling and yield prediction of water deficit-stressed crops. The canopy and air temperature difference (CATD) and stress degree days (SDD) are canopy temperature based stress indices available for this purpose. The assumption that crop T_c is a measure of plant water stress, is largely based on qualitative observations. Since plant water potential has gained wide acceptance as a fundamental measure of plant water status, it is of interest to compare such measurements with T_c data.

Water is one of the most important inputs for the assured production of crops. In view of the limited supplies of good quality water and increasing cost of water resource development and exploitation, there is now a growing realisation for efficient use of irrigation water. The predominant soil water properties such as hydraulic conductivity, soil water diffusivity, soil water flux, soil water distribution, moisture retention characteristics, are needed to be considered before taking final decision for when, how much and how to irrigate crops on a particular day through the efficient methods of water application.

Amongst them, border and ridges and furrows methods are commonly used by the irrigators. Efficient water application in furrow irrigation is dependent on the rate of advancement, infiltration characteristics of the soil, hydraulic resistance offered by the soil surface roughness, vegetable retardance and the longitudinal slope of the furrows. Sprinkler irrigation is a system which serves the purpose of uniform application of water in the form of a thin spray and water can be applied with a controlled rate thus ensuring high efficiency.

Amongst the sophisticated methods of irrigations, the drip irrigation method has proved its superiority over other irrigation methods due to direct application of water into the vicinity of root zone. In this method, water is applied at a low rate, over a long period, and at frequent intervals. The surface runoff, conveyance and deep percolation are eliminated to the maximum extent resulting into saving of water. However, the initial cost of drip and sprinkler irrigation equipments is the major limitation for their large scale adoption.

The main object of this investigation was to evaluate the parameters related to SPAC and to make use of this information in scheduling of irrigations to tomato crop. The scheduling of irrigations on climatological approaches has certain limitations. The soil and evaporative demand are the main considerations, whereas plant is not accepted as an indicator. In the present investigation tomato was selected as a test crop due to its peculiarity of moisture stress sensitivity and quick response to recovery. The important objectives of the present investigation are given below :

Objectives :

- i) Evaluation of pertinent properties of black soil related to soil water, its dynamics, and soil temperature in relation to different soil moisture regimes,
- ii) Determination of canopy environment such as canopy and air temperature differences ($T_c - T_a$) and stress degree days (SDD)
- iii) Evaluation of the periodical dry matter accumulation and leaf area index,
- iv) Estimation of crop response to variable water quantities, time and depth of water application,
- v) To study the yield and yield contributing parameters under different irrigation methods and
- vi) To correlate the crop response in terms of yield, and other parameters and attempt to develop different equations.

Chapter Opener Page

2. REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

This chapter deals with soil water properties, plant parameters, environmental conditions, plant response as by remote sensing, estimation of consumptive use either directly or by empirical formulae and yield response to variable soil moisture regimes created by different irrigation methods. Scheduling of irrigations to crops is decided by plant water deficit and evapotranspiration rate. Both factors can be either measured accurately or predicted within acceptable limits by empirical formulae. However, remote sensing techniques such as IR or leaf temperature are of important. Concepts of SDD can be excellent substitute for traditional criteria for irrigation. The crop response in the forms of bio-metric and yields created by different irrigation methods was reviewed for investigating above SPAC parameters.

Voluminous literature is available on SPAC, crop growth parameters, crop canopy temperatures, leaf water potential relationship and related aspects of evapotranspiration, consumptive use and water use efficiency, etc. It is rather a difficult task to include all available literature on these aspect. It is grouped into the following headings.

- 2.1 Soil-water-parameters,
- 2.2 Plant parameters and atmospheric effects,
- 2.3 Plant response to soil water and environment,
- 2.4 Remote sensing technique,

2.5 Water management techniques,

2.6 Crop response.

2.1 Soil Water Parameters

2.1.1 Soil plant atmosphere continuum (SPAC)

The current approach to the field water cycle is based on recognition that the field and its component such as soil, plant and atmosphere components are taken together to form a physically unified and dynamic system (Cowan, 1965) in which various processes occur inter-dependently. This unified system has been called the 'SPAC' (Philip, 1966).

The flow of water from soil through plants to the atmosphere takes place in response to water demand as imposed on plants by atmospheric evaporativity. The segments of SPAC to be considered for water movement are the soil, soil-roots interface and atmosphere. The movement of water within the soil is mediated by hydraulic gradient generated by non uniform distribution of soil water resulting mainly from evapotranspirational loss of water. Water flows to roots because of the sink that develops at the root surface as mediated by hydraulic gradient. The movement of water to roots has been approached on a macroscopic or root system basis (Molz, 1971) on a microscopic or single root basis (Gardner, 1960). Resistance to water flow at soil-root interface first quantified by Gardner (1964) depends upon the hydraulic conductivity near the root surface and root distribution function expressed on weight basis (Nimah and Hanks, 1973). The movement of water through xylem vessels is often thought to be conforming to Poiseuille's law of capillary flow. Water move from plant to atmosphere mainly through

stomata which are very sensitive to root and shoot environments (Hillel, 1980).

2.1.2 Soil water flow parameters

Soil moisture is measured on the basis of soil matric potential and potential gradient under unsaturated condition. It is, therefore, necessary to account for several factors related to soil moisture parameters such as hydraulic conductivity ($K(\theta)$), and soil water diffusivity $D(\theta)$, (Stone *et al.*, 1973).

2.1.2.1 Hydraulic conductivity

Basically Darcy's law has been used to describe water flow in an unsaturated soil (Gardner, 1956). The hydraulic conductivity of soil as a function of soil moisture content through porous media is influenced by the washing out of electrolytes and consequent modification of colloidal properties (Fireman, 1944), untrapped air (Allison, 1947), type of structure (O'Neal, 1949), temperature variation (Haridasan and Jensen, 1972), transport of the clay fractions and growth of micro-organisms (Gerard, 1974), surface soil physical conditions (Singh and Verma, 1975), antecedent soil moisture suction (DhanPal and Varade, 1976) and textural class of the soil. Roger and Klute (1971) showed that the hydraulic conductivity was a single valued function of water content exhibiting no hysteresis. Stone *et al.* (1973) calculated water flux V_z (cm/day) at a selected depth z (cm) and was given by :

$$V_z = \frac{0}{jz} \left(\frac{d\theta}{dt} \right) z, \text{ where } d\theta \text{ is the volumetric water content of soil} \\ \text{(cm}^3 \text{ cm}^{-3} \text{)} \text{ and } t \text{ is the time (days).}$$

Tripathi and Ghildyal (1975) observed that the calculated conductivities agreed closely with the measured values in tensiometer

range, while at higher suctions, the pore size distribution methods underestimate the hydraulic conductivity of clay loam soil of Pantnagar. DhanPal and Varade (1976) found that at higher suction, the capillary conductivity of clay loam soil was greater than that of sandy loam and loamy soils.

Magar et al. (1979) reported that unsaturated hydraulic conductivity ($K(\theta)$) exhibited an exponential relationship with hydraulic conductivity content in black clay soil of Parbhani. At low suction, $K(\theta)$ values increased with depth progressively which were consistent with the fact that unsaturated hydraulic conductivity in black cotton soil (Vertisols) with 58.5 per cent montmorillonite clay, varied in the order of 10^{-2} to 10^{-5} cm/sec when moisture content decreased from 0.70 to 0.30 cm cm (Magar et al. 1980). Gupta et al. (1981) stated that the pore size distribution model could be used to predict unsaturated hydraulic conductivity of vertisols. Patil (1982) showed that the unsaturated hydraulic conductivity of medium black soil exhibited an exponential relationship with volumetric water content (θ_v). Maximum values of K of 6.0×10^{-4} cm/day to 1×10^{-2} cm/day were estimated as soil water content changed from 0.19 cm cm to 0.46 cm cm respectively, in the surface layer. Similar observation were reported by Sarkar et al. (1984) and Patil (1986). Singh et al. (1988).

2.1.2.2 Soil water diffusivity

Childs and Collis-George (1948) first introduced the concentration-dependent diffusivity equation describing isothermal liquid flow in porous media when θ_v was a single valued function.

The diffusivity is based on water distribution as a function of time at fixed position in a horizontal infiltration system (Whisher et al., 1968). This method of estimating $D\theta$ was used by Magar and Kar (1981) and showed that the magnitude of $D\theta$ value ranged from 2.16×10^{-3} to 9.55×10^{-5} cm²/sec when moisture content decreased from 0.30 to 0.10 cm³/cm³. Bhatnagar (1973) stated that the diffusivity values increased with increase in moisture gradually in the initial stage. The diffusivity values increased but at higher moisture contents, the increase was very rapid.

Tripathi and Ghildyal (1976) found that soil water diffusivity variations ranged from 1002 to 1898 cm²/day. However, the differences were not large from just below saturation to field capacity. The change in soil water diffusivity was very rapid near saturation and below 0.3 bar. DhanPal and Varade (1976) reported that the moisture diffusivity was higher in sandy soil followed by Raipur red soil and Kharagpur sandy clay loam soil. Patil (1982) observed that the soil water diffusivity $D\theta$ also exhibited the exponential relationship with volumetric water content of medium black soil (Vertisol). Similar observations were reported by Bharambe et al. (1983, 1984) and Singh et al. (1985).

2.1.3 Dynamics of soil water transport

The process of liquid flow through porous media was first explained mathematically by Marshall (1954). Smiles and Rosenthal (1968) described the movement of water in swelling materials from the Darcy's law which indicated the relative flow of fluid to comparatively immobile particles of clay. Letey (1968) explained the movement of water through soil as influenced by osmotic pressure and temperature gradients by

describing steady state water flow through soil in response to hydraulic pressure or suction in unsaturated soil. Stone *et al.* (1978) concluded that little water moved through 150 to 180 cm layer during the study. Water movement took place in 150 to 180 cm layer and was predominantly upward. A slight water content change and slight water movement in silt loam soil in 150-180 cm layer indicated little root activity in this zone. Rose (1979) showed that in clay soil, between 5.8 to 4.2 pF water moves predominantly as vapour in a non-swelling silicate mineral. There was a significant liquid movement between 5.1 and 4.2 pF.

Kaul (1979) studied the movement of soil moisture from a point source in sandy loam soil of the research farm of IARI, New Delhi. He reported that the soil moisture in the wetted zone, extended to about 15 cm in length and 20 cm in diameter. Similar observations were also reported in case of tomato by Kataria (1982). Rama Devi (1980) reported that the moisture profile in the sandy loam soil of the reserach farm, IARI, New Delhi, closely approximated a semi-elliptical shape. Similar observations in deep black soil were also observed by Phadtare (1985) and Dhamal and Ghadge (1986).

2.1.4 Soil water balance

It is difference between the amount of water added (W_{in}) and the amount of water withdrawn (W_{out}) during a certain period and is equal to the change in water content W during the same period. The root zone water balance is expressed in integral form as : $\Delta S + \Delta V = (P+I+U) - (R+E+D+T)$ where, ΔS is change in root zone soil moisture storage, ΔV is increment of water incorporated in the plants, P is precipitation, I is irrigation, U is upward capillary flow into the root zone, R is runoff, D

is downward drainage out of the root zone, E is direct evaporation from the soil surface, and T is transpiration by plants. All quantities are expressed in terms of volume of water per unit area (equivalent depth units) during the period considered (Hillel, 1980; Acharya et al. 1984; Khara and Sandhu, 1988).

2.1.5 Soil water modelling

Soil water models were prepared by several research workers mostly on the aspects of infiltration (Brandt et al. 1972), water balance and SPAC (Hillel 1980). However, soil water modelling in respect of surface irrigation and drip irrigation methods are of immense importance. Brandt et al. (1972) analysed numerically the infiltration from the drip source with the assumption that the water entry zone is saturated. The width of saturated zone of loamy soil was approximately 220 to 580 mm for two discharges of 1.8 and 5.9 L/m/h, respectively. The time necessary to reach the maximum wetted area on the surface was of the order of 3 hours for the lowest discharge rate to nearly one day for the highest rate. Leonel Rolland (1972) found that the moisture spreads fairly widely at the surface but there was little infiltration downwards for low rates of flow in clay loam soil.

Warrick (1974) observed that the soil moisture decreased with distance from the source and the response was slower at a distance away from source. Rawlins and Reats (1975) worked out the wetted volume of a soil as a hemisphere. The radius of wetted hemisphere is $3r = \sqrt[3]{\frac{3}{f - O_i} q t}$ where r = radius in m, q = volumetric rate of application in m/h, t = application time in hour, f = final volumetric water content in, O_i = initial volumetric water content. The shallow rooted and widely

Spaced row crops, higher water application rates and for deep rooted and closely spaced row crops, lower rates should be used. Similar observations in tomato were reported by Kataria (1982).

Kaul (1979) found that the soil moisture in the wetting zone was identified to expand about 15 cm depth and 30 cm diameter. Lavin and Bravedo (1979) reported that the soil moisture distribution covered a wider area when trees were irrigated twice a week with 8 lph tricklers.

Rema Devi et al. (1980) concluded that the vertical advances of soil moisture front vs elapsed time resulting from drip irrigation with saline water at point source could be described by the exponential relationship upto salinity level of 10 mmhos/cm. Khepar et al. (1983) revealed that the vertical component of wetting zone increased with rate of water application in light textured soil, wetted volume of soil was increased with increased amount of water applied, wetting front moved to greater radial distance with the increased amount of water and in partially moist soil wetting front extended both in radial and vertical directions under drip irrigation.

Phadtare (1985) found that the radial spread was more for higher discharge rate (12 L/hr). Third order regressions were developed for radial spread at different depths below point source for various discharge rates. Magar and Sonawane (1987) observed that application of water at the rate of 2.5 lit/day/plant in vertisol resulted in the downward movement of water to the depth of 18, 45 and 65 cm on 1st, 5th and 7th day, respectively. It was observed that there was no much difference in case of vertical and horizontal water movement except that vertical movement was slightly higher than the horizontal one in deep black soils (Vertisol).

2.2 Plant parameters and atmospheric effects

2.2.1 Soil water and leaf water potential

Ehlig and Gardner (1964) observed simultaneous decrease in leaf water potential as soil water potential decreased after irrigation. Yang and Jong (1971) found a positive gradient of leaf water potential from soil to the top of the leaf and from base to top of the leaf. Richard et al. (1972) reported that the relative leaf water content decreased with increasing leaf temperature. Downey (1972) found a decrease in relative water content of maize by a decrease in soil water potential. Elfving et al. (1972) showed that in dry soil, leaf water potential became more negative than predicted, at the same flux of water under non-limiting conditions. Clark and Hiller (1973) compared soyabean leaf water potential to deficit and found that leaf water potential was most responsive. Water stress induces an increase in leaf temperature above air temperature.

Fisher (1973) concluded that during soil drying cycle, the difference in potential between plant top and bulk soil varied between -8 to -20 bar. Plant water potential was always lower presumably because water uptake lagged continuously behind water loss, indicating a large resistance to water transport in the soil plant system. A lower critical value of leaf water potential of -8 to -12 bars for stomatal closure of soybean in controlled environment was observed by Neuman et al. (1974), whereas for the same crop, the value obtained was -15 to -17 bars, and an increase in the diurnal amplitude of leaf water potential for maize, potato, soybean and groundnut, with a decrease in soil water content and with the age of the plant (Turner et al. 1978). Turner (1975) reported

that the values for leaf water potential of well watered and dry soil were -1.2 to -2.5 and -6 to 6.8 bars, respectively, which decreased in the afternoon to -8 to -13 bar and -15 bars for wet and dry soils, respectively.

Reicosky et al. (1975) observed that for maize, the minimum leaf water potential (LWP) occurred during the peak radiation load or stress, and it was dependent on soil matric potential and stage of plant development. Before tasselling, the minimum, LWP of -12 bar and -15 bar occurred in irrigated and unirrigated plots, respectively. At this time, the soil water potential at 15 cm depth was 0.08 bar for irrigated plots and 0.60 bar for unirrigated plots. Similar observations were reported by Bharambe and Varade (1982); Singh et al. (1984). Sharma et al. (1986) Nagarajarao and Mallick (1982) showed that during early stages of wheat growth, differences in leaf water potential were more or less same for the irrigated and non-irrigated sites after 80 days of sowing of the differences were conspicuously higher for unirrigated site than for irrigated conditions. Similar relations were reported for maize, potato, soybean and groundnut with a decrease in soil moisture content and with the age of the plant. The LWP and transpiration decreased with depletion of soil water Nagarajarao and Mallick (1979 and 1989) Naveen et al. (1984) and Ramana, (1989).

2.2.2. Soil temperature and leaf water potential

Cameron (1941) reported that in orange trees, decreasing soil temperature from 90 to 40 F resulted in a marked decrease in the rate of water loss, and that the leaf water deficits were higher at low soil temperatures. Similar observations in alfalfa were obtained by Ehrler

(1963). Tew *et al.* (1963) mentioned that soil temperature had a significant influence on sunflower leaf temperature. Cox and Boersma (1967) observed that a slight increase in leaf temperature was noted with increase in soil temperature, but the greatest increase occurred when the soil temperature exceeded the ambient temperature of 23.9 °C. Kirkham and Ahring (1978) found that leaf temperature in wheat was lower than the air temperature at all soil temperatures studied. Leaf water potential was the highest at 24.7 °C and lowest at 32.1 °C root temperature.

2.2.3 Atmospheric factor and leaf water potential

The diurnal variations in plant water status were closely related to radiation load or water stress (Klepper, 1968). Cary and Wright (1971) explained that daily changes in plant water potential varied from less than -5 bars to more than -20 bars in case of maize and wheat, and concluded that plant water potential was strongly influenced by microclimatic conditions near canopy. Miller (1971) found that leaf water potential and leaf temperature of spring barley were influenced by soil moisture content and day types. Mayer *et al.* (1980) observed that wheat plants with well developed root systems extracted 80 per cent of the available water at or near potential evapotranspiration rates.

2.2.4 Effect of soil and aerial temperatures on crop growth

Tew *et al.* (1963) reported that sunflower crop grown in soil held at a soil temperature of 10 °C had only 60 per cent as much as leaf area as the plants grown at 25 and 40 °C, though they had approximately the same area at the beginning. Abdelhafeez *et al.* (1971) stated that growth was reduced in tomato at soil and air temperatures below 17 °C and

20 C^o respectively. Water use was increased at higher soil temperatures. The results of Peters et al. (1971) showed that high night temperatures reduced soybean yield by about 10 per cent as compared to crops grown at cool night temperatures. High night temperature might have produced atmospherically induced water stress. Barr and Pellet (1972) found that soil temperature resulting in greater root growth of some woody plants was generally, lower than the soil temperature resulting in greatest top growth. Similarly, increased soil temperature was resulted in greater water use.

Koldrep (1975) grew spring wheat cultivars in moist and dry soils at 12, 15, 18, 21 and 24 C^o and observed that with increasing soil temperature, grain and straw yield decreased. Pirasteh and Welsh (1980) evaluated all cultivars of wheat headed more rapidly at higher temperatures (21 C^o day/12.7 C^o night). The rate of moisture use by wheat was more rapid at 27/12 C^o (day/night) temperatures, but the amount used was not different from that of at 22/12 C^o (Campbell et al. 1981). Mangat (1982) found a more pronounced increase in both fresh and dry weights of Phaseolus vulgaris L. plants, grown in the temperature regime of 15 C^o air and 28 C^o soil temperatures, than those grown under temperature regimes of same air and soil temperatures. Similar observations have been reported by various research workers (Kataria, 1982; Singh and Kumar, 1989).

2.3 Plant response to soil water and environment

2.3.1 Plant water deficit

The physically unified system of soil-plant-atmosphere continuum requires the ratio of root uptake of soil moisture and the

transpirational rate of the crop canopy. The plant water deficit is signalled through decrease in leaf water potential, increase in resistance to water flow and increase in leaf/canopy temperature. Hsiao (1973) identified various levels of stress in terms of relative water content (RWC). A drop in RWC by 8-10 per cent is indicative of severe stress. This criterion might not be much useful in aged and highly stressed plant leaves (Clark and Hiller, 1973).

It is often suggested that leaf water potential provides a better basis than RWC for comparing the degree of plant water deficit (Clark and Hiller, 1973). Leaf temperature is another important index of plant water deficit. Wiegand and Namken (1966) reported that a decrease in RWC from 83 to 59 per cent resulted in increase of 3.6 to 3.2 °C leaf temperature and leaf minus air temperatures, respectively. Jackson (1982) found that the canopy temperature was more than 10 °C below air temperature to quantify the relationship between canopy air temperature difference, and plant water stress (Wanjura et al., 1984).

On the basis of canopy temperature of plant, few indicators were developed to characterise the plant water deficits. They are stress day developed by Idso et al. (1981), temperature stress degree days by Clawson and Blad (1982) and crop water stress index developed by Jackson et al. (1981). Among these, SDD indicative of canopy air temperature difference at postnoon is the most commonly used index. Apart from sensing water stress, the cumulative SDD has been used to predict yield of soybean (Idso et al. 1980). Solar radiation from crop canopy has been related to plant parameters such as leaf area index chlorophyll content, biomass production and grain yield (Wiegand et al., 1979, Ramana, 1989).

2.3.2 Water requirement

2.3.2.1 Evapotranspiration

Estimation of evapotranspiration was done on the basis of aerodynamic (Penman, 1948) and mean monthly temperatures and day light hours (Thornthwaite, 1954 and Blaney and Criddle, 1950). Thornthwaite (1954) assumed that an exponential relationship existed between mean monthly temperature and mean monthly consumptive use. Penman (1948) proposed an equation for evaporation from open water surface based on the combination of energy balance and sink strength. Blaney and Criddle (1950) observed that the amount of water used by crops during their growing seasons was closely related to mean monthly temperature and day light hours.

Doorenbos and Pruitt (1975) proposed a modified Penman method for estimating fairly accurately the reference crop ET. The various parameters in the Penman equations are varied to determine their influence on the calculated evaporation and recharge amounts. Evaporation estimates are sensitive to albedo radiation, constants and wet bulb temperature (Howard and Lloyd, 1979). The influence of soil moisture content on evaporation from a 6 cm grass covered lysimeter and from USWB class A pan evaporimeter was assessed during summer. A sensitive analysis was applied to a modified Penman evapotranspiration equation to assess the errors associated with each of the parameters. Error estimates were utilized to assess the use of ET equation for irrigation scheduling (Trimmer and Weiss, 1979).

Hashemi and Habbian (1979) concluded that Thornthwaite method underestimates ET under arid conditions. Blaney-Criddle method, though developed in arid areas, has an insufficient sensitivity to the inter

annual variation of the evaporative demand of the atmosphere. The reference evapotranspiration (ET_o) from grass was about 90 per cent of the value calculated by Penman's method. The Penman's contribution equation is the most authentic method to compute reference evapotranspiration of any crop, provided all the requisite meteorological data are available. Therefore, to simplify calculation, specially for computing season or an yearly basis, a simple computer programme in FORTRAN Language has been developed by Surya Nath (1980). Ramana (1988) estimated an evapotranspiration in mustard and wheat crops using CATD technique.

2.3.2.2. Reference evapotranspiration, ET_o

Many methods, such as the Penman, Jensen-Haise, Hargreaves, Blaney-Criddle, pan evaporation, etc. are available to estimate the potential evapotranspiration of reference crops. Hargreaves and Samani (1985) tested an equation to estimate the ET_o of cool season grass, and found that the results were comparable with world-wide lysimeter data, and the values estimated using more complex equations. The equation needs minimum climatological data, and is yet general enough, does not require calibration for variation in climatic conditions. For these reasons, the method was incorporated to the ET simulation. Hargreaves-Samani's equation for the monthly average of the daily evapotranspiration of cool season grass, in mm per/day, can be written as:

$$ET_p = 0.0023 \times Ra \times (TC + 17.8) \times TD^{0.5}$$

where TC and TD are respectively the average of, and the difference between the mean monthly maximum and minimum daily temperatures in degrees celsius; and Ra is the monthly average value of the daily extra-terrestrial radiation, expressed in

equivalent evaporation, in mm per day. The ET_p values, in mm per day, for each month were based on the input values of monthly average of daily maximum and minimum temperatures, in degrees celsius, and latitude of the location under consideration. Chhabda et al. (1986) reported that Hargreaves method to estimate ET_0 in irrigated areas of Maharashtra can suitably be used. The Hargreaves method is simple to compute reference crop ET than modified Penman as it require only temperature data.

2.3.2.3 Crop coefficients, K_c

The values of the crop coefficients depend on the reference crop selected. Since the Hargreaves-Samani equation is based on grass as a reference crop, only the grass-based crop coefficients should be used. Doorenbos and Pruitt (1975) presented grass-based crop coefficients for many crops for different humidity and wind conditions. The growing season is divided into four or more stages : the initial stage consists of germination and early growth, when crop ground cover is less than 10 per cent; the crop development stage continues, until the effective crop cover reaches 70 to 80 per cent; the mid-season stage continues on to the beginning of maturation; and the late season stage ends at harvest. The duration of each stage varies with the local conditions. Doorenbos and Pruitt (1975) indicated typical lengths of these stages for various crops, and their averages can be used, where local information is not available. Burman et al. (1983) presented a procedure to develop crop coefficients taking rainfall and irrigation into account. K_c is assumed constant for all the days of the first stage, but for subsequent stages, the values are interpolated between given end points.

2.4 Remote sensing technique

2.4.1 Crop stress measurements by infrared thermometry

Tanner (1963) was one of the first to use infrared thermometry to detect moisture stress. Canopy air temperature difference ($T_c - T_a$) were proposed by Wiegand and Namken (1966) to be indicative of water stress. Carlson et al. (1972) showed that ($T_c - T_a$) values were negatively correlated with relative leaf water content. Ehrler (1973) suggested that leaf air temperature difference could be used to schedule irrigations. He found that the temperature differences ranged from -3°C to $+2^{\circ}\text{C}$ with the lower values occurring at high soil moisture values. Jackson et al. (1977) concluded that mid afternoon canopy temperature measurements as compared to air temperature were indicative of water stress. Consequently, they introduced the stress degree day (SDD) was related to 65 percent water extraction from the topmost meter of the soil. Ehrler et al. (1978) showed that for wheat the SDD index was related to leaf water potential. Gardner et al. (1981) concluded that a standard deviation of 0.3°C was indicative of maize plants experiencing water stress. Hatfield (1981) found that grain sorghum exhibited a linear relationship between leaf water potential and the SDD, with the canopy becoming warmer than air as the leaf water potential fall below -11 bars. This relationship has also been shown by Idso et al. (1981). Clawson and Blad (1982) suggested a difference greater than 0.7°C would indicate the need for irrigation in maize. Similar observations were reported by Tripathi et al. (1985), 'O' Toole and Real (1986) and Throssell et al. (1987).

2.4.2 Canopy temperature and leaf water potential

Measurements of plant water potentials and canopy temperatures for wheat revealed that as stress increased (decrease in LWP) the canopy air temperature difference (CATD) increased (Ehrler et al., 1978). They concluded that Tc measurement time at 14.00 hrs was the best time of the day to assess the water stress of wheat. The CATD reached a maximum of about 5 °C and increased only slightly with further decrease in plant water potential. Gardner et al. (1981) compared the difference in LWP between stressed and non-stressed sorghum and the canopy temperature difference between the two plots. They found that the LWP difference increased with an increase in the temperature difference to a maximum at about 4 °C, and then subsequently decreased. Novero et al. (1985) found LWP to be closely related to solar radiation flux density and decreases with decrease in irrigation water applied. The maximum difference in the Tc and LWP between stressed and well watered plots occurred at peak solar radiation. Similar observation in was reported by Tripathi et al. (1985) and in chickpea by Ramana, (1989).

2.4.3 Canopy temperature and stress degree days

The increase in canopy temperature was used as an indicator of plant water stress and temperature differences between unstress and stressed plants have been reported to be ranging from 1 to 2 °C up to 6 to 7 °C for many crops (Ehrler, 1973). The use of canopy temperature as method for scheduling of irrigations was accepted by many researchers (Clawson and Blad, 1982 ; Saha et al., 1986; Ramana, 1989). This concept was also applied to red kidney beans by Walker and Hatfield (1979). They found that final yield was inversely related to the SDD and concluded that the SDD was a valid representation of the effect of moisture stress on yield.

Gardner et al. (1981) described an index called the temperature stress day (TSD) which is the difference in temperature between a stressed and well watered plots of sorghum. Irrigations followed when the average of all canopy temperatures measured in the stressed plot during a particular time period were 10 °C warmer than the average canopy temperature of the well watered plot. Clawson and Blad (1982) tested the deviation of mid-day canopy temperatures for usefulness as an irrigation scheduling tool. They found a standard deviation of 0.3 °C in fully irrigated plots of maize, non-irrigated plots, the standard deviation was as great as 4.2 °C. With the SDD, plants were considered stressed if the value was positive and not stressed if negative. The critical CTV value to be used as a signal to irrigate may be influenced by the degree of variability of soil inherent within a field (Jackson, 1982). Bonano and Mack (1983) used the SDD method successfully scheduling of irrigations to snap beans. Saha et al. (1986) observed that the SDD values for irrigated chickpea were lower than those of unirrigated crop. Similar observations were reported in chickpea by Ramana (1989).

2.5 Water management technique

2.5.1 Surface irrigation - Furrow

In surface irrigation, the soil is saturated and void space is totally occupied by water. It creates temporary air stress condition for plant growth till soil attains field capacity. Similarly, before irrigation, available soil moisture allowable deficit (MAD) level results into water stress condition. This cycle of saturation (air stress) to drying (moisture stress) is in existence in both surface and sprinkler

irrigation methods (Sivanappan et al., 1987). Naturally behaviours of soil-plant-atmosphere-continuum (SPAC) will be entirely different when it will be compared with drip irrigation where soil moisture air continuum is maintained at desired optimum level (Magar et al., 1984). The results indicated that borders of 100 m length and 2.25 m width with 2 lps /m stream size cut-off at 90 per cent of length, with 0.3 per cent slope was suitable for sorghum which obtained sorghum yield from 30 to 40 q/ha (Magar et al., 1984b). In clay loam soil with 0.15 per cent slope, borders of 80. x 3 m are recommended with 2 lps/m stream and cut off 90 per cent. Borders with same dimensions but having 0.15 per cent slope should be irrigated with stream of 3.5 Lps/m width for higher irrigation efficiency. The results showed that the furrows of 100 x 0.75 m size and 0.20 per cent slope with 2 Lps stream size and cut off at 80 per cent gave the highest irrigation efficiency as compared to other combinations. In clay loam soil, 80 x 0.75 m furrow with 0.15 per cent slope was found to be efficient with 2 Lps stream. The grain yield of maize was 52.3 q / ha with WUE of 13.33 kg / ha - cm. When furrows were irrigated alternately with 2 Lps stream size on 0.30 per cent slope, the WUE was 14.45 kg ha - cm with grain yield of 28.8 kg / ha. (Magar et al. ,1984b).

2.5.2 Sprinkler irrigation

The sprinkler irrigation method is accomplished with the saving of irrigation water and consequently increase in the yield due to optimum-soil-water relationship. The efficiency of sprinkler irrigation in terms of water used was found to be 54 per cent greater than surface irrigation method. The sprinkler irrigation compared with flood irrigation for alfalfa. The yield was increased to the extent of 20

per cent along with significant saving in the quantity of irrigation water. Experiments conducted at Water Management Project, Mahatma Phule Agricultural University, Rahuri, on kharif chilli and groundnut of 1984 showed that sprinkler method saved 28 and 26 per cents of irrigation water with increased in yield to the extent of 31 and 33 per cents respectively when compared with traditional method of ridges and furrow (Magar et al., 1984b). Gupte and Deshpande (1984) indicated that the water saving was 28.5 per cent in case of sprinkler irrigation and obtained the yield of 86.4 and 95.9 q / ha for border and sprinkler irrigation respectively. Similar observation were reported by Gosavi and Deshmukh (1985) Lagad and Borude (1987), Jain and Pandule, (1987) and Bembalkar and Supekar, (1988).

2.5.3 Drip irrigation

Drip irrigation system is efficient from the water management point of view specially for frequency (Karmeli and Keller, 1975), uniformity (Nakayama and Bucks, 1986), saline water and daily water requirement (Karmarkar, 1985). Experiments on water saving and increase in yield were of enormous on several types of soils, crops, and climatic conditions. The experiment on tomato crop using drip irrigation showed that there was 50 per cent water saving and significant increase in yield (Barner, 1971). Another major contribution for drip irrigation for tomato was recorded by Sivanappan et al. (1987). An equal volume of water, the yield of tomatoes under drip irrigation doubled as compared to furrow irrigation in sandy loam soils. Crop yield and fruit quality were substantially improved by increasing the water application. Sivanappan and Padama Kumari (1980) reported that there is a saving in water to the



T. 244)

extent of 80 per cent along with increase in yield by 55 per cent when compared with traditional ridges and furrows method. However, enormous water saving and increase in the yield were not observed at Rahuri which was restricted respectively to 52 to 30 per cent (Mane *et al.* (1987). Similar type of results were obtained by Londe and Kalbhande (1980), Kataria (1982), Bafana, (1988), Magar, *et al.* (1989), Singh and Kumar, (1989). Sing, *et al.* (1989), and Jadhav (1989).

2.6 Crop Response

2.6.1 Root development

Water deficiency stimulates root growth, because of greater translocation of carbohydrates to the roots. Deep and extensive root system gets in contact with a large volume of soil for root extraction of water (Hurd, 1968), but it would also increase in axial resistance to water transport from the points of absorption in the deep soil layer (Mayer and Ritchie, 1980). Generally, the plants experiencing soil water stress in early growth phase did not get an opportunity to develop a deep root system (Ritchie *et al.*, 1972).

Bhatia *et al.* (1977) reported decrease in rooting depth with decreasing amount of available soil water. They found that the rooting depths of wheat were 60 and 90 cm with plant available water of 7.5 and 20 cm, respectively in loamy soils. According to Farman *et al.* (1983), the depth of irrigation did not effect total root production but deeply irrigated plants produced slightly more roots in the lower depths than shallow-rooted plants. They observed much greater root:shoot ratio in non-irrigated than in irrigated plants. Hegde and Srinivas (1989) reported that irrigation at -25 to -85 KPa soil moisture potential had no significant effect on root dry weight of tomato.

2.6.2 Growth, quality and other characters of tomato

Flocker *et al.* (1961) reported that highest irrigation rate reduced the total amount of solids per acre. The total solids on medium irrigation regime was at par with dry irrigation regime. Increased amount of irrigation delayed the maturity. Vittum and Flocker (1967) reported that frequent irrigations at the time of fruit expansion had an adverse effect on T.S.S. Aljibury and May (1970) found that the soluble solid content in tomato fruit was lowest due to the effect of frequent irrigation scheduling. However, Kimiridzi *et al.* (1972) reported that the frequent irrigations reduced the sugar content.

Ali and El Raggal (1982) observed that irrigating of the tomato plants at 70 per cent of field capacity resulted in better quality tomatoes as compared to fruits from plants irrigated at 50 per cent of field capacity. Vanadia *et al.* (1982) indicated that fruit size of tomato increased with irrigation rate at an interval of 5-9 days. Koning and Hurd (1983) observed that the stressed plants had smaller and fewer leaves and thinner stems. The leaves, and stem also had higher percentage of dry matter. Kosh-Khui and Azarakhsh (1983) observed that the soluble solids were higher in plants receiving the irrigation at 14 days interval. Alvino *et al.* (1986) observed that 30 cm of irrigation depth gave the highest yield of good quality fruits. Hegade and Srinivas (1989) reported that irrigation at -25 to -85 KPa soil matric potentials had no significant effect on plant height and branches/plant. However fruiting and dry matter production of tomato were significantly influenced by irrigation regimes. Total soluble solids was less with frequent irrigation and increased with irrigation. Acidity was maximum with

irrigation at -25 KPa. Similar observations were reported by Bafana (1988) Chaudhary (1988), and Naphade (1989).

2.6.3 Yield of tomato

Many production functions have been used to model the effect of a water deficit on crop yield. These have been summarized by Stewart et al. (1974), and Stegman et al. (1983). The relationships are mostly empirical, and may be linear or curvilinear (concave or convex) depending upon the parameter used to measure water deficit, the measurement accuracy, and site conditions. The most commonly used parameters are evapotranspiration or field water supply. Variation in yield due to non-uniform application of irrigation water over the field was accounted for by variations, and agronomic practices were lumped by Keller (1987) in to a parameter called "agronomic input level". The uniformity factor, UF, is an input value for the irrigation system used for the crop. The actual crop yield at a given level of agronomic input is calculated as : $Y = Y_a \times \text{AGINPL}$ where, Y is the actual crop yield per hectare, obtained under the agronomic input level defined by the input parameter AGINPL. The parameter is unity for a high level of agronomic input.

Dunkel (1966) observed that higher yield of tomato was obtained when sufficient moisture was available in the upper 20 cm soil layer and if moisture level dropped below 50 per cent field capacity, yield depressions occurred even if higher moisture content is present at greater depth. Bernstein and Francois (1978) recorded 30 per cent increase in yield in addition to saving of water due to drip irrigation, when compared to furrow or sprinkler irrigations and this was mainly due to

small controlled amounts of irrigation water and frequent intervals to the root system. Due to the continuous wetted zone in drip method, young plants thrived well over furrow and sprinkler irrigation methods. In the other two methods, the loss of turgor was occasionally observed which limited the growth.

Karmarkar (1985) observed that there was 30 per cent increase in the yield of tomato with subsequent decrease in water requirement to the extent of 60 per cent. Bar-Yosef (1977) conducted experiments on fine sandy loam soil and receiving various daily rates of water through trickle irrigation system and observed the highest tomato fruit yield. About 110 t/ha of tomato fruit yield was obtained when daily average water content in the soil root volume was about 50 per cent . He estimated daily water consumption by the plants which varied between 0.4 and 1 liter per plant per day depending on the leaf area of plants and climatic conditions. Dose *et al.* (1980) observed that the water requirement for tomato in loamy sand soil was only 16 cm compared to 34.5 cm and 37.4 ha-cm in furrow and sprinkler, respectively. Vasilev and Usunov (1980) showed that 21.45 per cent less water is required to irrigate tomato crop when irrigated with drip than furrow method.

Channappa (1979) reported 27.8 per cent higher yield and 49.5 per cent saving of water over surface irrigation method when tomato was irrigated with drip. Miller *et al.* (1971) indicated that very small differences in total tomato yields were observed from drip irrigation but they observed that drip enhanced fruit maturity. Benardo *et al.* (1981) showed that application of 3-6 mm/day or every alternate day irrigation gave the highest fruit yield of tomato (57.8 t/ha) and in addition the

fruit size was found to be increased. Similar results were reported by Kawade and Deokar (1988), Bafana (1988), Singh and Kumar (1989). Hegde and Srinivas (1989) reported that highest yield (68.7 ton/ha) of marketable tomato fruits (cv. Arka Sourabha) was obtained with irrigation at -65 KPa of soil matric potential.

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Chapter Opener Page

3. MATERIAL AND METHODS

3. MATERIAL AND METHODS

The research work was conducted at the Experimental Farm of the Department of Irrigation and Drainage Engineering, College of Agricultural Engineering, Mahatma Phule Agricultural University, Rahuri, during Rabi season of 1988 and 1989. The material and methods used in this investigation are described in detail. The chapter is grouped into ten broad topics as indicated below :

3.1 Soils

3.1.1. Location description

The experiments were conducted at the farm of Department of Irrigation and Drainage Engineering, CAE, MPAU, Rahuri. The University is situated in between $19^{\circ} - 47'$ and $19^{\circ} - 57'$ North latitude and between $74^{\circ} - 89'$ and $74^{\circ} - 19'$ East longitude.

