DEVELOPMENT OF SUBSURFACE PAD IRRIGATION SYSTEM FOR TOMATO

By

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THESIS

Submitted in partial fulfilment of the requirement for the degree

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DECLARATION

I hereby declare that this thesis entitled ***"Development of subsurface pad irrigation system for tomato"*** *is a bonafide record of research work done by me during the course of research and that this thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.*

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EXTERNAL EXAMINER

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M.K. ABDUL NASSAR

DEDICATED

TO

MY PARENTS

CONTENTS

ABBREVIATIONS

CU	-	Consumptive use
DAT	-	Days after transplanting
ET	-	Evapotranspiration
IW	-	Irrigation water
IW/CPE	-	Irrigation water / Cumulative pan evaporation
K Pa	-	Kilo Pascal
M Pa	-	Mega Pascal
SI	-	Surface irrigation
SSPI	-	Subsurface pad irrigation
WUE	-	Water use efficiency

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Introduction

INTRODUCTION

India is a country with fabulous water resources. As much as 400 million ha.m. of water is annually available in the country which has an irrigation potential of 114 m.ha. Though the country has created an irrigation potential of 86 m. ha. the current level of utilisation is only 68 m.ha. The utilisation of irrigation water especially of canal water is rather least cared by the people whereas the productive efficiency of ground water owned by the farmers is very appreciable. The overall efficiency of irrigation in the country is rather to the tune of 30-40 per cent if compared with as much as 95-99 per cent in Israel.

Kerala is a state blessed with enormous showers (3063 mm of rainfall) and 44 number of rivers. However it is paradoxical to observe that only 13.5 per cent of area is irrigated, cropping intensity is 134 per cent and dry spells and droughts are increasing year by year. The state is having 2.1 lakh ha area under vegetables which are mainly raised in the summer rice fallows as irrigated crop. Inadequacy of water is a serious constraint to the vegetable crop production in the state. Whatever limited quantity of water is available for irrigation, it is not properly utilised and the efficiency of application is reduced due to conveyance losses, evaporative losses and associated field problems.

So many frontier technologies are coming up in the field of irrigation management. Technologies have been developed and applied in the developed countries for effective utilisation of whatever little water resources are available and maximising productivity with rational economic considerations. In this context subsurface irrigation is a concept which needs appropriate technological back up for large scale adoption.

Subsurface irrigation is a method in which water is applied below the ground surface by maintaining an artificial water table at some depth depending upon the soil texture and the depth of the plant roots. Water reaches the plant roots through capillary action. The greatest benefit of this system is the increase in land area that can be irrigated as a result of the extra water made available. The major advantages of subsurface irrigation is in the reduction of evaporation and high water use efficiency. A permanent subsurface irrigation system requires less labour cost and longer life expectancy. As the surface soil gets dried, weed infestation will be very low.

Tomato is one of the most popular vegetables in the world. It has very good response to irrigation. But in Kerala, no detailed investigation has been undertaken so far to study the water requirement of tomato. Considering the above facts, the present investigation was undertaken with the following objectives:

1. Design and development of "subsurface irrigation pads" for tomato.
2. Its testing and working out of feasibility for large scale introduction in vegetable cropping.

Review of Literature

REVIEW OF LITERATURE

Subsurface irrigation is the *in situ* application of water directly to the root zone of a crop. This is a concept so far though has been a subject of experimentation since long back. Revolutionary changes taking place in the field of plasticulture greatly improved the possibility of subsurface irrigation. The main objective of subsurface irrigation is to supply water evenly and automatically to the root zone according to the demand with little contribution to losses.

This chapter provides a review of the relevant literature available in India and abroad on various aspects related to the present study under the following heads.

I Effect of subsurface/trickle irrigation on the growth and yield of vegetables especially tomato

II Comparative performance of different irrigation systems in vegetables especially tomato

III Moisture distribution pattern under trickle irrigation

IV Effect of subsurface/trickle irrigation on moisture use, water use efficiency and economics

V Use of organic materials in moisture conservation

I Effect of subsurface/trickle irrigation on growth and yield of vegetables especially tomato

a) Growth

Tomato is one of the most popular vegetables in many countries. It belongs to family Solanaceae which includes other important members like brinjal, potato and chilli. Tomato is an annual warm season crop. As a processing crop it ranks first among the vegetables.

Tomato plants put up its best growth in a sandy loam soil when the available soil moisture level ranged from 100-50 per cent (Dastane *et al.,* 1963).

Surface irrigation had greater effect on petiole length and plant height of taro (*Colocasia antiquorum* Schott.) than subsurface irrigation, when irrigation was given with 20 mm of water when pF reached 2.5 at 10 cm depth (Kudo, 1987).

Singh (1987) observed that irrigation equal to 60 per cent pan evaporation produced maximum fruit yield of okra cv. Clemson Spineless planted during May in a sandy loam soil at Fort Valley State College Agricultural Research Station in USA and significant reduction in yield was noted with an increase or decrease in the amount of irrigation.

Tomato cv. Roma VF produced maximum growth when soil moisture was held at field capacity at the depth of 0-90 cm of soil surface (Giardini *et al.*, 1988).

The average leaf area index values during vegetative growth, flowering, fruit set, fruit development and fruit ripening were 3.3, 3.7, 6.0, 5.7 and 5.1 respectively when tomato cv. IPA-5 plants were grown using conventional management practices (Andre and Mascr, 1992).

b) Yield

Tomato variety GCR-5 planted in March in a sandy loam soil at Sutton yielded the highest 177.75 t ha^{-1} when it was irrigated as per the wet treatment (cumulative loss prior to irrigation = 10mm) compared to 131.25 t ha^{-1} fruits produced in the dry treatment (cumulative loss prior to irrigation = 40 mm) (Waister and Hudson, 1970).

Sivanappan *et al.* (1972) observed that drip irrigated tomato variety CO-1 in sandy soil at Coimbatore during August to October season gave the yield of 23.56 t ha^{-1} compared to 18.04 t ha^{-1} by furrow irrigation. Yet another trial in this tract with the same variety yielded 8.872 and 6.137 t ha^{-1} of fruits respectively, when drip and furrow irrigation were adopted (Sivanappan *et al.*, 1974).

Trickle irrigation with 100 per cent ET soil moisture replacement produced the highest tomato fruit yield of 139.3 t ha^{-1} whereas trickle irrigation with 80 per cent ET soil water replacement gave 109.2 t ha^{-1} and furrow irrigation gave 102.6 t ha^{-1} (Hermus, 1986).

Sweeney *et al.* (1987) did not observe any significant difference between the tomato fruits produced when trickle and overhead irrigation systems were used in a loamy soil. The crop irrigated by former method produced 68.7 whereas the latter method produced 68.0 t ha^{-1} of fruits.

Subsurface trickle irrigated tomato cv. Sunny gave 38.5 t ha^{-1} fruit yield compared to 31.6 t ha^{-1} by furrow irrigation in the Lower Rio Grande Valley of Texas, Weslaco (Bogle *et al,* 1989).

Bar-Yosef *et al.* (1989) observed that the average yield of sweet corn was 23.46 t ha^{-1} by surface irrigation compared to 25.24 t ha^{-1} by subsurface irrigation in Israel.

The irrigation cum plant density study conducted by Gupta (1990) at Bangalore indicated that the maximum yield of okra (14.71 t ha^{-1}) was obtained when the crop was irrigated at 20 mm cumulative pan evaporation which was the shortest interval tested.

Phene *et al.* (1992) obtained red tomato yield exceeding 200 t ha^{-1} in large yield plot experiments with cv.UC-82 B in California with subsurface irrigation system.

The maximum yield of 32.1 t ha^{-1} was produced by potato variety Kufri Chandramukhi when drip irrigations were given on alternate days in loamy sand soil at Ludhiana. The crop irrigated by furrow method at 7 days interval produced only 25.4 t ha^{-1} (Saggu and Kaushal, 1993).

Shrivastava *et al.* (1994) observed in a moisture use study involving three regimes that tomato cv. Rupali grown in a clayey soil yielded maximum fruits (51 t ha^{-1}) when a drip irrigation scheduled at 0.4 of pan evaporation was adopted along with mulching with sugarcane trash.

II Comparative performance of different irrigation systems in vegetables, especially tomato

Subsurface irrigation system is becoming practical with the availability of inexpensive plastic pipes and sheets. The system is advantageous for the even and automatic application of water with less labour input, and low evaporative and other application losses. The critical part of any subsurface irrigation system is the device that applies water from the pipe into the soil. This underground applicator should be durable, resistant to root penetration, of continuous flow property, easily installable and replaceable, and having better economy (Davis, 1967).

Subirrigation can preferably be adopted in soils having a high infiltration rate and a low water holding capacity. Surface methods cannot be used and sprinkler is expensive in such cases. The optimum depth of crop water needs at different growth stages can be maintained by subirrigation. This method of irrigation is practised in order to a limited extend for growing vegetable crops around "Dal" lake in Kashmir and for irrigating coconut palms in Kuttanadu area in Kerala (Michael,1978). The greatest benefit of using any micro-irrigation system is the increase in land that can be irrigated as a result of the extra water made available (Moynihan and Haman, 1992). Drip irrigation has the benefits in terms of water conservation, crop productivity and high water use efficiency than furrow irrigation (Minasian *et al.*, 1994).

The trial conducted by Sivanappan *et al.* (1972) at the Millet Breeding Station, Agricultural College and Research Institute, Coimbatore during 1970 revealed that the better system of irrigation for tomato var. CO-1 was the drip compared to furrow for having better yield and 87 per cent economy of water. Further field trials conducted during 1973 to assess the efficacy of trickle method of irrigation in the red sandy soil with the same variety confirmed the supremacy of drip irrigation over furrow irrigation (Sivanappan *et al.,* 1974).

Low water tensions of the range of 10 to 20 centibars could be maintained in clayey soil with drip irrigation and these conditions considerably improved the yield and processing quality of tomatoes cv. VF-317 (Rudich *et al.*, 1977).

But according to Pill and Jacono(1984) subirrigation generally resulted in greater plant water stress than cyclical (surface) irrigation when Hydrogel was applied to the root zone of tomato.

According to Hermus (1986) soil water replacement by trickle irrigation with 100 per cent ET found to be the better method of irrigation in tomato than furrow irrigation.

Among the sprinkler, trickle and furrow methods of irrigation tried at Western Nobaria to produce quality tomato, trickle irrigation was found to be the best with respect to quality of tomato and economy (Younis, 1986).

Subsurface and surface irrigation performed equally better in taro plants (*Colocasia antiquorum* Schott). Here irrigation was scheduled with 20 mm of water when soil pF reached 2.5 at 10 cm depth (Kudo, 1987).