Soil used in the said investigation are categorised under Sawargaon soil series and order inceptisols. Further, these soils are also classified as shallow (≤ 25 cm depth), medium (25-60 cm depth) and deep black soils (60-100 cm or > 100 cm depth). The medium deep soil was used in the said experiment. Locally, it is also termed as black cotton soils in Deccan Plateau. The Locations of Indian Agricultural Research Institute (IARI), New Delhi and Mahatma Phule Agricultural University Rahuri; are shown in Fig 3.1

3.1.2 Genesis and classification of black cotton soil

The black soils are characterised by dark reddish brown to black colour, high montmorillonitic clay content, low organic matter content, high coefficient of expansion and shrinkage and deep cracking

during dry season. The soil is formed from basaltic material originating through volcanic eruption (Srinivasan *et al.*, 1969). The rocks are compact, very hard, greyish in colour and subjected to weathering under the influence of seasonal fluctuations in temperature.

As per the seventh approximation, the black soils in Deccan Plateau are classified under the order 'Vertisols', and are grouped under sub-order 'Usterts'. Further, the black cotton soils are placed under the great group of 'chromusterts' as the most chromas are more than 1.5 (Srinivasan, *et al.*, 1969). The extent of black soils (100%) in India is shown in Fig. 3.1.

3.1.3 Profile characteristics of sawargaon series

Sawargaon series consists of moderately deep to deep (40-70 cm) dark greyish brown to very dark brown, imperfectly drained, since loamy soil overlying substrata layer is 15-20 cm thick with moderately developed blocky structure. The description of Sawargaon series is given in Table 3.1.

3.1.4 Climate

The area comes under semi and sub-tropical type of climate with an average rainfall of 520 mm, mostly concentrated during the monsoon months from July to September. The number of rainy days vary from 59 to 83 per annum. The tract is the rain shadow area lying on the eastern side of western ghats. The area comes under drought prone conditions. The annual minimum temperature ranges from 8.5 to 25.6 °C and the maximum temperature from 25.2 to 41.6 °C in the months of December and May, respectively. The annual mean relative humidity ranges from 43 to 82 per cent respectively.

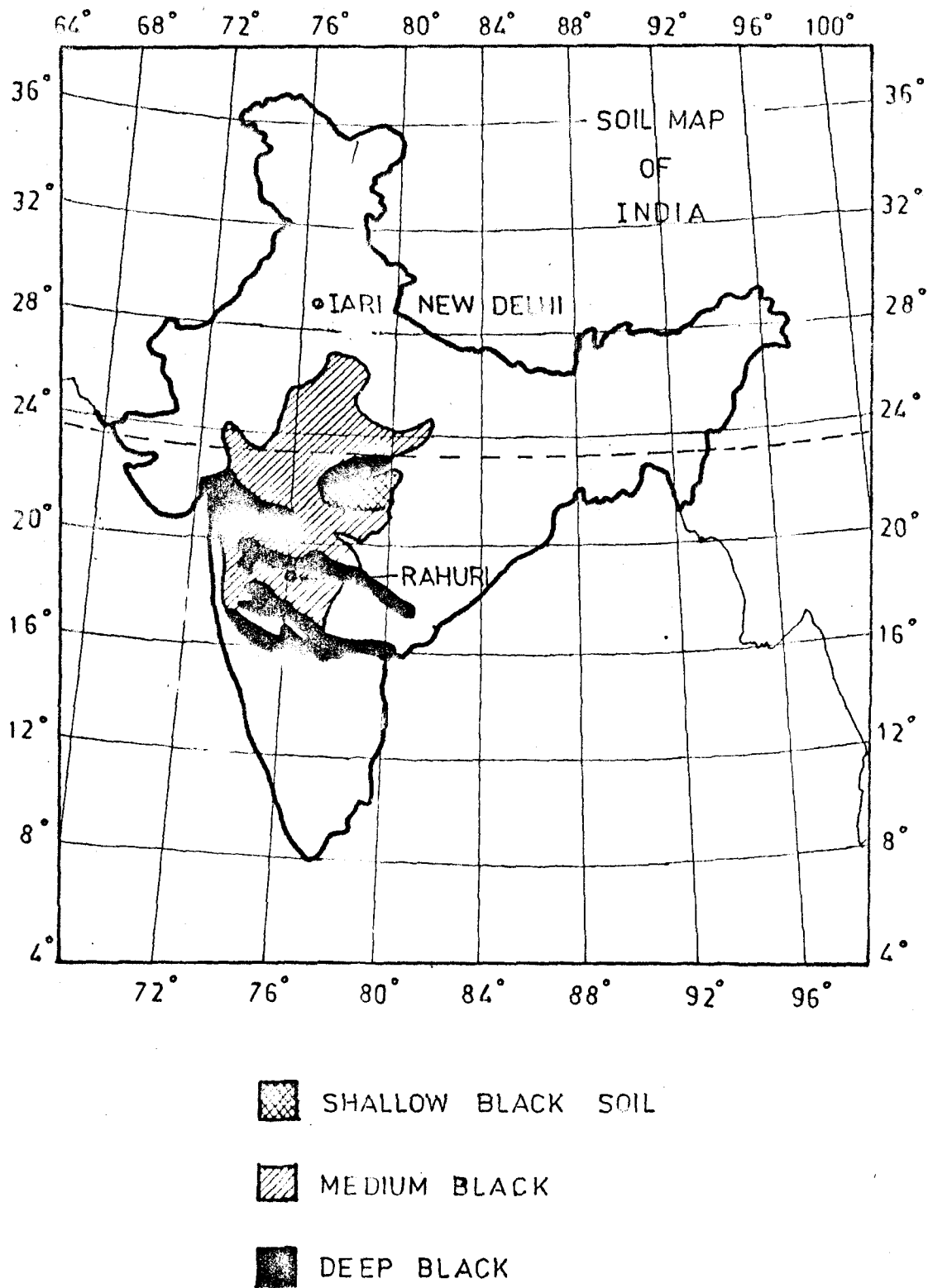


Fig. 3-1. Map of India showing locations and geographical positions.

Table - 3.1 The description of profile horizons of sawargaon series:

Horizon	Depth (cm)	Description
AP	0 - 15 cm	Dark greyish brown (10 YR 4/2) silty clay, very dark greyish brown (10 YR 3/2) when moist medium moderate sub-angular blocky ; dry hard, moist firm, wet sticky and plastic few fine lime nodule, strong effervescence (7.5% lime) many fine roots, moderately alkaline
B	15 - 30 cm	Dark brown (10 YR 3/3) clay , dark brown (10 YR 2/20) when moist medium strong angular blocky dry hard , moist firm , wet sticky and plastic ; few medium soft lime nodules ; few coarse light grey (10 YR 7/1) mottling ; strong effervescence (8 per cent lime) moderately alkaline (pH 8.1) ; many root diffuse and smooth boundary (16 to 20 cm thick)
B ca 3	30 - 60 cm	Very dark brown (10 yr 2/2 M) silty clay dark brown (10 YR 3/3 when dry medium moderate subangular blocky, dry hard, moist firm , wet sticky & plastic few to many medium lime nodules, strong effervescence (17% lime); few coarse greyish mottels, few gravels , few medium roots, moderatly alkaline (8.4 pH); diffuse and smooth boundry 20-30 cm (thick)
C ca 1	60 - 90 cm	Light brownish grey (10 YR 6/2 M) and yellowish brown (10 YR 5/8) silty clay loam; medium weak subangular blocky, dry slightly hard ,moist firm, wet sticky and plastic ;many soft lime nodules and disseminated powderylime deposition in pockets,many medium and coarse gravels coated with lime; violet effervescence (25% lime); moderatly alkaline (8.5 pH).

Source :- National Bureau of Soil Survey and land use planning, Nagpur
survey report, 1974.

The climatological parameters during the period of investigation for the years 1988-89 and 1989-90 recorded at the Meteorological Centre, Central Campus, Rahuri, are depicted in Fig. 3.2 and 3.3, respectively.

3.2 Experimental details

Pertinent physico-chemical properties were determined by following standard methods. The details of each property, and standard method used with its references are reported in Table 3.2. Some important physical and chemical properties of experimental plots were determined and data are reported in Table 3.2 and 3.4 respectively. The particle size distribution of the experimental plot was plotted on semilog paper and depicted in Fig. 3.4. The soil is categorised under clay texture of soils.

The quality of irrigation water is also an essential parameter and the water analysis in respect of pH, EC, cations and anions was carried out and data are presented in Table 3.5. The water was classified under C S class which is considered to be good for irrigation purpose.

3.2.1 Treatments

The treatment details with abbreviations and description are given in Table 3.6.

3.2.2 Experimental layout

The experiment was planned with nine treatments with sample plot techniques. The treatments were replicated seven times and out of seven replications three were selected randomly which were uniform in all condition and analysed with completely Randomised Design. This gives 27 plots. The gross plot size was 3.60 m x 3.0 m and the net plot was

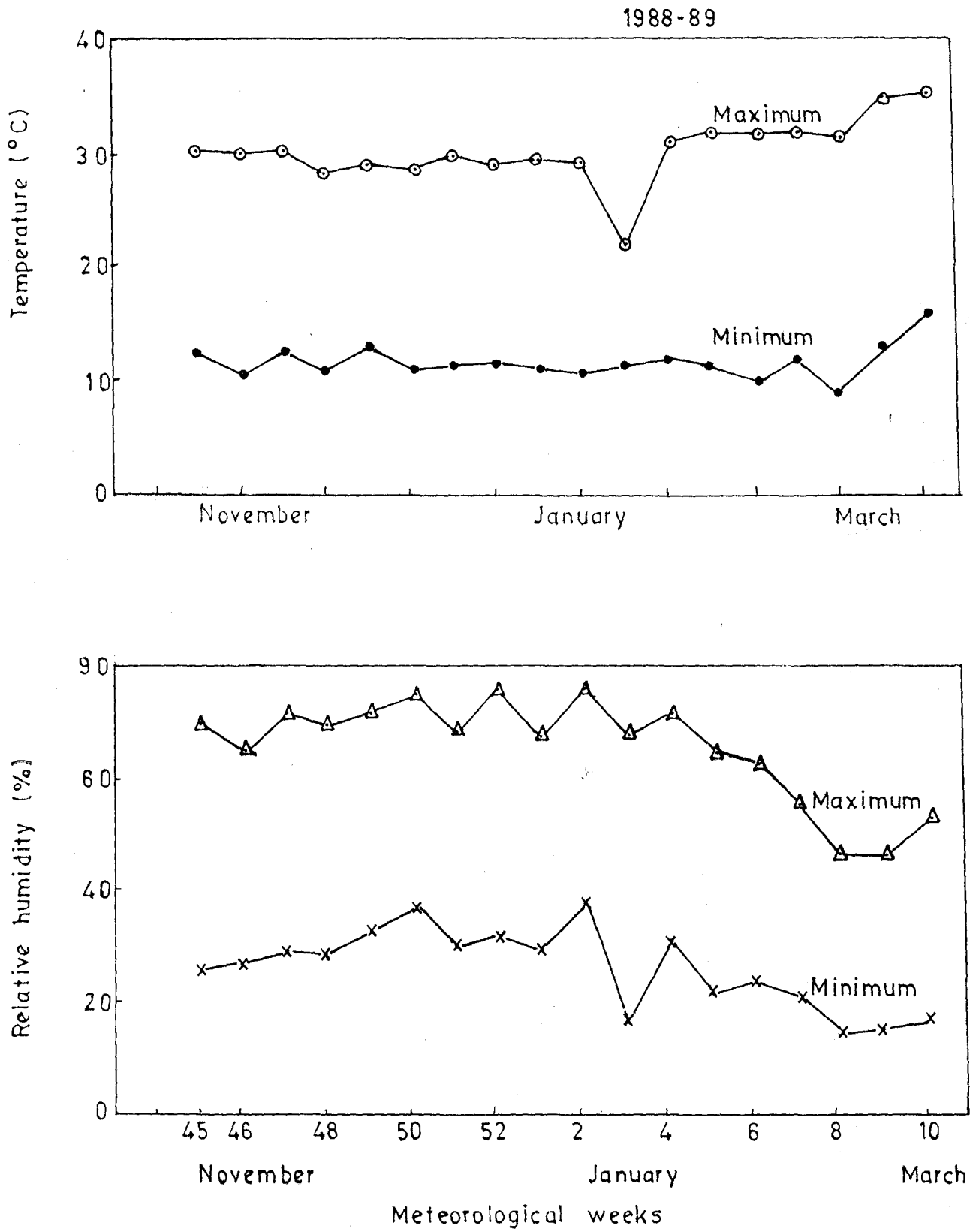


Fig. 3.2. Maximum and minimum temperature and relative humidity during crop growth period. (1988-89)

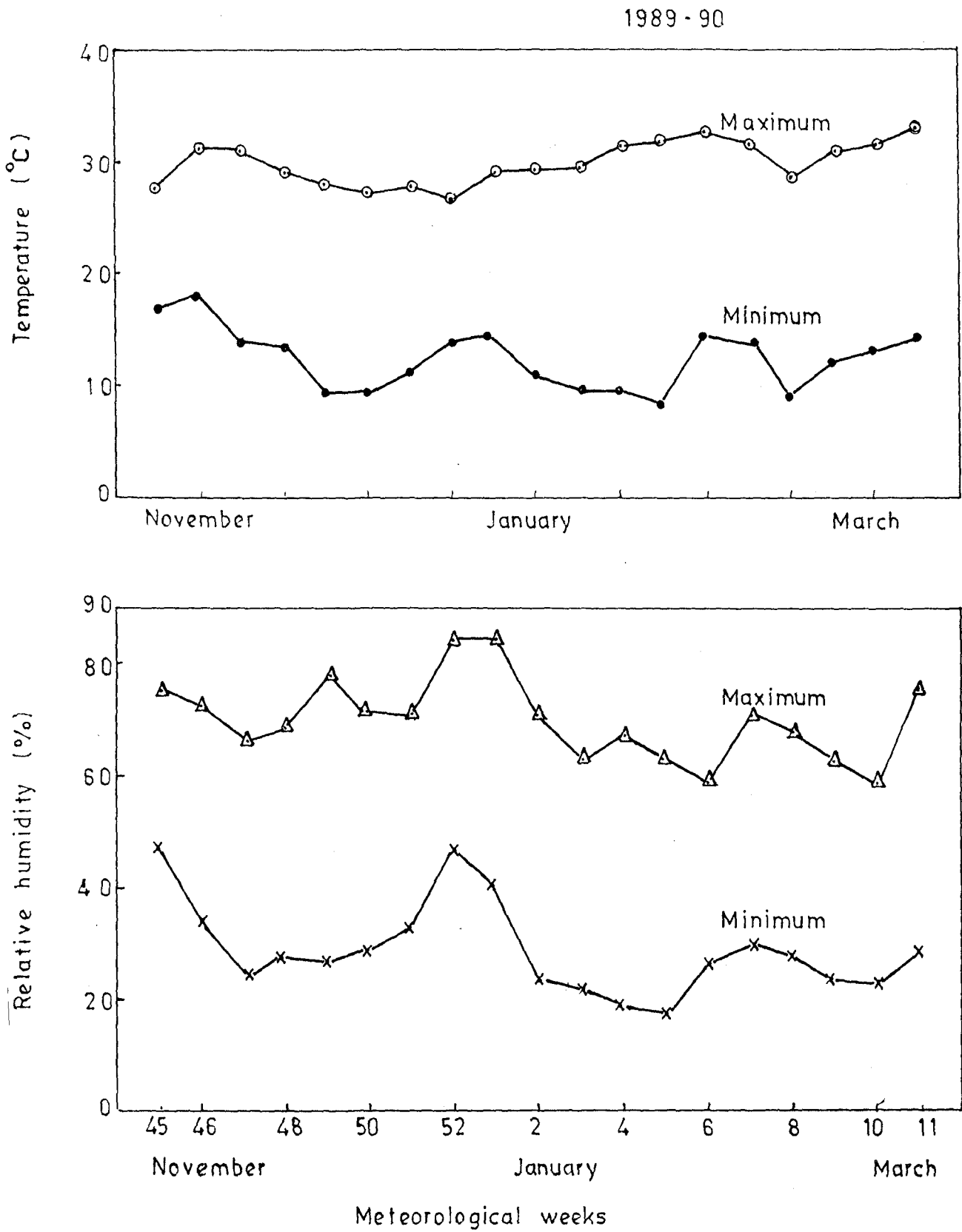


Fig. 3.3. Maximum and minimum temperature and relative humidity during crop growth period. (1989-90)

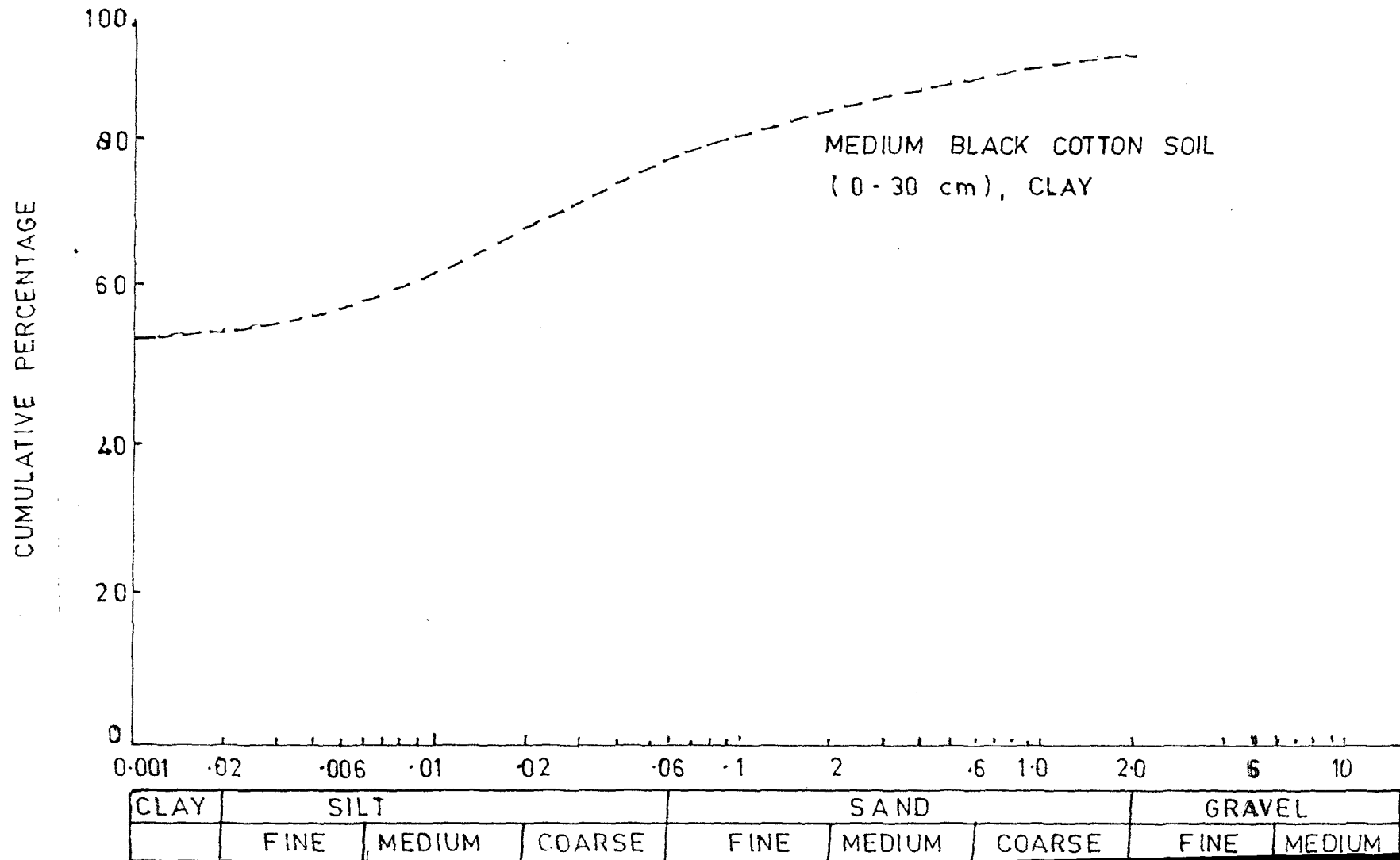


Table 3.2 Methods used for determination of physical and chemical properties of experimental soil.

Sr.	Property	Method adopted	Reference
A) Physical properties			
	Soil moisture	Gravimetric method	Klute <u>et al.</u> (1986)
	Particle size distribution	International pipette method	Klute <u>et al.</u> (1986)
	Bulk density	Core sampler	Bla k ^o and Hartage (1986)
	Infiltration rate	Double ring infiltrometer	Klute <u>et al.</u> (1986)
	Hydraulic conductivity	Constant head	Klute <u>et al.</u> (1986)
	Soil moisture characteristics curve	Pressure plate apparatus	Richard (1965)
	Liquid and plastic limits	Atterburg	Black <u>et al.</u> (1965)
B) Chemical Properties			
	pH	Potentiometric	Jackson (1973)
	EC	Conductometric	Jackson (1973)
	Organic carbon	Walk l ^y and Black method	Jackson (1973)
	Available N	Alkaline permangnate	Subbiah and Asija (1956)
	Available P	0.5 N NaHCO ₃ (pH 8.5)	Jackson (1973)
	Available K	1 N NH ₄ OAC	Jackson (1973)
	Calcium carbonate	Rapid titration	Piper (1966)

Table - 3.3 Pertinent physical properties of the experimental soil.

Sr. Physical No. properties	Soil depth layers (cm)							
	0-15	15-30	30-45	45-60	0-15	15-30	30-45	45-60
	1988-89				1989-90			
i) Particle size distribution								
Sand, per cent	18.1	18.2	14.5	13.8	19.2	18.4	17.5	17.0
Silt, per cent	22.0	26.3	28.7	27.0	23.4	26.7	27.2	26.2
Clay, per cent	56.4	54.2	52.8	58.0	54.2	53.1	51.2	55.0
ii) Textural class	-----Clay -----				-----Clay -----			
iii) Partical density, -3 g cm	-----2.65-----				-----2.65-----			
iv) Bulk density, g cm ⁻³	1.21	1.24	1.27	1.30	1.18	1.21	1.29	1.32
v) Infiltration rate, mm/hr	-----2.25-----				-----2.15-----			
vii) Field capacity, per cent	-----34.7-----				-----35.5-----			
viii) Permanent wilting point per cent	-----18.5-----				-----19.1-----			
ix) Lower plastic limit, per cent	-----24.5-----				-----25.4-----			
x) Liquid limit, per cent	-----40.3-----				-----41.2-----			
xi) Soil moisture retention at (wt.) - MPa								
0	56.1	55.3	54.4	53.1	-	-	-	-
0.03	34.3	34.7	33.2	33.1	-	-	-	-
0.5	30.2	29.3	28.7	28.3	-	-	-	-
1.0	24.5	24.1	23.5	23.1	-	-	-	-
1.5	18.9	18.0	17.7	17.3	-	-	-	-

Table 3.4 Pertinent chemical properties of the experimental soil:

Sr. No.	Chemical properties	Soil depth layers (cm)									
		0-15	15-30	30-45	45-60	0-15	15-30	30-45	45-60		
				1988-89				1989-90			
i)	Soil pH (1:2.5 soil water suspension) at 25 °C	7.90	7.95	7.90	7.85	7.90	8.00	8.0	7.95		
ii)	EC dS m at 25 °C	0.34	0.39	0.42	0.43	0.38	0.36	0.43	0.45		
iii)	Organic carbon, per cent	0.54	0.52	0.48	0.47	0.52	0.50	0.47	0.46		
iv)	Calcium carbonate, per cent	8.3	9.3	10.4	11.5	6.2	7.4	9.2	9.0		
v)	Available N, Kg/ha	132	127	123	120	152	135	140	138		
vi)	Available P, Kg/ha	12.3	11.3	10.4	10.2	14.2	12.3	11.2	10.4		
vii)	Available K, Kg/ha	470	485	491	510	480	492	495	480		

Table 3.5 Quality of irrigation water used for the experimental plot.

Sr. No.	Qualitative parameter	Unit	Value recorded	
			1988-89	1989-90
i)	pH	Dimensionless	8.00	8.05
ii)	Electrical conductivity	d S/m	0. 28	0. 30
iii)	Calcium	me/L	1.84	1.93
iv)	Magnesium	me/L	1.27	1.22
v)	Sodium	me/L	2.43	2.48
vi)	Carbonate	me/L	Traces	Traces
vii)	Bicarbonate	me /L	2.34	2.38
viii)	Chloride	me/L	1.27	1.31
ix)	Sulphate	me/L	1. 57	1.62
x)	SAR	Dimensionless	1.95	1.98
Irrigation water quality class			C S	C S
			1 1	1 1

Table 3.6 Description of furrow, sprinkler and drip irrigation treatments of the field experiment.

Symbol	Treatment	Description
IF 50	Furrow irrigation scheduled at 50 mm CPE	Depth of irrigation to be decided every time at 50 mm CPE.
IF 75	Furrow irrigation scheduled at 75 mm CPE	Depth of irrigation to be decided every time at 75 mm CPE.
IF 100	Furrow irrigation scheduled at 100 mm CPE	Depth of irrigation to be decided every time at 100 mm CPE.
IS 50	Sprinkler irrigation scheduled at 50 mm CPE	Depth of irrigation to be decided every time at 50 mm CPE.
IS 75	Sprinkler irrigation scheduled at 75 mm CPE	Depth of irrigation to be decided every time at 75 mm CPE.
IS 100	Sprinkler irrigation scheduled at 100 mm CPE	Depth of irrigation to be decided every time at 100 mm CPE.
ID 1	Daily water application through drip system	Quantity of water is to be decided on the basis of pan evaporation.
ID 2	Alternate day water application through drip system	Quantity of water is to be decided on the basis of pan evaporation.
ID 3	Three days water application through drip system	Quantity of water is to be decided on the basis of pan evaporation.

3.0 m x 2.40 m. The paired row planting geometry was preferred with a spacing of $60-45 \times 75$ cm for minimising the cost of drip irrigation installation. The buffer strip of 1.5 m was kept between the treatments. Irrigation layout of ridges and furrows was adopted with a spacing of 60 cm x 60 cm as per recommendation for pusa early dwarf variety.

The experimental layout showing the distribution of different irrigation treatments with water conveyance pipe system is shown in Fig. 3.5. The water measuring devices of drip, furrows and ridges (V notch) and sprinkler are shown in the same figure systematically.

3.2.3 Land preparation

Land preparation operations consisting of ploughing, cold crushing and harrowing were done before the transplanting of seedlings. The details of preparatory and secondary tillage operations and cultivation schedule are reported elsewhere.

3.2.4 Planning of irrigation treatments

3.2.4.1 Furrow irrigation

The ridges and furrows were of 60 cm height with a distance of 60 cm between two furrows were prepared with the help of tractor drawn ridger. The land slope was to the extent of 0.3 per cent. The design discharge was maintained to the extent of 2 l /sec/metre width of furrow as proposed by Magar *et al.* (1984). The total length of furrow was decided as per replications. Sufficient care was taken to maintain the ridges and furrows during the period of investigation.

The water measuring devices of 'V' notch and syphon tubes for measuring irrigation water under furrow irrigation are depicted in Plate-1 and 2. The calibration of 90° V notch was done and is reported in Table 3.7

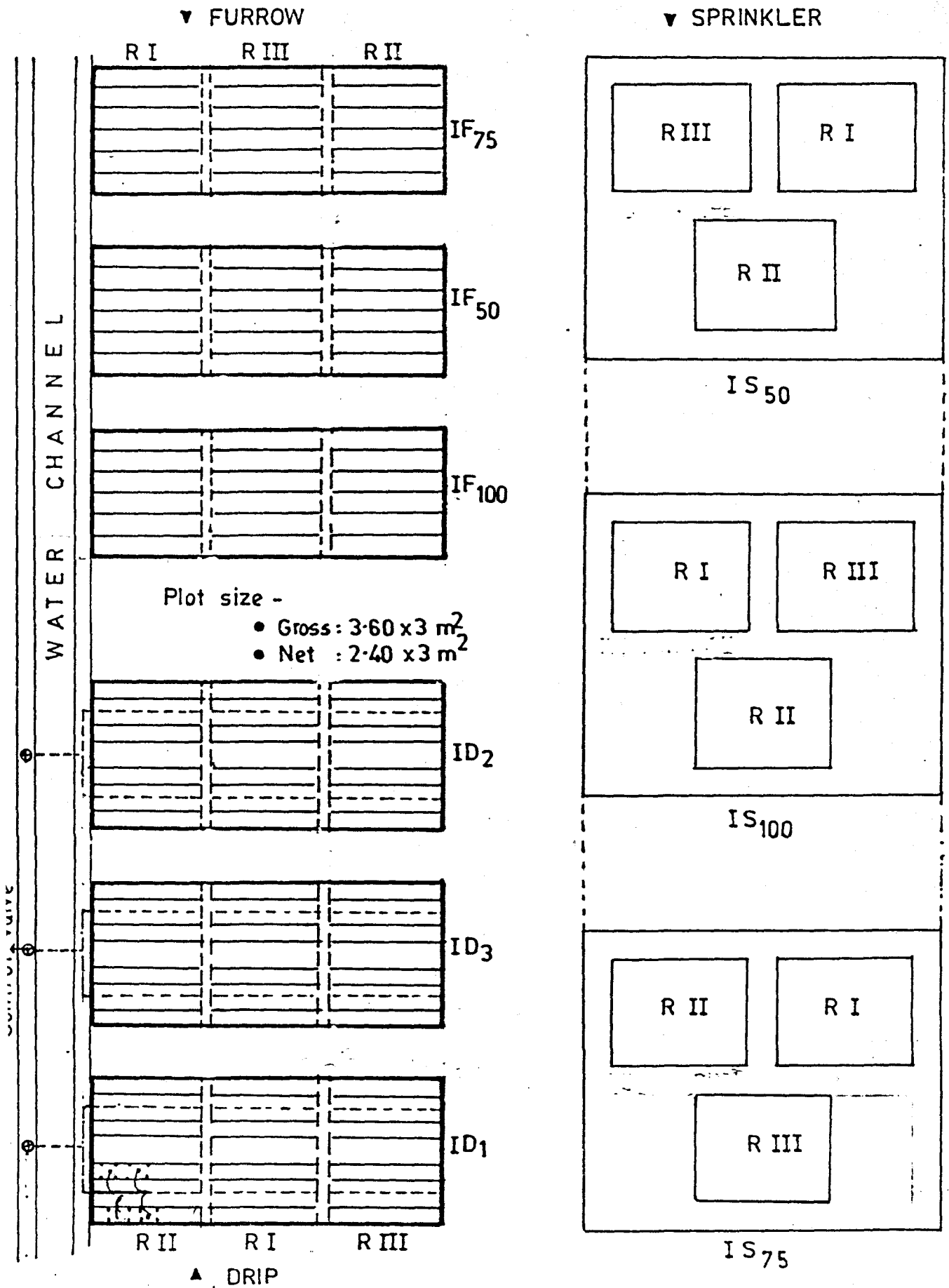


Fig.3.5. Experimental layout showing position of furrow, sprinkler and drip irrigation treatments

Table 3.7 Discharge through a 90 V-notch, Litres per second (Michael, 1986).

Height of water over V-notch	Discharge, litres/sec
4.0	0.45
4.5	0.60
5.0	0.80
5.5	1.0
6.0	1.2
6.5	1.5
7.0	1.8
7.5	2.2
8.0	2.5
8.5	2.8
9.0	3.4
9.5	3.9
10.0	4.5
10.5	5.1
11.0	5.7
11.5	6.3
12.0	7.1
12.5	7.8
13.0	8.6
13.5	9.5
14.0	10.5
14.5	11.3
15.0	12.3

PLATE - 1.

'V' notch for measurement of irrigation water under
furrow irrigation.

PLATE - 2.

Syphon tubes for measurement of irrigation water
under furrow irrigation.



PLATE - 3.

Experimental view of sprinkler irrigation system.

PLATE - 4.

Use of microtube supplying irrigation water for four
plants under drip irrigation.



3.2.4.2 Sprinkler irrigation

The irrigations were scheduled on the basis of climatological approach as per the treatments. The quantity of water applied per irrigation was calculated with the help of following equation.

$$d = (F C - M C_i) \times B D \times D$$

d = depth of irrigation, cm

whereas F C = Field capacity, per cent

B D = Bulk density, g cm⁻³

D = Effective root zone depth, cm

M C_i = Moisture content at the time of irrigation, per cent

The time of water application was calculated with the help of following expression;

$$t = D / q$$

whereas t = Time of operation, hours.

D = Depth of water, cm.

q = Sprinkling rate, cm/hr.

The components of sprinkler and drip irrigation system are shown in Table 3.8 and pictorial view of sprinkler is depicted in Plate-3

3.2.4.3 Drip irrigation

The drip unit used in this system is categorised under surface microtubing drip system. The one microtube was used for four plant. The pictorial view is shown in Plate-4 and the Low density polyethylene (LDPE) laterals with microtubes as emitters were used. The brass valve of 25 mm was provided for each treatment to maintain requisite pressure. The system was operated at 0.50 kg/cm² pressure. The design discharge through emitter was 4 L/hr.

Irrigation scheduling was done as per the treatments. Daily pan evaporation was measured with the help of USWB Class A open pan evaporimeter. The water to be applied was calculated with the help of the equation given by Karmeli and Keller (1975) which is as follows:

$$V = \frac{Se \times SL \times Pw \times Kc \times Ep \times E}{N}$$

Where V = Water to be applied per emitter (litre/day/plant)

Se = Spacing between emitters, m

SL = Spacing between laterals, m

Kc = Crop coefficient

Ep = Pan factors (0.7)

Pw = Area factor (0.6)

N = Number of plant (4)

E = Pan evaporation, mm/day

The Kc factor was estimated according to critical physiological growth stages given in F.A.O., Bulletin No. 24 (Doorenbos and Pruitt, 1975) and given in Table 3.9.

Table 3.9 Crop coefficient factor for tomato.

Critical growth stages	Kc factor
* Initial stage (0 - 20 days)	0.4 - 0.5
* Development stage (21 - 50 days)	0.7 - 0.8
* Mid season (51 - 80 days)	0.9 - 1.00
* Late season (80 - 100 days)	0.85 - 1.00
* At harvest (101 -120 days)	0.60 - 0.65

The crop coefficient values were plotted against the crop growth period and depicted in Fig 3.6.

3.2.5 Calibration of drip irrigation system

The uniformity of discharge from each emitter was ensured in drip especially for studying the movement of water into the soil

Table 3.8 Components of sprinkler and drip irrigation system.

Component	Specification
a) Sprinkler	
Electric motor and pump	10 HP
Diameter of main pipe line	100 mm
Diameter of lateral line	75 mm
Spacing between two laterals	12 m
Spacing between two nozzles	12 m
Type of sprinkler head	Twin nozzle
Height of the riser	1.2 m
Precipitation rate	1.33 cm/hr
Pressure at the nozzle	3.2 kg m ⁻²
Uniformity coefficient	0.86
b) Drip irrigation	
Water lifting device	Monoblock centrifugal pump of 1.5 HP with by-pass arrangement.
Main	25 mm PVC
Screen filter	150 mesh
Manifold	25 mm PVC
Lateral	12 mm LDPE low density polyethylene
Spacing between lateral	1.2 m
Spacing between emitter	1.2 m
Discharge of microtube	4 Lph at 0.5 kg cm ⁻²
Uniformity coefficient	0.95

(Fig 3.7). A calibration test for ^{the} discharge rate of water was conducted for determination of uniformity coefficient using Christianson's formula:

$$C_u = \frac{(1 - \frac{\sum X}{n}) \times 100}{m}$$

C_u = Uniformity coefficient, per cent,

m = Average value of all observations, mm

n = Total number of observations

X = Numerical deviation of individual observation from the average application rate, mm

3.2.6 Scheduling of irrigations, WR and daily water application in drip system.

The depth of water application under surface and sprinkler irrigation treatments at each irrigation was worked out and data in respect of date of water application and depth are reported in Table 3.10 and 3.11 for the year 1988-89 and 1989-90, respectively. The total water applied along with the number of irrigations are also reported in the said tables. The irrigations were scheduled at 50, 75 and 100 mm CPE as per pre-determined treatments. The quantity of water applied through the drip irrigation system under daily (ID₁), alternate day (ID₂) and after 3 days (ID₃) in terms of litres per day per plant for both years in reported in Table 3.12.

3.2.7 Cultivation practices of Tomato

The cultivation practices of Tomato for the year 1988-89 and 1989-90 are presented in Table 3.13.

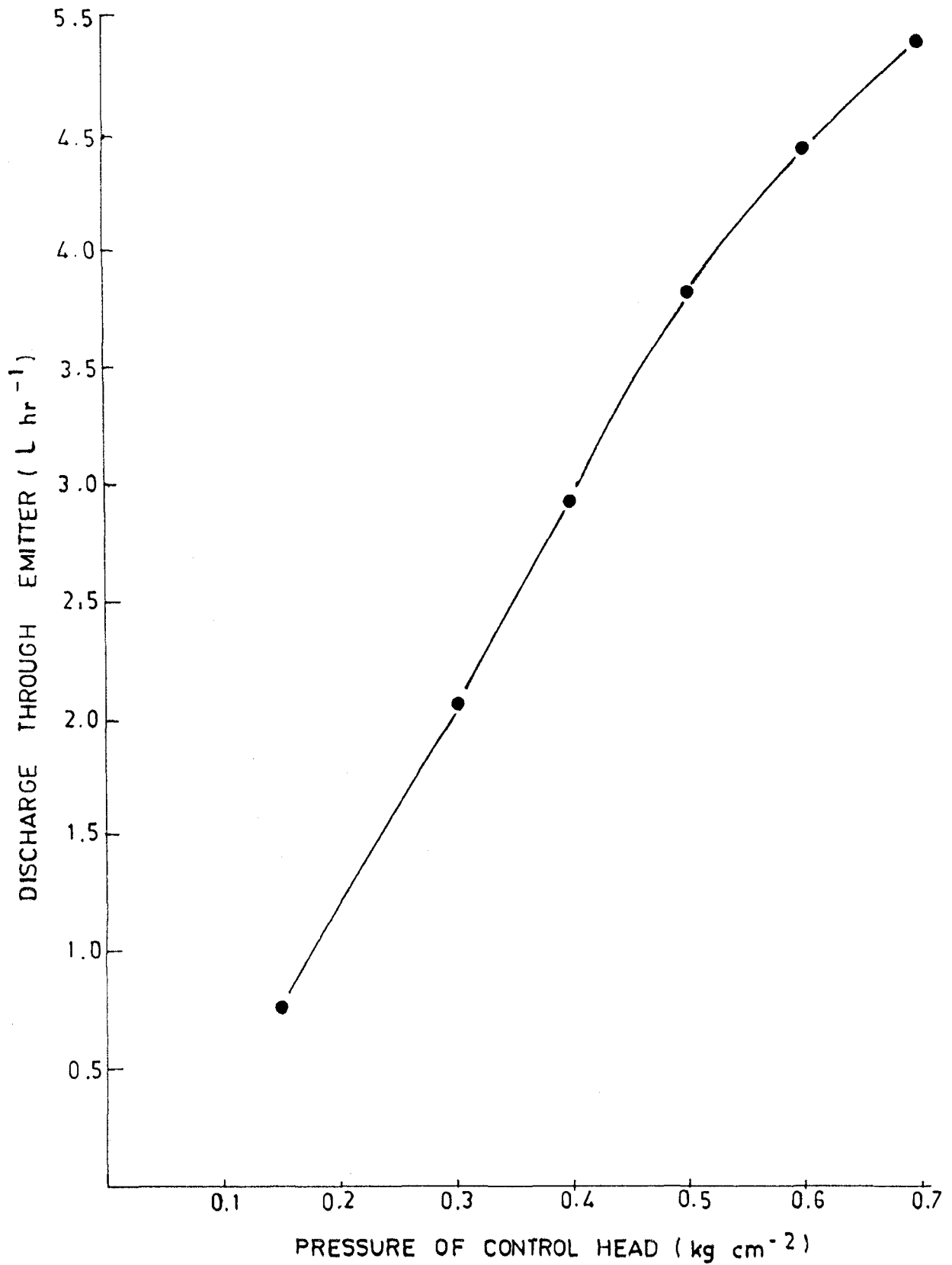


Fig. 3-7. Calibration of discharge through emitter as a function of pressure.