According to Phene *et al.* (1987), subsurface drip irrigation system possessed many advantages over surface installation. A permanent subsurface drip irrigation system required lesser labour cost and longer life expectancy. A dry surface soil situation reduced the threat of soil born diseases and weed infestations apart from providing easy traffic movement with least soil compaction. Water and nutrient use efficiencies were higher and yield as well as certain quality parameters of tomato were often improved with subsurface drip irrigation.

A study conducted for evaluating the effect on yield and nitrogen recovery by tomatoes on a loamy sand soil with factorial combinations of trickle and overhead irrigation with or without polythene mulch, 100 or 50 per cent NH_4NO_3 and 50 per cent sulfur-coated urea revealed that neither tomato yield nor nitrogen uptake was affected by irrigation methods (Sweeney *et al.,* 1987).

An irrigation study using tomato in a green house involving furrow irrigation, microtube irrigation (5 litre hr^{-1} per plant), drip irrigation (2 litre hr^{-1}, one emitter per plant) and subsurface irrigation using porous clay tube (5 litre hr^{-1}) placed 25 cm deep was conducted scheduling irrigation using tensiometers when tension reached above 0.02 M Pa. The study indicated that water use was 26 cm, 29 cm, 36 cm and 46 cm respectively for subsurface, drip, microtube and furrow irrigation. Though monthly yields were sometimes lower with subsurface irrigation, total yields did not significantly differ between the treatments (Chartzoulakis and Michelakis, 1988).

Subsurface drip irrigation given to tomato at 10-18 inches below the soil led to remarkably lower weed population and significantly higher yield, compared to furrow or sprinkler irrigation and the fruits matured more rapidly under subsurface drip irrigation (Grattan *et al.,* 1988).

Kaniszewski and Dysko (1988) observed that drip irrigation system (capillary system, thin-wall and combination emitter) and microjet system were better than hand watering by hose for green house tomato. Here the crop was irrigated when soil moisture tension reached $^{-}$0.02 M Pa and irrigation was given at the rate of 2 litre plant^{-1} .

The comparative performance of trickle and subirrigation systems such as filter capillary, water table and perforated pipes was studied in the sandy loam soil at Hissar using tomato crop. The subsurface irrigation systems buried 40-45 cm deep in the soil provided better yield and higher water use efficiency than trickle irrigation (Singh and Kumar, 1988).

Surface as well as sprinkler (movable or fixed) method of irrigation did not differ significantly between each other in producing tomato yield when tried at Khattara in Egypt (El-beheidi *et al.,* 1990).

A trial was conducted at Fresno, U.S.A. in processing tomatoes cv. VC 82 B using high frequency subsurface drip (SSD), high frequency surface drip (HFSD) and low frequency surface drip (LFSD) irrigation systems.

The subsurface drip system produced higher yields than the other two systems in 1985 and 1987 when P was applied to the crop. All the systems gave similar results in 1984 when only N was applied (Phene *et al.,* 1990).

When subsurface drip irrigation was used in processing tomatoes in clay loam soils of California the acceptable levels of seed emergence was obtained when drip tape was buried at depths of 6 and 9 inches than 12 inch (Schwankl *et al.,* 1991).

Sudnitsyn *et al.*(1991) compared subsurface irrigation with surface irrigation in cabbage, lettuce and spinach in the irrigated podzolic soil at Moscow, Russia. Subsurface irrigation was provided by perforated polythene hose of 15 mm diameter laid on a polythene film strip of 20 cm wide. Crop was irrigated when the soil moisture tension fell to $^{-}10$ to $^{-}30$ KPa. The study indicated that subsurface irrigation was more efficient than surface in terms of biomass yield and water use. Scheduling of irrigation at a tension of $^{-}10$ K Pa for cabbages and lettuce and $^{-}30$ K Pa for spinach were found to be optimum.

When saline water is used for irrigation, Hamdy(1992) observed that furrow irrigation method was better than drip irrigation for tomato at Bari in Italy, in keeping the salt accumulation away from the root zone.

According to Moynihan and Haman(1992) the surface irrigation system used 3.4 times more water than drip irrigation system, produced lesser yield and required more labour for irrigation of Callaloo (*Amaranthus viridus* L.) and Cucumber (*Cucumis sativus* L.) at St. Catherine, Jamaica.

Phene *et al.* (1992) obtained an yield exceeding 200 t ha^{-1} of red tomatoes cv. UC-82 B in large yield plot experiment at California under subsurface drip irrigation where the laterals were buried permanently 20-60 cm below the soil surface.

Ells *et al.* (1994) observed that trickle and furrow methods of irrigation in a clay loam soil did not differ in their response to influence the yield of *Cucurbita pepo* cv. Table King.

A subirrigation model study in Malaysia in which the influence of water levels in channels related to water flow to plants was conducted by Wylam (1995) in a marsh soil containing clay over peat. This study in which water was made available to plants by capillary rise showed that labour requirements as well as canal density were reduced and cropped area increased in the vegetable growing scheme.

Thus the overall review of work generally indicates that subsurface irrigation system increases yield and water use efficiency, reduces labour cost and improves quality of vegetables compared to surface system.

III Moisture distribution pattern under trickle irrigation

The soil moisture distribution pattern resulting from trickle sources is different from that resulting from the conventional methods of irrigation.

In the numerical analysis, Brandt *et al.* (1972) modelled infiltration from a drip source by assuming that the water entry zone was saturated and such a zone of saturation will occur for both line and point sources. The width of the saturated zone for Gilat loam soil was approximately 220 and 580 mm respectively for two discharge rates of 1.8 and 5.9 litre m^{-1} hr^{-1} for a line source. The time necessary to reach the maximum wetted area on the surface was in the order of 3 hr for the lowest discharge rate to nearly one day for the highest rate. When the point of application was isolated in a drip system, the soil was wetted in an axially symmetric pattern just like a bulb rather than in a one dimensional fashion. However, the wetted parts of the surface will close together if emitters were placed sufficiently close to each other. The pattern of wetting became two-dimensional (horizontal in the direction perpendicular to the source and vertical) rather than three dimensional in the extreme case when many emitters were put together closely on a line reflecting the result of an effective line or strip source (Howell *et al.,* 1980).

Different emitter discharges viz. 2, 3, 4 and 5 litre hr^{-1} were compared in a field experiment in a vertisol. A radial spread of 31.0 cm and 26.25 cm were observed at the surface for the lowest (2 litre hr^{-1}) and the highest

(5 litre hr^{-1}) discharges respectively. The vertical advances were 105.65 and 118.5 cm for 2 litre hr^{-1} and 5 litre hr^{-1} emitter discharges respectively indicating that the radial spread at the surface was greater for the lower discharge whereas vertical advance was greater for higher discharge. The maximum radial spread of 56.76 cm was observed at 59.61 cm below the soil surface for the 3 litre hr^{-1} emitter discharge (Phadtare *et al.*, 1992).

Mishra and Pyasi (1993) observed that the moisture distribution under drip irrigation at Karnal was more uniform within a 10 cm radius of the emitter with maximum uniformity at zero, while non uniformity increased with distance from the emitters.

Amir and Dag (1993) from a very low energy moving emitter study in heavy clay soil at Israel inferred that the instantaneous application rates increased the width and uniformity of wetting of soil, but it caused high lateral dispersion of soil and reduced the depth of soil irrigated.

The results of a time domain reflectometry technique done by Pelletier and Tan (1993) at Agriculture Canada, Research Station showed that a distinct cone shape of >50 per cent available soil water extending from the emitter down to a depth of >45 cm occurred in a drip irrigation whereas the 50 per cent available soil water zone in a microjet system was an elongated semicircle from the soil surface to a depth of 35 cm.

IV Effect of subsurface/trickle irrigation on moisture use, water use efficiency and economics

a) Moisture use

The tomato cv. Claudia Raf grown in plastic green house in the Jordan Valley under drip irrigation system consumed 859, 803 and 639 mm water when irrigation was scheduled at 30, 50 and 70 centibars measured at 30 cm depth, respectively. The average daily water consumption ranged from less than 2 mm for all plots during January, to 8.16, 8.21 and 6.6 mm for the three treatments respectively (Battikhi *et al.,* 1985).

Bangal *et al.* (1986) observed that tomato variety Pusa Ruby required 218 mm of water by trickle irrigation compared to 393 mm by furrow irrigation while producing comparable yields.

Neutron probe study conducted by Judah (1986) showed that the amount of water applied at each irrigation equalled to the amount absorbed by the tomato plants when irrigation was given at 2, 4 and 7 days interval and the total water applied to the crop were 980, 1000 and 976 mm respectively,

Though the total water discharged for the tomato cv. Dombito grown in an unheated green house during the September-June period varied between

460 mm for furrow irrigation, 360 mm for microtubes, 290 mm for drip and 260 mm for subsurface irrigation, this was not reflected in the ultimate yield of the crop (Chartzoulakis and Michelakis, 1988).

However, Michelakis and Chartzoulakis (1988) recorded the best result in the same variety in the same season under drip irrigation when 390 mm of water was applied compared to 310, 340 and 610 mm.

Chartzoulakis (1990) observed that drip system which led to a consumption of 366 mm of water by green house cucumber of 3.5 months duration was better than furrow, microtube, porous clay tube and porous plastic tube irrigation systems which led to the consumption of 507, 383, 342 and 292 mm of water, respectively.

Lysimetric studies indicated that the accumulated maximum ET and potential ET during the growth period of tomato cv. IPA-5 were 377 and 411 mm respectively (Andre and Mascr, 1992).

Yield of okra and tomato on a sandy loam soil at Ile-Ife, Nigeria, increased with increasing amount of water applied upto the point where total applied water (467-481 mm) closely matched the calculated total evapotranspiration of 460-470 mm (Fapohunda, 1992).

Muller (1993) observed that tomato cv. Delta transplanted in an alluvial soil yielded 14.9 t ha^{-1} when drip irrigated with 270 mm water while 65.5 t ha^{-1} when 699 mm water was applied under black plastic mulch.

Observations recorded at the Agronomic Research Station, Chalakudy in the water management experiment during the summer season of 1982-83 revealed that bittergourd extracted 66-71 per cent of the total water use from the top 30 cm soil layer. The total consumptive use of water by the crop was maximum (321.78 mm) when irrigation was scheduled at the IW/CPE ratio 1.2 compared to 0.4 and 0.8 (Thomas, 1984).

Lakshmanan (1985) observed that permissible level of depletion before scheduling irrigation to pumpkin, oriental pickling melon and ashgourd was 75 per cent depletion of available soil moisture in sandy clay loam soil at Mannuthy during the summer season. Moisture extraction was found to be higher from the surface layer (0-15 cm) and it was 38.03 per cent of the total.

Lysimetric studies in okra conducted in Jordan Valley during the season May-September showed that potential evapotranspiration of the crop was 485 mm (Ghawi *et al.*, 1986).