Table 3.10 Scheduling of irrigations to tomato under surface and sprinkler irrigation methods. (1988-89)

Sr No.	Meteorological weeks	Date	Days after planting	Depth of irrigation, mm					
				IF 50	IF 75	IF 100	IS 50	IS 75	IS 100
1.	45	5-11-88	--	70	70	70	70	70	70
2.	47	22-11-88	17	40	--	--	30	--	--
3.	48	28-11-88	23	--	75	--	--	44	--
4.	49	8-12-88	34	45	--	75	27	--	67
5.	52	25-12-88	51	40	65	--	33	49	--
6.	2	13-1-89	70	45	--	85	27	--	66
7.	3	21-1-89	78	--	60	--	--	52	--
8.	3	28-1-89	85	45	--	--	33	--	--
9.	6	10-2-89	98	40	65	80	30	55	52
10.	8	22-2-89	110	45	--	--	35	--	--
No of irrigations				8	5	4	8	5	4
Water requirement, mm				370	350	310	285	270	255

Table 3.11 Scheduling of irrigation to tomato under furrow and sprinkler irrigation. (1989-90)

Sr. No.	Meteorological weeks	Date	Days after planting	Depth of irrigation, mm					
				IF		IS		IS	
				50	75	100	50	75	100
1.	45	11.11.89.	-	70	70	70	70	70	70
2.	47	21.11.89.	11	40	--	--	22	--	--
3.	48	27.11.89.	17	--	50	--	--	44	--
4.	49	3.12.89.	23	45	--	80	33	--	66
5.	51	21.12.89.	41	40	65	--	27	38	--
6.	2	10.1.90.	61	40	--	80	22	--	59
7.	3	17.1.90.	68	--	60	--	--	44	--
8.	4	24.1.90.	75	40	--	--	33	--	--
9.	6	6.2.90.	88	40	60	90	27	44	66
10.	8	17.2.90.	99	40	--	--	22	--	--
11.	9	26.2.90.	108	40	65	--	33	38	--
No. of irrigations				9	6	4	9	6	4
Water requirement, mm				390	370	320	289	278	261

Table 3.12 Daily water requirement of tomato during the period of investigation under drip method.

Date	Pan evaporation, mm per day			Water requirement, litres per day per plant					
	1988-89	1989-90	Daily	Alternate	Three days	Daily	Alternate	Three days	
	2	3	4	5	6	7	8	9	
Nov,	1988-89			1989-90					
6	4	-	0.25	-	-	-	-	-	
7	4	-	0.25	0.50	-	-	-	-	
8	3	-	0.19	-	0.69	-	-	-	
9	2	-	0.13	0.32	-	-	-	-	
10	2	-	0.13	-	-	-	-	-	
11	2	4	0.13	0.26	0.39	0.39	-	-	
12	2	4	0.13	-	-	0.25	0.63	-	
13	2	4	0.14	0.27	-	0.25	-	0.88	
14	2	4	0.14	-	0.40	0.25	0.51	-	
15	2	4	0.14	0.27	-	0.26	-	-	
16	2	4	0.14	-	-	0.26	0.52	0.78	
17	2	4	0.15	0.28	0.42	0.27	-	-	
18	3	4	0.22	-	-	0.28	0.55	-	
19	4	4	0.30	0.52	-	0.29	-	0.84	
20	4	6	0.31	-	0.83	0.44	0.73	-	
21	6	4	0.47	0.78	-	0.30	-	-	
22	4	4	0.32	-	-	0.30	0.60	1.03	
23	4	4	0.33	0.65	1.12	0.31	-	-	
24	4	4	0.33	-	-	0.31	0.61	-	
25	4	4	0.34	0.67	-	0.31	-	0.92	
26	4	4	0.34	-	1.01	0.31	0.63	-	
27	4	4	0.35	0.69	-	0.33	-	-	
28	4	4	0.36	-	-	0.33	0.66	0.97	
29	4	4	0.36	0.72	1.07	0.33	-	-	
30	4	4	0.37	-	-	0.34	0.67	-	
Dec,	1988-89			1989-90					
1	2	4	0.19	0.56	-	0.34	-	1.01	
2	2	4	0.19	-	0.75	0.35	0.69	-	
3	2	4	0.30	0.49	-	0.36	-	-	
4	2	4	0.20	-	-	0.37	0.73	0.72	
5	2	4	0.21	0.41	0.70	0.38	-	-	
6	2	2	0.21	-	-	0.19	0.57	-	
7	2	3	0.21	0.42	-	0.29	-	0.86	
8	2	4	0.25	-	0.67	0.39	0.69	-	
9	3	4	0.33	0.58	-	0.40	-	-	
10	2	4	0.23	-	-	0.41	0.81	1.21	
11	3	2	0.34	0.57	0.90	0.21	-	-	
12	2	2	0.23	-	-	0.21	0.42	-	

Table 3.12 continue...

1	2	3	4	5	6	7	8	9
Dec,								
13	2	2	0.24	0.47	-	0.22	-	0.64
14	2	4	0.24	-	0.71	0.44	0.66	-
15	4	2	0.42	0.66	-	0.22	-	-
16	4	4	0.42	-	-	0.45	0.67	1.12
17	4	2	0.43	0.85	1.27	0.22	-	-
18	3	2	0.38	-	-	0.23	0.46	-
19	3	4	0.38	0.76	-	0.48	-	0.94
20	2	2	0.26	-	1.02	0.24	0.72	-
21	2	4	0.26	0.52	-	0.49	-	-
22	3	2	0.27	-	-	0.25	0.74	0.98
23	3	2	0.40	0.67	0.93	0.25	-	-
24	4	4	0.55	-	-	0.51	0.76	-
25	4	2	0.55	1.09	-	0.26	-	1.02
26	2	2	0.28	-	1.37	0.26	0.52	-
27	3	2	0.42	0.70	-	0.26	-	-
28	4	2	0.57	-	-	0.26	0.53	0.79
29	4	2	0.57	1.14	1.56	0.27	-	-
30	4	2	0.57	-	-	0.27	0.54	-
31	4	2	0.57	1.15	-	0.27	-	0.81
Jan,								
1	2	2	0.29	-	1.44	0.27	0.54	-
2	2	2	0.29	0.58	-	0.27	-	-
3	3	3	0.44	-	-	0.41	0.69	0.96
4	2	2	0.29	0.73	1.02	0.27	-	-
5	2	4	0.30	-	-	-	-	-
6	2	4	0.30	0.59	-	0.56	0.83	-
7	2	4	0.30	-	0.89	0.56	-	1.40
8	2	4	0.30	0.59	-	0.56	-	-
9	3	4	0.45	-	-	0.57	1.14	-
10	2	4	0.30	0.75	1.04	0.57	-	1.71
11	3	4	0.45	-	-	0.57	1.14	-
12	2	3	0.30	0.75	-	0.43	-	-
13	2	3	0.30	-	1.05	0.43	0.87	1.45
14	4	3	0.30	0.60	-	0.44	-	-
15	4	3	0.60	-	-	0.44	0.88	-
16	4	3	0.60	1.21	1.51	0.44	-	1.33
17	4	3	0.60	-	-	0.44	0.89	-
18	3	4	0.45	1.06	-	0.60	-	-
19	3	2	0.45	-	-	0.30	0.90	1.35
20	2	4	0.30	0.76	-	0.60	-	-
21	2	4	0.30	-	-	0.60	1.20	-
22	3	4	0.45	0.76	1.06	0.60	-	1.81
23	3	4	0.45	-	-	0.60	1.20	-
24	4	4	0.60	1.06	-	0.60	-	-
25	4	4	0.60	-	1.66	0.60	1.20	1.81

Table 3.12 continue...

1	2	3	4	5	6	7	8	9
26	2	4	0.30	0.91	-	0.60	-	-
27	4	4	0.60	-	-	0.60	1.20	-
28	4	4	0.60	1.20	1.50	0.60	-	1.81
29	4	4	0.60	-	-	0.60	1.20	-
30	4	4	0.60	1.20	-	0.60	-	-
31	4	4	0.59	-	1.79	0.60	1.20	1.81
Feb,								
1	4	4	0.59	1.18	-	0.60	-	-
2	4	4	0.59	-	-	0.60	1.20	-
3	4	4	0.58	1.16	1.75	0.60	-	1.80
4	4	4	0.57	-	-	0.59	1.18	-
5	4	4	0.57	1.14	-	0.58	-	-
6	4	3	0.56	-	1.70	0.43	1.01	1.60
7	4	4	0.56	1.12	-	0.57	-	-
8	4	4	0.55	-	-	0.57	1.14	-
9	4	4	0.54	1.09	1.65	0.56	-	1.70
10	4	4	0.53	-	-	0.55	1.11	-
11	4	4	0.52	1.06	-	0.54	-	-
12	5	4	0.64	-	1.70	0.54	1.09	1.64.
13	6	4	0.76	1.40	-	0.53	-	-
14	4	6	0.49	-	-	0.79	1.33	-
15	5	4	0.61	1.11	1.87	0.52	-	1.85
16	4	6	0.48	-	-	0.80	1.32	-
17	4	4	0.48	0.96	-	0.51	-	-
18	4	4	0.46	-	1.42	0.74	1.25	2.05
19	4	6	0.46	0.92	-	0.75	-	-
20	4	4	0.45	-	-	0.49	1.24	-
21	4	4	0.45	0.90	1.36	0.49	-	1.73
22	4	6	0.44	-	-	0.67	1.16	-
23	5	6	0.54	0.98	-	0.71	-	-
24	6	6	0.64	-	1.63	0.63	1.35	2.02
25	4	6	0.42	1.07	-	0.69	-	-
26	4	6	0.42	-	-	0.69	1.38	-
27	6	4	0.62	1.03	0.84	0.45	-	1.83
28	6	6	0.07	-	-	0.66	1.11	-
March,								
1	5	6	0.50	1.10	-	0.66	-	-
2	5	6	0.48	-	1.59	0.65	1.31	1.97
3	5	6	0.47	0.95	-	0.62	-	-
4	5	6	0.45	-	-	0.62	1.26	-
5	-	6	-	-	-	0.61	-	1.88
6	-	4	-	-	-	0.39	1.01	-
7	-	8	-	-	-	0.57	-	-
8	-	6	-	-	-	0.75	1.32	1.72
9	-	8	-	-	-	0.54	-	-

Table 3.13 Schedule of cultural and other operations followed for tomato. (cv. Pusa Early Dwarf)

Sr. No.	Cultural operations and cultivation details	Date of operations	
		1988-89	1989-90
1.	Seed sowing on raised bed	4-10-88	6-10-89
2.	Preparatory tillage		
	Ploughing	15-10-88	10-10-89
	Cold crushing	27-10-88	30-10-89
	levelling	27-10-88	30-10-89
3.	Transplanting of seedlings	5-11-88	10-11-89
4.	Fertilizer application Half the dose of N and full dose of P O and K O 2 5 2	5-11-88	10-11-89
5.	Post sowing operations		
	a) Irrigation	As per treatment	As per treatment
	b) Weeding	As per requirement	As per requirement
	c) Fertilizer application (half the dose of N)	3-12-88	10-12-89
6.	Root study	4-3-89	9-3-90
7.	Harvesting	4-3-89	9-3-90

3.3 Field observations and data collection

3.3.1 Soil moisture distribution and soil temperature

After transplanting the seedlings, soil samples were taken to assess the water distribution patterns. The samples were collected below the emitter of drip at an interval of 50 mm CPE of furrow and sprinkler irrigation and at the same time, the soil temperature was recorded at an interval. In the case of sprinkler and furrow methods, soil samples were collected before each irrigation to assess the available soil moisture status and at the same time soil temperature was recorded. The pictorial view while measuring a soil temperature is depicted in Plate-5.

In drip irrigation, before transplanting soil moisture samples were taken as a function of depths and radial distances. Accordingly, the soil samples were collected at 0, 15, 30, 45 and 60 cm depths and radial distances of 0, 15, 30, 45, and 60 cm the following standard procedure described by Black *et al.* (1965) was adopted. The soil sample preserving wooden box designed and developed by Magar *et al.* (1984) was used to minimise the error in the method.

3.3.1.1. Measurement of soil matric potential

Soil water potential upto -0.8 bar was measured directly from tensiometers installed at different depths in the soil columns. The soil moisture contents corresponding to soil water potential values were interpolated from moisture retention curves already prepared for the soil. Soil moisture monitoring by tensiometers under drip irrigation treatments is depicted in Plate-6.

PLATE - 5.

Recording of soil temperature with the help of
digital soil temperature indicator.

PLATE - 6.

Monitoring of soil moisture by tensiometers under drip
irrigation.



3.3.1.2. Wetting front

Advancement of wetting front after the application of irrigation water was studied by monitoring the soil moisture scrupulously and advancement of wetting was estimated as a function of distance and depth from the point source. The soil moisture was determined with the help of gravimetric method at the soil depth intervals at 0-15, 15-30 and 45-60 cm depth just below the emitter and at the distance of 15, 25, and 35 cm away from the emitters. These observations of soil water content were recorded before the planting of tomato.

3.3.2 Hydarulic properties of soil

3.3.2.1. Hydraulic conductivity

Air dried equilibrated soil samples were used for the determination of hydraulic conductivity. The constant head device was employed for the determination of this parameter (Richards, 1954) and the hydraulic conductivity was calculated by Darcy's law.

$$q = K \Delta H/L$$

where $q = V/AL = \text{Flux}$

$K = \text{Hydraulic conductivity, cm/hr}$

$\Delta H = \text{Hydraulic head difference}$

$L = \text{Length of soil column, cm.}$

The Hydraulic conductivity values of the normal soils were 0.095 and 0.147 cm/hr for Typic chromustert and Vertic Ustropept, respectively (Pati, 1986).

3.3.2.2 Soil water diffusivity, $D\theta$

Soil water diffusivity is the soil moisture dependent and may be mathematically defined as : $d(\theta) = K(\theta)/(d\theta/d\psi)$ where $d\theta/d\psi$ is the specific soil water capacity (C) and ψ is the in cm of water column.

3.4 Physical properties.

3.4.1. Bulk density

The bulk density for different soil depth layers as influenced by different soil moisture regimes created by treatments was determined by the standard method described by Blake and Hartage (1986). Core samples were collected with the help of double ring pneumatic foot power operated core sampler. These undisturbed soil cores were used for bulk density determination.

3.4.2 Soil moisture retention characteristics curve

Soil moisture retention characteristics was determined with the help of pressure plate extractor (Richards, 1947). Sufficient care was taken for saturation and removal of entrapped air in the samples. The core samples were subjected to different pressure levels. The moisture retention characteristics curve of experimental plot is depicted in Fig. 3.8.

3.5 Remote sensing technique

3.5.1 Crop canopy temperature

Infrared thermometry is a non-contact method for estimating the surface temperature of a target. The canopy temperature and crop canopy atmospheric temperature difference were measured with infra-red thermometer (Tele temp AG-42). The measurements were made for each plot by

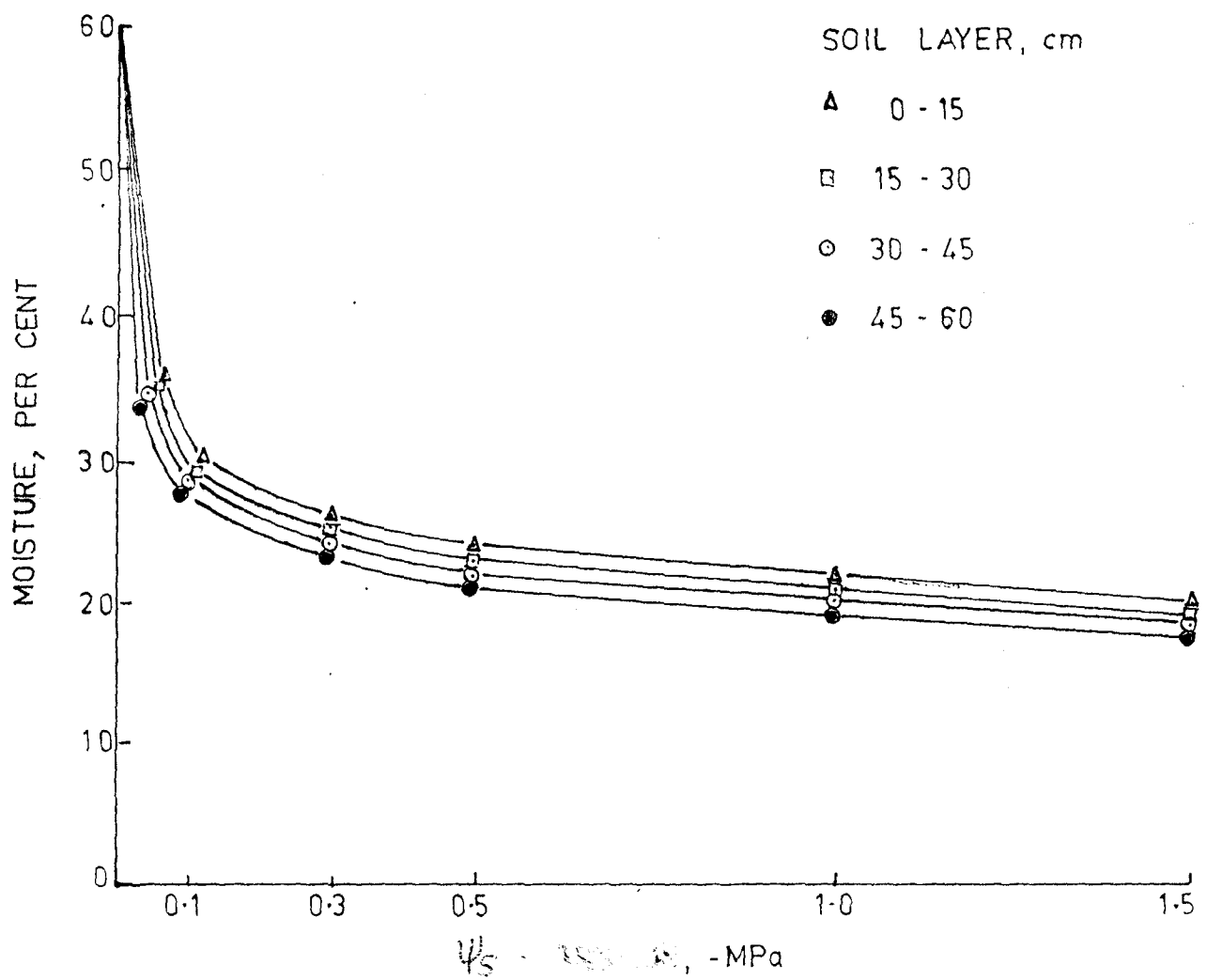


Fig. 3.8. Soil moisture retention characteristics for different soil layers.

the instrument to the centre of the plot at an angle of 45° and is depicted in Plate-7.

3.5.2 Stress degree days

Crop canopy temperature data were collected at an interval of 10 days. The data obtained on the T_c and T_a were used to calculate the stress degree day (SDD). This concept was developed by Idso *et al.* (1977) and is defined $SDD_i = \sum (T_c - T_a)_i$ where, T_c is the canopy temperature and T_a is the air temperature at 14.30 hours. If the plant has adequate water, $T_c - T_a$ will be near zero or negative. If it is water stressed, $T_c - T_a$ will be greater than zero. The sum of accumulated positive values of $T_c - T_a$ can serve as an index for scheduling of irrigation.

3.6 Plant parameters

3.6.1 Leaf area index

Three representative plants from each treatment were selected randomly. The green leaf portions were separated and the area of leaves was obtained with the help of leaf area meter (LICOR, Li-3100). The leaf area was calculated from regression as developed by Garg and Mandahar (1972) and is as follows ; $Y = -0.4 + 0.211 X$ where Y = leaf area and X = length x Breadth.

The green leaf area thus obtained was divided by the soil area covered by the plants gives the leaf area index (LAI) of the crop. The LAI was determined at an interval of 30 days.

3.6.2 Leaf water potential

Leaf water potential was measured on a fully matured compound leaf from the top with the help of a HP-115 microprocessor leaf water potential data system and pressure chamber technique (Scholander *et al.*

065). The leaf water potential values were determined at 30 days interval or the entire crop season. The pictorial view of HP-115 microprocessor leaf water potential is depicted in Plate-8.

7. Biometric observations

3.7.1. Plant height

The height from base to the top of the three selected plants from each treatment was recorded at 70 th days after transplanting. Average of each of the three replications was recorded. The pictorial view of a tomato plant indicating plant height is depicted in Plate-9.

3.7.2. Number of branches per plant

The number of branches of the three representative plants from each treatment was counted at 70 th days after planting and an average number of branches per plant on each was recorded.

3.7.3 Number of fruits per plant

The total number of fruits from three plants separately counted at 70th days after planting and the value is presented as mean number of fruits per plant.

3.7.4 Weight of individual fruit

The weight of fruits (both normal and cracked ones) harvested from the three plants under each treatment was summed up. The average of the sum is presented as mean weight of fruit under each treatment.

3.7.5. Dry matter content per plant

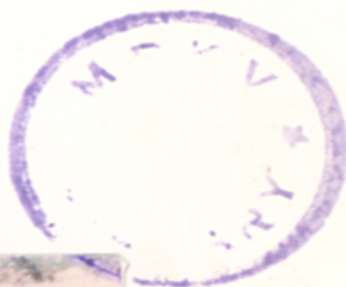
The randomly selected plants were uprooted for separately grown lots for determining the dry matter at an interval of 30 days, they were washed with running tap water, weighed and then dried in the hot air oven at 70 C for 24 hours separately. The drying process was repeated until

PLATE - 8.

Measurement of leaf water potential with the help
of HP-115 microprocessor.

PLATE - 9.

Pictorial view of tomato crop under furrow irrigation
treatments indicating the plant height.



successive weights were constant. At this stage, the weight of each of the two dried plants was recorded. The mean dry weight of three plants was worked out and is presented as dry matter content. The vegetative growth of tomato plant under furrow sprinkler and drip irrigation are depicted in Plate-10 to 12.

3.7.6 50 per cent of flowering

The date of initiation of flowering was recorded as soon as a single flower bud was seen on any of the plants in the treatment. Similarly date of flowering was recorded when 50 per cent of plants produced a couple of flower buds. Accordingly, the number of days required for flowering was calculated from the date of planting.

3.7.7 Total marketable yield of tomato fruits per hectare

The total marketable yield of tomato fruits/plot was calculated by subtracting the cracked fruits from total yield of tomato fruits for each treatment. It was then converted into ton/ha.

3.7.8 Volume of individual fruit

The randomly selected three fruits from the third picking under each treatment were placed in water filled cylinder and the water displaced was recorded of each fruit. Mean of the three fruits from each treatment was worked out and presented as a volume of individual fruit.

3.8 Root study

Observations on root study were taken in all treatments after the harvest of tomato crop. A trench of 60 X 60 X 60 cm was excavated around three plants in each plot.

The trenches were watered and roots were collected from the trench after 24 hours. They were washed with dilute sodium hexa meta

Chapter Opener Page



**RESULTS AND
DISCUSSION**

4. RESULTS AND DISCUSSION

4.1 Soil moisture

4.1.1 Moisture distribution - Furrow irrigation

Soil moisture contents in four layers were monitored before each irrigation for the treatments of IF₅₀, IF₇₅, IF₁₀₀ and available moisture content data during the entire crop growth period are reported in Table 4.1. The gravimetric soil moisture content data were converted into depth of available water as proposed by Dastane (1972). Thus data on available soil moisture during the entire growth period under the irrigation treatments are plotted against crop growth period and depicted in Fig. 4.1 and 4.2 for furrow irrigation respectively for the years 1988-89 and 1989-90. Number of irrigations including presowing irrigation were to 8,5,4 and 9,6,4 under 50, 75, 100 mm CPE treatments, respectively.

Naturally, available soil moisture had gone below the level of maximum allowable deficit (MAD) under IF₁₀₀ treatment and was much more higher in case of IF₅₀ treatment. It was reported in FAO Bulletin No. 24 that MAD deficit index for tomato crop ranged from 0.3 to 0.4 (Doorenbos and Pruitt, 1975). It is clearly visible from the figures that low MAD range and corresponding moisture stress were under irrigation treatments of 75 and 100 mm CPE. Soil moisture content before irrigation was from 26.0 per cent under IF₅₀ and 31.0 per cent under IF₁₀₀ treatments (Table 4.1). The corresponding maximum allowable deficit comes to 0.53, 0.58 and 0.63 for the irrigation treatments of IF₅₀, IF₇₅ and IF₁₀₀ respectively. There was slight difference in the soil moisture content at the time of commencement of irrigation under each treatment even though the actual interval between two

Table 4.1 Soil moisture content before irrigation as influenced by irrigation treatments during crop growth period.

Crop growth period, days	Irrigation interval, days			Soil moisture, per cent					
	50	75	100	IF	IF	IF	IS	IS	IS
	mm	mm	CPE	50	75	100	50	75	100
							1988-89		
17	17	-	-	30.8	-	-	31.2	-	-
23	-	23	-	-	27.5	-	-	28.8	-
34	17	-	34	30.5	-	26.8	31.2	-	26.9
51	18	28	-	30.9	28.6	-	31.5	29.2	-
70	19	-	36	30.5	-	26.0	30.9	-	27.8
78	-	27	-	-	28.2	-	-	29.0	-
85	15	-	-	30.6	-	-	31.0	-	-
98	13	20	28	31.0	28.8	26.4	32.0	29.5	28.0
110	12	-	-	30.5	-	-	31.2	-	-
							1989-90		
11	11	-	-	32.0	-	-	32.8	-	-
17	-	17	-	-	30.0	-	-	31.0	-
23	12	-	23	32.0	-	27.5	32.0	-	28.0
41	18	24	-	31.8	29.8	-	31.2	30.0	-
61	20	-	38	32.1	-	27.4	32.0	-	27.5
68	-	27	-	-	30.2	-	-	30.0	-
75	14	-	-	32.0	-	-	31.8	-	-
88	13	20	27	32.2	30.0	26.6	32.7	31.0	28.0
99	11	-	-	31.8	-	-	32.1	-	-
108	9	20	-	32.1	29.7	-	31.8	30.0	-

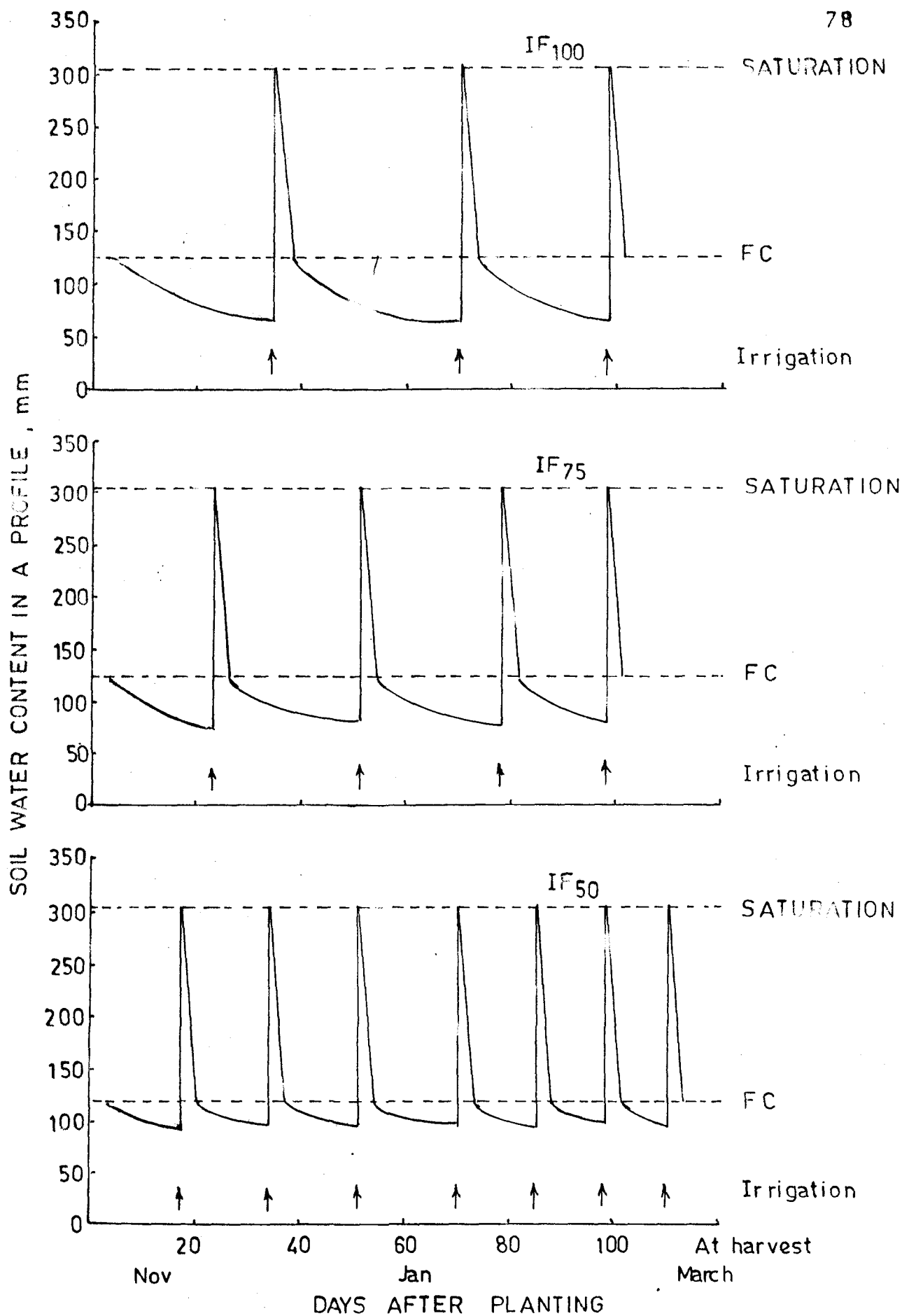


Fig. 4.1. Soil water content in a profile under furrow irrigation during crop growth. (1988-89)

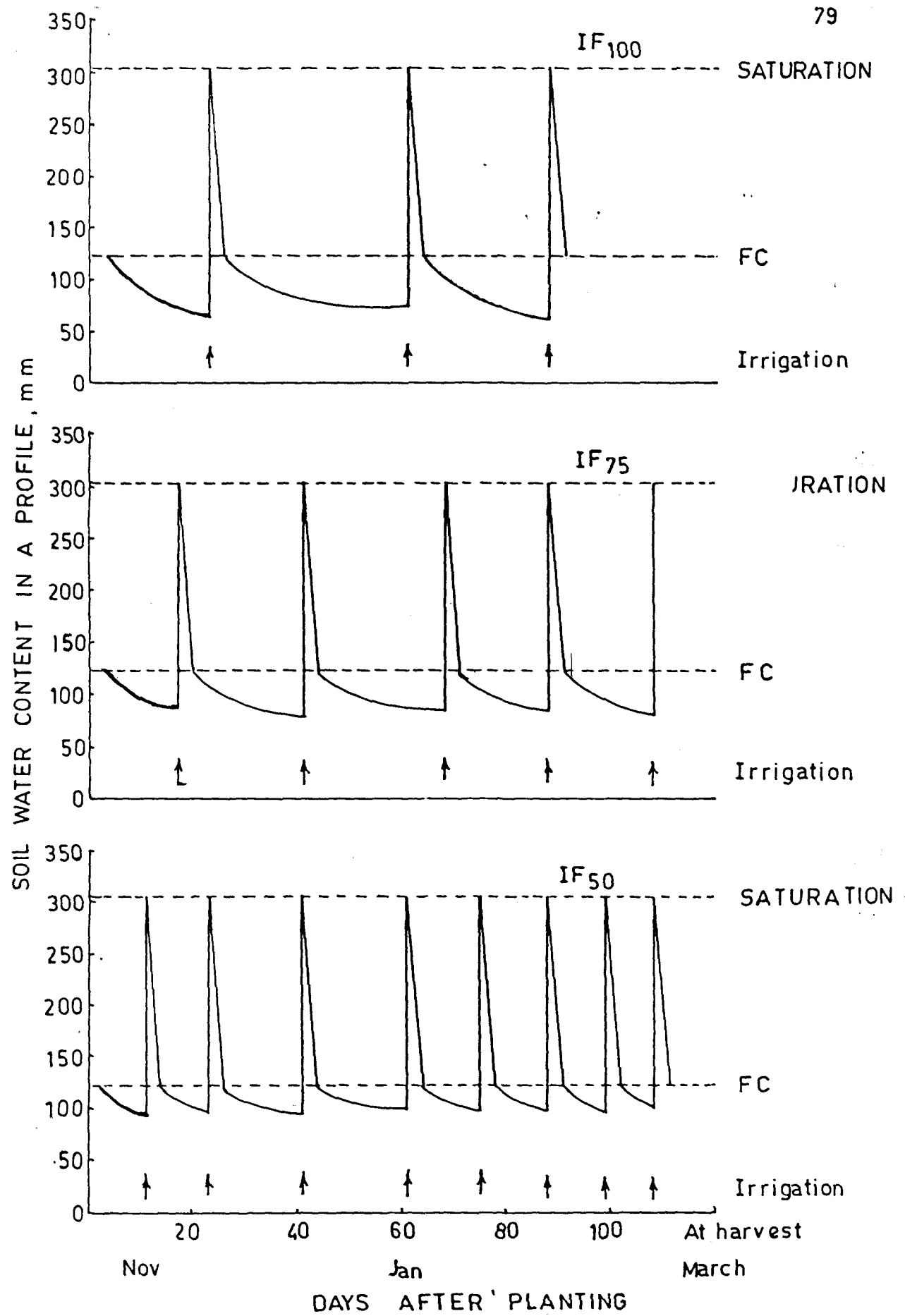


Fig.42. Soil water content in a profile under furrow irrigation during crop growth. (1989-90)

irrigations varied to the extent of 2 to 3 days. This range was 26.0 to 26.8, 27.5 to 28.8 and 30.5 to 31.0 per cents in the treatments of IF₁₀₀, IF₇₅ and IF₅₀, respectively.

Available soil moisture study during the crop growth under surface irrigation system was reported by Sivanappan *et al.* (1987), Similar efforts were made by Karmarkar (1985), Magar *et al.* (1989), Soil moisture status as influenced by the processes of precipitation and irrigation was explained by Gardner (1964) and Philip (1966) for different set of conditions. Tripathi and Ghildyal (1978) correlated the aspects of soil moisture status and leaf water potential. Analysis of soil moisture status as a function of depth and time between two irrigations and layerwise contribution of ASM in black soil (Vertisol) was made by Magar *et al.* (1984 a). The contribution of first and second layer of 15 cm each was to the extent of 60 per cent.

4.1.2 Moisture distribution - Sprinkler irrigation

The gravimetric moisture content data before each irrigation under sprinkler irrigation treatments i. e. IS₅₀, IS₇₅ and IS₁₀₀ are presented in table 4.1 for both years. The data in terms of ASM are plotted against crop growth period and showed in Fig. 4.3 and 4.4, respectively for the years 1988-89 and 1989-90 for the treatments of IS₅₀, IS₇₅ and IS₁₀₀.

Soil moistures depletion was under sprinkler irrigation treatments like furrow irrigation. The moisture contents ranged from 30.9 to 32.0, 28.8 to 29.5 and 26.9 to 28.0 per cents in case of IS₅₀, IS₇₅ and IS₁₀₀, respectively. In general, irrigation interval for the treatments of 50, 75, 100 mm CPE under sprinkler irrigation system was

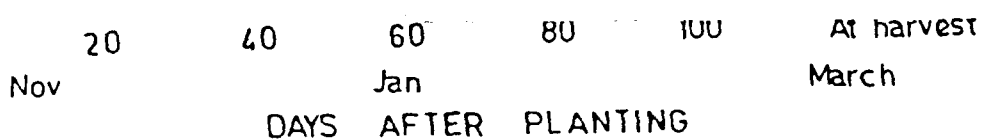


Fig. 4.3. Soil water content in a profile under sprinkler irrigation during crop growth. (1988-89)

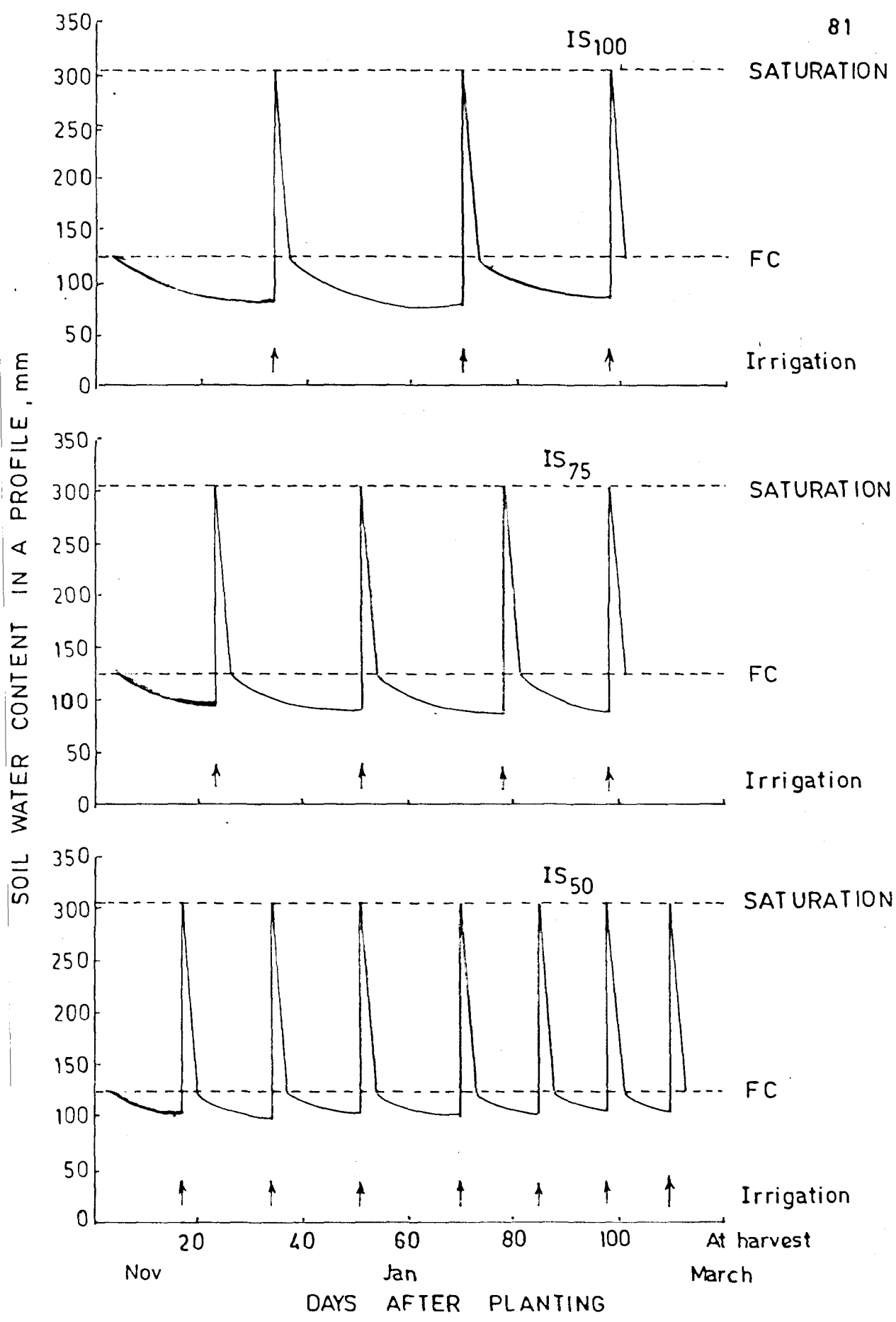


fig. 4.3. Soil water content in a profile under sprinkler irrigation during crop growth. (1988-89)

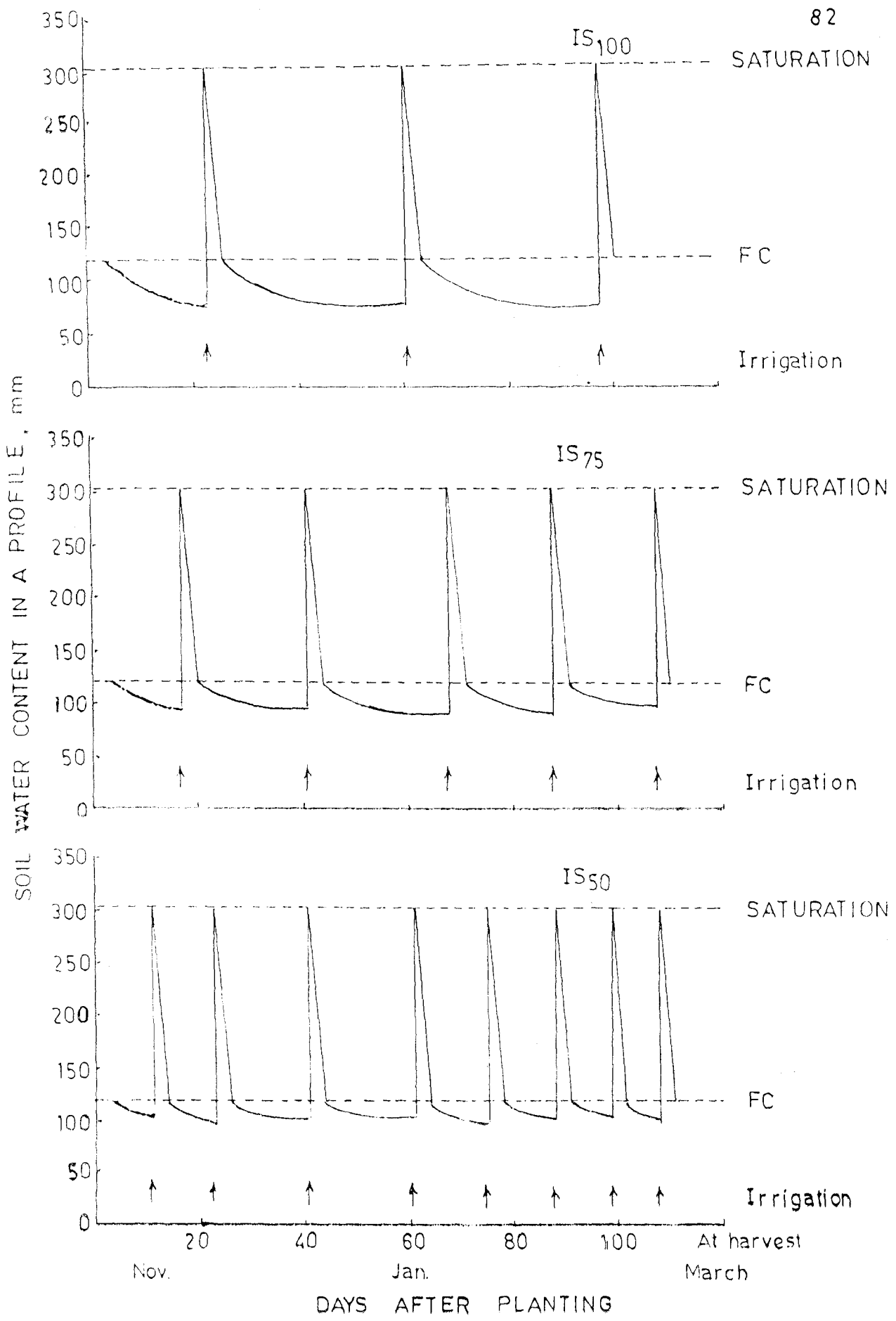


Fig.4.4. Soil water content in a profile under sprinkler irrigation during crop growth (1989-90)

found to be 12 to 19, 20 to 28 and 28 to 36 days, respectively.

The available soil moisture also had gone down to level of management allowable deficit (MAD) limit of tomato under IS and IS treatments. The soil moisture content before irrigation was 26.9 per cent under IS and 32.0 per cent under IS treatments. The interval between two irrigations under particular type of treatment on the basis of CPE varied to the extent of 2 to 3 days. Similar trend was observed in the year 1989-90.

4.1.3 Profile moisture distribution - Drip irrigation

The available soil moisture data are plotted against crop growth period for the treatments of ID₁, ID₂ and ID₃ and depicted in Fig. 4.5 for the years 1988-89 and 1989-90. The number of irrigations were 120, 60 and 40 under ID₁, ID₂ and ID₃ treatments respectively. It is clearly visible from the figures that available soil moisture was nearly to the field capacity in above three treatments. The soil moisture content range before irrigation was from 34.5 to 32.5 per cent under ID₁, ID₂ and ID₃ treatments. Similar trend was observed in the year 1989-90. Excellent synthesis of ASM during the crop growth period under drip system was done by Sivamppan *et al.* (1987), Nakayama and Bucks (1986), Karmeli and Keller (1975). The available soil moisture fluctuations in black cotton soil under drip irrigation system were reported by Karmarkar (1985) and Magar *et al.* (1989).

4.1.4 Moisture redistribution and wetting front

Pilot experiment was conducted to study the soil moisture distribution under surface irrigation system under bare soil conditions. The soil moisture data as a function of depth and time are depicted in Fig. 4.6. Initial moisture contents in the effective root zone of 60 cm

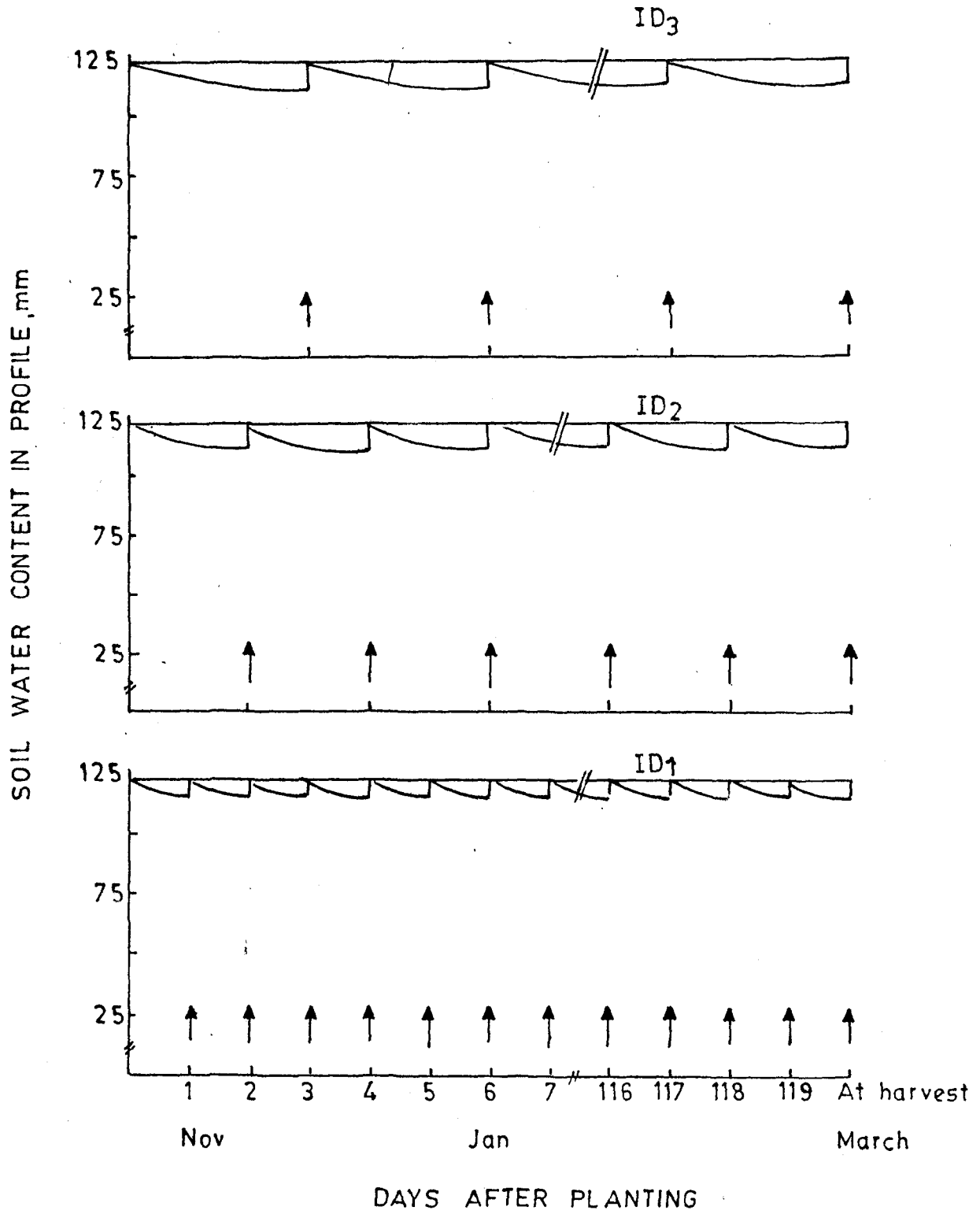


Fig. 4.5. Soil water content in a profile under drip irrigation during crop growth.

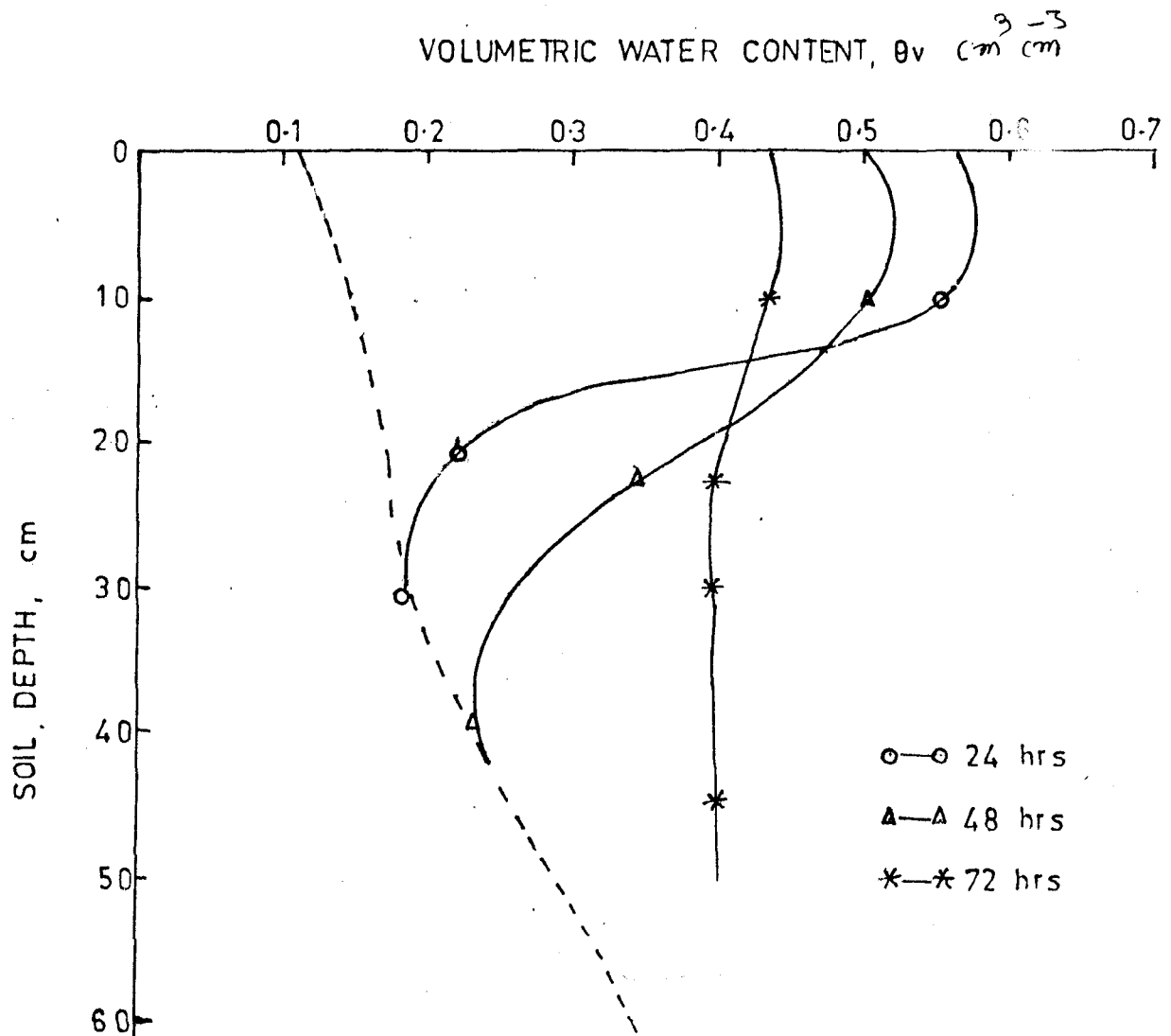


Fig.4.6. Volumetric water content as a function of depth just below the emitter.

before water application are also reported in said figure. The moisture content at the surface layer was $0.11 \text{ cm}^3 \text{ cm}^{-3}$ which had increased to the extent of $0.32 \text{ cm}^3 \text{ cm}^{-3}$ at the soil depth layer of 45 to 60 cm soil moisture content.

Philip (1967) reported the phenomenon of water movement through porous media. At low suction, $K\theta$ values progressively increased with depth and this is in consistent with the fact that water retentivity and specific surface area increase with the depth as shown by Richards and Moore (1952).

4.1.5 Advancement of wetting front under uniform frequency of water application

The advancement of wetting front as a function of depth and distance from one point source is depicted in Fig. 4.7. It is a function of soil porosity, hydraulic conductivity, infiltration rate, duration of water application, spacing of emitters, evaporation and initial soil moisture content (Sivanappan and Padmakumari, 1980). It is interesting to note from the figure that the wetting front advanced to a distance of 20 cm on either side of microtube and 60 cm below the microtube after 72 hours and before the execution of next turn of water application. The wetted front advanced since beginning of water application at 30 cm on either side of the emitter when the equilibrium reached after 144 hours. The wetted bulb was more or less semi-elliptical in shape with maximum and minimum diameter of 57 and 50 cm, respectively. Roth (1974) measured the wetting fronts and found that rather than being in a hemispheric form, the wetted volume was elongated in the vertical direction in sandy loam soil. Karmarkar (1985) reported that in deep black soil, the wetting front advance was 30 cm on either side of the lateral and 67 cm

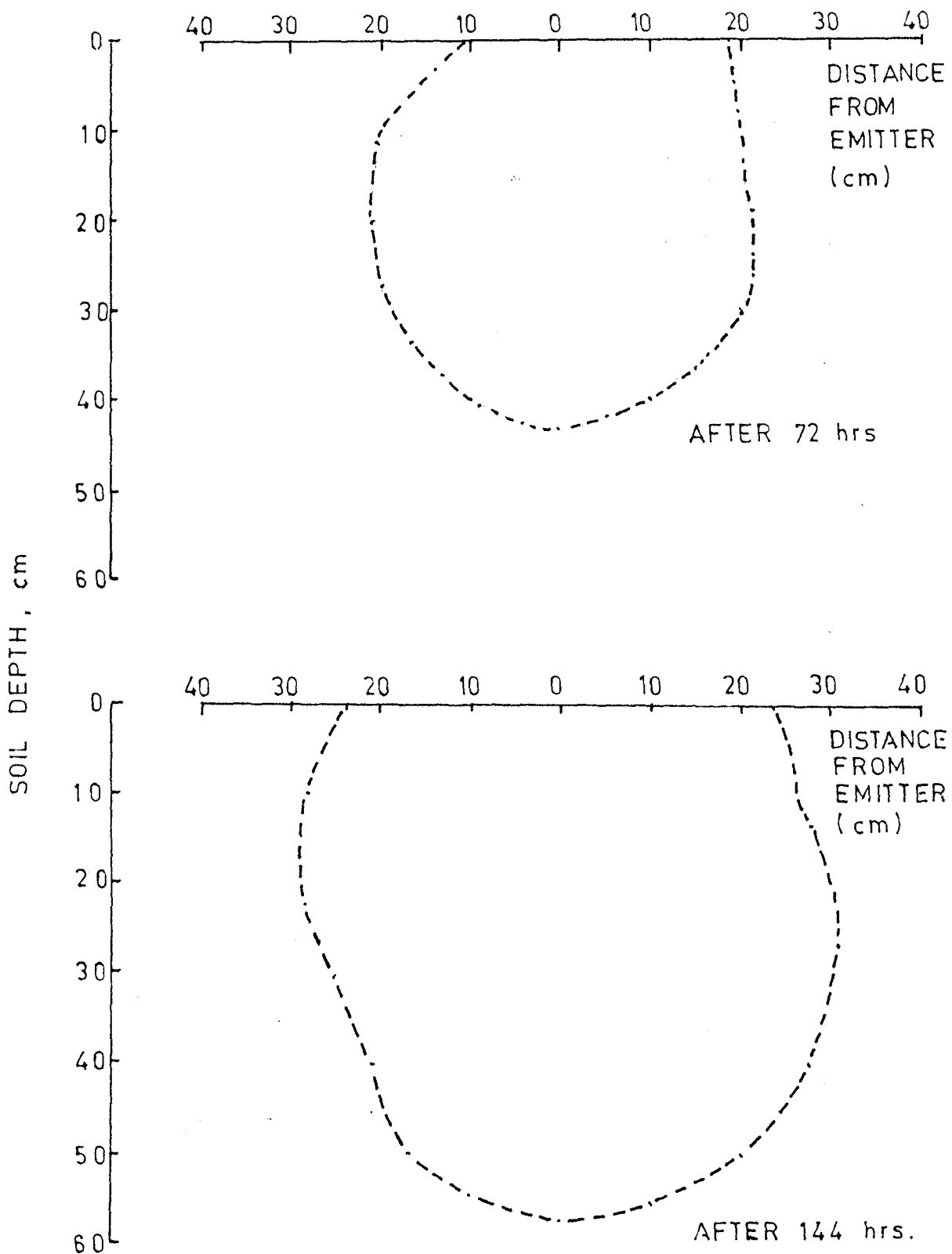


Fig. 4.7. Advancement of wetting front from the point source (emitter) after 72 and 144 hrs time.

vertically downwards at the end of irrigation cycle of 144 hours.

4.2 Pertinent soil properties

4.2.1 Soil water properties

4.2.1.1 Hydraulic conductivity

The values of unsaturated hydraulic conductivity ($K(\theta)$) versus soil water content for 0-15, 15-30, 30-45 and 45-60 cm soil depth are depicted in Fig. 4.8. Hydraulic conductivity decreased logarithmically with the decreasing soil water content showing exponential relationship on semi-log scale. Large soil water content variation was recorded from 0.40×10^{-3} to 0.56×10^{-3} cm³ cm⁻³ by giving maximum values of $K(\theta)$ in the range of 8.5×10^{-4} to 2.5×10^{-2} cm/day, respectively in the surface layer. The 45-60 cm layer exhibited minimum $K(\theta)$ range from 0.5×10^{-2} to 9.2×10^{-3} cm/day when water content changed from 0.63 to 0.69 cm³ cm⁻³ during drying period. This could probably be due to a small magnitude of potential gradient in the micropores system. Philip (1957) reported the phenomenon for water movement through porous media. The hydraulic conductivity values ranged between 0.1 to 0.0006 cm/day for soil depth intervals. The values of hydraulic conductivity in black cotton soil (Vertisols) with 58.5 per cent montmorillonitic clay content determined by Magar *et al.* (1980) varied in order of 10^{-2} to 10^{-5} cm/day when moisture content decreased from 0.70 to 0.30 cm³ cm⁻³. These values were in agreement with the value of $K(\theta)$ reported by them.

The figure clearly indicated that $K(\theta)$ showed an exponential relationship with volumetric water content of suction (m). The values of $K(\theta)$ decreased sharply with a slight decline in θ_v . It was due to the fact that the large pores conducting more water, became empty. At low suction $K(\theta)$ value progressively increased with depth and is

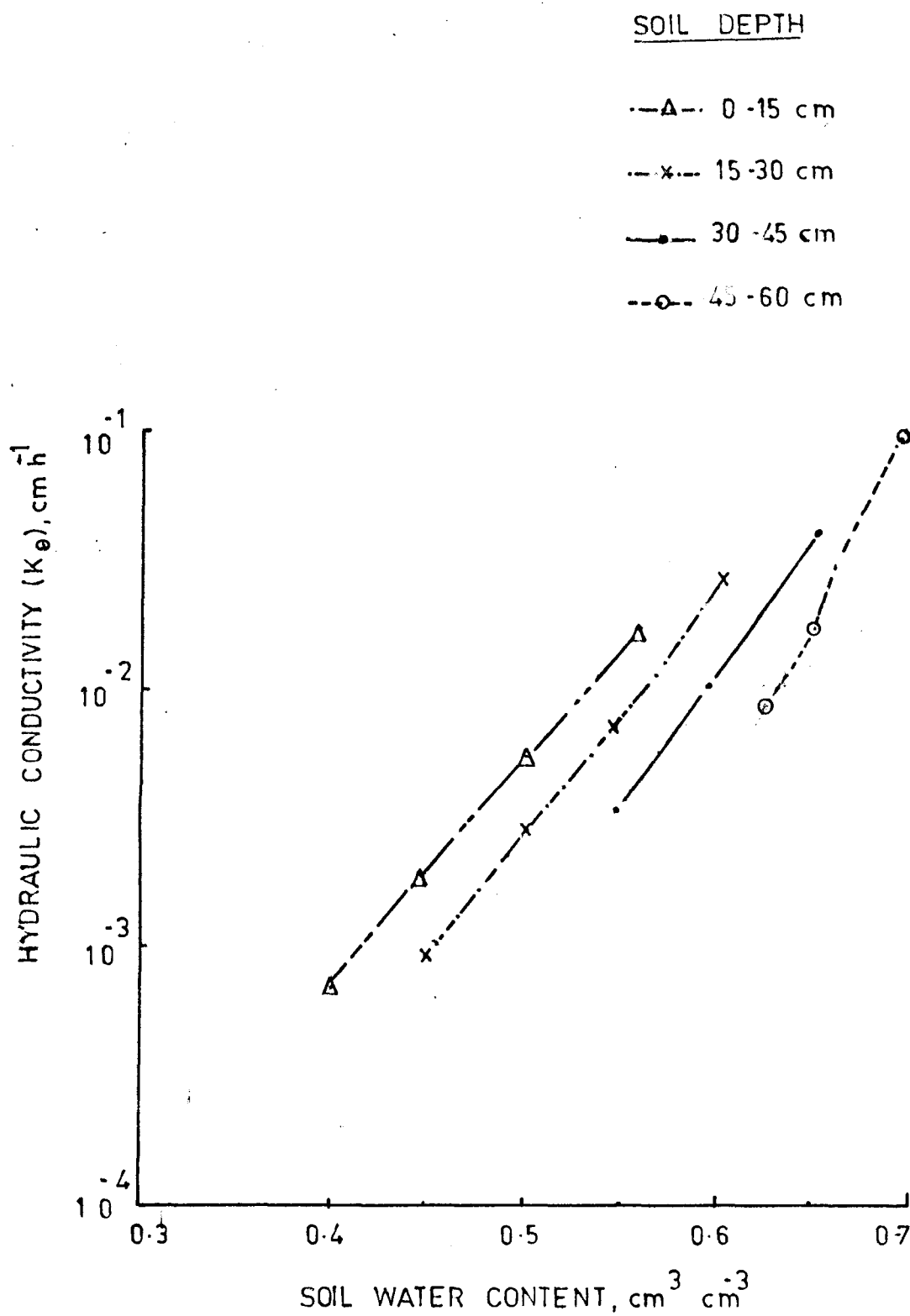
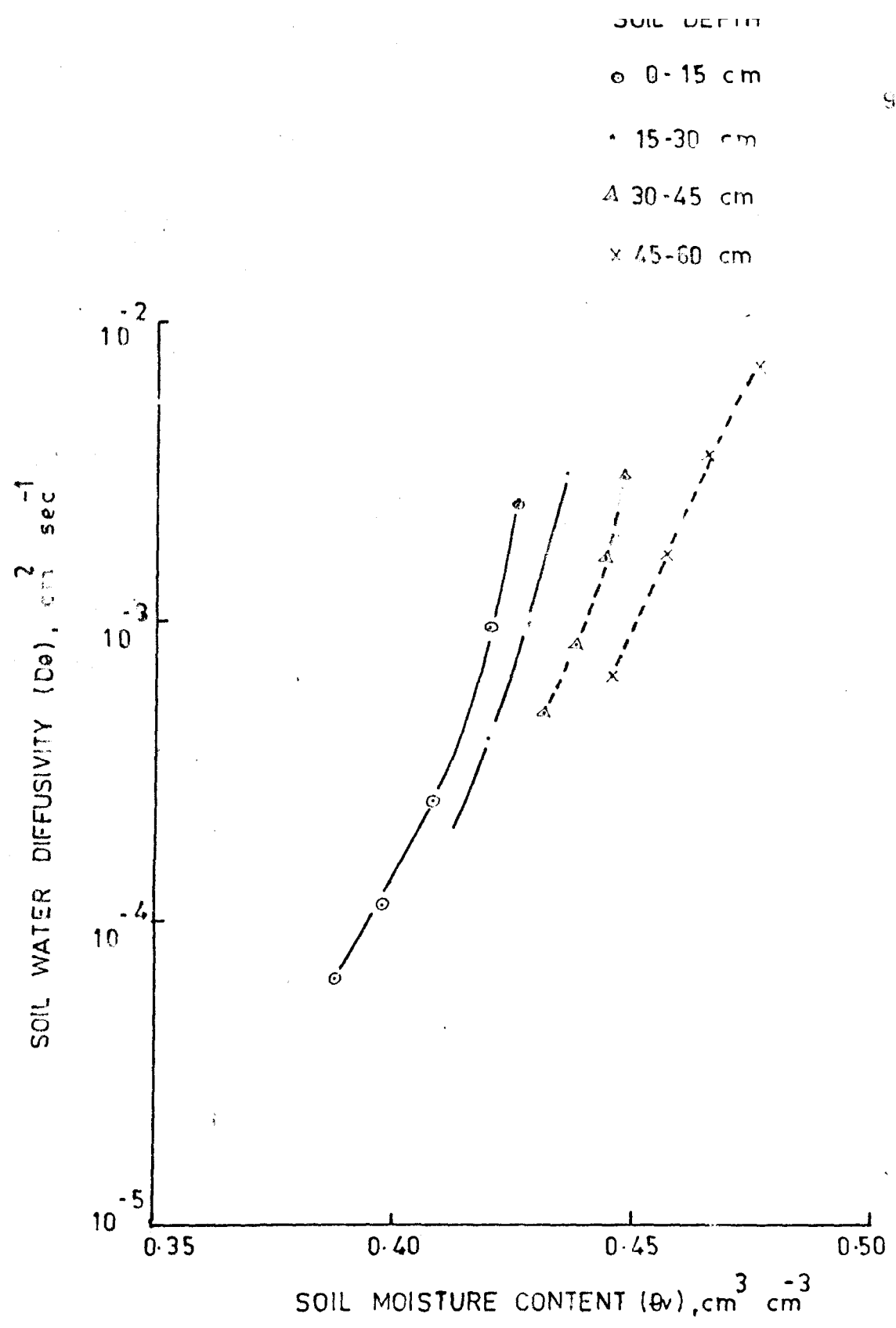


Fig.4.8. Hydraulic conductivity as a function of water content in different depth intervals of black soil.

consistent with the fact that the water retentivity and specific surface area increased with the depth shown by Richards and Moore (1952). As the crop growth advanced, more water was consumed by the crop. The deeper layers contributed higher capillary conductivity compared to that by the relatively surface soil layer due to the presence of high volume fractions of water. This phenomenon was explained by Philip (1957) based on cross sectional area available for flow which decreases with time. Similar observation in deep black soil were observed by Patil (1981) and Patil (1982) and Patil (1986).

4.2.1.2 Soil water diffusivity

Soil water diffusivity $D(\theta)$ as a function of moisture content at four different soil depths viz. 0-15, 15-30, 30-45 and 45-60 cm was plotted on semilog paper and presented in Fig. 4.9. The soil water diffusivity values decreased logarithmically as that of $K(\theta)$ exhibited approximately exponential relationship with water content when plotted on a semilog paper. $D(\theta)$ values of surface layer (0-15 cm) were maximum in the range of 7.5×10^{-5} to 5×10^{-3} cm²/sec at 0.38 and 0.42 cm cm moisture contents, respectively. 45-60 cm soil layer exhibited minimum variation in the $D(\theta)$ values from 8×10^{-4} to 8.5×10^{-3} cm²/sec at 0.44 and 0.47 cm cm moisture contents, respectively. The 45-60 cm soil layer exhibited minimum variation in the $D(\theta)$. Magar and Kar (1981) showed that the magnitude of $D(\theta)$ value ranged from 10^{-3} to 10^{-5} cm²/sec when moisture content decreased from 0.30 to 0.10 cm cm in black soils. Tripathi and Ghildyal (1976) found that $D(\theta)$ variation at saturation ranged from 1002 to 1898 cm²/day. Thus maximum values $D(\theta)$ occurred at saturation, but variation in this case was attributable to the error in this period. The maximum soil water diffusivity occurred at certain



.Fig.4-9. Soil water diffusivity versus moisture content in different depth intervals of black soil.

moisture content, less than saturation mostly falling in the range of 0.25 to 0.30 $\text{cm}^3 \text{cm}^{-3}$ moisture content as shown by DhanPal and Varade (1976). The bulk density largely affected the values of $K(\theta)$ and $D(\theta)$.

4.2.2 Physical properties

4.2.2.1 Bulk density

The bulk density as a function of soil depth is depicted in Fig. 4.10. The bulk density at the surface layer of 0-15 cm was 1.18 g cm^{-3} , which showed an increasing trend as a function of depth. Maximum bulk density of 1.39 g cm^{-3} was recorded in the layer of 45-60 cm. Bulk density was more at the lower layer depth and ultimately porosity was decreased as the depth increased. Bulk density variation due to soil moisture content has been reported by the various researchers. In swelling black clay soils, bulk density at all depths decreased with increase in the moisture content. The rate of increase in the bulk density due to soil moisture depletion was higher in the clay soil as compared to that in the light textured soils (Magar et al. 1979 and Patil, 1982).

Large volume changes are characteristic of soils with a high content of expanding clays. The degree of volume change in response to changes in water content depends upon the amount and type of clay, the particle arrangement, composition of soil solution, organic and chemical bonding agents (Larson and Allmaras, 1972). Bondman and Constantin (1965) reported that the packing relationship of the particles in a soil with its bulk density. They observed high bulk densities where the sand fraction ranged from 50 to 85 per cent. The soil surface particles can change their position to a great extent by rolling or sliding. It is the major factor contributing to volume change in unsaturated granular soils. For fine grained, partly saturated soils,

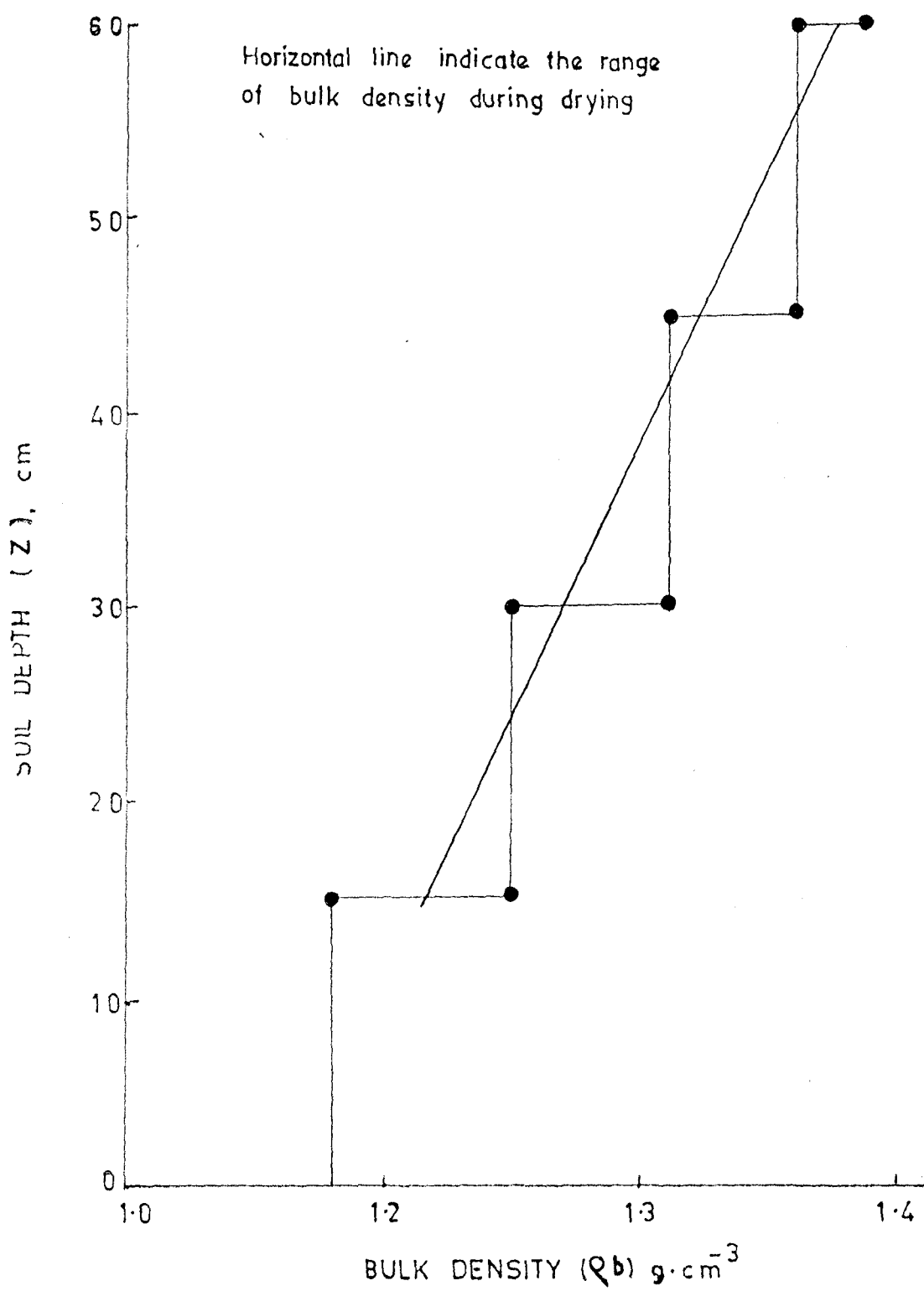


Fig. 4.10. Bulk density as a function of depth.

predominantly composed of clay, the volume changes depend upon reorientation of the particles and displacement of water molecules between particles. The change in state of bulk density resulting from rearrangement of the particles is primarily due to the change in volume of the voids (Magar *et al.* 1979).

4.2.2.2 Soil moisture constants

Soil moisture constants such as maximum water holding capacity, field capacity and permanent wilting point of the representative soil samples are given in Table 4.2. It is obvious from the table that surface layer (0-15 cm) exhibited maximum water holding capacity and available soil moisture content. Available soil moisture content decreased as a function of depth. Capacity use factor and available moisture content data of deep black soils have been reported by Magar *et al.* (1984). The porosity was estimated from the particle density and it decreased as a function of depth. There was a reduction of 7.1 per cent in the porosity status in between surface layer of 0-15 and 45-60 cm soil layers. However concomitant reduction was observed in case of field capacity and permanent wilting point. The average field capacity and PWP were 34.7 and 18.5 per cents, respectively. The total available soil moisture in the effective root zone of 60 cm was 125 mm.

4.2.2.3 Soil temperature

The soil temperature at 15 cm depth was monitored before each irrigation under furrow irrigation (IF to IF). The data plotted against crop growth are depicted in Fig. 4.11 and 4.12 for the years 1988-89 and 1989-90, respectively. The number of irrigations including presowing irrigation were 8,6,4 and 9,6,5 under 50,75 and 100 mm CPE treatments respectively.