Bhindi grown during summer season on loamy sand soils at Chalakudy, extracted 71.56 per cent of the total water use of 229.5 mm from the top 30 cm layer when irrigated at 30 mm CPE. Total consumptive use increased with increase in irrigation frequency and was the highest when irrigated at 30 mm CPE compared to 45, 60 and 75 mm CPE (Kumar, 1986).

b) Water use efficiency

Battikhi *et al.* (1985) observed no significant difference between water use efficiencies of direct sown tomato cv. Claudia Raf in plastic green house when irrigated under soil moisture tensions of 30, 50 and 70 centibars observed at 30 cm depth in the Jordan Valley.

The water use efficiency of tomato variety Pusa Ruby grown was 7.87 and 4.65 kg ha^{-1} m^{-1} of water under trickle and furrow system respectively (Bangal *et al,* 1986).

Chartzoulakis and Michelakis (1988) observed that the efficiency of applied water for tomato cv. Dombito grown in an unheated green house was highest with drip irrigation (47.7 kg m^{-1} water applied) and lowest with furrow irrigation (27.8 kg m^{-1} water).

Subsurface irrigation led to higher water use efficiency than trickle irrigation when tomato cv. HS-101 was planted in March in sandy loam soil at Hissar. Water table irrigation enhanced WUE by 72 per cent over perforated pipe irrigation and 98 per cent over filter capillary irrigation with 1:2 filter capsules (Singh and Kumar, 1988).

Water use efficiency for cucumber was highest with drip irrigation (27.7 kg m^{-2} water) and lowest with furrow irrigation (16.8 kg m^{-2}) when furrow, microtube, drip, porous clay tube and porous plastic tube irrigation systems were compared (Chartzoulakis, 1990).

Hartz (1993) observed that water use efficiency of tomato cv. Bingo was 0.33 to 0.42 kg ha^{-1} m^{-1} of water when single drip line was used in a sandy loam soil at California.

c) Economics

Sivanappan *et al.* (1972) reported that the cost of the deviced equipment for drip irrigation system at Millet Breeding Station, Coimbatore in 1970 came to about Rs.1500/- per 2700 sq. feet.

According to Singh and Kumar (1988), the cost of installation for all subsurface irrigation systems should be much lower than trickle irrigation system as it did away with the need of drippers and wider lateral spacing.

Ahmad *et al.* (1989) observed that installation costs were high for leaky pipe subsurface irrigation systems. He outlined a subsurface irrigation system using hose-fed earthenware containers buried in the soil, which was a low cost one.

The Benefit Cost ratio for tomato cv. Pusa Ruby production was 5.15 with drip irrigation and 2.96 with furrow irrigation (Jadhav *et al.,* 1990).

Adoption of drip irrigation system for the single and double cropped production alternatives resulted in lower levels of expected returns and higher levels of risk when compared to semiclosed subirrigation system. Among the various production enterprises, the highest level of risk was associated with tomatoes (Prevatt et al, 1992a).

According to Prevatt *et al.* (1992b) the semi-closed subirrigation system was determined to be the lowest cost tomato irrigation system under present fuel cost and non-limiting water supply conditions. The investment cost of the drip irrigation system was significantly greater when compared to semi-closed subirrigation (seepage) and fully enclosed subirrigation (seepage) systems and the variable cost for semi-closed system was less than that for fully enclosed and drip irrigation systems.

Results of an economic analysis of four drip irrigation systems in comparison with a furrow irrigation in Iraq indicated that drip irrigation was economically attractive in arid or semi-arid regions. Drip systems with injected emitters were more economical than those with extruded emitters, especially when the systems were used for several seasons. For single season use, the bi-wall pipe system and spiral on-line emitter system were economically preferable (Minasian *et al.,* 1994).

V Use of organic materials in moisture conservation

Crop residues and other plant waste products like straw, stover, leaves, corn cobs, saw dust, wood chips etc. acted as cheap source of organic material readily available permitting water to enter the soil readily. When maintained at adequate levels, these materials reduced evaporation and increased water content in soil (Gupta, 1975).

Raghothama (1981) observed that paddy husk and coir dust were most effective in conserving soil moisture and reducing the number of irrigation required for cardamom.

Singh *et al.,* (1987) observed that paddy straw mulching gave potato tuber yield of 10.34 - 11.54 t ha^{-1} compared to 8.24 - 9.15 t ha^{-1} without mulch. Mulch decreased soil water depletion and water use under both irrigated and rainfed conditions.

According to Singh *et al.,* (1988), mulching with 6t rice straw ha^{-1} reduced the maximum soil temperature by 1 to 6°C at 10 cm depth and increased the minimum temperature by 0.5 to 2°C, conserved soil water, suppressed weed growth and increased water use efficiency even then it did not affect tuber yield of potato.

By providing a 5 cm thick coir pith layer and 45 cm deep trench for planting 'Kew' pineapple produced highest fruit yield of 68.6 t ha^{-1} when compared with unmulched plants (36.4 t ha^{-1}) planted in 15 cm deep trenches (Uthaiah *et al.,* 1990).

Yield of pineapple cv. Smooth Cayenne mulched to a depth of 5 cm with rice husks, sawdust and wood chips was 176,169 and 194 t ha^{-1} respectively, compared to 107 t ha^{-1} with no mulch (Obiefuna, 1991).

Asoegwu (1991) attributed that mulching in pineapple plot with wood shavings, rice husk and sawdust enhanced soil moisture retention compared with no mulch control.

Growth of coconut seedlings cv. West Coast Tall was encouraged by coir pith mulch compared to other mulching materials like paddy husk, plastic sheet and Jalashakthi (hydrophilic polymer), in coastal Karnataka, but the treatments did not significantly affect plant height, number of leaves produced $year^{-1}$ and frond characters (Uthaiah *et al.,* 1993).

Materials and Methods

MATERIALS AND METHODS

The experiment, designing and developing subsurface pad irrigation system, and testing and working out its feasibility for large scale introduction to tomato cropping, was conducted during the summer season (Feb-April) of 1995 in the paddy fallow lands of Agricultural Research Station, Mannuthy, of Kerala Agricultural University. The experimental materials used and methodology followed during the course of investigation are presented in this chapter.

3.1 Climate and weather conditions

Geographically the Agricultural Research Station, Mannuthy is located at 22.5 m above the mean sea level at 12° 32' N latitude and 74° 20' E longitude. The area experiences tropical monsoon climate.

The hottest month generally is March with a mean maximum air temperature of 36° C. The coldest period is in January when minimum air temperature reaches to the lowest values of 21-22° C. Thereafter, temperature rises upto May and goes down with the advent of South West monsoon. The mean annual total rainfall data for twelve years (1983-1994) indicates that 2668.6 mm rainfall is received annually out of which about 75 per cent falls during the South-West monsoon (June to September), 16.6 per cent during North-East monsoon and the rest being distributed in the summer months. Pan evaporation value attains the peak of nearly 7.0 mm/day during

February-March while remains the lowest of 2.8 mm/day in June-July. The wind blows with a mean velocity of 6.7 km h^{-1} during the transplanting period (February) and 4.9 km h^{-1} at the harvesting time (April).

The weekly weather data for the cropping period obtained from the Department of Agricultural Meteorology, College of Horticulture, Vellanikkara are graphically presented in Figure 1 while the absolute values are given in Table 1. The mean monthly weather data for summer season averaged over twelve years (1983 - 1994) are given in Appendix 1. Appendix 2 gives the absolute values for daily evaporation and rainfall data for the cropping period.

The crop received 58.1 mm rainfall during its growth period. A normal year receives 66.5 mm total rainfall during the corresponding period. Mean evaporation was 6.6 mm/day during the growth period. The normal evaporation during this period is 5.8 mm/day. The mean maximum and minimum temperatures during same period were also nearly normal.

3.2 Soil

The soil of the experimental field was sandy clay loam in texture and acidic in reaction with a pH of 5.6. The physico-chemical properties of the soil observed before the commencement of experiment are given in Table 2. The soil was medium in organic carbon and available potassium and high in available phosphorus.

Table 1 Mean weekly weather parameters for the crop growth period

Standard Week No.	Month and date	Maximum temperature (°C)	Minimum temperature (°C)	Sunshine hours (h)	Relative humidity (%)	Wind speed (km h^{-1})	Total evaporation (mm)	Total Rainfall (mm)
1	Jan 01 - Jan 07	31.8	22.1	9.5	57	11.2	40.5	-
2	Jan 08 - Jan 14	33.3	21.5	8.5	69	4.3	29.0	-
3	Jan 15 - Jan 21	31.7	23.8	9.7	57	10.5	43.5	-
4	Jan 22 - Jan 28	33.3	21.8	10.4	56	9.6	46.0	-
5	Jan 29 - Feb 04	33.9	24.2	10.8	53	10.8	48.9	-
6	Feb 05 - Feb 11	34.7	23.4	10.3	54	10.2	52.7	-
7	Feb 12 - Feb 18	35.6	22.6	9.9	59	4.6	39.2	-
8	Feb 19 - Feb 25	36.1	23.4	9.7	70	3.8	34.6	0.5
9	Feb 26 - Mar 04	37.2	23.1	9.0	64	4.3	39.1	-
10	Mar 05 - Mar 11	36.9	23.8	8.6	62	4.6	38.5	1.8
11	Mar 12 - Mar 18	37.8	23.8	9.3	62	3.3	40.5	1.0
12	Mar 19 - Mar 25	38.9	23.7	10.3	54	5.2	53.2	-
13	Mar 26 - Apr 01	36.5	24.5	9.5	67	4.6	41.5	-
14	Apr 02 - Apr 08	37.5	24.4	8.9	68	4.4	41.8	54.8

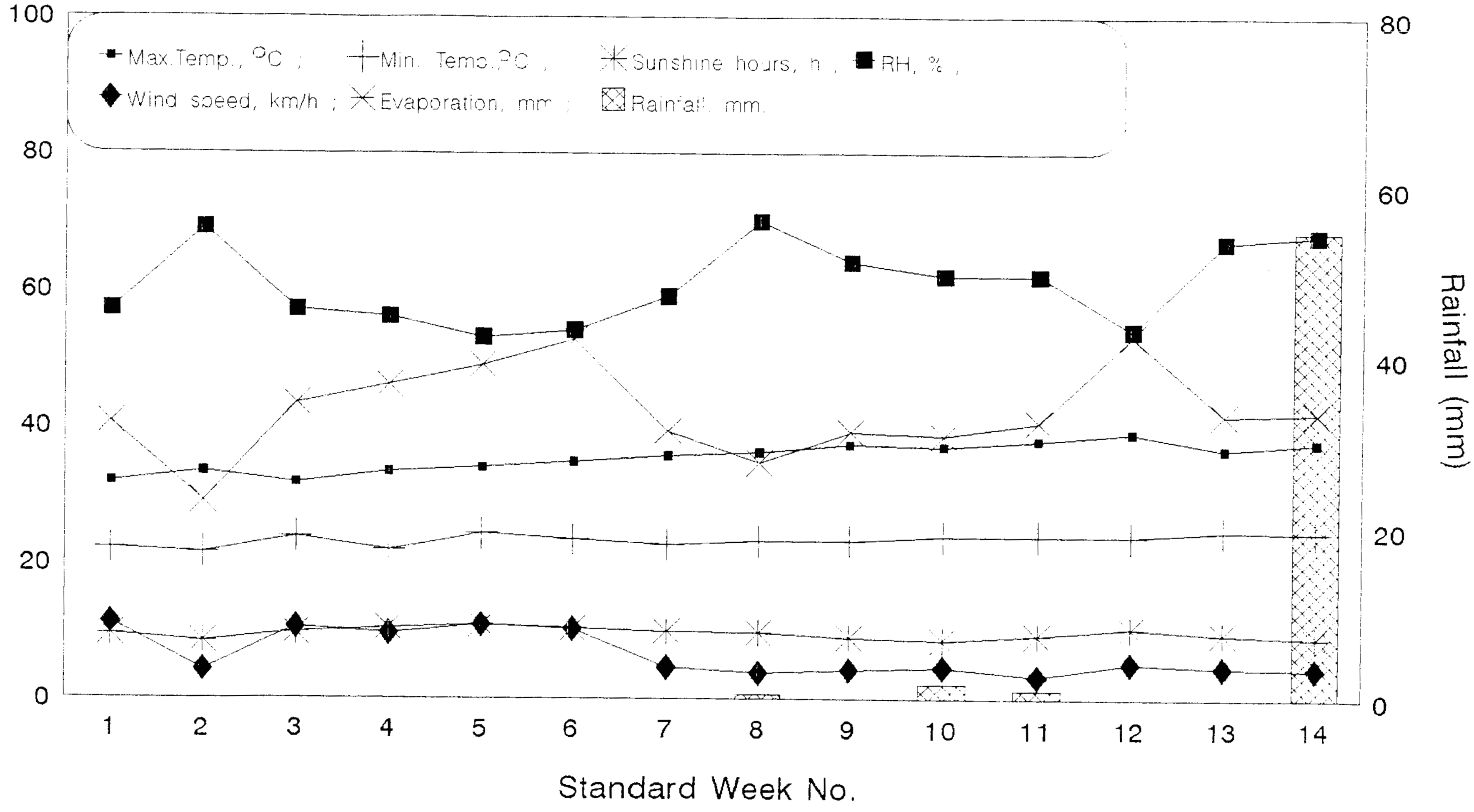


Fig.1. Meteorological data (Weekly) during the crop period

(Temperature, sunshine hours, RH and wind speed data represent average for the week. Evaporation and rainfall data represent weekly total)

Table 2 Physico-chemical properties of soil in the experimental field

Particulars	Value (per cent)	Method employed
A. Mechanical composition		
Coarse sand	27.2	Robinson's International
Fine sand	23.8	Pipette method
Silt	22.6	(Piper, 1966)
Clay	26.4	
Textural class	Sandy clay loam	I.S.S.S. system

B. Physical composition of the soil

Constant	Value	Procedure adopted
Field capacity (0.3 bars)	23.69 % w/w	Pressure plate apparatus (Richard, 1947)
Permanent wilting Point (15 bars)	9.54 % w/w	Pressure plate apparatus (Richard, 1947)
Bulk density		
0-15 cm depth	= 1.50 g cm^{-3}	Core method (Blake, 1965)
15-30 cm depth	= 1.52 g cm^{-3}	

Contd......

Table 2 contd....

C. Chemical composition

Particulars	Value	Method employed
Organic C	0.579 %	Walkley and Black method (Soil Survey Staff, 1992)
Total N	0.084 %	Semi-microkjeldahl method (Soil Survey Staff, 1992)
Available N	279.30 kg ha^{-1}	Alkaline permanganate distillation (Subbiah and Asija, 1956)
Available P	79.79 kg ha^{-1}	Bray-1 extractant - Ascorbic acid reductant method (Soil Survey Staff, 1992)
Available K	112 kg ha^{-1}	Neutral normal ammonium acetate extractant - flame photometry (Jackson, 1973)
pH	5.6	1 : 2.5 Soil : Water suspension using pH meter (Jackson, 1973)
Electrical conductivity	1.25 dS m^{-1}	Supernatant of 1 : 2.5 Soil : Water suspension using EC bridge (Jackson, 1973).

3.3 Cropping history of the experimental site

The experimental area was a double crop paddy land where a semi-dry crop during April-May to August-September and a wet crop during September-October to December-January were usually cultivated. Vegetable crop is raised in this field during summer months.

3.5 Details of experiment

The field experiment was conducted during summer season of 1995. The layout plan is given in Figure 2. The technical programme followed is as follows:

I Design : Randomised Block Design

II Replications : Three

III Treatments:

T_1 - Subsurface pad irrigation at IW/CPE ratio = 1.2

T_2 - Subsurface pad irrigation at IW/CPE ratio = 0.9

T_3 - Subsurface pad irrigation at IW/CPE ratio = 0.6

T_4 - Subsurface pad irrigation at IW/CPE ratio = 0.3

T_5 - Surface irrigation at IW/CPE ratio = 1.2

T_6 - Surface irrigation at IW/CPE ratio = 0.9

T_7 - Surface irrigation at IW/CPE ratio = 0.6

T_8 - Surface irrigation at IW/CPE ratio = 0.3

IW = 40 mm

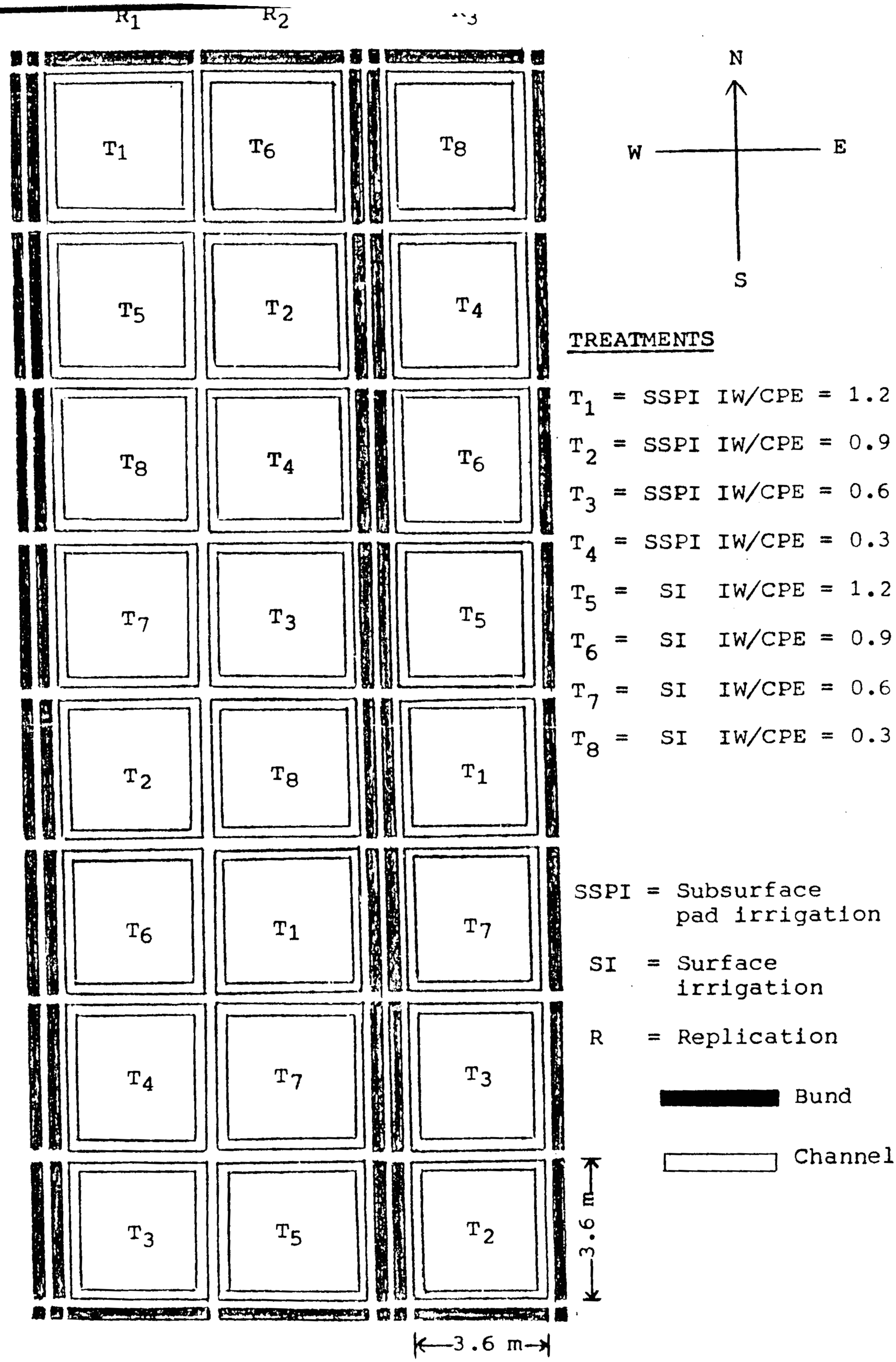


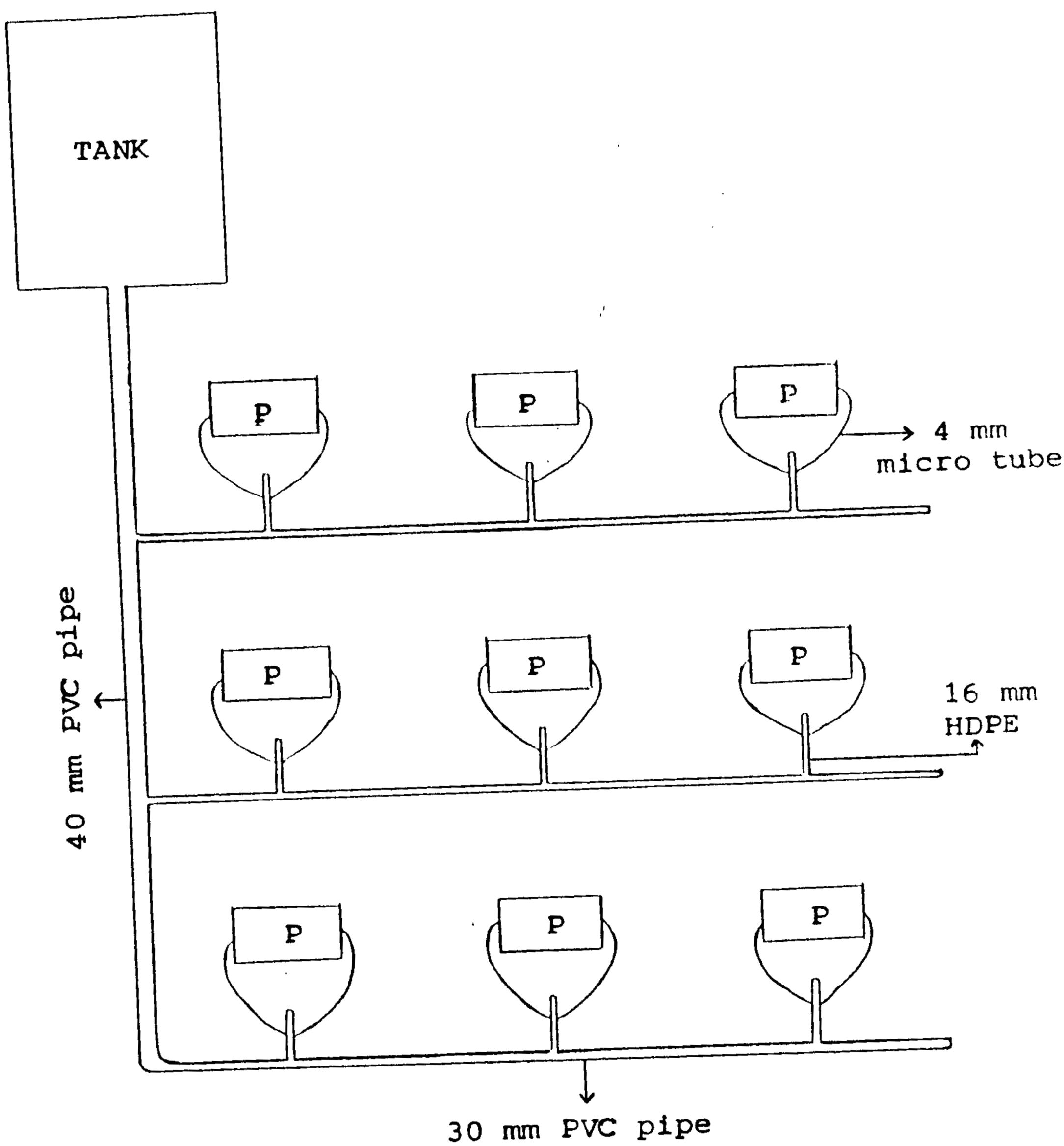
Fig.2 Layout plan of the experiment

Subsurface irrigation pads were prepared using 400 gauge polybags of 45 cm length and 30 cm width, each filled with saw dust and sealed. Nine circular holes of radius 4 mm were punctured on the upper side of the bag. These pads were top buried keeping holes facing upwards in the pits at a depth of 45 cm spaced 1.2 m apart. Each pad will act as a reservoir of moisture. Nine pads, each supplying moisture to four plants spaced 0.6 m apart were installed in each plot of size 3.6 m x 3.6 m. Each pad received two numbers of 4 mm HDPE distributary which originate from 16 mm HDPE sublaterals through pin connectors. These HDPE sublaterals are connected to 30 mm PVC pipe through start end washer. The sublateral join to the main pipe of PVC through 'T' joints and main is connected to reservoir tank of 200 litre capacity through PVC wheel valves. Each pad receives water through two distributor pipe which delivers water @ 4 litre hour^{-1} per distributor. A schematic diagram showing the layout of subsurface pad irrigation system is given in Figure 3.

As the pad is filled with sawdust, it holds water and act as a reservoir. The pads supply moisture to the root zone depending upon the depletion caused by the transpirational pull exerted by crop canopy. The water supply to the reservoir depended upon the irrigation.

IV	Plot size	:	3.6 m x 3.6 m
V	Crop	:	Tomato *(Lycopersicon esculentum* Mill.)
VI	Variety	:	LE 79 (Sakthi)

Fig.3 Layout of subsurface pad irrigation system



P = PAD

Sakthi is a new tomato variety, developed at Kerala Agricultural University. It has resistance against bacterial wilt. The duration of the crop is 90 days (45 - 60 days after transplanting). The yield potential of Sakthi is 15 - 25 t ha^{-1}.

3.6 Cultural operations

3.6.1 Nursery practice

Nursery was raised by mixing sand, soil and farm yard manure in the ratio of 1:1:1. The soil medium was sterilised using formaldehyde (0.5%) one week prior to sowing of seeds in order to reduce mortality of seedlings. Care was taken to provide adequate moisture, drainage and plant protection measures in the nursery.

3.6.2 Preparation of main field

The experimental field was ploughed using tractor drawn disc plough. Plots of 3.6 m x 3.6 m size were earmarked providing irrigation channels, buffer bunds and buffer canals of 30 cm each around each plot. A spacing of 60 cm x 60 cm was given to accommodate 36 plants in each treatment. At the centre of the inter space of 4 plants pit of 45 cm^3 was dug out, the pads installed and pits were refilled. The distributary and sublaterals were also buried in the soil. Ridges were formed 60 cms apart to facilitate transplanting.

3.6.3 Manures and fertilizers and their application

Well decomposed farm yard manure at the rate of 20 t ha^{-1} was applied uniformly to all plots as basal dose. Urea, super phosphate and muriate of potash were the fertilizer materials used for supplying the nutrients. N, P_2O_5 and K_2O were applied as per Package of Practices recommendation of Kerala Agricultural University (1993) @ 75:40:25 kg N, P_2O_5 and K_2O ha^{-1} respectively. Half of nitrogen and potassium and full of phosphorus were applied as basal dose at the time of transplanting. One fourth of nitrogen and half of potash were applied 25 days after transplanting. The remaining nitrogen was applied 55 days after transplanting.

3.6.4 Transplanting

One month old seedlings were transplanted in furrows at the spacing of 60 cm x 60 cm. One irrigation was given immediately after transplanting by using rose cans. Shading was provided using green leaved twigs and were removed after three days. The gap filling was done within one week after transplanting.

3.6.5 Irrigation

The crop was irrigated as per the treatments included in the experiment. A measured quantity of 40 mm of water was applied with the help of Orifice to the surface irrigated plots at each irrigations. A measured quantity of 518 litres of water was applied to each plot with subsurface pad through tanks.

Pan evaporation data observed using USWB class A open pan evaporimeter maintained at the observatory of College of Horticulture was used for calculating IW/CPE ratios. The rainfall received in between two irrigations was adjusted while determining cumulative pan evaporation values to the extent as it was considered effective.

The details of irrigations applied are given in Table 3.

3.6.6 After cultivation

The plots were kept free of weeds through out the crop growth period by hand weeding.

3.6.7 Plant Protection

Damping off of seedlings was controlled in the nursery by applying 0.2 % captan. Streptocyclin at the rate of 1g/40 litres of water was applied for controlling wilting of seedlings in the main field. Leaf miner attack was controlled by two sprayings of Dimethoate, 0.05 %. As a prophylactic spray against fruit borer, 0.2 % carbaryl was sprayed.

3.6.8 Harvesting

Fruits were harvested at red ripe stage as indicated by colour change from green to red and seeds were extracted from the harvested fruits.

The dates of sowing of seeds in the nursery, transplanting in the main field and harvesting are given in Appendix III.

3.7 Biometric observations

The plants in the outer row were considered as the border plants and were excluded from observations. From the remaining plants available, four plants were randomly selected from each plot, tagged and used as 'sample plants' for recording observations.

3.7.1 Growth, yield attributes and yield

The following growth and yield characters were recorded during the course of investigation.

1. Height of plant
2. Number of leaves $plant^{-1}$
3. Number of fruiting branches $plant^{-1}$
4. Leaf area index
5. Number of flowers $plant^{-1}$
6. Number of fruits $plant^{-1}$
7. Weight of fruits $plant^{-1}$
8. Yield ha^{-1}

Table 3 Details of irrigations given

Treatment	No. of Irrigations given	Datesof irrigation
T1 and T5 (IW/CPE = 1.2)	10	06.02.95, 11.02.95, 17.02.95, 24.02.95, 03.03.95, 09.03.95, 16.03.95, 21.03.95, 27.03.95 & 02.04.95
T2 and T6 (IW/CPE = 0.9)	8	06.02.95, 13.02.95, 22.02.95, 03.03.95, 11.03.95, 19.03.95, 25.03.95 & 02.04.95
T3 and T7 (IW/CPE = 0.6)	6	06.02.95, 17.02.95, 02.03.95, 15.03.95, 24.03.95 & 04.04.95
T4 and T8 (IW/CPE = 0.3)	3	06.02.95, 02.03.95 & 24.03.95

3.7.1.1 Height of plant

The height of the four sample plants was recorded at fifteen days interval. Height from soil surface to the tip of top most leaf was recorded. The mean height of four sample plants is reported.

3.7.1.2 Number of leaves Plant^{-1}

The total number of standing green leaves on the four sample plants were recorded at 15 days interval and the mean is reported.

3.7.1.3 Number of fruiting branches Plant^{-1}

The total number of fruiting branches on the four sample plants were recorded at 15 days interval and the mean is reported.

3.7.1.4 Leaf area index

The leaf area of one plant from each plot was recorded. The area of one leaf was measured graphically and total leaf area of the plant was calculated by taking the dry weight of the whole leaves and the leaf area index worked out as per the following calculation.

$$TLA = \frac{LAS \times TDL}{DLS}$$

$$LAI = \frac{TLA\ (cm^2)}{60cm \times 60cm}$$

Where, TLA = Total leaf area in cm^2

LAS = Graphical leaf area (cm^2) of the sample leaf

TDL = Total dry weight of all the leaves in the plant in g.

DLS = Dry weight of sample leaf in g.

3.7.1.5 Number of flowers plant^{-1}

The number of flowers of the four sample plants were recorded at fifteen days interval and the mean of the total is reported.

3.7.1.6 Number of fruits plant^{-1}

The total number of fruits of the four sample plants were recorded and the mean is reported.

3.7.1.7 Weight of fruits per plant^{-1}

The weight of fruits of the four sample plants were recorded and the mean is reported.

3.8 Soil moisture studies

1. Bulk density of soil
2. Field capacity
3. Permanent wilting point
4. Gravimetric estimation of soil moisture before cropping, before irrigation, 48 hours after irrigation and after cropping at 15, 30 and 60 cm layer depth in case of surface and subsurface irrigated plots.
5. Gravimetric estimation of soil moisture distribution at 15 cm segments upto 45 cm radial distance on either sides of the pad at 15 and 30 cm vertical depth in case of pad irrigated plots.

3.8.1 Bulk density of soil

The bulk density of the soil at 0 - 15 and 15 - 30 cm depth from surface was found out by using core sampler.

3.8.2 Field capacity

The field capacity of the soil was found out by using pressure-plate apparatus. The moisture content of the soil at 0.3 bar was found out gravimetrically and taken as the field capacity.

3.8.3 Permanent wilting point

The permanent wilting point was found out by using pressure-plate apparatus. The moisture content of the soil at 15 bar was found out gravimetrically and taken as the permanent wilting point.