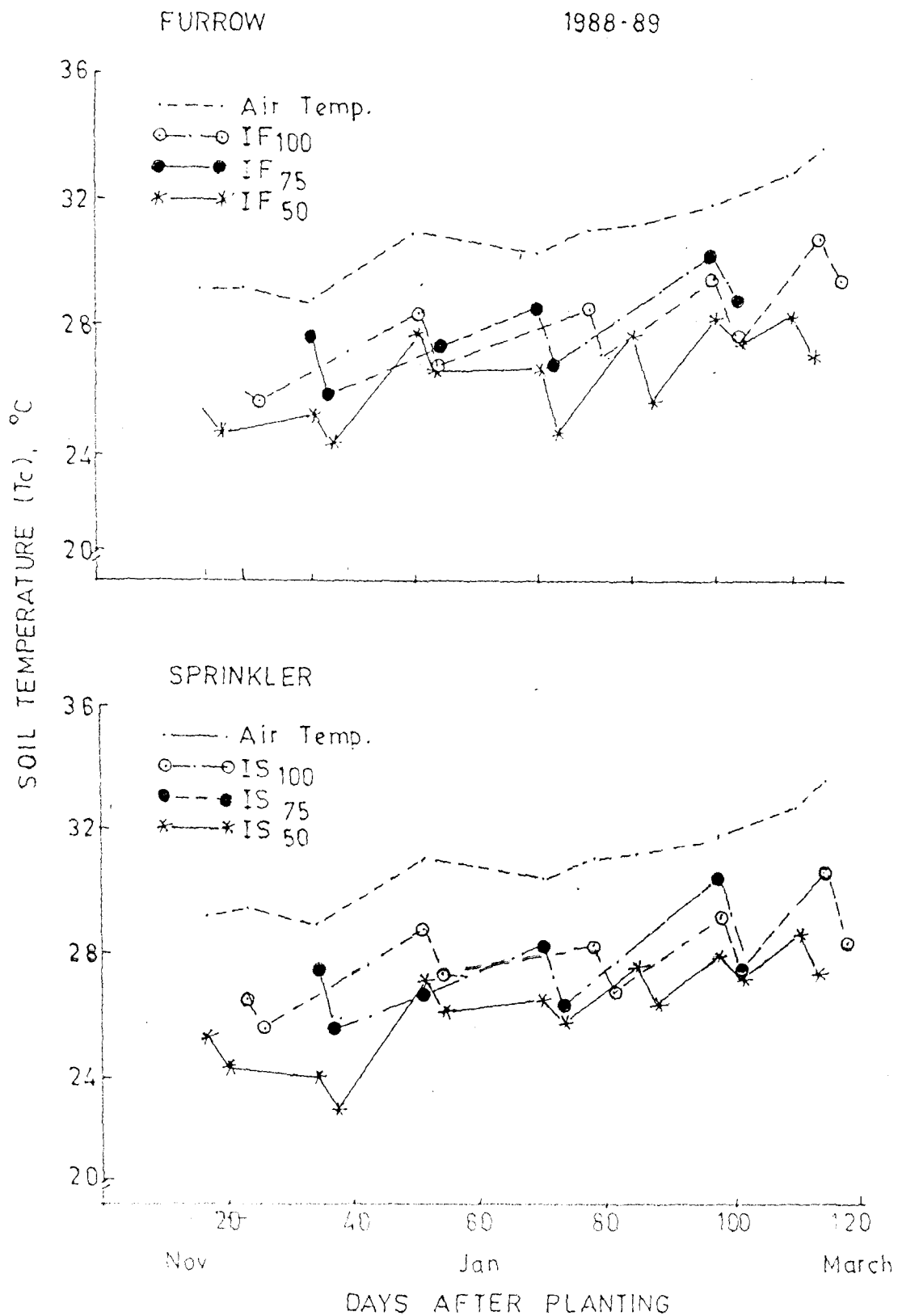


Fig. 4-11. Soil temperature in relation to different soil moisture regimes under furrow and sprinkler irrigation during crop growth. (1988-89)

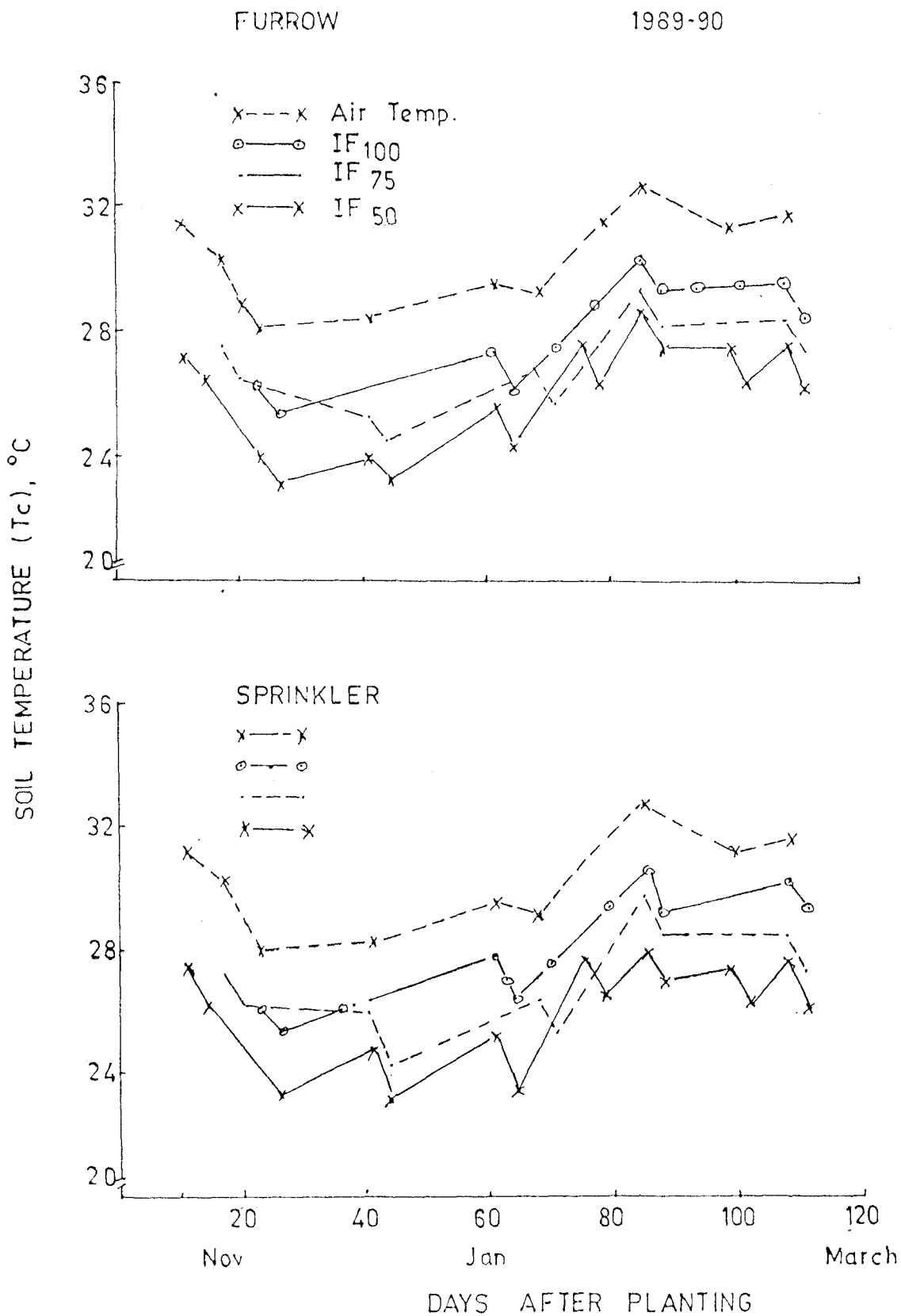


Fig. 4.12. Soil temperature in relation to different soil moisture regimes under furrow and sprinkler during crop growth. (1989-90)

Table 4.2 Details of soil moisture constants and other related physical properties in effective root zone.

Soil depth layers, cm	Bulk density -3 g cm	Total porosity, per cent	Maximum water holding capacity, per cent	Field capacity, per cent	Permanent wilting point, per cent	ASM, per cent
0-15	1.21	55.8	54.7	36.4	19.4	17.0
15-30	1.24	52.4	50.9	35.1	18.8	16.2
30-45	1.27	50.2	48.16	35.0	18.3	16.7
45-60	1.30	48.7	45.3	32.4	17.5	14.9
Mean	1.25	51.17	49.8	34.7	18.5	16.2

Soil temperature was compared with air temperature and it was inferred that soil temperature was 3.8 to 4.3, 2.8 to 3.5 and 1.8 to 1.2 °C less in the treatments of 50,75, 100 mm CPK of furrow irrigation under similar set of conditions. In case of sprinkler irrigation treatments soil temperature reduction was slightly more than the furrow irrigation treatments. The reduction in soil temperatures at 15 cm soil depth was attributed to such as specific heat of soil matrix and water. The soil temperature data in the drip irrigation are plotted against the crop growth period and depicted in Fig. 4.13. The soil temperature in ID₁ treatment was 5 to 5.7 °C less than the air temperature. Similar temperature was observed in ID₂ and ID₃ treatment. The soil temperature reduction in drip irrigation was more than that in the furrow and

1988-89

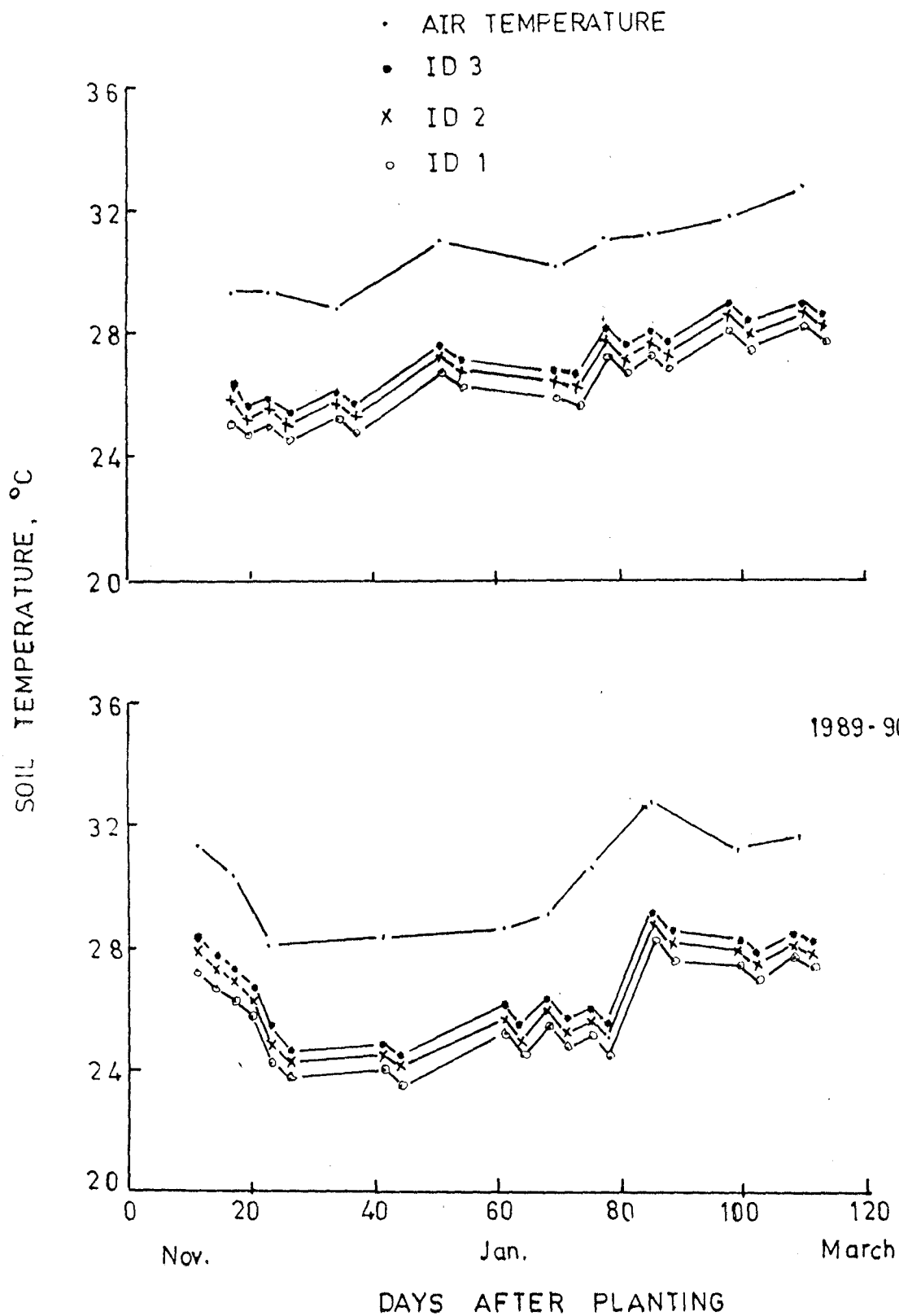


Fig. 4-13. Soil temperature in relation to different soil moisture regimes under drip irrigation during crop growth period.

sprinkler irrigation. This might be due to the fact that in drip irrigation, soil moisture is maintained at field capacity.

Soil temperature is dependent upon soil moisture. Chaudhary and Sandhu (1982) reported that the effect of irrigation on soil temperature depends upon the relative temperature of soil and irrigation water, the atmospheric conditions, the type of mulch and the nature and extent of crop cover. In tropical areas, irrigation generally causes a rapid and substantial reduction in maximum soil temperature in summer. There was a temperature reduction of 11.4 °C at 5 cm and 4.8 °C at 20 cm soil depth during early growing season in June with 80 mm irrigation. The effect was large, rapid and short lived in the surface layer, and it was small, slow and long lived in deeper layers. The moderating effect of irrigation lasted for 4 to 9 days in the top of 20 cm soil. Similar results have been reported by Dhesi *et al.* (1964), Khera *et al.* (1976), and Sandhu *et al.* (1980). The damping effect of irrigation was attributed to the lower temperature of the irrigation water than that of soil high specific heat of water and greater evaporative cooling in irrigated soils.

Magar *et al.* (1979) reported that the low value of thermal conductivity of 0.6 m cal/cm/sec °C at 5 cm depth in the black cotton soil with a high clay content (montmorillonite) is in agreement with the view that λ is lower in more fine textured soils. The value of λ depends on the shape and size of contacts of separate particles and on the quantity of water and air between them (de Vries, 1963). The rate of increase in λ is greater at the lower moisture content while at higher moisture content λ slowly increases. Dravid (1940) while working on black soil obtained a value of 0.4 m cal/cm/sec / °C for thermal conductivity at

5 cm depth. The soils with higher clay content and lower sand content have lower effective thermal conductivity. Apparently, communication of soil diminishes, the air between its particles, the smaller the pore size the smaller the coefficient of thermal conductivity of air in them resulting in a decrease in the effective thermal conductivity. Most probably air becomes less mobile in smaller sized pores, diminishing the part played by convection, the part played by radiation in overall heat transfer becomes less, and finally there is an increase in the number of low conductivity contacts between the particles.

The maximum value of D ($3.8 \frac{\text{cm}^2}{\text{sec}}$) attained at the moisture content of $0.40 \frac{\text{cm}^3}{\text{cm}^3}$ declined gradually as the moisture content increased thereafter. As in the case of thermal conductivity, thermal diffusivity D , also increased from $1.2 \frac{\text{cm}^2}{\text{sec}}$ to $3.8 \frac{\text{cm}^2}{\text{sec}}$ with increase in moisture content from 0.20 to $0.40 \frac{\text{cm}^3}{\text{cm}^3}$. Further increase in moisture content beyond $0.40 \frac{\text{cm}^3}{\text{cm}^3}$ a decrease in thermal diffusivity has resulted. The curve for thermal conductivity as a function of moisture content has a tendency to flatten out. In general, the thermal diffusivity of the soil varies with its moisture content. This might be attributed to the fact that with increase of moisture water fills, the inter-space between the soil particles, driving away the air which has a low thermal diffusivity. From the depth of 5 cm there was an increase in diffusivity following saturation because the thermal conductivity increased roughly three fold versus a two fold change in heat capacity associated with the marked increase in soil water content (Kolyasev and Gupalo 1958). The thermal diffusivity reaches its maximum at such a moisture content where the water film meniscus mechanism changes into the capillary mechanism. Further increase in moisture content resulted in

capillary mechanism. Further increase in moisture content resulted in decrease in thermal diffusivity due to flattening tendency of thermal conductivity curve.

Soil heat fluxes were computed and the heat flux was compared for 5 and 15 cm depths during drying. The profile of volumetric water content, the soil initially was moist and dried rapidly at the surface as time progressed. As the depth, increased from 5 cm to 58 cm, the soil temperature after saturation decreased from 33.4 to 28.2 °C at 3 p.m. in black cotton soil (Magar et al., 1979).

4.2.3 Pertinent chemical properties.

4.2.3.1 Soil pH

Variation in soil pH as influenced by different irrigation treatments during the period of investigation is reported in Table 4.3. There was not much differences in pH values under furrow, sprinkler and drip irrigation methods. Eventhough the variable water quantity was applied under different methods at different CPE it did not influence the soil pH.

4.2.3.2 Electrical conductivity, EC

The values for EC of surface layer of 0-15 cm were measured at 30, 60, 90 and 120 days after planting and these are reported in Table 4.4. Initial EC values of surface soil samples did not change significantly due to irrigation treatments. However, EC values increased during the crop growth period due to imposition of irrigation treatments. In drip irrigation treatments there was slightly increased in the salt status. It is true that an increasing trend was seen in second year for all irrigation treatments. The values were found to be increased at harvest. It is rather difficult to draw certain conclusion within short period in

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Table 4.3 Soil pH as influenced by different soil moisture regimes during crop growth.

Treatments	Soil pH			
	Crop days			
	30	60	90	At harvest
	1988-89			
IF	7.95	7.98	8.02	8.02
50				
IF	7.93	7.97	8.00	8.01
75				
IF	7.92	7.95	7.98	8.00
100				
IS	7.95	7.98	7.98	8.01
50				
IS	7.93	7.96	7.97	8.00
75				
IS	7.92	7.94	7.95	7.98
100				
ID	7.97	8.00	8.02	8.04
1				
ID	7.96	7.98	8.01	8.02
2				
ID	7.95	7.97	8.00	8.01
3				
	1989-90			
IF	7.97	8.00	8.02	8.04
50				
IF	7.96	7.98	8.01	8.03
75				
IF	7.95	7.97	8.00	8.02
100				
IS	7.97	8.00	8.01	8.04
50				
IS	7.96	7.98	8.00	8.03
75				
IS	7.95	7.97	7.99	8.01
100				
ID	8.00	8.02	8.04	8.07
1				
ID	7.98	8.01	8.03	8.05
2				
ID	7.97	8.00	8.02	8.04
3				

Table 4.4 Soil EC as influenced by different soil moisture regime during crop growth .

Treatments	Soil EC, dSm			
	----- Crop Days -----			
	30	60	90	At harvest
1988-89				
IF 50	0.38	0.42	0.45	0.47
IF 75	0.37	0.41	0.43	0.46
IF 100	0.36	0.40	0.42	0.44
IS 50	0.38	0.41	0.43	0.45
IS 75	0.37	0.40	0.41	0.44
IS 100	0.35	0.38	0.40	0.42
ID 1	0.29	0.43	0.46	0.50
ID 2	0.38	0.42	0.45	0.49
ID 3	0.38	0.42	0.44	0.49
1989-90				
IF 50	0.43	0.46	0.48	0.50
IF 75	0.42	0.44	0.46	0.49
IF 100	0.40	0.42	0.45	0.47
IS 50	0.43	0.45	0.46	0.49
IS 75	0.42	0.43	0.44	0.48
IS 100	0.40	0.42	0.43	0.46
ID 1	0.44	0.48	0.52	0.55
ID 2	0.43	0.47	0.51	0.52
ID 3	0.43	0.46	0.50	0.52

the absence of LR and water table studies.

4.3 Water budgeting

4.3.1 Consumptive use

Consumptive use of total pan evaporation and other related parameters of tomato monitored during the period of investigation are given in Tables 4.5 and 4.6, respectively for the years 1988-89 and 1989-90. Total number of irrigations was considered including first common irrigation (70 mm) applied at the time of transplanting of seedlings. The number of irrigations under furrow and sprinkler irrigation treatments was 8, 6 and 4 for 50, 75 and 100 mm CPE, respectively in the year 1988-89. Number of irrigations were increased by one irrigation under IF₅₀ and IF₁₀₀ in the second year. The irrigations were scheduled on the basis of climatological approach and were dependent on total pan evaporation during the entire crop growth period. The concept of drip irrigation was to meet the depleted available soil moisture on daily, alternate and three days. Hence, number of irrigations was maximum at 120, 60 and 40 in case of ID₁, ID₂ and ID₃ treatments respectively. The corresponding average of 1, 2 and 3 days interval between two irrigations is also reported in the said tables. It gives just tentative idea of rotation period for all treatments. Numbers of irrigations had given the estimation of the quantity of water applied. Irrigation interval was comparatively less in first year as compared to second year. However, it was nil in first year and contributed little to the extent of 5.5 mm in second year. This tract does not get late rabi or pre-monsoon rains. Total pan evaporation was 401 and 461 mm during the entire crop growth period for the years 1988-89 and 1989-90, respectively. Average daily pan evaporation was worked out and it was 3.34 and 3.84 mm/day for the years 1988-89 and 1989-90

respectively (Tables 4.5 and 4.6).

Consumptive use was estimated from the available soil moisture depletion data. There is a large variation in consumptive use amongst different irrigation methods as well as amongst different scheduling of irrigation treatments under the same method. Maximum Cu was recorded under IF treatments amounting to 395 mm. It was followed by 375 and 355 mm under IF₁₀₀ and IF₇₅ treatments, respectively (Table 4.6).

The consumptive use in respect of IF₇₅ and IF₁₀₀ was 5.8 and 8.8 per cent more than IF₅₀ treatments. The reduction in irrigations resulted into lowering down the Cu and maintaining low soil moisture status particularly under IF₁₀₀ treatments. The reduction in irrigation with subsequent lowering down of Cu was noticed under sprinkler irrigation treatment. Available soil moisture quantity was recouped then the variable depth of irrigation at each irrigation treatment had resulted into lowering down the consumptive use. It was 285, 270 and 255 mm under IS₅₀, IS₇₅ and IS₁₀₀ irrigation treatments respectively (Table 4.5). The reduction amongst irrigation treatments under sprinkler irrigation was also not prominent. It was due to the application of requisite quantity of water which was depleted during the irrigation interval. The liquid phase is considered initially and it was useful to introduce the concept of hydraulic conductivity by first considering flow through a saturated system. There is no need for an elaborate treatment of fluid

Table 4.5 Consumptive use, average daily consumptive use, total pan evaporation, average daily pan evaporation and average evapotranspiration ratios in irrigation. (1988-89)

Parameters	Treatments								
	IF 50	IF 75	IF 100	IS 50	IS 75	IS 100	ID 1	ID 2	ID 3
1. No. of irrigations	* 7+1=8	* 5+1=6	* 3+1=4	* 7+1=8	* 5+1=6	* 3+1=4	120	60	40
2. Average interval, days	15.0	20.0	30.0	15.0	20.0	30.0	1	2	3
3. Effective rainfall, mm	-	-	-	-	-	-	-	-	-
4. Consumptive use, mm	370	350	310	285	270	255	155	155	155
5. Average daily consumptive use, mm/day	3.08	2.91	2.58	2.37	2.25	2.12	1.29	1.29	1.29
6. Total pan evaporation, mm	401	401	401	401	401	401	401	401	401
7. Average daily pan evaporation, mm/day	3.34	3.34	3.34	3.34	3.34	3.34	3.34	3.34	3.34
8. ET/PE	0.92	0.87	0.77	0.70	0.67	0.63	0.38	0.38	0.38

* Common irrigation applied at the time of transplanting of tomato seedlings.

Table 4.6 Total consumptive use, average daily consumptive use, total pan evaporation, average daily pan evaporation and average evapotranspiration rates in irrigation. (1989-90)

Parameters	Treatments								
	IF 50	IF 75	IF 100	IS 50	IS 75	IS 100	ID 1	ID 2	ID 3
1. No. of irrigations	* 8+1=9	* 5+1=6	* 4+1=5	* 8+1=9	* 5+1=6	* 4+1=5	120	60	40
2. Average interval, days	13	20	24	13	20	24	1	2	3
3. Effective rainfall, mm	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
4. Consumptive use, mm	395	375	325	294	283	266	180	180	180
5. Average daily consumptive use; mm/day	3.29	3.12	2.70	2.45	2.36	2.21	1.50	1.50	1.50
6. Total pan evaporation, mm	461	461	461	461	461	461	461	461	461
7. Average daily pan evaporation, mm/day	3.84	3.84	3.84	3.84	3.84	3.84	3.84	3.84	3.84
8. ET/PE	0.85	0.81	0.70	0.63	0.61	0.57	0.39	0.39	0.39

* Irrigation applied at the time of transplanting of tomato seedlings.

flow in saturated solids as many reviews of this topics are available (Philip, 1957, Philip and de Vries, 1957).

The consumptive use in the case of drip irrigation was 155 mm which was equal for all treatment (Table 4.5 and 4.6). The irrigation treatments of IF and IS were considered for optimal consumptive use on the basis of highest yield obtained. The yield obtained which was 2.4 and 1.8 times for IF and IS more respectively as compared to drip irrigation. Average daily consumptive use showed similar trend. There is a vast difference between the values of average daily consumptive use of surface irrigation and drip irrigation treatments. These values were 2 to 2.5 times more than the furrow and sprinkler irrigation treatments. Similar trends were recorded in the case of ET/PE ratio for both the years.

4.3.2 Water use efficiency

The consumptive use efficiency and water saving under different irrigation treatments are presented in Table 4.7. The water use efficiency values were highest in the case of drip irrigation systems, exhibiting the range of 29.0 to 29.9 Kg/ha-mm for the year 1988-89 and 21.7 to 22.7 Kg/ha-mm in the year 1989-90. In general, the water use efficiency in the year 1989-90 was relatively less as compared to first year values. This is attributed to high consumptive use and relative low yield. The consumptive use efficiency ranged from 9.7 to 9.8 Kg/ha-mm under furrow irrigation and 12.1 to 14.0 Kg/ha-mm for sprinkler irrigation treatments. In general, water use efficiency values in the case of drip irrigation were 2 to 3 times more than sprinkler and furrow irrigation treatments.

Table 4.7 Consumptive use efficiency and relative water savings under different irrigation treatments for both years of investigation.

Treatments	Consumptive use, mm		Consumptive use efficiency, Kg/ha-mm		Water saving, per cent <i>in drip.</i>	
	1988-89	1989-90	1988-89	1989-90	1988-89	1989-90
IF 50	370	395	9.7	8.2	55.9	55.2
IF 75	350	375	9.7	8.1	55.5	52.8
IF 100	310	320	9.8	8.5	50.0	43.7
IS 50	285	294	14.0	12.1	45.3	37.1
IS 75	270	283	13.5	11.8	42.3	37.1
IS 100	255	261	12.1	10.8	39.2	31.0
ID 1	155	180	29.4	22.5	-	-
ID 2	155	180	29.9	22.7	-	-
ID 3	155	180	29.0	21.7	-	-

On the basis of lowest consumptive use, the comparisons were made in respect of water savings and percentage water savings reported in Table 4.7. In general, there was a significant water saving ^{due to drip} to the maximum extent of 55.9, as compared to furrow and 45.3 per cent in sprinkler irrigation treatments. Water saving values were relatively less in the year 1989-90.

4.4. Assessment of water stress by Infrared Thermometry

Irrigation scheduling methods currently used are soil moisture measurements, plant measurements and ET models. The role of remote sensing into these various approaches has been investigated by a number of workers (Jackson *et al.* 1977, Clawson and Blad 1982, Hatfield *et al.* 1980 and Geyser *et al.* 1980). Evapotranspiration model could be developed with a leaf area index. A comparison of midday canopy and air temperature could be used to estimate water requirement. The leaf water potential is also related to a comparison of crop canopy (T_c) minus air temperature. These data suggested that remote sensing inputs could be effectively utilized for evaluating crop stress and irrigation scheduling.

4.4.1 Midday crop canopy temperature, T_c

Canopy temperatures were measured before and after irrigation at 14.30 hours with infrared thermometers and crop canopy temperature data as influenced by different irrigation treatments of furrow and sprinkler methods manifesting soil water potential are reported in Fig. 4.14 and 4.15 respectively for the years 1988-89 and 1989-90.

The crop canopy temperature before irrigation was less than air temperature by 2.1 to 3.2 °C under IF₅₀, 1.5 to 2.3 under IF₇₅, 0.5 to 0.9 °C under IF₁₀₀ treatments in the year 1988-89. Similar trend was

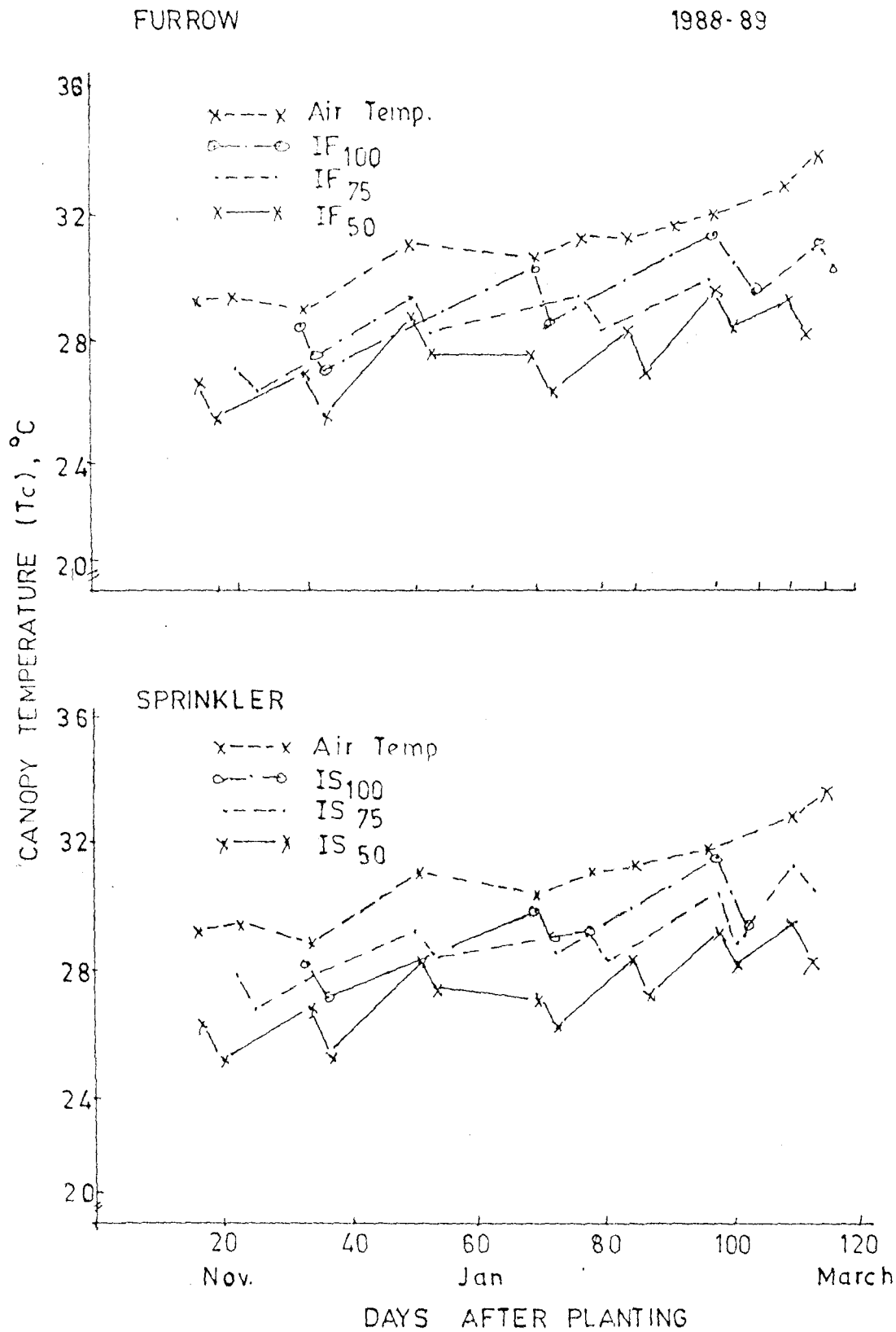


Fig.4.14. Crop canopy temperature in relation to different soil moisture regimes under furrow and sprinkler irrigation during crop growth. (1988-89)

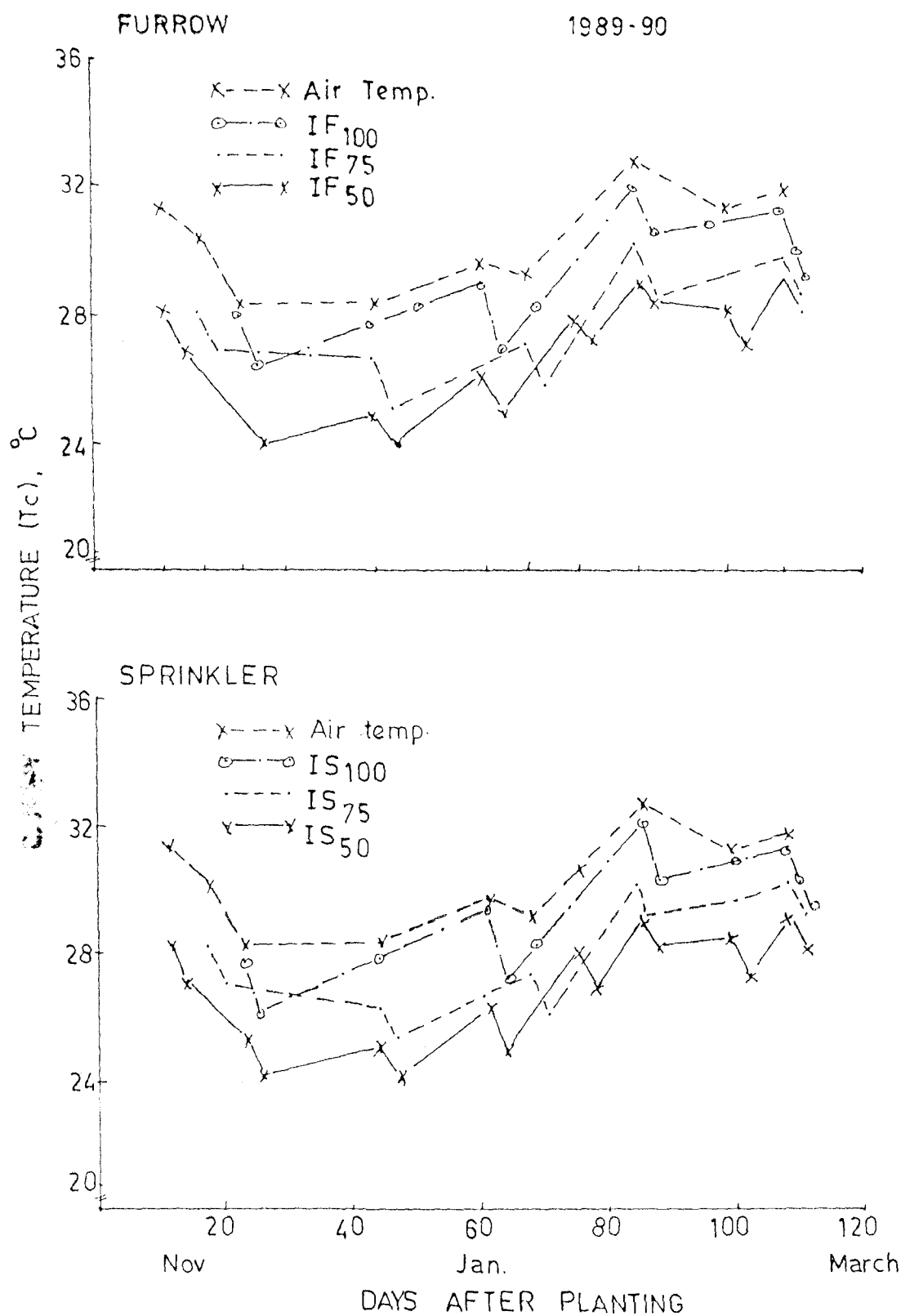


Fig. 4.15. Crop canopy temperature in relation to different soil moisture regimes under furrow and sprinkler irrigation during crop growth. (1989-90)

observed in the year 1989-90. Crop canopy temperature (T_c) minus air temperature (T_a) differences decreased as irrigation prolonged and available soil moisture in the profile reduced concomitantly. The values for available soil depletion (MAD) were 0.52, 0.55 and 0.65 before each irrigation scheduled at 50, 75 and 100 mm CPE respectively. It is evident that as the soil moisture become limiting, crop canopy temperatures were generally high and $T_c - T_a$ difference become zero or positive (Hatfield, 1980). Air temperatures increased slowly from the 48th meteorological week and were maximum (32.8°C) at the time of harvest.

Crop canopy temperatures were also recorded after water application at field capacity as per the furrow treatments and depicted in Fig. 4.14 and 4.15. It gave an idea of crop canopy temperature range which existed during the each rotation scheduled as per furrow treatments. It is interesting to note that available moisture content in the soil profile played a major role in controlling crop canopy temperature, when the crop was rewatered at 100 mm CPE. The $T_c - T_a$ values decreased and the canopy was cooler before irrigation temperatures or air temperature. The differences in the temperatures recorded before irrigation and after irrigation ranged from 1.0 to 1.4°C , 1.5 to 1.8°C and 1.7 to 1.8°C in case of 50, 75 and 100 mm CPE respectively in furrow method. A similar trends was recorded in the case of sprinkler irrigation scheduled at 50, 75 and 100 mm CPE.

Crop canopy temperatures under drip irrigation treatments were recorded at an equal interval of 50 mm CPE from transplanting and depicted in Fig. 4.16. Corresponding air temperatures were also measured and showed for of comparison. It is evident from the figure that crop

canopy temperatures in ID₁, ID₂ and ID₃ treatments were almost same with slight difference of about 1°C in both the years. Initially high values of crop canopy temperature in the year 1989-90 was attributed to high aerial temperature data. Less temperature differences amongst the treatments were due to the lower water potential data maintained by daily, alternate day and three days water application system. On basis of NIR, the water was applied as per the treatments. Crop canopy temperature, (T_c) and air temperature (T_a) difference were found to be negative.

4.4.2 Air temperature

Whenever crop canopy temperatures in different irrigation treatments were recorded, air temperature was also recorded by infrared thermometer at that time. Air temperature and crop canopy temperature data are depicted in comparison with furrow and sprinkler irrigation treatments for the year 1988-89 (Fig. 4.14). Air temperature data as function of time during both years of investigation showed the increasing trend from 47th meteorological week onwards. Air temperature was in the range of 28.9 to 32.8°C and 28.1 to 31.9°C from the 47 to 8 meteorological weeks for the years 1988-89 and 1989-90 respectively.

4.4.3 CATD (T_c-T_a)

Canopy temperature is simply deducted from air temperature to work out an index which was considered as a substitute for the approach of scheduling of irrigation on the basis of cumulative pan evaporation. Data on canopy and air temperature before each irrigation scheduled on the basis of CPE or specific period in different treatments are reported in Table 4.8 and 4.9 for the years 1988-89 and 1989-90 respectively.

The comparison is made for $T_c - T_a$ differences under furrow and sprinkler irrigation methods at specified period fixed on the basis of CPE. However, the comparison was also made at soil moisture constant of field capacity. The soil moisture was almost at field capacity in all drip irrigation treatments. The negative differences were very large in case of drip irrigation treatments i.e. 3.1 to 4.5 °C (88-89) and 3.5 to 4.5 °C (89-90) even though difference amongst treatments were meagre. It was totally controlled by uniform SWP(ψ_s) values existed during entire crop growth period, under drip irrigation method. Hatfield (1980) and others explained these concepts and relationship between $T_c - T_a$ and SWP(ψ_s) values were manifested either by rainfall or irrigation. Measurement of crop canopy and air temperatures differences (CATD) would be alternative for scheduling irrigations under specified conditions.

Crop canopy and air temperature differences (CATD) as influenced by soil water potential levels created by different irrigation treatments are reported in Table 4.10, for both the years of experimentation for the purpose of isolation. The mean values of CATD were -2.81, -1.85 and -0.7 °C for the irrigation treatments of IF₅₀, IF₇₅ and IF₁₀₀, respectively. There were little differences in CATD values in respect of furrow and sprinkler irrigation methods scheduled at 50, 75 and 100 mm CPE. However, CATD values were slightly different in the second year under furrow as well as sprinkler irrigation methods scheduled at 50, 75 and 100 mm CPE values. CATD values were comparatively less by 0.2 in the first year. The CATD range was much greater in case of 50 mm CPE treatment than 75 and 100 mm CPE treatments. It is evident

Table 4.8 contd...

Days after plant ing	Canopy temperature, °C											
	IS			ID			ID			ID		
	100			1			2			3		
	Tc	Ta	CATD (-)	Tc	Ta	CATD (-)	Tc	Ta	CATD (-)	Tc	Ta	CATD (-)
17	-	-	-	25.2	29.2	4.0	25.3	29.2	3.9	25.3	29.2	3.9
23	-	-	-	25.0	29.3	4.3	25.2	29.3	4.1	25.2	29.3	4.1
34	28.0	28.9	0.9	25.3	28.9	3.6	25.5	28.9	3.4	25.8	28.9	3.1
51	-	-	-	26.8	31.0	4.2	26.8	31.0	4.2	27.0	31.0	4.0
70	39.5	30.3	0.8	26.0	30.3	4.3	26.2	30.3	4.1	26.5	30.2	3.8
78	-	-	-	27.0	31.0	4.0	27.2	30.0	3.8	27.2	31.0	3.8
85	-	-	-	27.2	31.2	4.0	27.2	31.2	4.0	27.5	31.2	3.7
98	30.8	31.9	1.1	28.0	31.9	3.9	28.2	31.9	3.7	28.5	31.9	3.4
110	-	-	-	28.2	32.8	4.6	28.2	32.8	4.6	28.5	32.8	4.3

that as the soil moisture became limiting, the daily CATD values were generally positive. When the crop was watered at 100 mm CPE, the CATD values decreased and the canopy was cooler than air. The response of the crop was almost immediate after waterings. In this connection, it is interesting to place the zero line of $T_c - T_a$ with the corresponding available soil moisture depletion level. Hatfield (1981) working with the wheat, the zero line for $T_c - T_a$ placed at the extraction limit of 65 per cent of the available water and in these data when the water availability dropped below this point, leaf temperature remained elevated above air temperature.