3.8.4 Gravimetric estimation of soil moisture content

Soil moisture content of the soil at 15, 30 and 60 cm layer depth was found out gravimetrically before cropping, before irrigation, 48 hours after irrigation and after cropping.

3.8.5 Gravimetric estimation of soil moisture distribution

Soil moisture content upto a radial distances of 45 cm on either sides of the pad at 15 cm interval at 15 and 30 cm depth was worked out gravimetrically to study soil moisture distribution.

3.9 Estimated parameters

1. Soil moisture distribution pattern
2. Irrigation requirement
3. Consumptive use of water
4. Crop water use efficiency and Field water use efficiency.

3.9.1 Soil moisture distribution pattern

The Soil moisture extracted from each layer was estimated and converted into per cent utilization over the total moisture used by the crop upto 60 cm depth to express soil moisture distribution pattern.

3.9.2 Irrigation requirement

Irrigation requirement was estimated by directly adding water used for irrigation in each treatment.

3.9.3 Consumptive use of water

The consumptive use of water by the crop under different treatments was worked out using the formula described by Dastane (1972).

$$Cu = \sum_{i=1}^{N} (E_p \times 0.6) + \sum_{1}^{n} \frac{(M_{ai} - M_{bi})}{100} \times A_{si} \times Di + ER$$

Where,

Cu = Consumptive use of water (mm)

E_p = Pan evaporation value from USWB class A open pan evaporimeter for the period from the date of irrigation to the date of soil sampling after irrigation.

0.6 = A constant used for obtaining ET value from E_p value for the given period of time.

M_{ai} = Per cent soil moisture (w/w) of the i^{th} layer of the soil at the time of sampling after irrigation.

M_{bi} = Per cent soil moisture (w/w) of the i^{th} layer of the soil at the time of sampling before irrigation.

A_{si} = Apparent specific gravity of i^{th} layer of soil.

D_i = Depth (mm) of i^{th} layer of soil.

ER = Effective rainfall, if any, during the period under consideration in mm.

n = Number of soil layers.

N = Number of days between irrigation and post irrigation soil moisture sampling.

3.9.4 Crop water use efficiency (CWUE) and Field water use efficiency (FWUE)

CWUE and FWUE were computed using the following formula and are expressed as kg fruit m^{-3} of water.

$$\text{CWUE} = \frac{\text{Fruit yield (kg)}}{\text{Consumptive water use } (m^3)}$$

$$\text{FWUE} = \frac{\text{Fruit yield (kg)}}{\text{Total water applied } (m^3)}$$

3.10 Statistical analysis

The data recorded were subjected to statistical analysis by applying 'Analysis of Variance' technique for 'Randomised Block Design'. The variance ratio test was employed to identify the significance of treatment effects (Cochran and Cox, 1957). Standard error of means (S.Em±) and critical difference (CD) at 5 % significance level were worked out for each character.

The estimated parameters such as soil moisture distribution pattern, irrigation requirement, consumptive use of water and crop water use efficiency are explained only based on comparative performance.

Results

RESULTS

The data recorded and results obtained during the course of investigation on the growth and yield of tomato, soil moisture distribution pattern, irrigation requirement, consumptive use of water and water use efficiency under both subsurface pad irrigation (SSPI) and surface irrigation (SI) systems at different IW/CPE ratios are presented in this chapter.

4.1. Studies on growth and yield of tomato as influenced by systems and frequencies of irrigation

4.1.1. Plant height

The data pertaining to plant height recorded at different growth stages are given in Table 4. The plant height in general increased with increase in IW/CPE ratio and attained maximum values at the IW/CPE ratio of 1.2.

The effect of irrigation on height was not visible at 15 and 30 DAT (days after transplanting). However plants irrigated by surface method at the IW/CPE ratios of 1.2, 0.9 and 0.6 and that by SSPI method at the IW/CPE ratio of 1.2 grew remarkably taller than the plants irrigated under other treatments, when observed at 60 and 75 DAT. This increase in height was also visible at 75 DAT in plants receiving SSPI at the IW/CPE ratio of 0.9.

Table 4 Height of tomato plants (cm) as influenced by systems and frequencies of irrigation

Treatment	Days after transplanting				
	15	30	45	60	75
SSPI IW/CPE = 1.2	10.17	23.33	40.00	45.67	48.17
SSPI IW/CPE = 0.9	10.67	26.33	38.33	41.83	44.67
SSPI IW/CPE = 0.6	10.17	23.33	37.50	40.00	41.67
SSPI IW/CPE = 0.3	10.83	25.00	36.50	40.83	41.67
SI IW/CPE = 1.2	10.00	26.67	43.33	48.83	50.67
SI IW/CPE = 0.9	9.33	23.17	40.67	46.50	48.33
SI IW/CPE = 0.6	10.17	25.50	42.17	47.33	48.17
SI IW/CPE = 0.3	7.33	19.17	32.83	39.00	41.83
S.Em ±	1.237	2.364	1.952	1.602	1.979
CD (P = 0.05)	NS	NS	5.920	4.859	6.002

NS - Not significant

The crop performed equally, without variation in respect of height when irrigated under SSPI method at the IW/CPE ratios of 0.9, 0.6 and 0.3.

4.1.2. Number of green leaves

The data in respect of the number of green leaves are presented in Table 5. Effect of irrigation was conceivable only from 45 DAT.

The data indicated that the surface irrigated tomato plants at the IW/CPE ratios of 1.2, 0.9 and 0.6 produced significantly more number of green leaves at 45, 60 and 75 DAT than that irrigated under other treatments.

When leaf production was observed at 45, 60 and 75 DAT, the plants irrigated under SSPI produced similar number of leaves irrespective of level of irrigation and this was on par with surface irrigated plants at the IW/CPE ratio of 0.3.

4.1.3. Number of branches

The mean data regarding total number of branches per plant recorded at 45, 60 and 75 DAT are given in Table 6.

Methods as well as frequencies of irrigation did not affect branching significantly. However more number of branches was noticed in surface

Table 5 Number of green leaves of tomato plants as influenced by systems and frequencies of irrigation

Treatment	Days after transplanting				
	15	30	45	60	75
SSPI IW/CPE = 1.2	8.17	13.83	21.83	23.67	24.67
SSPI IW/CPE = 0.9	7.83	17.50	22.50	24.17	23.50
SSPI IW/CPE = 0.6	8.00	14.50	24.67	25.67	24.00
SSPI IW/CPE = 0.3	8.33	14.33	19.83	21.50	22.17
SI IW/CPE = 1.2	7.17	20.33	33.83	36.00	36.00
SI IW/CPE = 0.9	6.83	15.17	34.67	36.33	37.50
SI IW/CPE = 0.6	8.00	19.17	27.83	29.16	33.50
SI IW/CPE = 0.3	6.83	11.33	17.33	20.33	23.00
S.Em ±	0.77	3.833	3.371	3.066	3.171
CD (P = 0.05)	NS	NS	10.22	9.299	9.618

NS - Not significant

Table 6 Number of branches of tomato plants as influenced by systems and frequencies of irrigation

Treatment	Days after transplanting		
	45	60	75
SSPI IW/CPE = 1.2	2.33	2.33	2.50
SSPI IW/CPE = 0.9	2.17	2.33	2.33
SSPI IW/CPE = 0.6	2.67	2.67	2.67
SSPI IW/CPE = 0.3	2.17	2.17	2.17
SI IW/CPE = 1.2	3.67	3.67	3.67
SI IW/CPE = 0.9	3.50	3.50	3.50
SI IW/CPE = 0.6	3.33	3.33	3.33
SI IW/CPE = 0.3	2.17	2.33	2.33
S.Em ±	0.537	0.515	0.523
CD (P = 0.05)	NS	NS	NS

NS - Not significant

irrigated plants at the IW/CPE ratios of 1.2, 0.9 and 0.6. The branching was relatively low in plants irrigated by SSPI.

4.1.4. Leaf Area Index

Leaf area index of tomato was more when irrigated by surface method at the IW/CPE ratio of 1.2 and 0.9 or by SSPI method at the IW/CPE ratio of 1.2 (Table 7).

The plants when surface irrigated at the IW/CPE ratio of 1.2 produced significantly maximum number of leaf area index than all other treatments at 30 and 60 DAT.

The leaf area index was proportionally reduced with decrease in the frequency of irrigation in each method. But at the IW/CPE ratio of 0.3, the plants irrigated under SSPI produced more leaf area index than the ones irrigated by surface method when observed at 30 and 60 DAT.

4.1.5. Number of flowers per plant

The total number of flowers produced per plant is given in Table 8. The plants irrigated by surface method at all levels produced significantly more flowers than the one irrigated by SSPI method at respective levels except the

Table 7 Leaf area index of tomato plants as influenced by systems and frequencies of irrigation

Treatment	Days after transplanting	
	30	60
SSPI IW/CPE = 1.2	2.22	3.91
SSPI IW/CPE = 0.9	2.04	3.59
SSPI IW/CPE = 0.6	1.83	3.31
SSPI IW/CPE = 0.3	1.53	3.18
SI IW/CPE = 1.2	2.62	5.29
SI IW/CPE = 0.9	2.32	4.12
SI IW/CPE = 0.6	2.08	3.89
SI IW/CPE = 0.3	1.09	2.72
S.Em ±	0.045	0.052
CD (P = 0.05)	0.136	0.158

Table 8 Total number of flowers of tomato plants as influenced by systems and frequencies of irrigation

Treatment	Number of flowers per plant
SSPI IW/CPE = 1.2	18.05
SSPI IW/CPE = 0.9	15.21
SSPI IW/CPE = 0.6	10.17
SSPI IW/CPE = 0.3	7.35
SI IW/CPE = 1.2	32.82
SI IW/CPE = 0.9	24.50
SI IW/CPE = 0.6	18.55
SI IW/CPE = 0.3	5.71
S.Em ±	0.847
CD (P = 0.05)	2.569

ratio of 0.3. On an average surface irrigated crop produced 61 per cent more flowers than the crop irrigated by SSPI. The flower production was significantly lowered in each method, by the decrease in frequency of irrigation.

Surface irrigated plants produced significantly more number of flowers than subsurface irrigated ones at the IW/CPE ratios of 1.2, 0.9 and 0.6. But the subsurface irrigated plants at the IW/CPE ratio of 0.3 produced more number of flowers compared to surface irrigated at this level.

4.1.6. Number of fruits per plant

The production of fruits followed similar trend as observed in flower production (Table 9). The total number of fruits produced per plant was significantly higher in surface irrigated plants at the IW/CPE ratio of 1.2 than all other treatments. At this ratio surface irrigated plants put forth 94 per cent more fruits than the SSP irrigated crop.

The surface irrigated plants produced more number of fruits at the IW/CPE ratios of 1.2, 0.9 and 0.6 compared to subsurface pad irrigated tomato plants at these respective levels. But at the IW/CPE ratio of 0.3, the subsurface pad irrigated plants produced similar number of fruits as that of surface irrigated ones.