The ($T_c - T_a$) or CATD values of grand mean for the CPE of 50, 75 and 100 mm CPE came to -2.88, -1.96 and -0.62 respectively under furrow irrigation for tomato crop. The difference in furrow irrigation and sprinkler irrigation methods are meagre. These CATD values were estimated before irrigation at the same achievement of the soil moisture constant of field capacity. Exact quantity of water was estimated and applied to bring the soil at field capacity. However, relatively more quantity of water was applied in furrow irrigation system to meet hydraulic demand for moving water. Hence, soil moisture status under furrow and sprinkler irrigation methods were almost similar from the point at field capacity to water application. Idso *et al.* (1981) and Jackson *et al.* (1981) emphasised the need of refinement for the aspect stress degree-day which could become positive after 65 per cent of the available water depletion.

The CATD values under drip irrigation treatments of ID₁, ID₂ and ID₃ are reported in Table 4.10 and 4.11. The mean value of CATD recorded at certain time interval was -4.5 C. The soil moisture

Table 4.9 Crop canopy and air temperature differences data in relation to soil moisture regimes created by different treatments during the crop growth. (1989-90)

Days after plant ing	Corres-ponding meteoro-logical week	Canopy temperature, °C														
		IF 50			IF 75			IF 100			IS 50			IS 75		
		Tc	Ta	CATD (-)	Tc	Ta	CATD (-)	Tc	Ta	CATD (-)	Tc	Ta	CATD (-)	Tc	Ta	CATD (-)
11	47	28.5	31.3	2.8	-	-	-	-	-	-	28.4	31.3	3.3	-	-	-
17	48	-	-	-	28.2	30.3	2.1	-	-	-	-	-	-	27.5	30.3	2.8
23	49	25.3	28.1	2.8	-	-	-	27.8	28.1	0.3	24.5	28.1	3.6	-	-	-
44	51	25.2	28.4	3.2	26.3	28.4	2.1	-	-	-	25.0	28.4	3.4	26.0	28.4	2.4
61	2	26.4	29.7	3.3	-	-	-	29.5	29.7	0.2	26.0	29.7	3.7	-	-	-
68	3	-	-	-	27.3	29.2	1.9	-	-	-	-	-	-	27.1	29.2	2.1
75	4	28.2	30.9	2.7	-	-	-	-	-	-	27.5	30.9	3.4	-	-	-
85	6	27.2	30.2	3.0	27.8	30.2	2.4	29.2	30.2	1.0	27.0	30.2	3.2	28.2	30.2	2.0
99	8	28.5	31.3	2.8	-	-	-	-	-	-	28.0	31.3	3.3	-	-	-
110	9	29.2	31.9	2.7	30.02	31.9	1.7	31.2	31.9	0.7	28.8	31.9	3.1	29.0	31.9	2.9

Table 4.9 contd...

Days after planting	Canopy temperature, °C											
	IS			ID			ID			ID		
	100			1			2			3		
	Tc	Ta	CATD (-)	Tc	Ta	CATD (-)	Tc	Ta	CATD (-)	Tc	Ta	CATD (-)
11	-	-	-	27.4	31.3	3.9	27.5	31.3	3.8	27.8	31.3	3.5
17	-	-	-	26.3	30.3	4.0	26.5	30.3	3.8	26.8	30.3	3.5
23	27.5	28.1	0.6	24.2	28.1	3.9	24.2	28.4	4.2	24.4	28.1	3.7
44	-	-	-	24.0	28.4	4.4	24.2	28.4	4.2	24.4	28.4	4.0
61	29.0	29.7	0.7	25.2	29.7	4.5	25.3	29.7	4.4	25.6	29.7	4.1
68	-	-	-	25.4	29.2	3.8	25.6	29.2	3.6	25.6	29.2	3.6
75	-	-	-	26.0	30.9	4.9	26.2	30.9	4.7	26.4	30.9	4.5
85	29.5	30.2	0.7	28.3	32.8	4.5	28.3	32.8	4.5	28.5	32.8	4.3
99	-	-	-	27.4	31.3	3.9	27.6	31.3	3.7	27.7	31.3	3.6
110	31.1	31.9	0.8	27.8	31.9	4.1	28.0	31.9	3.9	28.0	31.9	3.9

Table 4.10 Crop canopy and air temperature differences (Tc-Ta)
before irrigation under furrow and sprinkler irrigation
methods of tomato.(1988-89)

Days after plant ing	CATD, °C					
	IF 50	IF 75	IF 100	IS 50	IS 75	IS 100
17	-2.9	-	-	-2.5	-	-
23	-	-1.5	-	-	-2.3	-
34	-2.5	-	-0.7	-3.0	-	-0.5
51	-2.1	-2.3	-	-2.5	-1.7	-
70	-3.2	-	-0.5	-2.9	-	-0.3
78	-	-2.0	-	-	-1.8	-
85	-2.8	-	-	-3.1	-	-
98	-2.8	-1.6	-0.9	-2.5	-2.1	-0.7
110	-3.4	-	-	-3.7	-	-
Mean	-2.81	-1.85	-0.7	-2.88	-1.98	-0.57

Table 4.11 Crop canopy and air temperature differences (Tc-Ta) before irrigation under furrow and sprinkler irrigation methods of tomato.(1989-90)

Days after planting	CATD, °C					
	IF 50	IF 75	IF 100	IS 50	IS 75	IS 100
11	-3.1	-	-	-3.3	-	-
17	-	-2.2	-	-	-2.3	-
23	-2.8	-	-0.4	-3.1	-	-0.1
41	-3.2	-2.1	-	-3.4	-1.8	-
61	-3.3	-	-0.5	-3.5	-	-0.7
68	-	-1.9	-	-	-2.2	-
75	-2.8	-	-	-2.9	-	-
85	-3.0	-2.0	-0.6	-3.1	-2.4	-0.8
99	-2.8	-	-	-3.1	-	-
110	-2.7	-1.7	-0.7	-2.7	-2.4	-0.6
Mean	-2.9	-2.0	-0.5	-3.1	-2.1	-0.5
Grand mean	-2.9	-1.9	-0.6	-3.0	-2.0	-0.5

contents were at field capacity and in the depleted soil moisture was recouped with in short interval in all treatments. These values were found to be minimum in case of drip irrigation. The canopy temperature is related to the rate of transpirations as the energy is utilized for the evaporation of water. It reduced the temperature of plant under the treatment of drip irrigation as availability of a water was more and there was a every possibility of higher transpiration rate which might have appeared in reducing the canopy temperature (Daubenmire, 1970 and Gupta, 1988).

4.4.4 Stress degree days (SDD)

The values of SDD as influenced by different irrigation treatments are reported in Table 4.12 for both years. These values are summed up for fixed period and plotted against different treatments have been depicted in Fig. 4.17. It is true that the stress degree day values did not decrease to zero, but it was due to management allowable deficit level maintained above the critical limit. A similar effect was noted in the year 1989-90 under same set of treatments. It is observed that $T_c - T_a$ values were always negative during the said investigation and extent of available soil moisture was below the critical level under 100 mm CPE treatment in both surface and sprinkler methods. However, ID treatment recorded lower SDD (-344) than IF₅₀ and IS₁₀₀ treatment (-213 and -52). Hatfield (1981) indicated the zero lines for $T_c - T_a$ at the extraction limit of 65 per cent of the available water for grain sorghum crop. This point could not be reach in the present investigation as the crop was not subjected to severe stress conditions in any of the treatments under present investigation. However, the main object of evaluation of CATD

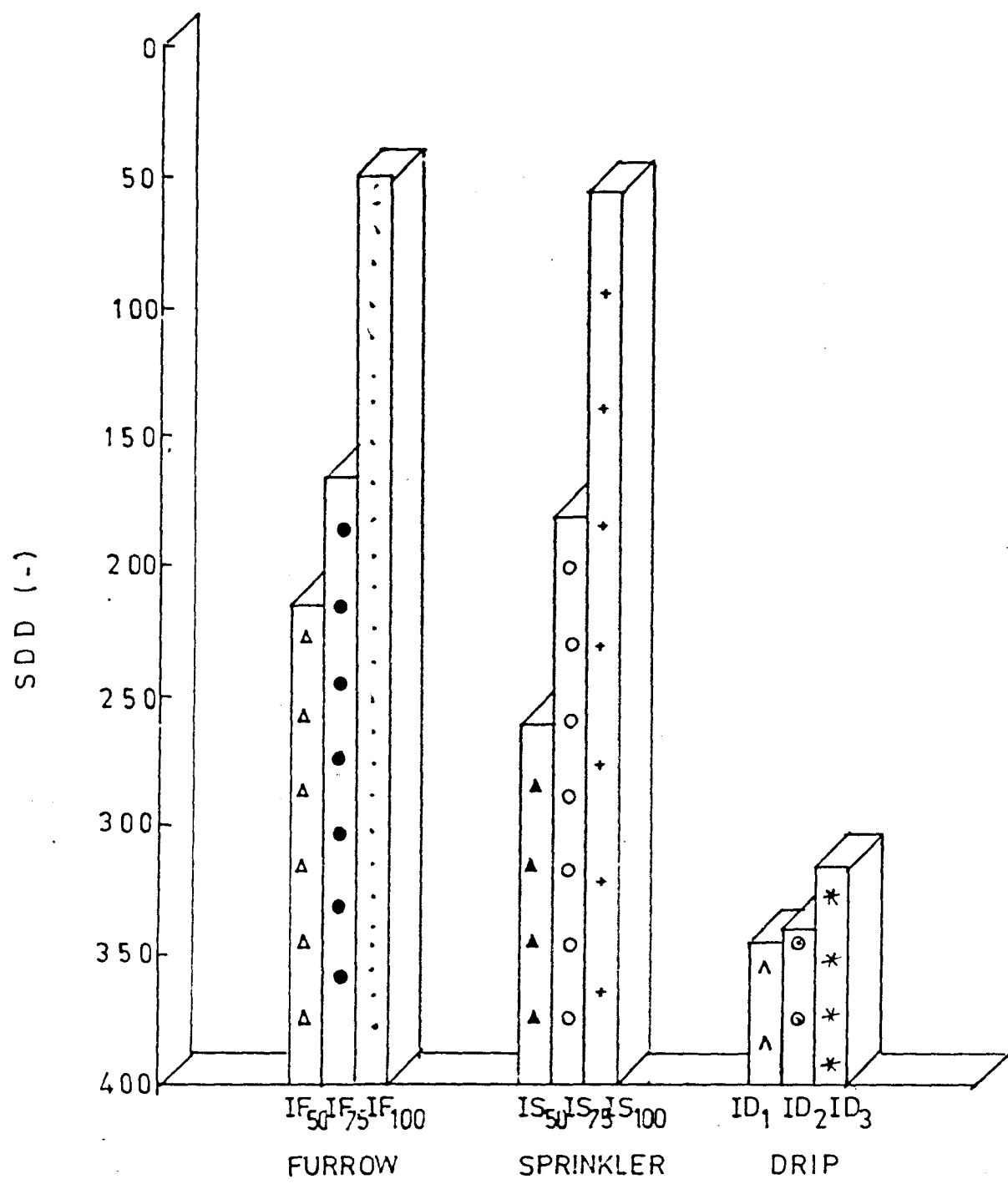


Fig. 4.17. Summation of stress degree day as influenced by different soil moisture regimes.

for the purpose of scheduling of irrigation was achieved to the maximum extent.

Stress-degree-days is a similar concept like CATD which is worked out from crop canopy and air temperature difference ($T_c - T_a$) measured at mid day (Idso *et al.* 1977). The cumulative value of the SDD over the entire crop growth period season is known as cumulative stress degree day ($\sum SDD$) and many researchers have tried to relate the $\sum SDD$ to grain yield (Hatfield, 1981 and Tripathi *et al.* 1985). The SDD values were summed up for the period from 23 to 108 days from planting and are presented in Table 4.12. It is negatively related to the

Table 4.12 Summation of Stress-degree-day as influenced by different soil moisture regimes during crop growth period.

Treatments	$\sum SDD (-)$		Mean (-)
	1988-89	1989-90	
IF	221.5	205.2	213
50			
IF	151.7	178.4	165
75			
IF	40.8	49.3	45
100			
IS	248.0	279.0	263
50			
IS	169.2	189.2	179
75			
IS	61.2	43.0	52
100			
ID	348.0	340.0	344
1			
ID	355.0	328.0	341
2			
ID	330.0	324.0	327
3			

cumulative stress degree day. These results are similar to that of Hatfield,(1981) for grain sorghum and Walker and Hatfield (1979) for kidney beans. However, Walker and Hatfield (1979) had previously shown that the stress degree days does not indeed relate to water stress to which the crop is subjected. Unfortunately, the water stress range was little in the present investigation and can be questioned for establishment of such water use : SDD relationship, as a full project. It is encouraging here that the data available in 9 treatments grouped into 4 types i.e. 3 CPE treatments plus one drip treatment for 1988-1989 and 1989-90 will fit into the population. With this type of relationship, it is reasonable to expect that the stress degree day approach would provide a method of irrigation scheduling, However, it is necessary that the time period be expressed in days rather than a complete phenological stage.

4.5 Leaf water potential (Ψ_L)

An attempt was made to establish the relationship between plant parameters (as dependent variable) and available soil moisture (as independent variable) in terms of percentage available moisture in the root zone. Available soil moisture fluctuation were recorded for 60 cm soil profile depth, as influenced by different irrigation treatments. Afternoon (14.30 hours) leaf water potential (Ψ_L) data recorded before and after each irrigation during the entire crop growth period in case of furrow and sprinkler methods are reported in Table 4.13 for 1988-89 and 1989-90 respectively. Afternoon LWP values under drip irrigation on the same date of observation by IF and IS treatments of furrow and sprinkler methods are presented in Table 4.14.

Table 4.13 Leaf water potential (ψ_L) of a tomato as influenced by furrow and sprinkler irrigation methods.

Days after planting	Leaf water potential (ψ_L) - MPa											
	IF 50		IF 75		IF 100		IS 50		IS 75		IS 100	
	BI	AI	BI	AI	BI	AI	BI	AI	BI	AI	BI	AI
	<u>1988-89</u>											
17	1.09	0.95	-	-	-	-	1.05	0.90	-	-	-	-
23	-	-	1.14	1.00	-	-	-	-	0.11	0.96	-	-
34	1.15	1.00	-	-	1.24	1.11	1.12	0.98	-	-	1.22	1.08
51	1.21	1.08	1.30	1.15	-	-	1.20	1.04	1.27	1.10	-	-
70	1.29	1.16	-	-	1.45	1.30	1.26	1.09	-	-	1.40	1.25
78	-	-	1.38	1.22	-	-	-	-	1.34	1.17	-	-
85	1.36	1.22	-	-	-	-	-	-	1.30	1.15	-	-
98	1.42	1.25	1.47	1.30	1.59	1.40	1.36	1.19	1.42	1.25	1.54	1.37
110	1.51	1.35	-	-	-	-	1.44	1.26	-	-	-	-
	<u>1989-90</u>											
11	1.24	1.10	-	-	-	-	1.21	1.02	-	-	-	-
17	-	-	1.36	1.22	-	-	-	-	1.34	1.12	-	-
23	1.33	1.18	-	-	1.42	1.28	1.27	1.04	-	-	1.40	1.25
41	1.40	1.26	1.41	1.26	-	-	1.32	1.17	1.40	1.25	-	-
61	1.42	1.27	-	-	1.51	1.37	1.37	1.20	-	-	1.49	1.33
68	-	-	1.49	1.33	-	-	-	-	1.46	1.30	-	-
75	1.44	1.28	-	-	-	-	1.41	1.26	-	-	-	-
85	1.49	1.32	1.57	1.40	1.68	1.51	1.47	1.22	1.53	1.35	1.60	1.43
99	1.52	1.35	-	-	-	-	1.50	1.34	-	-	-	-
108	1.57	1.40	1.69	1.51	1.76	1.58	1.53	1.35	1.64	1.45	1.74	1.56

BI = Before irrigation, AI = After irrigation

Table 4.14 Leaf water potential (Ψ_L) of tomato as influenced by different soil moisture regime under drip irrigation

Days after planting	Leaf water potential, (Ψ_L)- MPa					
	ID 1		ID 2		ID 3	
	BI	AI	BI	AI	BI	AI
	<u>1988-89</u>					
17	0.91	0.85	0.91	0.86	0.93	0.87
23	1.00	0.95	1.05	0.97	1.07	0.98
34	1.06	1.00	1.08	1.01	1.09	1.02
51	1.10	1.05	1.12	1.96	1.14	0.07
70	1.13	1.08	1.15	1.09	1.16	1.10
85	1.21	1.13	1.23	1.14	1.24	1.15
98	1.25	1.16	1.26	1.17	1.27	1.18
110	1.30	1.20	1.30	1.21	1.31	1.22
	<u>1989-90</u>					
11	1.01	0.98	1.08	1.00	1.10	1.02
17	1.05	1.00	1.10	1.01	1.13	1.04
23	1.10	1.05	1.15	1.07	1.17	1.08
41	1.12	1.07	1.19	1.08	1.20	1.10
61	1.17	1.12	1.22	1.13	1.23	1.15
68	1.20	1.14	1.25	1.15	1.26	1.17
75	1.22	1.17	1.27	1.19	1.29	1.20
85	1.26	1.19	1.29	1.20	1.30	1.25
99	1.31	1.24	1.32	1.25	1.34	1.27
110	1.36	1.26	1.38	1.27	1.40	1.28

The variation in afternoon leaf water potential at two extreme levels of moisture during the critical growth stages of crop coupled with irrigation were governed by environmental and plant resistances. Afternoon LWP value of -1.01 MPa was decreased to -1.51 MPa before irrigation however it decreased from -0.95 (first irrigation) to -1.3 MPa (last irrigation) at field capacity (after irrigation) under furrow irrigation scheduled at 50 mm CPE. It gave highest frequency of 7 irrigations during entire crop growth period. The differences of LWP values between the period of after irrigation and before irrigation were almost similar at all irrigations. Similar trends were recorded under IF₇₅ and IF₁₀₀ treatments as well as under sprinkler irrigation treatments. 10) These inferences were confirmed by the second year study.

The range of LWP under furrow and sprinkler irrigation treatments was also indicated that there was consistency in plant behaviours as influenced by environmental as well as plant factors. Eventhough, there was uniform trend of LWP but LWP values in second year crop were relatively low as compared to first year under similar set of soil moisture regimes. Particularly under soil moisture stress conditions the LWP values had increased to -1.57 and -1.54 MPa for the treatments of IF₁₀₀ and IS₁₀₀ respectively. As soil water potential decreases or soil leaf resistance increases, the leaf water potential (ψ_L) should become more negative. A number of environmental factors including the air and soil temperature, absolute relative humidity, and soil water availability are known to influence LWP (Nagarajao, 1984). Besides the environmental and soil parameters, plant resistance are also important (Weatherley, 1976). The basic driving force for both liquid and vapour movements is the differences in water potential. However, liquid flow is directly

proportional to the gradient in water potential while vapour flow is not but it is proportional to the vapour pressure gradient.

The variation in LWP before and after water applications was minimum under drip system in all treatments at particular period of observations. There was hardly differences of -0.1 to -0.2 MPa under drip system (Table 4.14). However, leaf water potential (ψ_L) values decreased as vegetative growth of plant increased during the crop growth period. Initial values of LWP (about -1.0 MPa) decreased to -1.30 MPa at maturity. This was attributed to the frequent water application and maintaining steady soil water potential at field capacity level. The critical values of were the vegetative stage of wheat at higher water potential but stomatal opening was ensured during reproductive stage at lower total water potential (Teare *et al.* 1974).

Several workers have reported that scheduling of irrigations using plant based measurements are likely to lead to increased water use efficiency (Stegman *et al.* 1976). Hiler *et al.* (1974) have shown that irrigation water can be used more efficiently if plant water to base need for irrigation. Teare *et al.* (1974) stated that ideally the plant should signal when to irrigate and soil should indicate how much water to apply.

However, recognizing the highly dynamic nature of plant water status data on several aspects have to be obtained to determine the "critical values" of plant factors when the yield is affected, which may be used to indicate the need for irrigation. If one is able to relate the LWP to the SWP and the transpiration rate and stomatal resistance to the LWP (the LWP at which stomatal closure occurs) the estimation of LWP

becomes a possible aid in irrigation scheduling (Nagarajarao and Mallick, 1989).

4.6 Crop growth modelling

The crop water index such as crop canopy air temperature difference, SDD and leaf water potential closely paralleled the removal of water from the root zone. These results suggest that remote sensing input into irrigation scheduling would be feasible and practical. The data on canopy temperature and LWP obtained to evaluate them as indices for water stress, for tomato grown under different levels of water input are to be utilized in developing growth under different levels of water growth and yield models in conjunction with other parameters. The regression equations between LAI and vegetative indices as well as yield and consumptive use of tomato crop are discussed.

4.6.1 CATD and LWP relationship

The crop canopy-air temperature difference and LWP relationship existed between the period of two irrigations under different soil moisture regimes created due to treatments under furrow, sprinkler and drip methods are graphically shown in Fig.4.18. A comparison of the regression coefficient for CATD and LWP showed the linear relationship. The zero line of $T_c - T_a$ is placed at the specific LWP but it did not reach the zero limit in the present investigation as the crop was not subjected to the severe moisture stress. However, large range of CATD (-3.65 to -1.55) was recorded when LWP values were fluctuated between -1.0 to -1.6 MPa. As the LWP decreased, the values of CATD increased from negative towards zero, and linear relationship is significant. Ehrler *et al.* (1978) obtained a linear relationship between plant water potential and CATD upto about -5°C . Further the values of CATD increased slightly

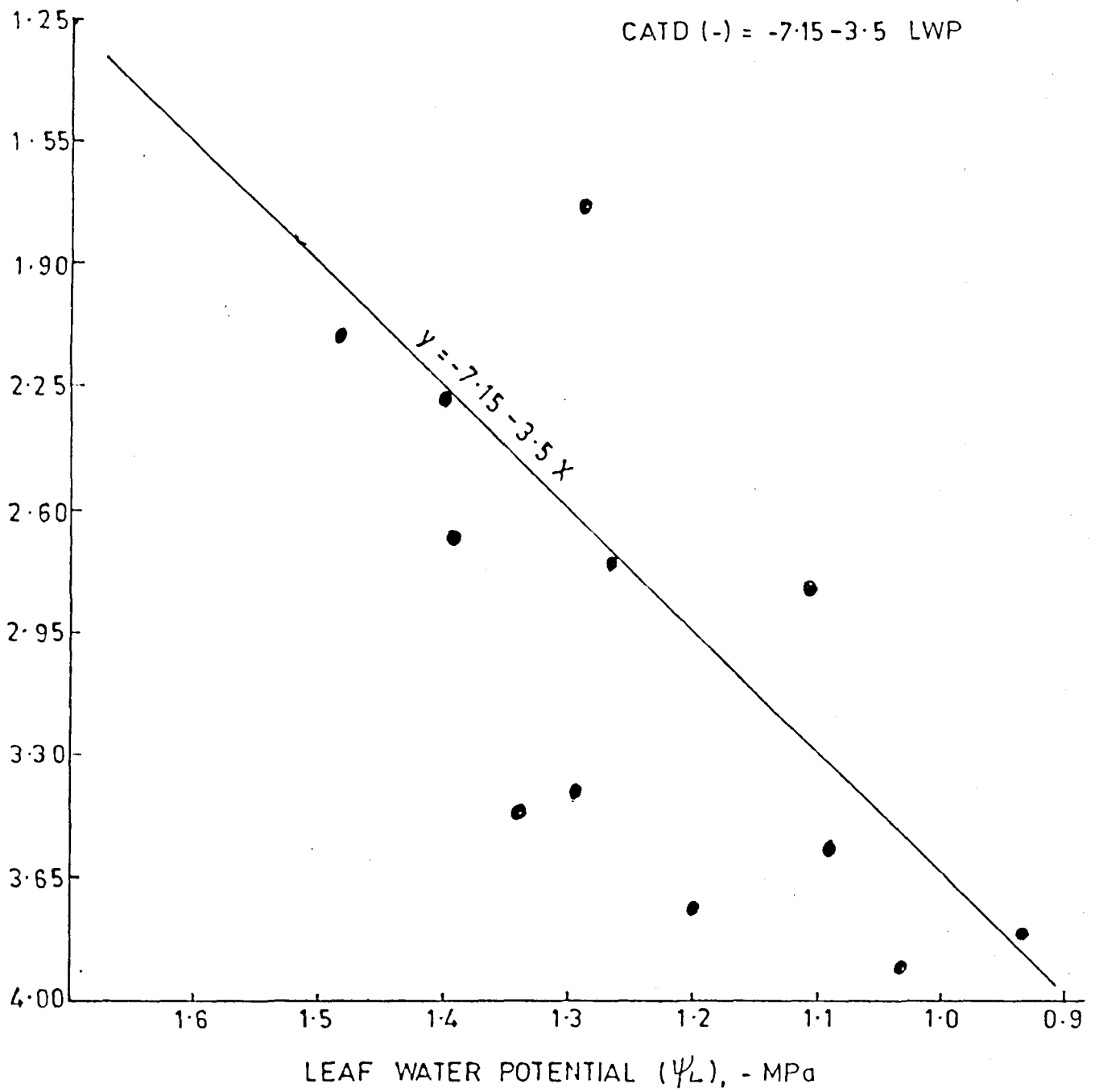
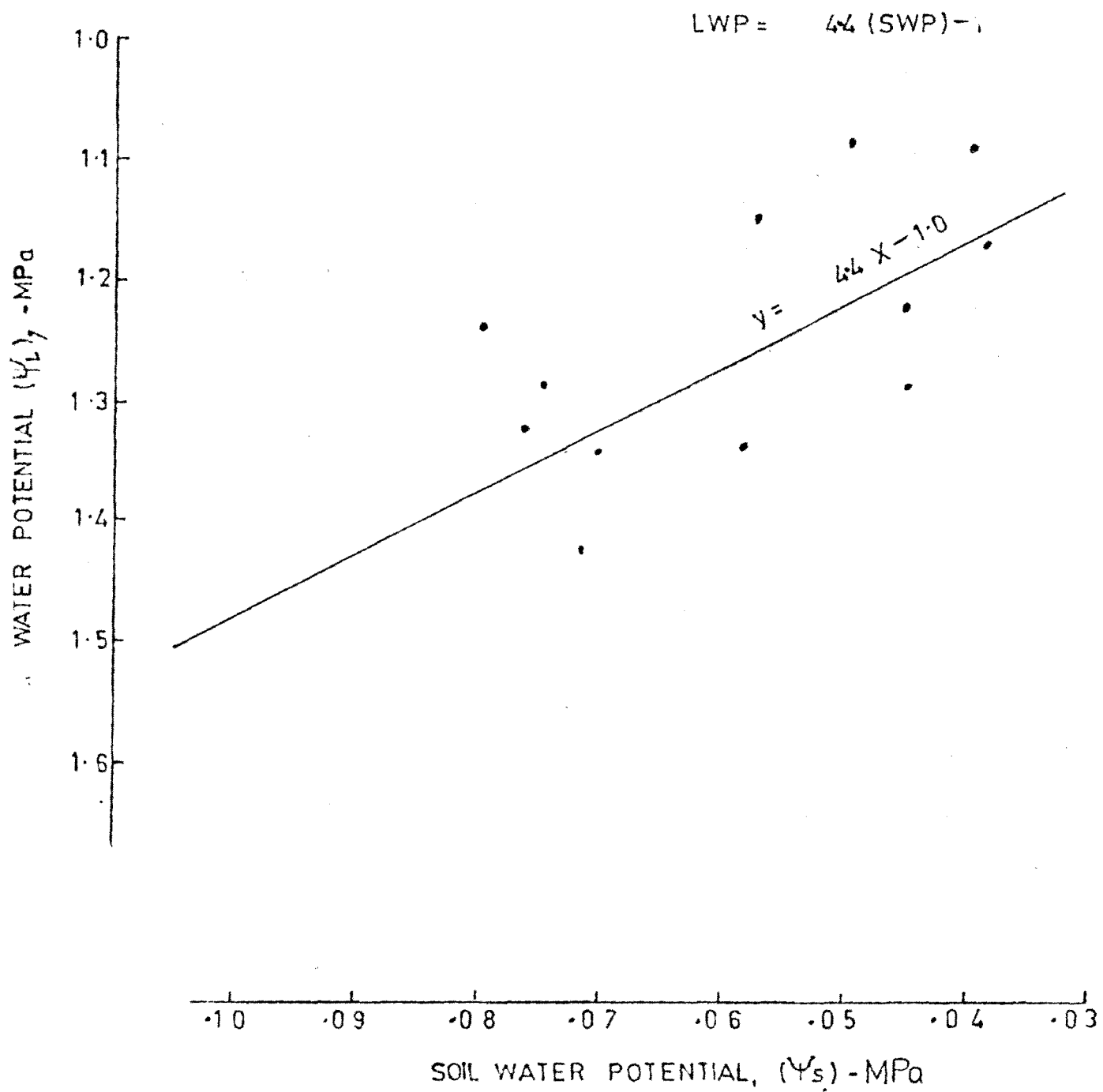


Fig. 4.18. Canopy air temperature difference vs. Leaf water potential (Ψ_L) of tomato.

with decrease in plant water potential. However, Jackson (1982) concluded that canopy temperature would be better measurement or indicator of plant water stress at least during the early stages of stress. The reason was indicated about the relationship of transpiration rate and leaf temperature. As water becomes limiting the transpiration is reduced and leaf temperature increased exhibiting certain relationship. The fit is extremely good with the largest deviation at very low LWP where the problems in attaining a good measurement are difficult. Hatfield *et al.* (1980) reported that as soon as the leaf becomes warmer than air, the leaf water potential decreases below -11 bars. In that investigation the values below this potential have been used as indicative of water stress with prolonged exposure to this level of stress. These data suggest that days with leaf temperature above that of air would be an indicative of stress but should provide a test of the crop stress approach suggested by Idso *et al.* (1981). As the LWP decreased the CATD values increased from negative to positive side.

4.6.2 Soil Water Potential (ψ_s) and leaf water potential (ψ_L) relationship.

Leaf water potential (ψ_L) is dependent on soil moisture content and stomatal resistance as indicated by transpiration rate. The regression coefficient was worked out between these two parameters and the relationship is depicted in Fig. 4.19. Usually increase in the values of SWP had resulted into increase in leaf water potential. The values of LWP at different critical crop growth stages as well as during the different irrigation rotation cycles. It is true that the values of LWP at field capacity stage followed by irrigation did not change. At early stages LWP at field capacity status were comparatively less as compared



Leaf water potential (Ψ_L) of tomato vs Soil water potential (Ψ_s)

to grand growth and maturity critical stages. This was mainly due to physiology and stomatal resistance of the plant. Stegman et al. (1976) suggested that LWP sensitivity to available moisture depends upon the hydraulic properties of the soils. Nagarajrao (1984) reported that there is a progressive development of stress after sun-rise and at 1400 hours. This induces a greater change in LWP per unit change in relative humidity. Both available soil moisture and relative humidity significantly influenced LWP independent of each other.

4.6.3 Stress-degree-day, consumptive use and yield of tomato

The relationship between the water use under different irrigation treatments and summation of stress degree day is given in Fig. 4.20. Similarly the yield of tomato was also correlated to the summation of stress degree day and depicted in Fig. 4.21. It is interesting to note that water use and yield of tomato are negatively related to the accumulation of the stress degree day. Walker and Hatfield (1979) has previously shown that the relationship of CU v/s \sum SDD represents a general confirmation that the stress-degree-day does indeed relate to water stress to which the crop is subjected. Nagarajrao (1984) reported the encouraging data fit into the same population. With this type of relationship it is reasonable to accept the stress degree day approach to provide a method of irrigation scheduling, however, it is necessary that the time period be expressed in days rather than a complete phenological stage. Therefore effect was made to develop a relationship between the stress degree day and water use of a tomato for development of approach for scheduling of irrigations. In the present investigation, yield of tomato v/s \sum SDD relationship was found to decreased the yield of tomato

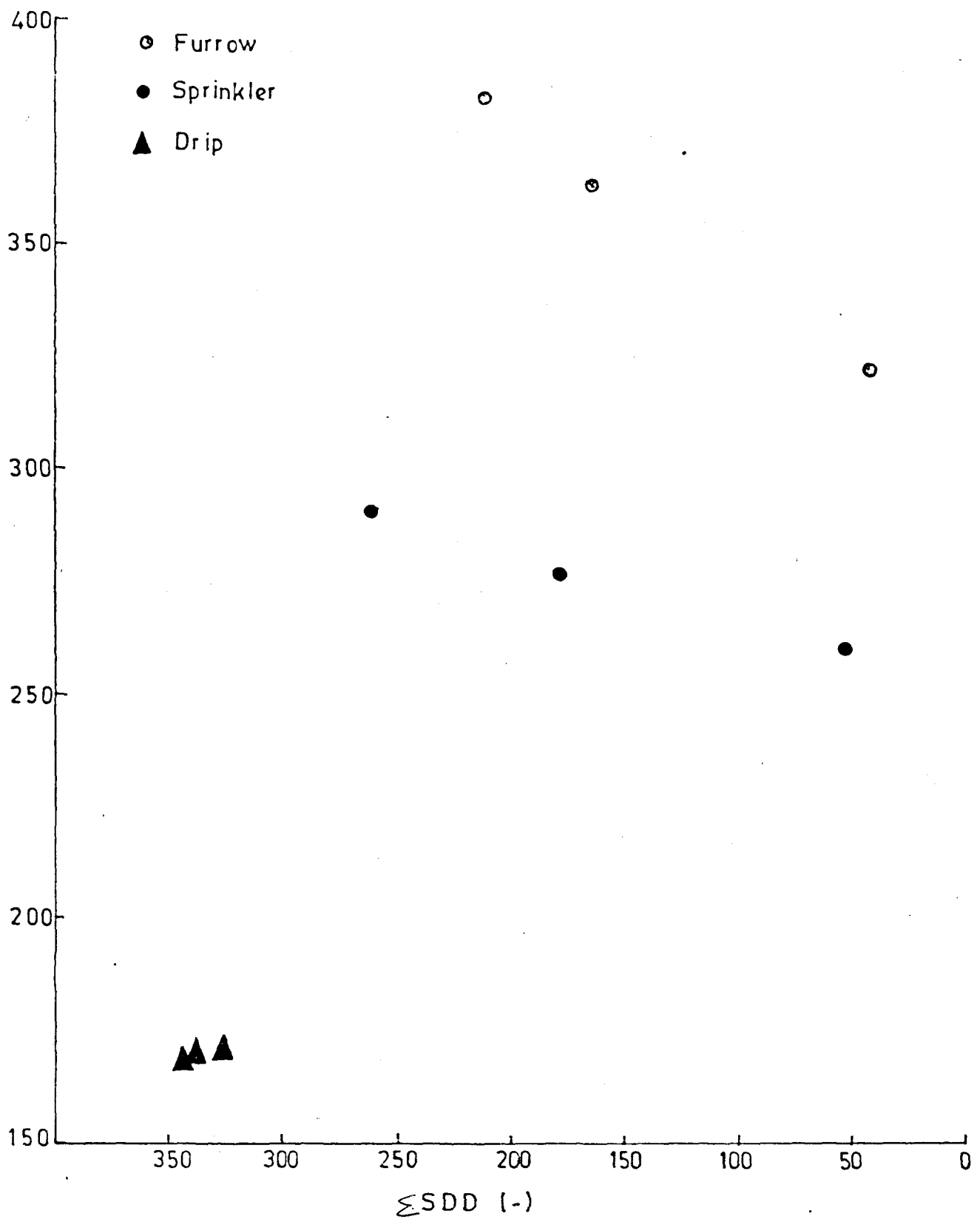


Fig.4.20 Soil moisture use and summation of Stress Degree-Days for tomato crop (Pooled mean)

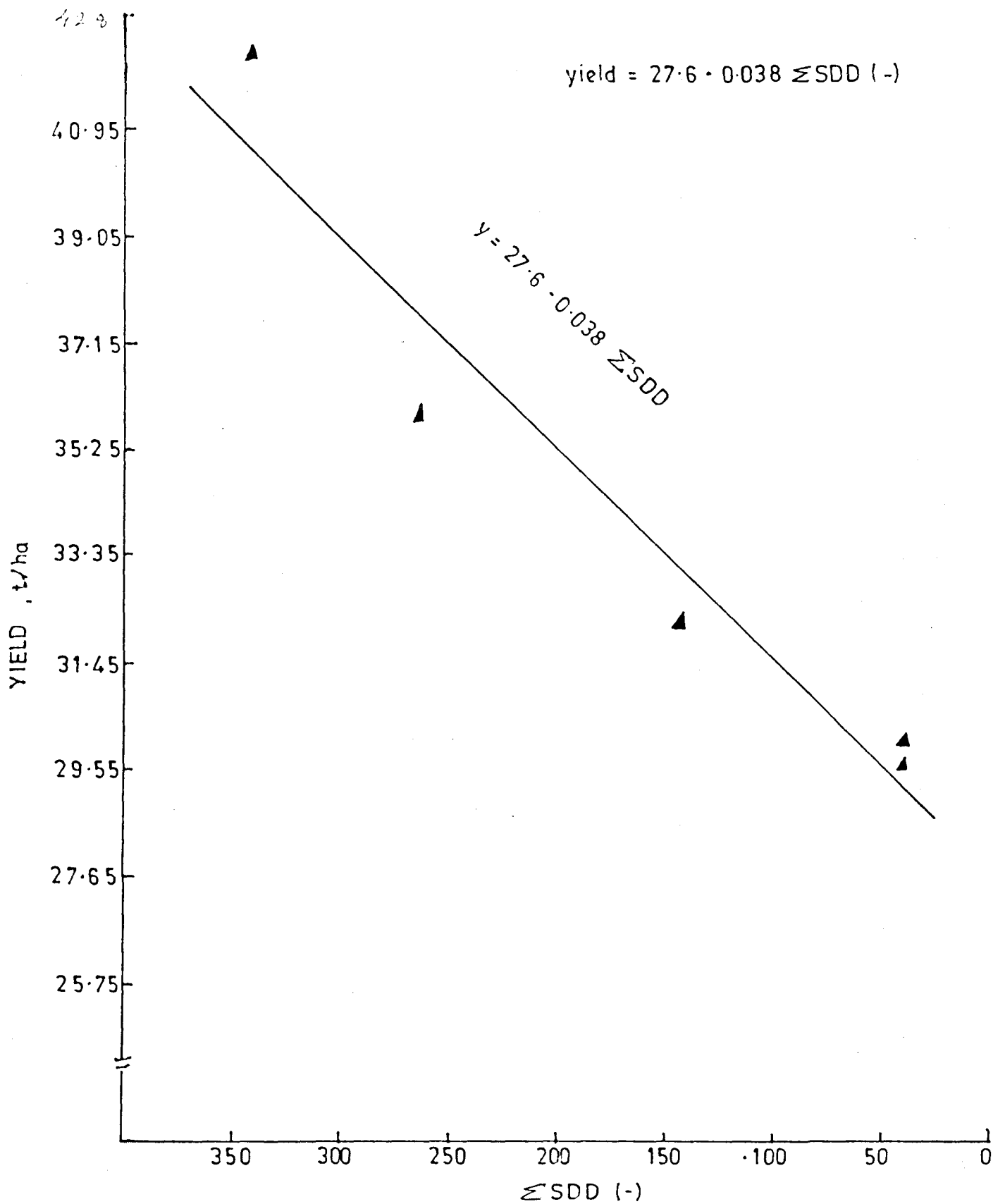


Fig. 4.21. Yield of tomato (t/ha) vs summation of stress degree days.

was also decreased linearly.