Table 9 Total number of fruits of tomato plants as influenced by systems and frequencies of irrigation

Treatment	Number of fruits per plant
SSPI IW/CPE = 1.2	11.38
SSPI IW/CPE = 0.9	7.94
SSPI IW/CPE = 0.6	3.55
SSPI IW/CPE = 0.3	2.43
SI IW/CPE = 1.2	22.06
SI IW/CPE = 0.9	18.15
SI IW/CPE = 0.6	9.30
SI IW/CPE = 0.3	1.53
S.Em ±	0.327
CD (P = 0.05)	0.992

4.1.7. Total weight of fruits per plant

The surface irrigated plants in general produced more fruit weight per plant compared to subsurface pad irrigated plants at the IW/CPE ratios of 1.2, 0.9 and 0.6 (Table 10). This was to the tune of 124 per cent.

Maximum fruit weight per plant was obtained by surface irrigation at IW/CPE ratio of 1.2. This was 108 per cent more than the fruit weight of 228 g per plant obtained under SSPI at the same level of irrigation. When irrigation was scheduled at the IW/CPE ratio of 0.3, the fruit weight per plant was similar under both methods of irrigation.

4.1.8. Yield per hectare

The surface irrigated plants in general gave 124 per cent more yield per hectare compared to subsurface irrigated plants at the IW/CPE ratios of 1.2, 0.9 and 0.6 (Table 11).

Surface irrigation at the IW/CPE ratio of 1.2 gave maximum fruit yield of 13.13 tonnes per hectare. Eventhough the yield at the IW/CPE ratio of 0.3 was 36 per cent more under SSPI compared to surface irrigation, no statistical significance was attached to it.

Table 10 Total weight of tomato fruits per plant (gram) as influenced by systems and frequencies of irrigation

Treatment	Weight of fruits per plant (g)
SSPI IW/CPE = 1.2	227.64
SSPI IW/CPE = 0.9	158.75
SSPI IW/CPE = 0.6	70.92
SSPI IW/CPE = 0.3	34.15
SI IW/CPE = 1.2	472.57
SI IW/CPE = 0.9	363.01
SI IW/CPE = 0.6	188.76
SI IW/CPE = 0.3	25.04
S.Em ±	6.182
CD (P = 0.05)	18.75

Table 11 Yield of tomato in Mega gram per hectare as influenced by systems and frequencies of irrigation

Treatment	Yield of tomato ($M.g\ ha^{-1}$)
SSPI IW/CPE = 1.2	6.323
SSPI IW/CPE = 0.9	4.410
SSPI IW/CPE = 0.6	1.970
SSPI IW/CPE = 0.3	0.950
SI IW/CPE = 1.2	13.127
SI IW/CPE = 0.9	10.083
SI IW/CPE = 0.6	5.243
SI IW/CPE = 0.3	0.697
S.Em ±	0.172
CD (P = 0.05)	0.522

4.2. Soil moisture studies

4.2.1. Consumptive use

The data regarding total quantity of water applied through irrigation total consumptive use of water by the crop, and per cent of soil moisture extracted upto a root zone depth of 60 cm from the surface are given in Table 12. The total quantity of water applied through life saving irrigation and at similar ratios as per treatments were identical irrespective of method of irrigation. The crop receiving irrigations scheduled at the IW/CPE ratios of 1.2, 0.9, 0.6 and 0.3 received irrigation water of 420, 340, 260 and 140 mm of water. However, the consumptive use differed based on the schedules and methods.

The crop receiving irrigation through subsurface pad irrigation consumed 299, 232, 153 and 113 mm of water at the IW/CPE ratios of 1.2, 0.9, 0.6 and 0.3 respectively. These were remarkably lower than that of the crop receiving irrigation by surface method. The decline in consumptive use of water by the crop receiving irrigations through subsurface pad irrigation system at the IW/CPE ratios of 1.2, 0.9, 0.6 and 0.3 over that receiving through surface method were to the tune of 22, 30, 40 and 18 per cent respectively.

4.2.2. Soil moisture extraction

The data regarding soil moisture extraction pattern are given in Table 12. The data indicate that the surface 0-15 cm layer contributed nearly

Table 12 Consumptive use of water and soil moisture extraction by the crop as influenced by systems and frequencies of irrigation

Treatments	Total water applied (mm)	No. of irrigations	Total CU (mm)	Moisture use (mm) at different soil depth			% moisture use at different soil depth			% decrease of CU in SSPI compared to S I
				0-15 cm	15-30 cm	30-60 cm	0-15 cm	15-30 cm	30-60 cm	
T_1	420	10	298.89	185.74	76.43	36.72	62.14	25.57	12.29	21.86
T_2	340	8	231.93	155.17	56.81	19.95	66.90	24.49	8.61	29.53
T_3	260	6	152.58	95.21	44.37	13.00	62.40	29.08	8.52	40.26
T_4	140	3	113.23	79.29	26.84	7.10	70.03	23.70	6.27	18.38
T_5	420	10	382.51	244.87	85.31	52.33	64.02	22.30	13.68	-
T_6	340	8	329.14	209.37	73.39	46.38	63.61	22.29	14.09	-
T_7	260	6	255.41	159.86	58.18	37.37	62.59	22.78	14.63	-
T_8	140	3	138.73	86.16	31.11	21.46	62.11	22.42	15.47	-

CU = Consumptive use

to 2/3 of the total moisture use by the crop. This pattern was identical in both the methods of irrigation. In case of subsurface pad irrigation, the second layer (15-30 cm) contributed 24-29 per cent of total CU, whereas in surface irrigation it was only 22-23 per cent. The third layer (30-60 cm), contributed nearly to 6-12 per cent of total moisture use in case of subsurface pad irrigation whereas this was only 13-15 per cent in case of surface irrigation.

4.2.3. Soil moisture re-distribution pattern

The data regarding gravimetric soil moisture content observed at 15 cm radially from the pad and at 15 and 30 cm vertical depth before and after irrigation are given in Table 13. The data showed that soil moisture was re-distributed rapidly in case of surface irrigation whereas moisture re-distribution was gradual in case of subsurface pad irrigation. In case of surface irrigation the mean content of soil moisture before irrigation (14.04 %) was lesser by 9.9 per cent over that available under subsurface pad irrigation (15.59 %). However, in the case of IW/CPE ratio of 1.2, under surface irrigation system the mean moisture content before irrigation at the depth of 0-30 cm was 15.15 per cent and this was greater by 7.5 per cent over the moisture available under subsurface pad irrigation 14.09 %.

The data further indicate that at surface 0-15 and 15-30 cm layers, the soil moisture content after 48 hours of irrigation was 19.6 and 21.0 per cent

Table 13 Moisture per cent (w/w) in soil at 15 cm radial distance from the pad under SSPI and SI systems

IW/CPE ratio	Method of Irrigation	Soil depth (cm)	1st irrigation		2nd irrigation		3rd irrigation		4th irrigation	
			BI	AI	BI	AI	BI	AI	BI	AI
1.2	SSPI	15	13.11	16.90	14.70	16.45	13.80	14.32	12.34	13.45
		30	13.23	17.50	15.92	18.30	14.82	15.27	12.95	14.62
	SI	15	12.27	20.57	14.31	19.54	13.25	20.69	15.10	19.14
		30	15.28	21.63	16.57	20.78	15.93	21.53	17.29	20.09
0.9	SSPI	15	13.73	16.32	14.81	18.23	16.10	18.12	15.04	19.08
		30	16.98	19.48	16.81	18.46	17.31	21.64	17.71	19.87
	SI	15	13.44	19.41	12.11	20.03	11.39	20.46	14.77	19.79
		30	15.75	21.88	16.09	21.64	14.47	21.33	16.55	20.89
0.6	SSPI	15	14.76	16.64	14.50	17.59	15.15	17.27	15.92	18.64
		30	15.84	18.27	14.90	18.61	15.91	19.87	16.81	18.28
	SI	15	12.46	19.21	11.43	18.49	12.51	17.27	11.33	19.73
		30	16.24	21.19	14.55	20.97	16.66	21.08	14.37	21.44
0.3	SSPI	15	14.40	19.28	14.57	18.09	14.50	18.69	-	-
		30	17.98	21.09	13.43	19.33	15.72	20.22	-	-
	SI	15	11.23	20.47	12.13	19.23	11.87	19.86	-	-
		30	14.41	21.96	14.39	20.97	14.41	21.48	-	-

Contd......

Table 13 (Contd....)

IW/CPE ratio	Method of Irrigation	Soil depth (cm)	5th Irrigation		6th Irrigation		7th Irrigation		8th Irrigation		9th Irrigation		10th Irrigation	
			BI	AI	BI	AI	BI	AI	BI	AI	BI	AI	BI	AI
1.2	SSPI	15	11.15	15.92	11.66	15.81	11.16	16.20	10.90	14.11	11.67	14.39	12.62	15.63
		30	13.81	17.27	13.22	16.32	12.58	15.58	12.99	15.33	11.64	15.38	13.36	16.74
	SI	15	12.43	20.12	15.12	20.54	14.44	19.08	14.03	19.41	12.54	19.51	17.72	19.83
		30	16.38	21.47	15.39	21.03	16.94	20.69	17.21	20.78	16.33	21.23	16.38	21.04
0.9	SSPI	15	14.84	15.37	15.33	17.16	14.80	16.44	15.51	18.40	-	-	-	-
		30	15.73	19.28	16.53	19.58	17.90	19.07	17.43	20.63	-	-	-	-
	SI	15	11.39	20.45	14.09	19.93	13.63	20.43	12.98	20.08	-	-	-	-
		30	16.07	21.91	14.48	20.18	15.39	21.40	15.55	21.32	-	-	-	-
0.6	SSPI	15	15.95	18.16	15.67	17.87	-	-	-	-	-	-	-	-
		30	16.84	17.99	16.27	19.21	-	-	-	-	-	-	-	-
	SI	15	10.75	18.06	11.71	18.56	-	-	-	-	-	-	-	-
		30	13.33	20.37	15.04	21.02	-	-	-	-	-	-	-	-

SSPI = Subsurface pad irrigation SI = Surface irrigation BI = Before irrigation AI = 48 hours after irrigation respectively in case of surface irrigation. The respective values were 15.3 and 16.2 per cent in case of subsurface pad irrigation. The trend was identical in all the IW/CPE ratios.

4.2.4. Radial distribution of moisture

The data regarding radial distribution of moisture from the pad upto the distance of 45 cm on either sides at the depths of 15 and 30 cm are given in Table 14.