Maximum negative value of SDD for the entire crop growth period was found to be -40.9. Even the pooled data (in all respects) also showed significant relationship. The observations were taken from grand growth (30 days) to 50 per cent flower initiation in all treatments but summation of SDD was considered for the entire crop growth period. Nagarajrao (1984) considered the relative humidity and the regression coefficient for relative humidity ranged from 1.38 to 6.80 which may be due to the wider variation recorded in the RH values. Stegman *et al.* (1976) have indicated that relating plant water stress development to variables indicative of prevailing atmospheric environment will enable scheduling of irrigation. In the future investigation further critical evaluation needs to be on the basis of requisite irrigation period.

Similarly leaf water potential (Ψ_L) versus per cent available soil moisture remaining in the root zone relationship is shown in Fig. 4.22. The regression coefficient for ASM were approximately of the same order in all cases. Nagarajrao (1984) reported the regression coefficient of the order of 3.82 to 5.38. Very interesting data on correlation coefficient for relationship between LWP and per cent ASM remaining in the root zone and per cent humidity above crop canopy (RH) of a wheat are reported by Nagarajrao (1984).

Different mathematical equations based on the soil water, plant, atmospheric parameters, yield contributing and quality parameters are presented in Tables 4.15 to 4.16.

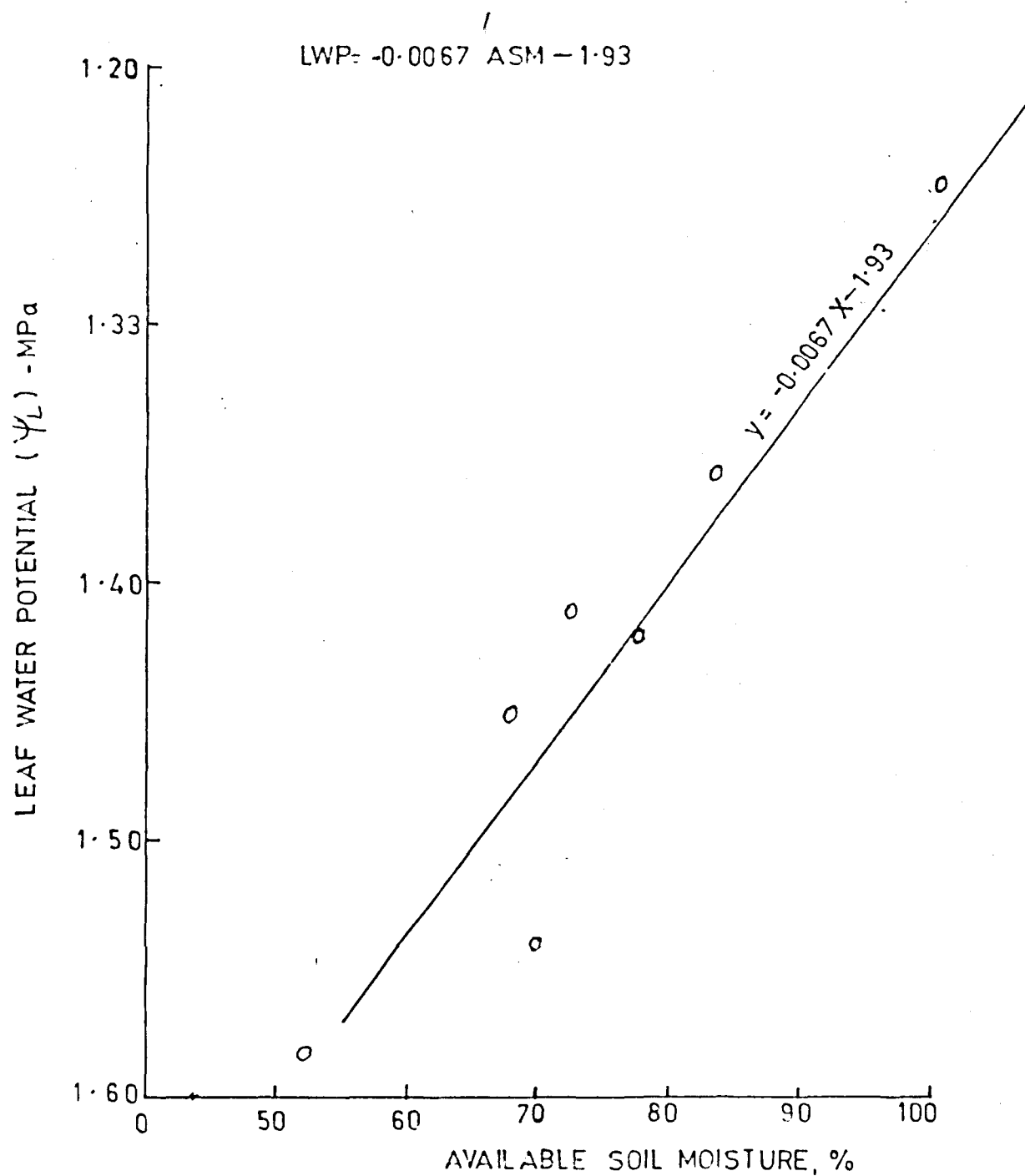


Fig. 4.22 Relationship of available soil moisture in the rootzone and leafwater potential of tomato

Table 4.15 Different mathematical equations of different variables

Sr. No.	Equation	R ²
1	$Y = -7.15 - 3.5 \text{ LWP}$ <p>Where, Y = CATD, C (-)</p> <p>LWP = Leaf water potential, -MPa</p>	0.52
2	$Y = -1.0 + 4.41 \text{ SWP}$ <p>Where, Y = Leaf water potential, -MPa</p> <p>SWP = Soil water potential, -MPa</p>	0.72
3	$Y = 27.65 - 0.038 \text{ SDD} (-)$ <p>Where, Y = Yield, t/ha</p> <p>SDD= Cumulative stress degree days</p>	0.81
4	$Y = 50.9 - 0.053 \text{ CU}$ <p>Where Y = Yield, t/ha</p> <p>Cu = Consumptive use, mm</p>	0.84
5	$Y = 0.64 + 0.011 \text{ DAP}$ <p>Where Y = Leaf area index</p> <p>DAP = Days after planting</p>	0.57
6	$Y = 0.90 + 0.014 \text{ DM}$ <p>Where Y = Leaf area index</p> <p>DM = Dry matter per plant, g.</p>	0.78
7	$Y = 27.0 + 0.34 \text{ DAP}$ <p>Where Y = Dry matter per plant, g.</p> <p>DAP = Days after planting</p>	0.84
8	$Y = -1.93 + 0.0067 \text{ ASM}$ <p>Where Y = Leaf water potential, - MPa</p> <p>ASM= Available soil moisture content, per cent</p>	0.61

N= No. of observations, 18

Table 4.16 Different mathematical equations based on the yield contributing and quality parameters.

Sr. No.	Equation	R ²
1	2	3
1.	$Y = 91.43 - 1.04 X$ Y = Yield of tomato, t/ha X = Days for 50% flowering	0.98
2.	$Y = 5.13 + 0.76 X$ X = Weight of fruit, g.	0.97
3.	$Y = -7.22 + 0.82 X$ X = Volume of a fruit, ml.	0.96
4.	$Y = 1.98 + 0.65 X$ X = Number of fruits per plant	0.97
5.	$Y = -240.31 + 63.13 X$ X = pH of a juice.	0.94
6.	$Y = 363.00 - 75.36 X$ X = Total soluble solids, °Brix.	0.96
7.	$Y = -29.08 + 0.88 X$ X = Juice percentage of tomato.	0.95
8.	$Y = 130.68 - 113.53 X$ X = Total acidity per cent.	0.96
9.	$Y = -7.91 + 0.60 X$ X = Weight of a shoot, g.	0.97
10.	$Y = 9.70 + 2.05 X$ X = Weight of root, g.	0.99

Table 4.16 contd.....

	Equation	R^2
11.	$Y = 19.13 + 1.37 X$ X = Number of branches per plant.	0.98
12.	$Y = -8.63 + 0.60 X$ X = Height of a plant, cm.	0.93
13.	$Y = -6.97 + 0.81 X^{-2}$ X = Leaf area, dm.	0.98
14.	$Y = 0.65 + 0.61 X + 0.32 X^2 - 0.12 X^3$ X = Weight of a fruit, g. X = Volume of a fruit, ml. X = Number of fruits per plant.	0.98
15.	$Y = 37.18 + 0.56 X + 1.65 X^2 + 0.0042 X^3 - 0.54 X^4$ X = Number of branches per plant. X = Height of a plant, cm. X = Leaf area, dm	0.92
16.	$Y = -99.14 + 0.57 X - 0.41 X^2 + 0.94 X^3 - 33.31 X^4 - 7.78 X^5 - 0.80 X^6 + 41.56 X^7$ X = Weight of a fruit, g. X = Volume of a fruit, ml X = Number of a fruits per plant X = pH of juice X = Total soluble solids of tomato. X = Juice percentage.	0.95

Table 4.16 contd.....

Equation	R^2
X = Total acidity of tomato.	
17. $Y = -7.20 + 0.066 X + 0.72 X^2$	0.98
X = Weight of a fruit, g.	
X = Volume of a fruit, ml.	
Equation 1 to 17 are significant at .05 level,**	
N = No. of observations, 18	

4.7 Crop Growth-Yield

4.7.1 Plant growth parameters

4.7.1.1 Height of plant

The plant height was recorded on 70th day and data are depicted in Fig. 4.23. Soil moisture regimes created in furrow and sprinkler irrigation under 50, 75 and 100 mm CPE were almost uniform in nature, Hence plant height as influenced by different CPE treatments was almost similar. However, sprinkler method is superior than surface-furrow method. Probably this could be due to complete saturation and oxygen stress during the period from water application to field capacity under furrow irrigation.

Amongst the irrigation treatments scheduled on the basis of 50 mm CPE treatment significantly increased the plant height upto 70.2, and 72.4 cm at 70th day after planting under sprinkler and furrow methods respectively. The mean plant height under ID treatment of drip irrigation was highest amongst all treatments. These findings are in conformity with the results of Bernstein and Francois (1973), Bafana (1988) and Naphade (1989).

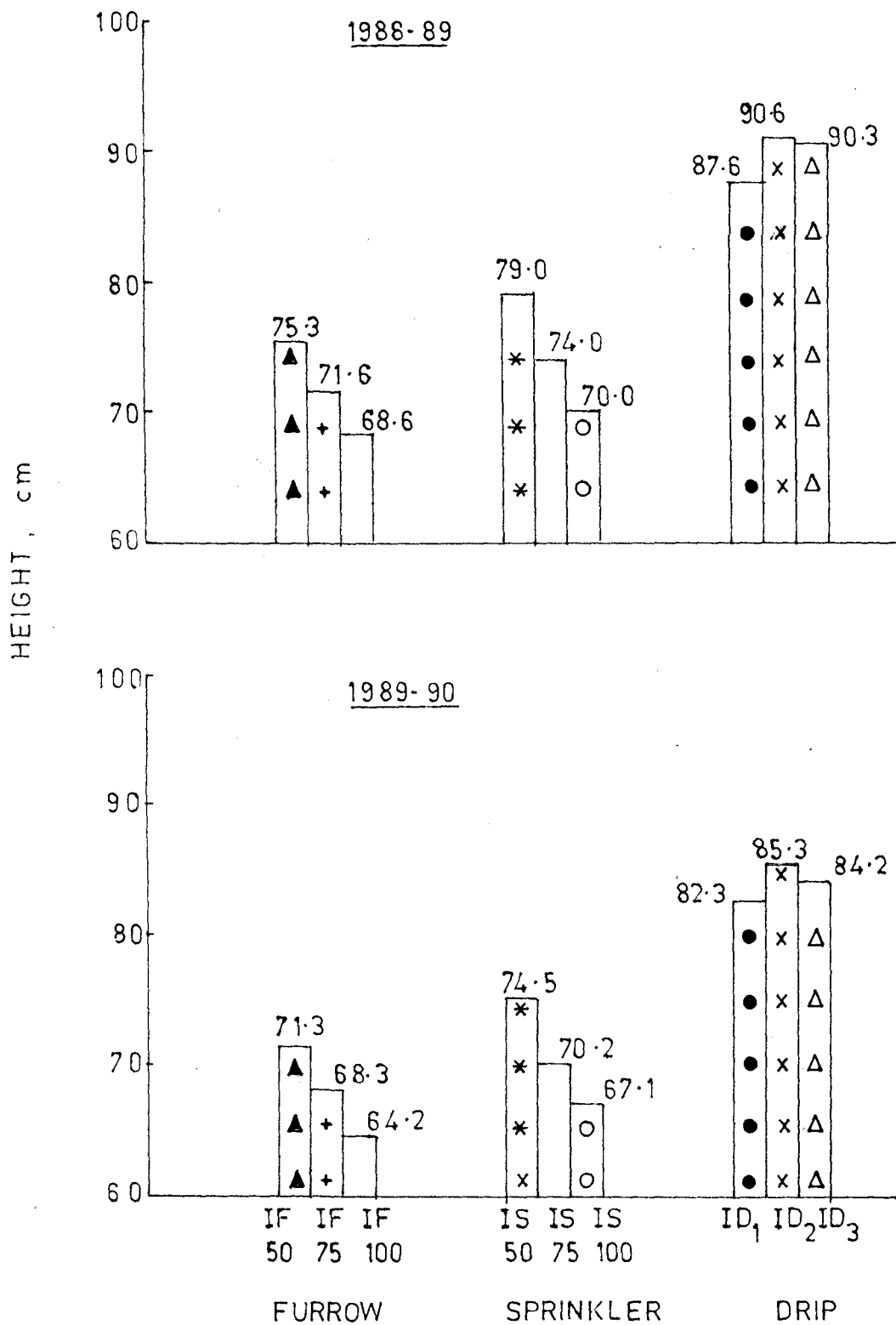


Fig.4.23. Height of a plant as influenced by different soil moisture regime.

4.7.1.2 Number of branches per plant

The data pertaining to the mean number of branches as influenced by various treatments are graphically shown in Fig.4.24. In general, it is revealed that there was an increase in the number of branches with higher soil moisture regime. Amongst the irrigation treatments scheduled at different CPE, the mean number of branches of 13.9 and 11.9 per plant at 70th days after planting were recorded respectively for sprinkler and furrow methods.

Amongst all treatments ID treatment recorded the highest number of branches per plant during both years. The drip irrigation method was found to be superior than sprinkler and furrow irrigation methods. Irrigations scheduled at 100 mm CPE in surface, furrow and sprinkler methods had resulted into decline of management allowable deficit level causing moisture stress. It is the usual trend and is in agreement with several research workers.

4.7.1.3 Leaf area per plant

The data on leaf area per plant as influenced by different treatments are presented in Table.4.17 and 4.18. The mean leaf area per plant recorded at all intervals was found to be significantly influenced by the various irrigation treatments. The treatment of alternate day drip irrigation (ID) recorded the maximum leaf area per plant of 113.4 and 110.3 dm^2 respectively for the years 1988-89 and 1989-90 and was found to be significantly superior to the rest of treatments. Similar observations were also recorded by (Gamayan,1980 and Naphade, 1989).

4.7.1.4 Leaf area index

The data on leaf area index are graphically shown in Fig. 4.25 and 4.26. The leaf area index per plant was highest (3.15 and 2.81) under

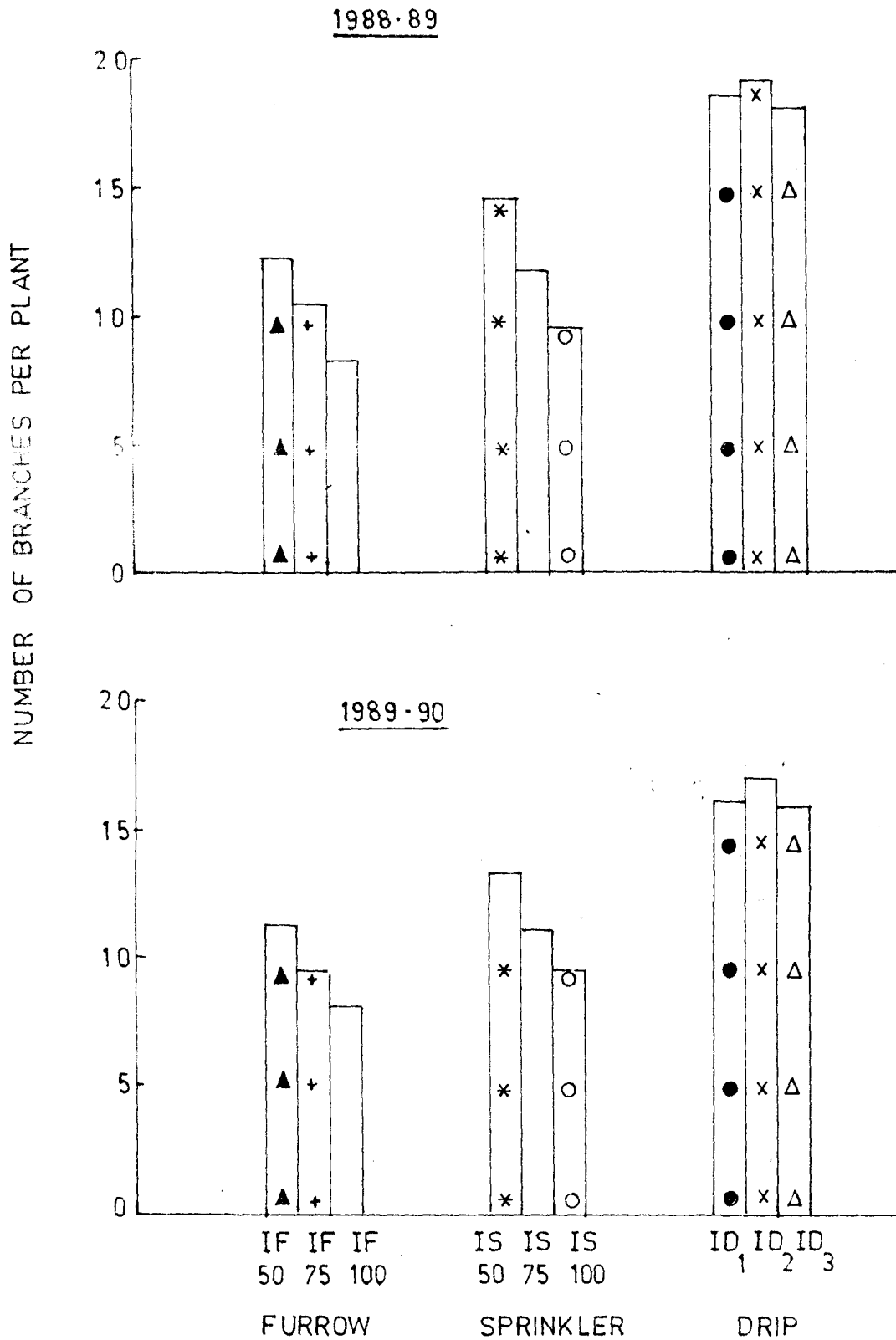


Fig.4:24. Number of branches per plant as influenced by different soil moisture regime.

Table 4.17. Leaf area of tomato as influenced by different soil moisture regimes during crop growth. (1988-89)

Treatments	Leaf area/plant, dm ⁻²			
	Crop days			
	30	60	90	At harvest
IF 50	19.0	50.1	78.5	46.4
IF 75	18.5	47.3	75.1	44.2
IF 100	17.3	45.2	69.0	41.9
IS 50	20.3	52.3	81.3	48.1
IS 75	19.4	49.7	77.1	46.2
IS 100	18.6	47.8	69.2	44.1
ID 1	22.3	58.1	100.3	52.1
ID 2	23.1	58.3	101.3	52.8
ID 3	22.1	57.9	98.9	51.9
Trial mean	20.1	51.8	83.4	47.5
S.E. +	0.6	0.5	0.6	0.6
CD at 0.05	1.7	1.6	1.8	1.7

Table 4.18. Leaf area of tomato as influenced by different soil moisture regimes during crop growth. (1989-90)

Treatments	Leaf area/plant, dm ⁻²			
	Crop days			
	30	60	90	Atharvest
IF 50	20.2	59.4	88.2	52.1
IF 75	19.7	57.2	82.6	49.4
IF 100	18.3	55.3	76.5	47.4
IS 50	21.3	61.2	92.4	55.3
IS 75	20.7	59.0	86.3	52.2
IS 100	19.3	57.4	80.5	48.5
ID 1	24.1	64.3	109.1	61.1
ID 2	24.9	64.7	113.4	62.2
ID 3	24.0	64.0	108.5	61.3
Trial mean	21.4	60.3	93.0	54.3
S.E. +	1.1	0.5	0.6	0.5
CD at 0.05	3.3	1.7	1.9	1.8

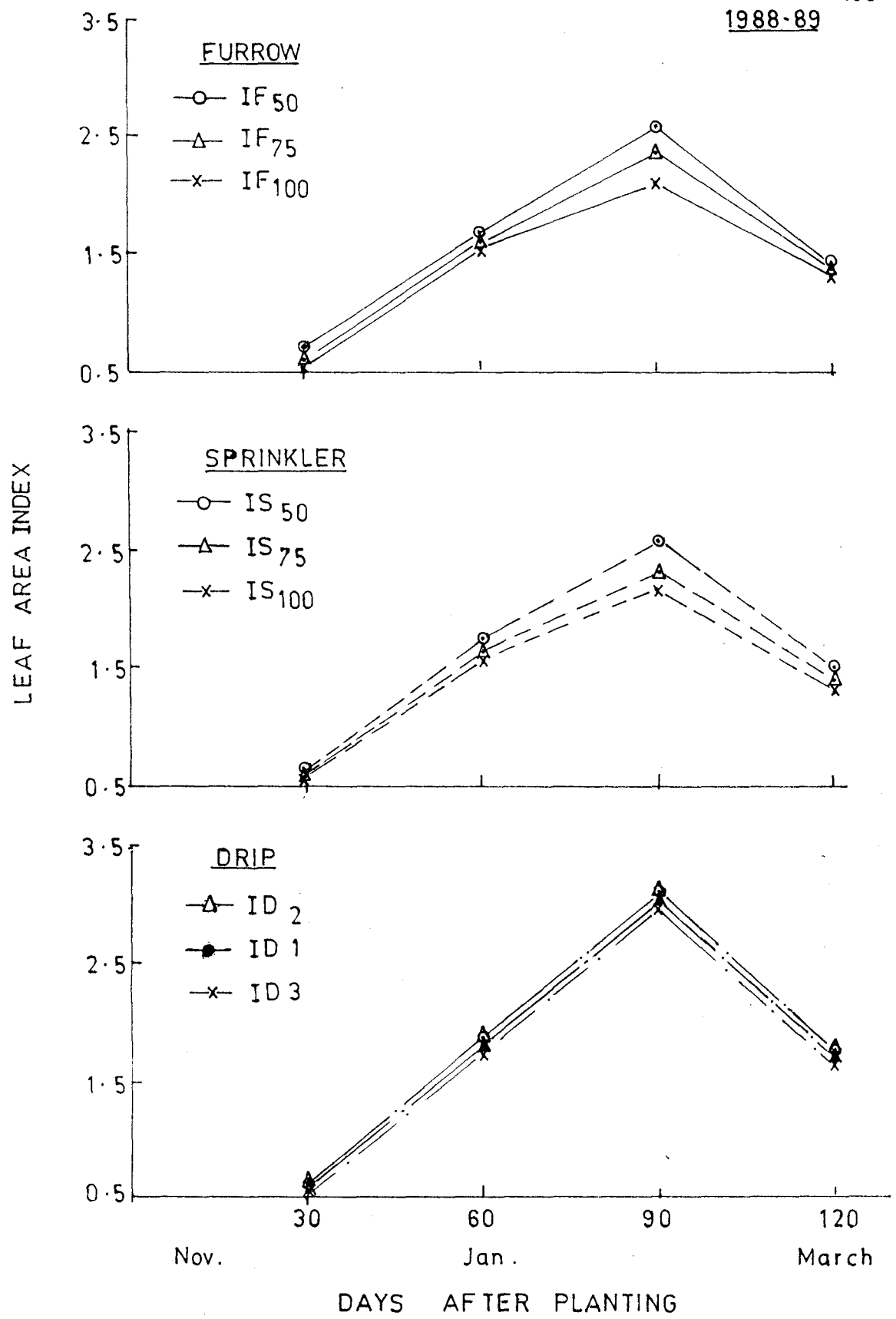


Fig. 425. Leaf area index of tomato plant as influenced by different soil moisture regime. (1988-89)

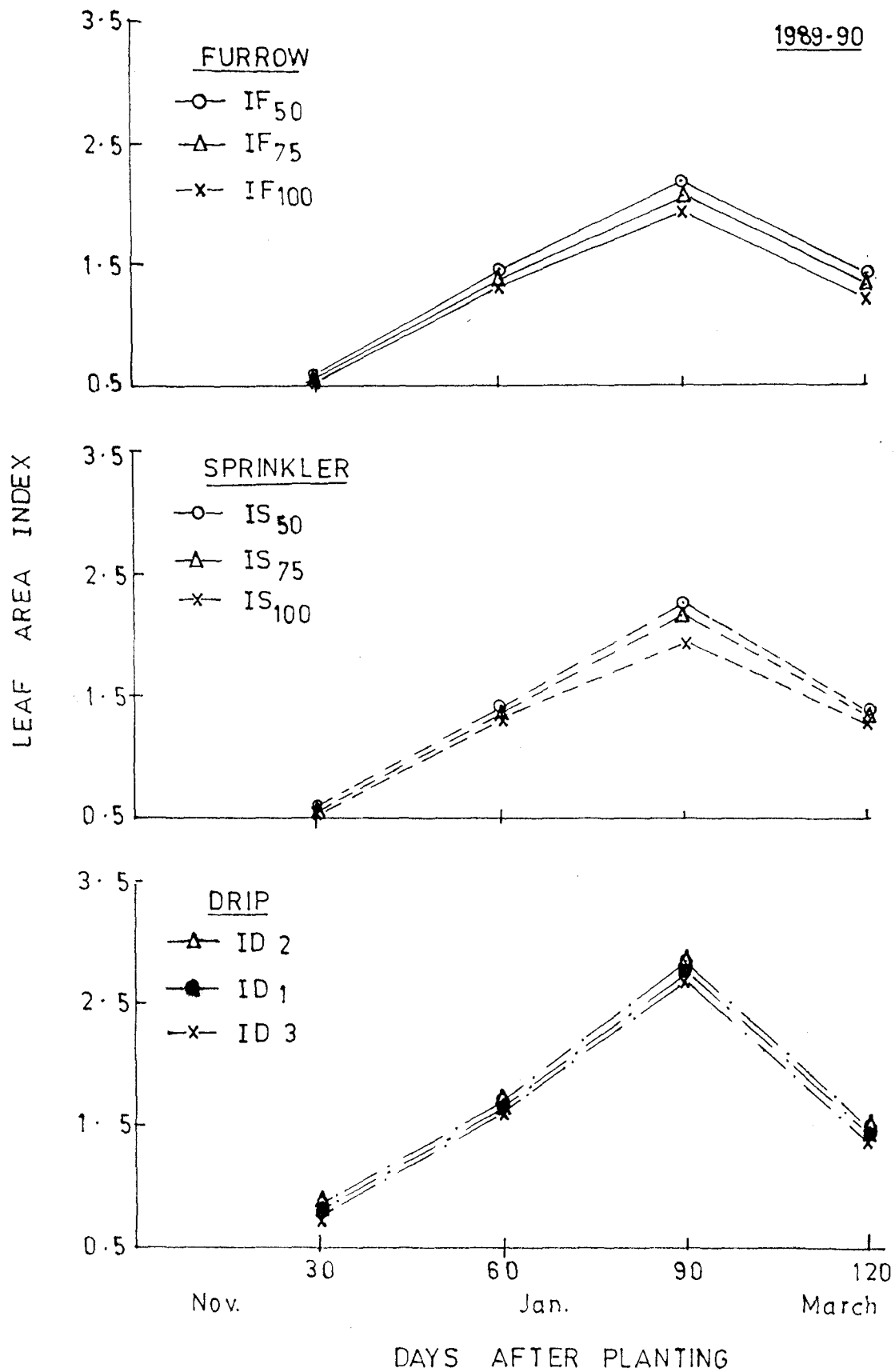


Fig.4.26. Leaf area index of tomato plant as influenced by different soil moisture regime (1989-90)

drip irrigation (ID₂) on 90th days after planting during both the years and was found to be significantly superior to that of furrow and sprinkler irrigation treatments. The lowest leaf area index was recorded in IF₁₀₀ treatment during both the years. Similar observations were also reported by Chaudhary (1988) and Naphade (1989).

4.7.1.5 Dry matter content per plant

The data regarding dry matter content per plant as influenced by the various treatments are depicted in Fig. 4.27 and 4.28. The dry matter was recorded at an interval of 30 days. The maximum dry matter content of 98.4 and 89.7 gm was found on 90th day after planting under ID₂ treatment respectively during the years 1988-89 and 1989-90. After 90 days, the dry matter content of all the treatments decreased. This might be due to the dropping of matured leaves. The similar trend was also reported by Chaudhary, (1988).

The plant maintains a turgid condition during the day time under drip irrigation as compared to sprinkler and furrow irrigation. There is a possibility of wide opening of stomata for longer period which might have resulted into high exchange of gases. Similarly, leaves might have remained turgid and produced more leaf surface. Thus, it helps in absorption of more light and solar radiation. It has resulted into higher rate of photosynthesis and increased the photosynthetic capacity which ultimately might have resulted into higher dry matter accumulation in the plants (Daubenmire 1970 and Gupta, 1988).

4.7.1.6 Number of days for 50 per cent flowering

The data on mean number of days required for 50 per cent flowering are presented in Table 4.19. The data revealed that the number of days for 50 per cent flowering was significantly influenced

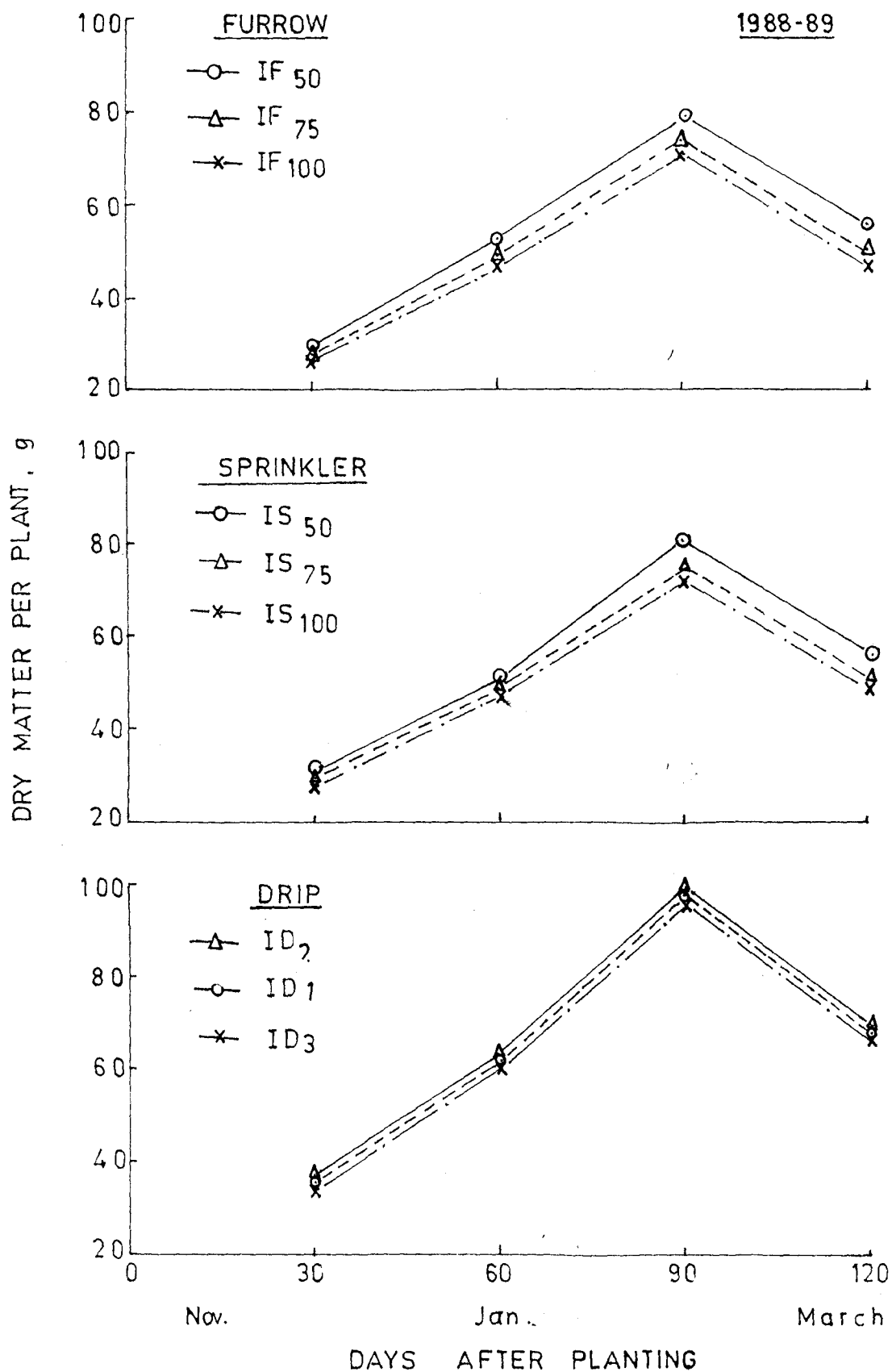


Fig. 4.27. Dry matter accumulation of plant as influenced by different soil moisture regime. (1988-89)

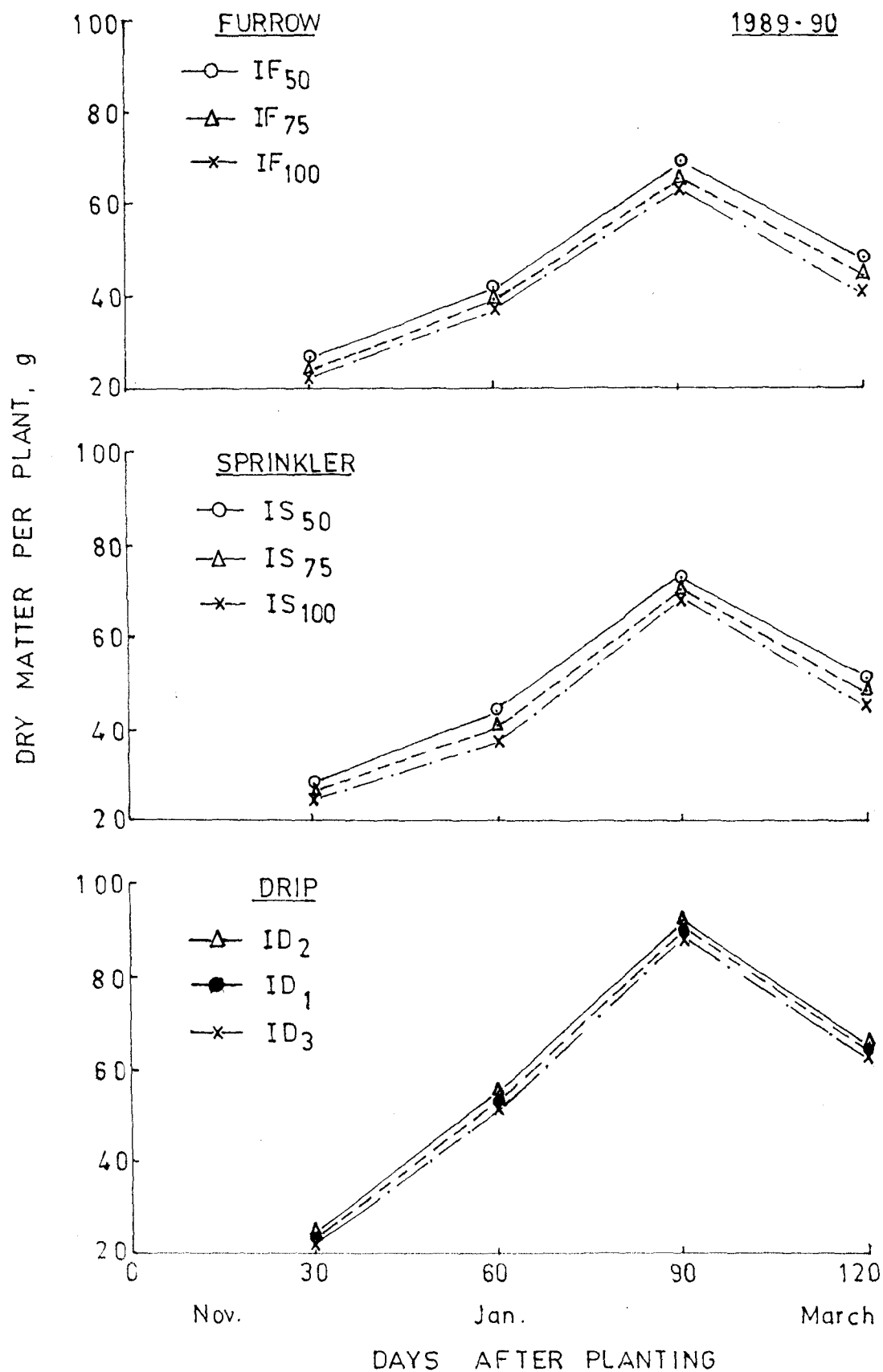


Fig.4:28. Dry matter accumulation of a plant as influenced by different soil moisture regime (1989-90)

Table 4.19. Days for 50 per cent flowering of tomato crop as influenced by different soil moisture regimes.

Treatments	Days for 50 per cent flowering		
	1988-89	1989-90	Pooled
IF 50	54.6	53.5	54.0
IF 75	55.6	55.6	55.6
IF 100	59.0	58.4	58.7
IS 50	52.3	50.3	51.3
IS 75	55.0	52.4	53.7
IS 100	57.0	55.6	56.3
ID 1	47.3	45.2	46.3
ID 2	47.0	43.1	45.5
ID 3	49.3	44.3	46.8
Trial mean	53.1	50.9	46.8
S E +	0.94	0.92	0.90
CD at 0.05	2.75	2.76	1.96

due to the different treatments. The alternate day drip (ID₂) irrigation required least period (47 and 43 days). Amongst the treatment IF₁₀₀ took maximum period (59 and 58 days) in both the seasons. It is also interesting to note that the period required for 50 per cent flowering varied between 59 in the lowest irrigation regime (IF₁₀₀) and 47 days in the highest irrigation regime (ID₂). These observations are in confirmity with those reported by Naphade, (1989).

4.7.1.7 Root and shoot biomass

The roots of tagged plants under each treatment were carefully collected, dried, weighed and the data on root weight, shoot weight and root : shoot ratio are reported in Table 4.20. Root weight data indicated that the irrigation treatment did not influence their weight. Probably this may be attributed to the methodology in extraction of roots in Black cotton soil. However, shoot weight data reported in the said table revealed that irrigation treatments had strong influence over shoot biomass. Shoot weight was maximum under ID₂ treatment which was on par with ID₁ and ID₃ and significantly superior over rest of furrow and sprinkler irrigation treatments. From the data pooled for two years it could be included that ID₂ treatment increased the shoot biomass to the extent of 14.7 per cent and 19.4 per cent over IF₁₀₀ and IS₅₀ treatments. It means that soil water plant relationship under drip system was excellent which resulted into production of maximum biomass. These observations are in confirmity with those reported by Bafana (1988). The ratio of root and shoot biomass was considered as influenced by irrigation and reported in Table 4.20. The roots were increased

Table 4.20. Root, shoot weight and their ratio as influenced by different soil moisture regimes after harvest of the tomato crop.

Treatments	Root weight, _____ g/plant _____	Shoot weight, _____	Root/shoot, ratio
IF 50	12.08	71.65	0.16
IF 75	11.29	68.50	0.16
IF 100	10.06	64.60	0.15
IS 50	13.53	74.40	0.18
IS 75	12.39	69.35	0.17
IS 100	11.23	67.20	0.16
ID 1	16.26	84.90	0.19
ID 2	16.52	85.55	0.19
ID 3	16.21	85.00	0.19
Trial mean (X)	13.28	74.62	0.17
SE +	0.39	0.81	0.007
CD at 0.05	1.30	2.31	0.018

significantly under the irrigation treatments of IF₁₀₀ and IS₁₀₀ which had imposed the soil moisture stress conditions. It is evident that roots are moving in search of moisture within the profile (Kramer, 1979). Even under stress conditions, the root weight were not reduced to the extent of shoot reduction. The rest of the treatments are on par with each other including drip irrigation where soil moisture status was maintained to the level of field capacity throughout its growing period. However, significant differences were recorded between the treatments of IF₅₀ and IS₅₀ as well as IF₇₅ and IS₇₅. The ratio had increased significantly under drip irrigation treatments over sprinkler and furrow irrigation methods. Similar observations were reported by Bafana (1988), Hegde and Srinivas, (1989).

4.7.2 Yield contributing parameters

4.7.2.1 Number of fruits

The data pertaining to mean number of fruits per plant on 70th days after planting are graphically shown in Fig. 4.29. The treatment of alternate day drip irrigation (ID₂) produced the highest number of fruits per plant (70 and 62) in both the seasons. The pooled mean also differed significantly showing almost similar trend. Pill and Lambeth (1980) reported that the decrease in soil water potential reduced the fruit set and number of fruits in tomato. Similar results were also reported by Bafana (1988) and Naphade (1989).

4.7.2.2 Weight of fruits

The data pertaining to mean weight of fruits as influenced by different treatments are graphically shown in Fig. 4.30. The treatment of (ID₂) recorded the highest fruit weight of 52.0 and 53.0 gm during the

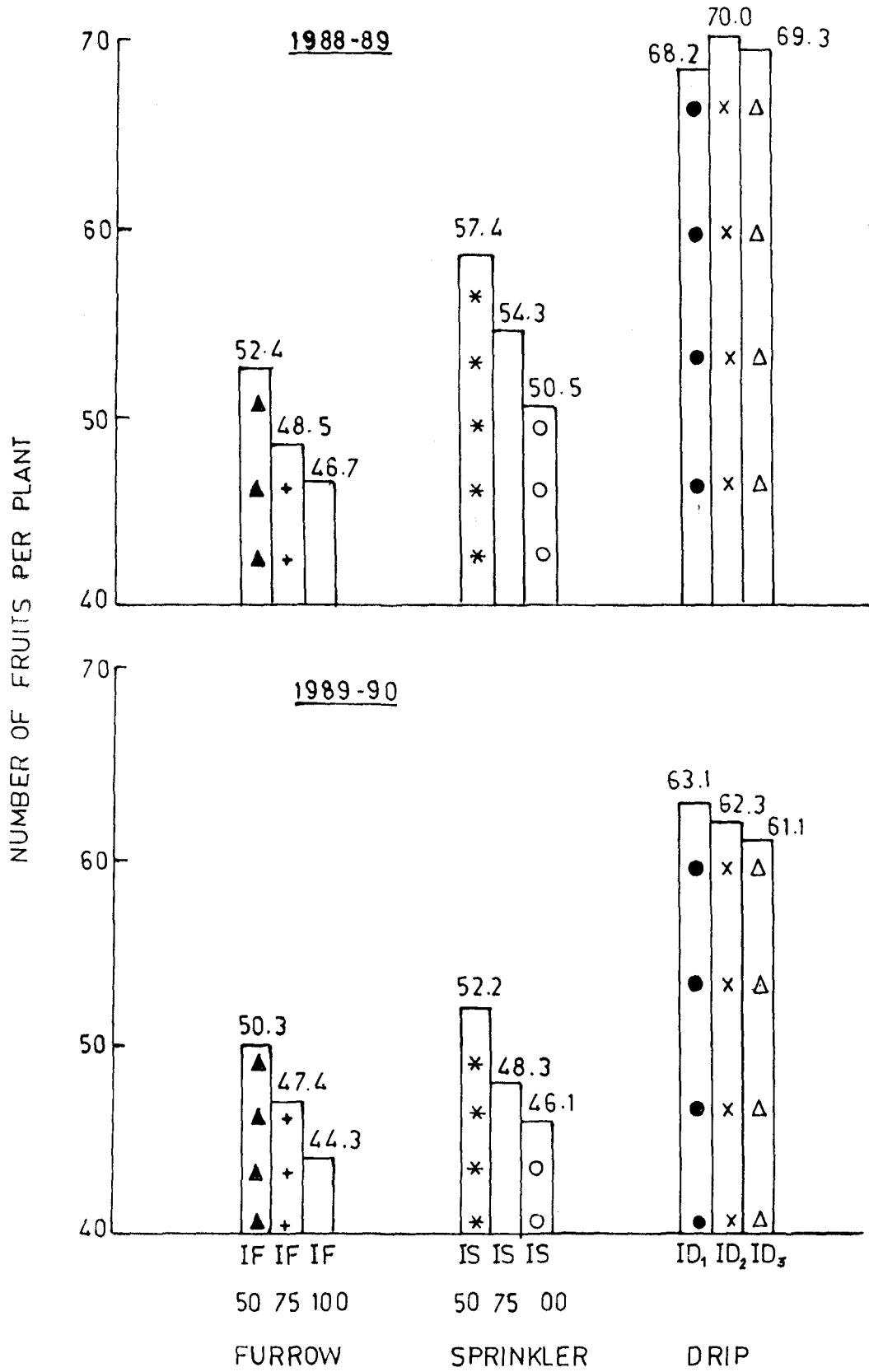


Fig.4:29. Number of fruits per plant as influenced by different soil moisture regime.

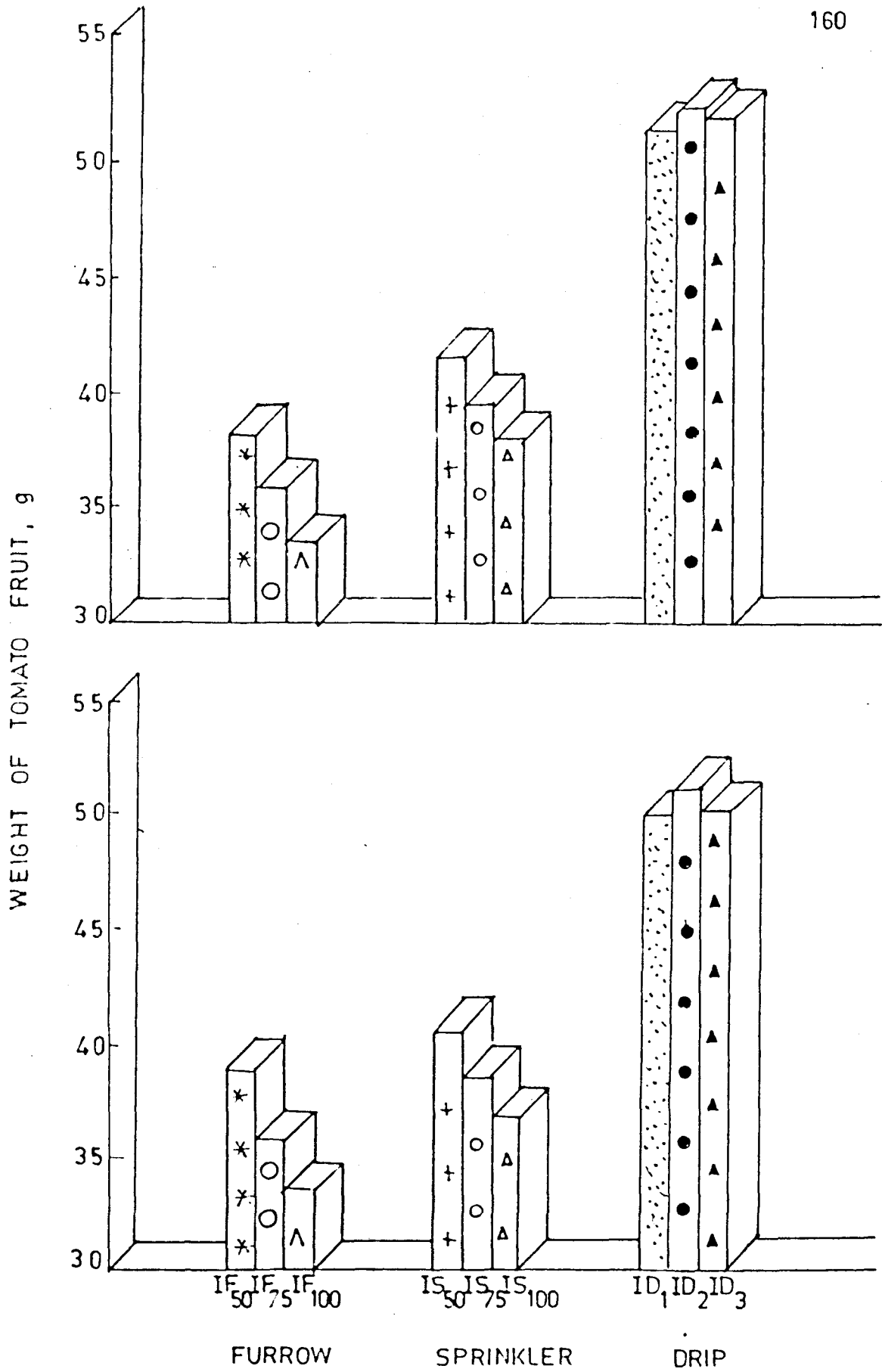


Fig. 4-30 Weight of individual fruits as influenced by different irrigation methods.

year 1988-89 and 1989-90, respectively. Available soil moisture content under drip irrigation treatments remained at about F.C. which had resulted into excellent SPAC conditions. Treatment ID had slightly superior over ID₁ and ID₂. Saturation (air stress) and moisture stress had adverse effect on plant growth (Sivanappan, *et al.* 1987). Almost similar trend was observed in the pooled mean weight of fruit. A reduction in fruit weight in IF₁₀₀ treatment (high moisture stress conditions) could be attributed to the process of photosynthetic activity. The similar observation were reported by Vanadia *et al.* (1982). Bafana, (1988) and Naphade (1989). Vanadia *et al.* (1982) obtained increased fruit size from the plants frequently irrigated at an interval of 5 to 9 days. Pill and Lambeth (1980) obtained reduced average weight of tomato fruit with the decrease in soil water potential.

4.7.2.3 Volume of a individual fruit

The data pertaining to the volume of a fruit are graphically shown in Fig.4.31. The irrigation of alternate day drip (ID₂) irrigation produced the highest volume of 63.5 ml in the year 1988-89 and 63.4 ml during the year 1989-90. The 100 mm CPE (IF₁₀₀) under furrow irrigation recorded the volume 45.5 and 46.3 ml respectively during the years 1988-89 and 1989-90. Similar trend was observed in the pooled analysis. These findings are in line with those reported by Vanadia *et al.* (1982). and Bafana (1988).

4.7.3 Yield

The data on fresh marketable tomato fruit yields as influenced by different methods of irrigation are presented in Table 4.21 and graphically shown in Fig.4.31. The comparison of the means revealed

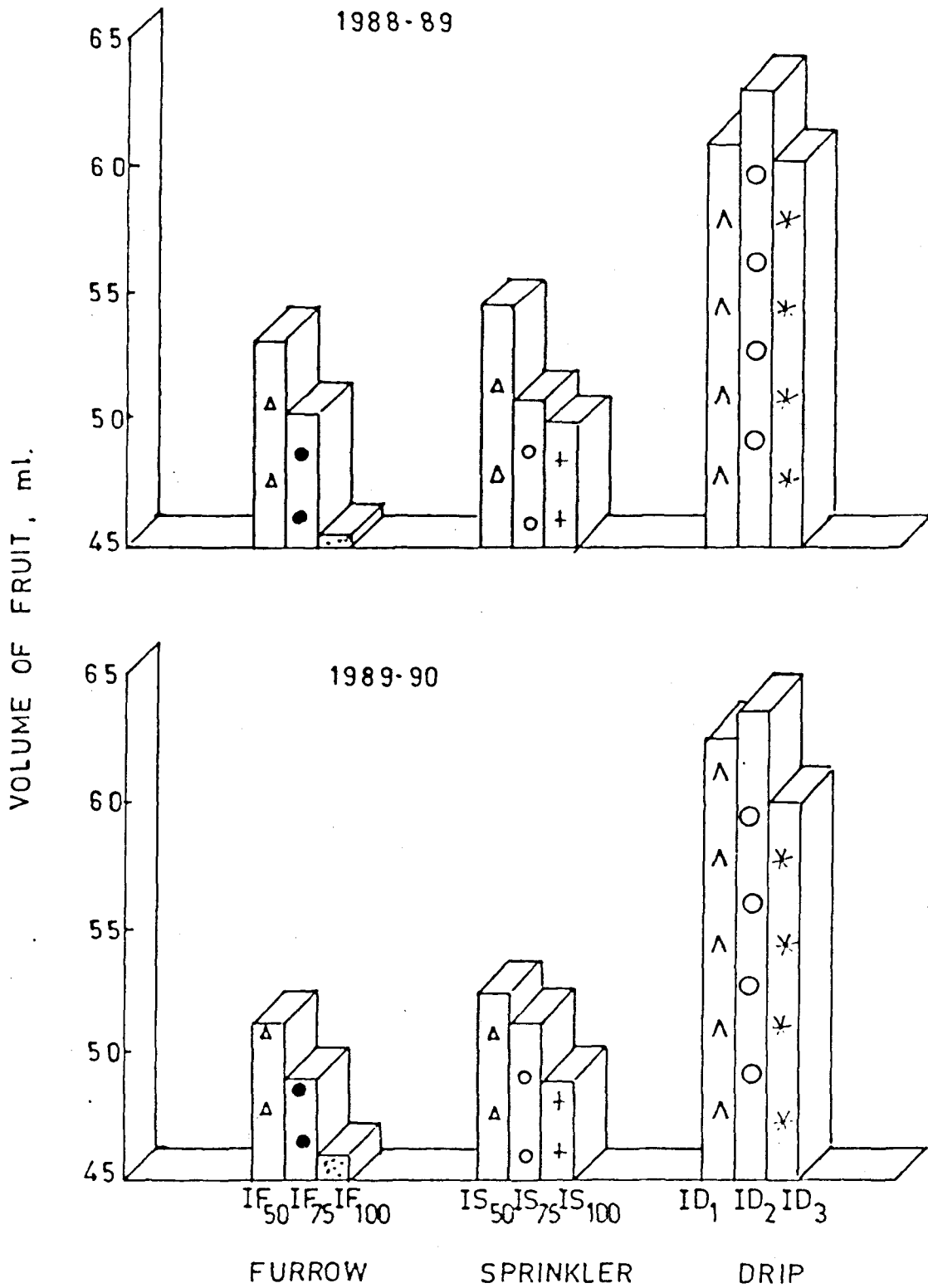


Fig. 4.31 Volume of a individual fruits as influenced by different irrigation treatments.

that yields of tomato fruits were significantly affected due to the drip irrigation during both the years and consequently in pooled analysis.

The yield data clearly indicate that the treatment of an alternate day of irrigation (ID₂) was given highest yield which was significantly superior over the treatments of furrow and sprinkler irrigation. However yields of remaining two treatments (ID₁ and ID₃) were on par with the ID₂ treatment. Similar trend was observed in second year of investigation. All nine treatments could be grouped into surface furrow (IF₅₀, IF₇₅, and IF₁₀₀), sprinkler (IS₅₀, IS₇₅, IS₁₀₀) and drip (ID₁, ID₂ and ID₃) irrigation methods. Yield levels in all treatment in second year were relatively low. It might be due to the climatic and management variable which were less favourable. Minimum yields under IF₁₀₀ and IS₁₀₀ treatments were mainly attributed to moisture stress situation arisen due to delayed irrigation and depletion of ASM contents.

It is also interesting to note the soil environment created at the time of water application due to surface furrow and sprinkler irrigation methods. The low water application rate (2.5 cm/hr) and replenishment of depleted ASM in sprinkler irrigation methods had certainly helped in bringing the soil profile under field capacity condition without driving out complete air. The maintenance of aeration status during the course of irrigation through sprinkler irrigation. The increase in the yield due to superimposition of sprinkler treatments was to the extent of 9.6, 9.4 and 9.8 per cent under IS₅₀, IS₇₅ and IS₁₀₀ respectively over IF₅₀, IF₇₅ and IF₁₀₀ treatments.

Increase in the yield under drip system was also compared with CPE treatments of 50, 75 and 100 mm of furrow and sprinkler methods. The

Table 4.21 Yield of a tomato as influenced by different soil moisture regimes. (t/ha)

Treatments	Yield, t/ha		
	1988-89	1989-90	Pooled
IF 50	36.38	32.20	34.29
IF 75	34.00	30.03	32.01
IF 100	30.45	27.23	28.84
IS 50	40.01	35.16	37.58
IS 75	36.50	32.06	34.28
IS 100	31.10	28.20	29.65
ID 1	45.63	40.60	43.16
ID 2	46.66	40.90	43.78
ID 3	45.20	40.16	42.68
Trial mean	38.43	34.06	36.24
SE +	0.64	0.57	0.53
SE -			
CD at 0.05	1.76	1.69	1.51

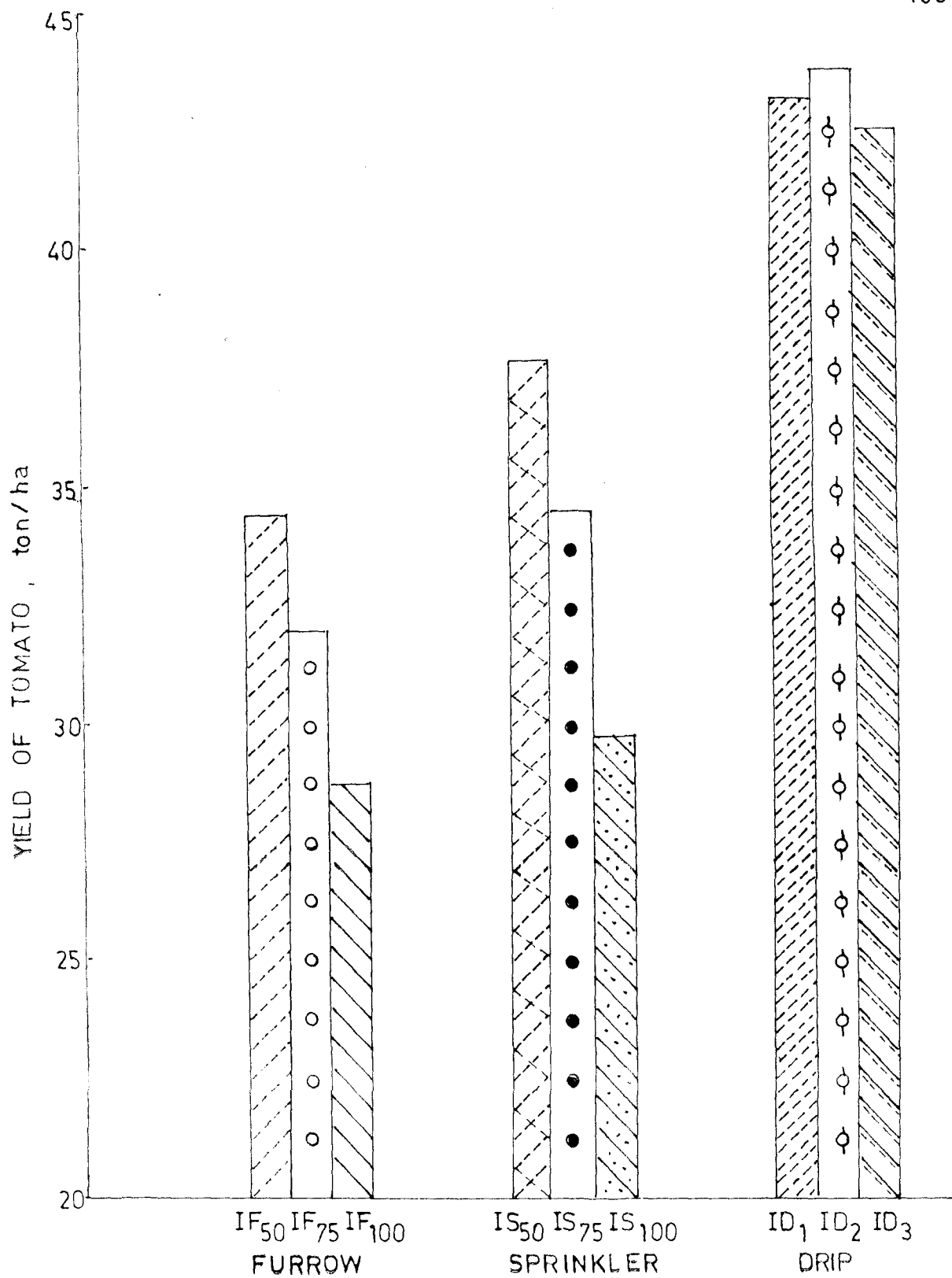


Fig. 4.31. Yield of a tomato as influenced by different soil moisture regimes.

yield under ID was compared with IS₂, IS₅₀ and IS₇₅ and increase of 16.5, 24.3 and 3.7 per cent was recorded respectively. When it was compared with IF₅₀, IF₇₅ and IF₁₀₀, the increase in yield were, 27.7, 36.8 and 43.9 per cent respectively. Naturally benefits are two folds in addition to fertilizer saving which has not been considered here. Dell (1983) reported 40 per cent higher tomato yield under drip irrigation than other methods. Similar results were also obtained by Torantino and Rubino (1982). Meek *et al.* (1983) also reported the increase in yield of tomato due to drip irrigation and the reason for such increase was mainly due to more precise control for maintaining the matric potential in the desirable range than the flood irrigation. Subbaramma Reddy and Dakshinamurti (1976) reasoned that flood irrigation not only results in wastage of water by percolation below the root zone, but also sets a chain undesirable reactions such as leaching of available plant nutrients beyond the root zone, and consequently development of soil problems of poor aeration resulting in meagre crop yields. The pioneering type of work on drip irrigation in comparison with surface furrow and ridges layout was carried out by Savanappan *et al.* (1987) and Karmarkar (1985).

4.7.4. Quality of tomato fruits

4.7.4.1. Juice and T.S.S.

The quality of fresh marketable tomato fruits is determined on the basis of juice, total soluble solids (TSS), pH and acidity as influenced by irrigation. The data on juice percentage and TSS treatment are presented in Table 4.22. As that of yield contributing characters, these two parameters indicating the quality represented the differences due to irrigation treatment. The alternate day drip irrigation treatment was

Table 4.22 Juice percentage and TSS (brix) of tomato as influenced by different soil moisture regimes.

Treatment	Juice percentage			Total soluble solids		
	1988-89	1989-90	Pooled mean	1988-89	1989-90	Pooled weighted mean
IF 50	73.3	71.4	72.3	4.38	4.36	4.36
IF 75	72.0	71.5	71.7	4.40	4.39	4.39
IF 100	69.6	69.0	69.3	4.43	4.42	4.42
IS 50	75.6	73.3	74.4	4.33	4.30	4.30
IS 75	72.6	71.2	71.9	4.36	4.34	4.34
IS 100	70.3	70.2	70.1	4.40	4.37	4.37
ID 1	84.6	81.3	82.9	4.25	4.24	4.24
ID 2	84.0	82.3	83.1	4.28	4.23	4.23
ID 3	83.0	80.0	81.5	4.30	4.28	4.28
Trial mean	76.1	74.4	75.3	4.34	4.32	4.32
SE +	1.4	1.2	0.89	0.14	N.S.	N.S.
CD at 0.05	4.3	3.5	2.52	0.43		

significantly superior over furrow (IF) and sprinkler (IS) treatment and on par with ID and ID treatments. While making comparison with irrigation methods, viz. furrow, sprinkler and drip methods, it was clearly seen that juice percentage in drip methods increased to about 11 to 15 per cent for furrow and 9 to 14 per cent for sprinkler irrigation methods.

Studies on juice extraction percentage showed that 72.3 percent juice is available in tomato fruits under normal irrigation of ridges and furrow methods. Drip irrigation has certainly got specific advantage for quality aspects (Sivanappan *et al.* 1987). Total soluble solids (TSS) were also studied in relation to different irrigation treatments. However, the said parameter did not influence significantly due to irrigation treatments.

4.7.4.2. Acidity and pH

Acidity and reaction of juice are important parameters. They were determined for all irrigation treatments and data on acidity are presented in Table 4.23. In general higher values for juice percentage, pH of tomato fruit was noticed from drip irrigation plots while, per cent TSS and acidity were highest in furrow irrigation followed by sprinkler irrigation. Similar result was reported by Bafana (1988). Lin *et al.* (1983) while comparing the quality of fruits under drip and furrow irrigation did not show appreciable difference in fruit quality.

4.8 Correlation

The correlation with different variables were worked out and presented in Table 4.24. The yield contributing parameters like days for 50 per cent flowering, weight of fruits, volume of a fruits, number of branches, height, leaf area and yield of a tomato. The quality parameters

Table 4.23 Total acidity and pH of tomato juice as influenced by different soil moisture regimes.

Treatments	Total acidity, per cent			pH of tomato juice		
	1988-89	1989-90	Pooled,wt	1988-89	1989-90	Pooled,wt
			mean			mean
IF 50	0.84	0.82	0.83	4.30	4.28	4.28
IF 75	0.87	0.86	0.86	4.25	4.26	4.25
IF 100	0.89	0.87	0.88	4.20	4.21	4.20
IS 50	0.82	0.80	0.81	4.35	4.35	4.35
IS 75	0.84	0.82	0.83	4.30	4.32	4.31
IS 100	0.87	0.85	0.86	4.26	4.28	4.27
ID 1	0.77	0.75	0.76	4.40	4.43	4.42
ID 2	0.79	0.74	0.78	4.45	4.42	4.42
ID 3	0.78	0.76	0.77	4.35	4.38	4.37
Trial mean	0.83	0.80	0.82	4.31	4.32	4.31
SE +	0.013	-	-	0.075	-	-
CD at 0.05	0.037	N.S.	N.S.	0.219	N.S.	N.S.

Table 4.22. Correlation studies.

Sr. No.	Variables	50 per cent flowering	Fruit weight, g.	Fruit number	Yield, t/ha	Juice, per cent	Root weight g.	Shoot weight g.	Root/shoot ratio.	Leaf area	Height, cm
1.	Shoot weight	-0.98	+0.99	+0.99	+0.98	+0.99	+0.99	--	-0.75	+0.99	+0.99
2.	Root weight	-0.99	+0.98	+0.99	+0.98	+0.98	--	+0.99	-0.75	+0.99	+0.99
3.	Root shoot ratio	+0.77	-0.66	-0.68	-0.75	-0.65	-0.75	-0.68	--	-0.73	-0.71
4.	Height	-0.99	+0.98	+0.99	+0.98	+0.98	+0.99	+0.99	-0.71	+0.99	--
5.	Leaf area	-0.99	+0.99	+0.99	+0.99	+0.99	+0.99	+0.99	+0.73	--	+0.99
6.	50 per cent	--	-0.98	-0.98	-0.99	-0.98	-0.99	-0.98	+0.77	-0.99	-0.99
7.	Fruit weight	-0.98	--	+0.99	+0.98	+0.99	+0.98	+0.99	-0.66	+0.99	+0.99
8.	Fruit number	-0.98	+0.99	--	+0.98	+0.99	+0.99	+0.99	-0.68	+0.99	+0.99
9.	Yield	-0.99	+0.98	+0.98	--	+0.97	+0.99	+0.98	-0.75	+0.99	+0.98
10.	Juice per cent	-0.98	+0.99	+0.99	+0.97	+0.98	+0.98	+0.99	-0.65	+0.99	+0.98

like pH of a juice, TSS and juice per cent. Root development like weight of a root, root shoot ratio and were studied with different combination.

Height of plant was positively correlated with weight of fruit, Volume of fruit, number of fruit, yield and negatively correlated with the 50 per cent flowering but in quality parameters, it is positively correlated with pH of a juice and juice per cent and negatively correlated with brix and acidity percentage.

Leaf area per plant was positively correlated with weight of fruits, volume of fruits, yield of tomato, pH of juice and juice percentage and negatively correlated with the days for 50 per cent flowering, brix and acidity per cent.

Total soluble solids were positively correlated with root shoot ratio, acidity and days for 50 per cent flowering and negatively correlated with other parameters.

Yield of a tomato was positively correlated with weight of root, weight of a shoot, number of branches, height, leaf area, weight of fruits, volume of fruits, number of fruits, pH of juice, juice percentage and negatively correlated with days for 50 per cent flowering, TSS and acidity of Tomato.

Chapter Opener Page

5. SUMMARY AND CONCLUSION

The conclusions were drawn from each table or figure and summarized in brief. Conclusions drawn are given below.

1. An available moisture of 125 mm below the level of MAD under IF treatment however, drip irrigation maintained the available moisture contents nearly to field capacity storage throughout growth period.
2. The wetting front from the point source in drip system was more or less semi-elliptical in shape with maximum diameter of 57 cm, and depth of 60 cm.
3. The unsaturated hydraulic conductivity exhibited an exponential relationship with volumetric water content. The values of $K(\theta)$ of 8.5×10^{-4} to 2.5×10^{-2} cm/day were estimated as soil water content changed from 0.40 to 0.56 cm/cm respectively in the surface layer. The 45-60 cm layer exhibited minimum $K(\theta)$ range from 0.5×10^{-2} to 9.2×10^{-2} cm/day which attributed to minimum soil moisture variation.
4. Soil water diffusivity, $D(\theta)$ exhibited exponential relationship with volumetric water content. The $D(\theta)$ values of surface layer were in the range of 7.5×10^{-5} to 5×10^{-3} cm/sec at the moisture content from 0.38 to 0.42 cm/cm. The 45-60 cm layer exhibited minimum variation in the $D(\theta)$ values from 8×10^{-4} to 8×10^{-3} cm/sec at 0.44 and 0.47 cm/cm moisture contents.
5. Soil temperature reduction at FC moisture ranged from 5 to 5.7 °C which was dependent on radiation compared to air temperature. Soil temperature reduction was more under drip than furrow and sprinkler irrigation compared to air.

6. Consumptive use of 370 mm under 75 mm CPE treatment was considered as optimum on the basis of highest yield under furrow irrigation. The optimum consumptive use was reduced by 33 and 59 per cent in case of sprinkler and drip systems respectively. This was mainly attributed to the methods where requisite quantity of water was applied maintaining better soil water plant relationship. Alternate day water application by drip method had excellent performance in terms of CATD, SDD and leaf water potential.
7. Water use efficiency was higher with drip irrigation than sprinkler (two times) and furrow (3 times) irrigation methods.
8. Crop canopy and air temperature differences ($T_c - T_a$) were 2.9 and 3.1 °C for furrow and sprinkler irrigation methods respectively. This critical limit of $T_c - T_a$ could be considered for fixing the criteria for scheduling of irrigations at Rahuri conditions in Vertisols on the basis of highest yield and optimum soil moisture regime. Probably $T_c - T_a$ concept may require very high precision for drip irrigation system.
9. Summation of stress-degree day concept is as an alternative approach for scheduling of irrigations to tomato crop. It works well for furrow and sprinkler methods. SDD values under drip system were low compared to furrow and sprinkler irrigation methods.
10. Initial leaf water potential values recorded before irrigation under furrow irrigation were found to be -1.09 M Pa and -1.24 M Pa for optimum (50 mm CPE) and severe (100 mm CPE) stress conditions respectively which were decreased at the maturity stage of tomato crop to the extent of -1.42 and -1.59 M Pa. Leaf water potential decreased constantly as the age of the crop growth increased.

Similar observations were recorded in case of sprinkler irrigation with a decline of values of - 0.02 to -0.05 M Pa. These values were constants under drip irrigation system.

11. Following equations were developed for the different parameters.
 - i) $Y = 27.65 - 0.038 (ESDD)$ where , $Y = \text{Yield, t/ha}$
 - ii) $Y = - 1.0 + 4.41 (SWP)$ $Y = \text{Leaf water potential, -M Pa}$
 - iii) $Y = -7.15 + 3.5 (LWP)$ $Y = \text{CATD (-)}$
12. The height of the tomato plants was significantly increased with increase in soil moisture regime. Irrigation regime under alternate day drip irrigation recorded the maximum height compared to furrow and sprinkler irrigation.
13. The irrigation regime of alternate day drip irrigation significantly increased the number of branches per plant during both the seasons.
14. The increase in soil moisture regime under ID treatments increased the leaf area index and dry matter production per plant.
15. The earliest flowering and fruit maturity were observed in alternate day drip irrigation than furrow and sprinkler irrigation methods.
16. The yield of tomato fruits in case of alternate day drip irrigation was highest(43.3 t/ha) amongst all treatments. Amongst different methods, the drip method proved its superiority over sprinkler and furrow irrigation methods. The increase in yield was 28.2 and 16.6 per cent over furrow and sprinkler irrigation methods respectively. Irrigations need to be scheduled at 50 mm CPE if surface or sprinkler methods are to be followed.
17. The total acidity and pH of tomato juice did not change with different irrigation treatments. However, juice percentage under ID treatment had significantly increased and was significantly superior

over furrow and sprinkler methods.

The stress degree day concept is a valid indicator of crop stress as shown by the available soil water and leaf water potential data. Further refinements, such as those suggested by Idso *et al.* (1981) and Jackson *et al.* (1981) would appear to improve the capability of this technique into irrigation scheduling programs. The change in leaf-air temperature is closely related to availability of water under the climatic condition of Rauri under medium black soils which suggests a critical soil water content when stress becomes detrimental to crop growth.

Chapter Opener Page

6. LITERATURE CITED

6. LITERATURE CITED

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* Originals not seen.

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Chapter Opener Page

7. APPENDICES

APPENDIX-I

Meteorological parameters at the experimental site. (Rabi 88-89)

Std week Nos.	Period (1988-89)	Temperature		Relative humidity		Pan evaporation	Wind velocity	Sunshine	Soil temp at 14.30 hrs. soil depth, cm			V.P. mm	
		°C				Class 'A'		hrs	5	15	30	Morn.	Even
		Maximum	Minimum	Maximum	Minimum	USWB, mm	m/sec						
45	5-11 November	28.8	12.4	69.0	25.0	2.7	1.3	10.0	43.1	28.2	26.3	10.2	7.7
46	12-18 Nov	29.2	10.2	64.2	25.7	2.1	1.1	10.1	42.4	26.8	24.4	8.2	7.7
47	19-25 Nov	29.3	12.0	70.4	25.7	2.1	0.9	9.7	42.4	26.4	24.6	9.4	7.8
48	26-2 Dec	27.8	10.4	69.0	27.9	3.4	0.7	9.1	39.8	25.9	24.1	8.5	6.2
49	3-9 Dec	28.8	12.2	71.0	31.4	2.2	0.8	9.3	42.2	25.4	23.8	9.4	9.1
50	10-16 Dec	28.1	10.2	74.5	36.0	2.7	1.2	9.0	37.8	24.4	23.6	9.2	9.3
51	17-23 Dec	29.3	11.0	67.1	29.5	2.8	0.9	9.4	40.5	24.3	22.7	7.8	8.5
52	24-31 Dec	28.5	11.0	75.6	31.6	3.6	1.0	9.5	33.4	20.8	22.5	8.7	8.8
1	1-7 January	28.7	10.3	67.0	28.4	2.1	1.1	9.6	42.0	23.7	22.5	8.0	8.5
2	8-14 Jan	28.4	10.1	75.1	37.0	2.2	1.2	9.6	40.7	24.4	22.7	8.8	10.5
3	15-21 Jan	21.7	10.8	67.1	15.7	3.1	0.7	9.4	42.1	24.9	23.4	7.5	7.9
4	22-28 Jan	30.7	11.8	71.8	30.8	3.4	0.7	9.5	44.4	25.4	23.9	8.4	9.6
5	29-4 February	31.4	11.7	64.0	21.8	4.0	0.8	10.2	46.1	26.1	24.6	7.7	7.3
6	5-11 Feb	31.2	9.9	62.5	23.1	4.0	0.8	10.4	46.4	26.6	24.3	7.0	7.2
7	12-18 Feb	31.5	11.3	55.2	20.4	4.5	1.0	10.5	46.4	27.0	24.6	7.0	7.1
8	19-25 Feb	31.0	8.6	46.4	14.0	4.4	1.1	10.5	46.5	26.0	24.2	5.0	3.9
9	26-4 March	34.1	13.3	47.0	15.1	5.2	1.2	10.2	47.6	28.6	26.1	6.6	5.9
10	5-11 Mar	35.3	16.3	53.6	17.0	6.0	1.3	8.9	49.5	30.1	28.3	9.4	7.0

APPENDIX-II

Meteorological parameters at the experimental site. (Rabi 89-90)

Std week Nos.	Period (1988-89)	Temperature °C		Relative humidity	Pan evaporation Class 'A' US&B,mm	Wind velocity m/sec	Sunshine hrs	Soil temp at 14.30 hrs. soil depth, cm			V.P. mm		
		Maximum	Minimum					5	15	30		Morn. Even	
45	10-11 November	27.4	16.9	74.5	47.0	4.0	1.16	7.5	37.0	27.1	25.1	17.1	19.5
46	12-18 Nov	31.4	18.0	72.7	37.7	4.0	0.65	8.9	41.7	28.6	26.2	17.4	16.8
47	19-25 Nov	31.0	14.1	66.2	24.5	4.2	0.78	10.0	41.8	27.5	25.9	14.5	10.5
48	26-2 December	29.9	13.5	69.8	27.7	4.0	1.36	9.8	41.8	26.1	25.0	12.2	11.3
49	3-9 Dec	27.8	9.3	77.2	26.5	3.5	0.98	9.8	37.4	24.6	23.1	10.0	10.1
50	10-16 Dec	27.1	9.1	71.8	29.5	2.8	0.84	9.5	36.0	23.1	22.6	11.0	9.3
51	17-23 Dec	27.6	10.9	70.7	33.2	2.5	0.98	9.1	34.1	23.0	22.1	11.1	12.1
52	24-31 Dec	26.9	13.7	84.7	46.1	2.2	0.78	6.1	33.2	24.7	23.0	13.9	15.7
1	1-7 January	29.0	14.2	86.0	40.1	2.8	0.83	8.5	36.1	24.8	23.8	16.9	13.4
2	8-14 Jan	29.6	10.9	70.2	23.8	3.3	0.83	10.0	36.5	24.7	23.0	11.0	8.0
3	15-21 Jan	29.9	9.4	63.4	21.4	3.2	0.83	1.2	38.9	24.4	22.8	8.4	8.9
4	22-28 Jan	31.1	9.7	67.2	19.1	4.0	0.85	10.3	40.5	25.8	23.5	9.0	8.6
5	29-4 February	31.8	8.4	63.1	17.7	4.0	0.85	9.5	39.4	25.5	23.8	9.3	8.4
6	5-11 Feb	32.5	14.4	59.0	26.4	3.8	1.45	10.5	42.0	26.7	24.0	11.1	10.7
7	12-18 Feb	31.2	13.8	71.2	30.1	4.8	1.33	9.7	40.9	26.4	25.7	11.8	12.0
8	19-25 Feb	28.4	8.7	67.7	28.8	5.4	1.17	10.6	42.0	26.3	24.3	6.9	8.4
9	26-4 March	30.7	12.3	63.50	27.0	5.7	1.8	10.4	43.1	28.0	25.6	8.2	10.4
10	5-11 Mar	31.6	12.7	59.5	22.7	6.6	1.65	10.4	43.1	28.6	22.4	6.7	10.4

Chapter Opener Page

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T.244)