Soil moisture contents before irrigation in case of surface irrigation were to tune of 12.65 and 15.43 per cent at 15 and 30 cm depths respectively. The respective moisture contents after irrigation were 19.62 and 21.03 per cent without showing any remarkable difference in the moisture content with respect to radial distance from the plant. Whereas in case of subsurface irrigation the moisture content before or after irrigation was maximum at the radial distance of 15 cm from the pad on either sides. The average moisture contents in this case before irrigation were 14.11, 16.67, 16.13 and 15.47 respectively for the IW/CPE ratio of 1.2, 0.9, 0.6 and 0.3 whereas the respective moisture content after 48 hours of irrigation were 16.46, 19.18, 18.75 and 19.46 per cent.

Table 14 Mean moisture content (% w/w) of soil before and after irrigations under SSPI and SI systems at different lateral distances from the pad on both sides

IW/CPE ratio	System of Irrigation	Depth of soil (cm)	Radial distance from pad on both sides (cm)					
			45 L		30 L		15 L	
			BI	AI	BI	AI	BI	AI
1.2	SSPI	15	12.13	15.32	13.33	16.01	14.57	16.72
		30	13.25	16.23	14.04	16.74	14.86	17.39
	SI	15	13.72	19.84	13.91	19.92	13.84	19.92
		30	16.37	21.03	16.38	21.18	16.51	21.21
0.9	SSPI	15	15.01	17.39	15.84	18.44	16.66	19.12
		30	17.05	19.75	17.54	20.45	18.02	21.20
	SI	15	12.97	20.07	13.19	19.91	13.07	20.02
		30	15.54	21.31	15.73	21.34	15.80	21.07
0.6	SSPI	15	15.33	17.68	15.79	18.02	16.26	18.37
		30	16.10	18.71	16.62	19.31	16.92	19.93
	SI	15	11.70	18.55	11.62	18.36	11.56	18.89
		30	15.03	21.01	15.25	20.96	15.30	21.07
0.3	SSPI	15	14.49	18.68	14.94	19.21	15.31	19.73
		30	15.71	20.21	16.66	20.84	17.53	21.38
	SI	15	11.68	19.85	12.22	19.77	11.75	19.79
		30	14.40	21.47	14.91	20.86	14.34	21.14

Contd....

Table 14 Contd.....

IW/CPE ratio	System of Irrigation	Depth of soil (cm)	Radial distance from pad on both sides (cm)					
			15 R		30 R		45 R	
			BI	AI	BI	AI	BI	AI
1.2	SSPI	15	15.22	16.94	14.40	16.05	13.42	15.25
		30	15.34	17.61	14.55	17.00	14.01	16.29
	SI	15	14.01	20.08	13.80	19.99	13.88	19.91
		30	16.54	21.08	16.44	21.10	16.35	20.98
0.9	SSPI	15	16.54	19.32	15.73	18.35	14.79	16.94
		30	18.29	21.10	17.47	20.61	17.06	17.47
	SI	15	12.95	20.04	13.09	20.29	13.18	20.03
		30	15.66	21.14	15.59	21.11	15.42	20.94
0.6	SSPI	15	16.23	18.32	15.54	17.86	14.59	17.17
		30	17.32	20.58	16.81	19.92	16.01	19.16
	SI	15	11.79	18.66	11.87	18.58	11.66	18.60
		30	15.00	21.02	14.86	20.96	15.25	21.12
0.3	SSPI	15	15.28	18.51	14.27	17.72	13.41	17.30
		30	16.77	20.27	15.98	20.11	15.32	19.57
	SI	15	12.11	20.32	12.09	19.79	12.04	19.80
		30	14.89	20.80	14.12	20.79	14.64	20.06

SSPI = Subsurface pad irrigation SI = Surface irrigation BI = Before irrigation AI = 48 hours after irrigation

L = Left side of the pad R = Right side of the pad

Water use efficiency

The mean data regarding both crop WUE and field WUE are given in Table 15. The surface irrigated plants have more crop WUE and field WUE at the IW/CPE ratios of 1.2, 0.9 and 0.6 compared to subsurface pad irrigated tomato plants at respective levels. But at the IW/CPE ratio of 0.3, the subsurface pad irrigated plants have more crop WUE and field WUE than that of surface irrigated ones.

Table 15 Crop WUE and Field WUE (kg m $^{-3}$) of tomato plants as influenced by systems and frequencies of irrigation

Treatment	Crop WUE	Field WUE
SSPI IW/CPE = 1.2	2.12	1.51
SSPI IW/CPE = 0.9	1.90	1.30
SSPI IW/CPE = 0.6	1.29	0.76
SSPI IW/CPE = 0.3	0.84	0.68
SI IW/CPE = 1.2	3.43	3.13
SI IW/CPE = 0.9	3.06	2.97
SI IW/CPE = 0.6	2.05	2.02
SI IW/CPE = 0.3	0.50	0.49

WUE - Water use efficiency

Discussion

DISCUSSION

Water has a prominent role in determining the productivity of a crop like tomato which produce fleshy fruits of berry type. Moisture status of any plant depends on the parameters related to soil, atmosphere and plant itself. The 'soil plant atmosphere continuum concept' developed by van den Honert (1948) has established this fact. Moisture status in any plant is in a dynamic state.

Subsurface irrigation is conceptually an irrigation technology for rootzone irrigation for maximising water use efficiency and minimising moisture losses. Water is delivered to a confined region in a controlled and continuous manner in subsurface pad irrigation (SSPI) restricting evaporative surface. Once the water is stored in the storage pad, the flow from it is governed by gravity, matric potential of the soil, evapotranspirational pull of the plant and adsorptive forces of filler material in the pad. The flow is multidirectional. The dynamics of the flow will be more complex to ascertain.

Quantification of flow in subsurface pad irrigation is also difficult since there is continuous supply of moisture governed by above said forces. An attempt has been made in this chapter to explain the cause - effect relationships of the results obtained during the experimentation and presented in the previous chapter.

Growth of tomato as influenced by systems and frequencies of irrigation.

Under the present investigation methods and frequencies of irrigation are the variable environmental factors. Growth is invariably affected by level of irrigation and within the permissible limit increasing supply of moisture enhances growth (Kramer, 1983). Among the various physiological processes in the plant, growth is the most sensitive process to water stress (Boyer, 1970 and Acevedo *et al.,* 1979). An assured moisture supply throughout growth period is vital for high yield of tomato. Restricted moisture supply at any stage of growth will have a cumulative effect on the ultimate yield of the plant (Rudich and Luchinsky, 1986).

Higher levels of irrigation irrespective of method in the present investigation has led to increase in height of the plant (Table 4). The growth of a plant is controlled by cell division and cell elongation which are affected by internal moisture status of a plant. Cell elongation is more sensitive to changes of the water potential than cell division. Cell division is inhibited only secondarily with the drop in water potential (Kirkham *et al.,* 1971).

Production of photosynthetic area was limited under SSPI system compared to surface method at the same moisture supply of the IW/CPE ratios of 1.2, 0.9 and 0.6. At these levels the plants under SSPI produced lesser number of leaves as well as leaf area index (Table 5&7 and Fig.4&5).

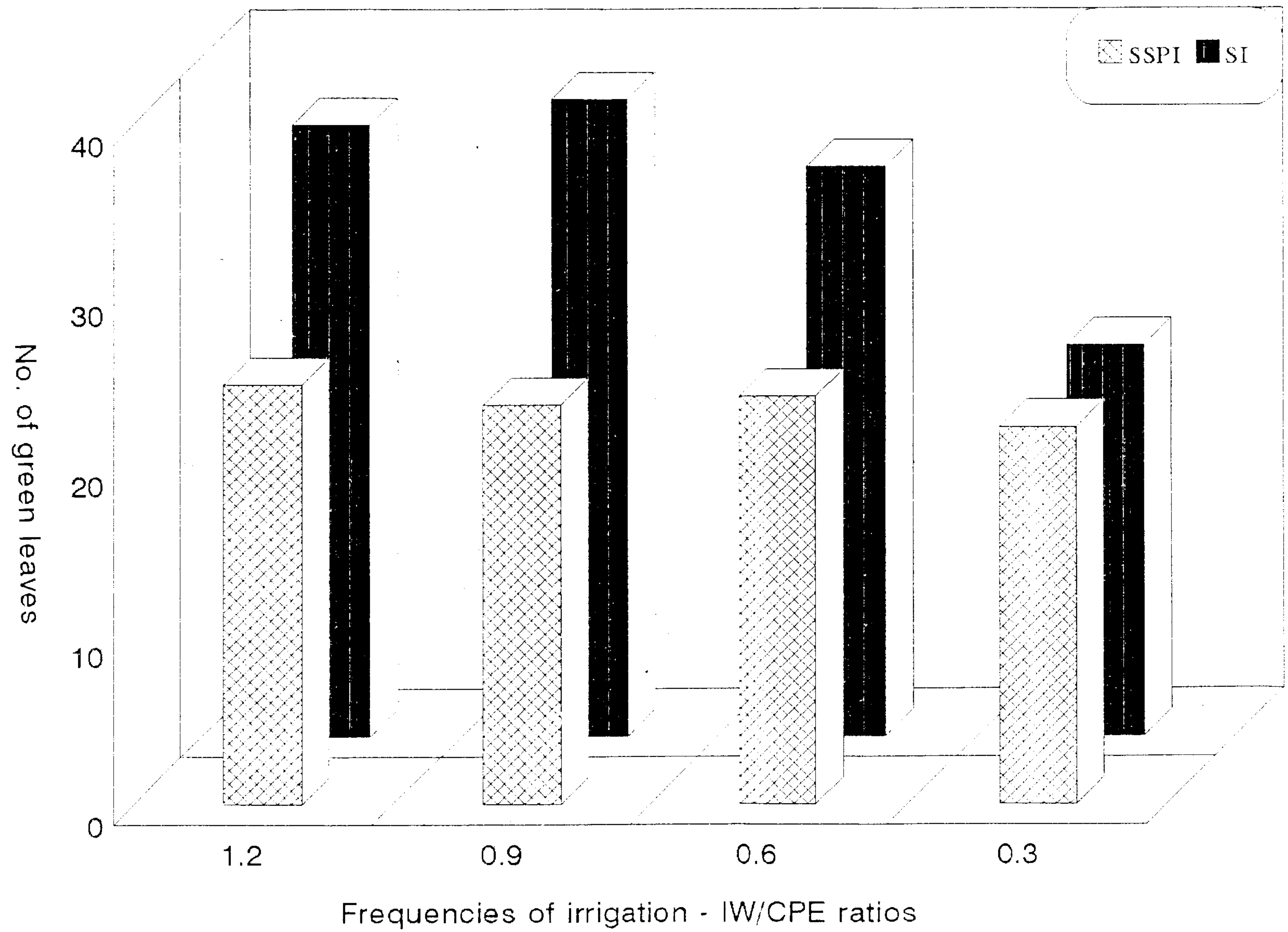


Fig.4 Total number of green leaves of tomato plants at 75 DAT as influenced by systems and frequencies of irrigation

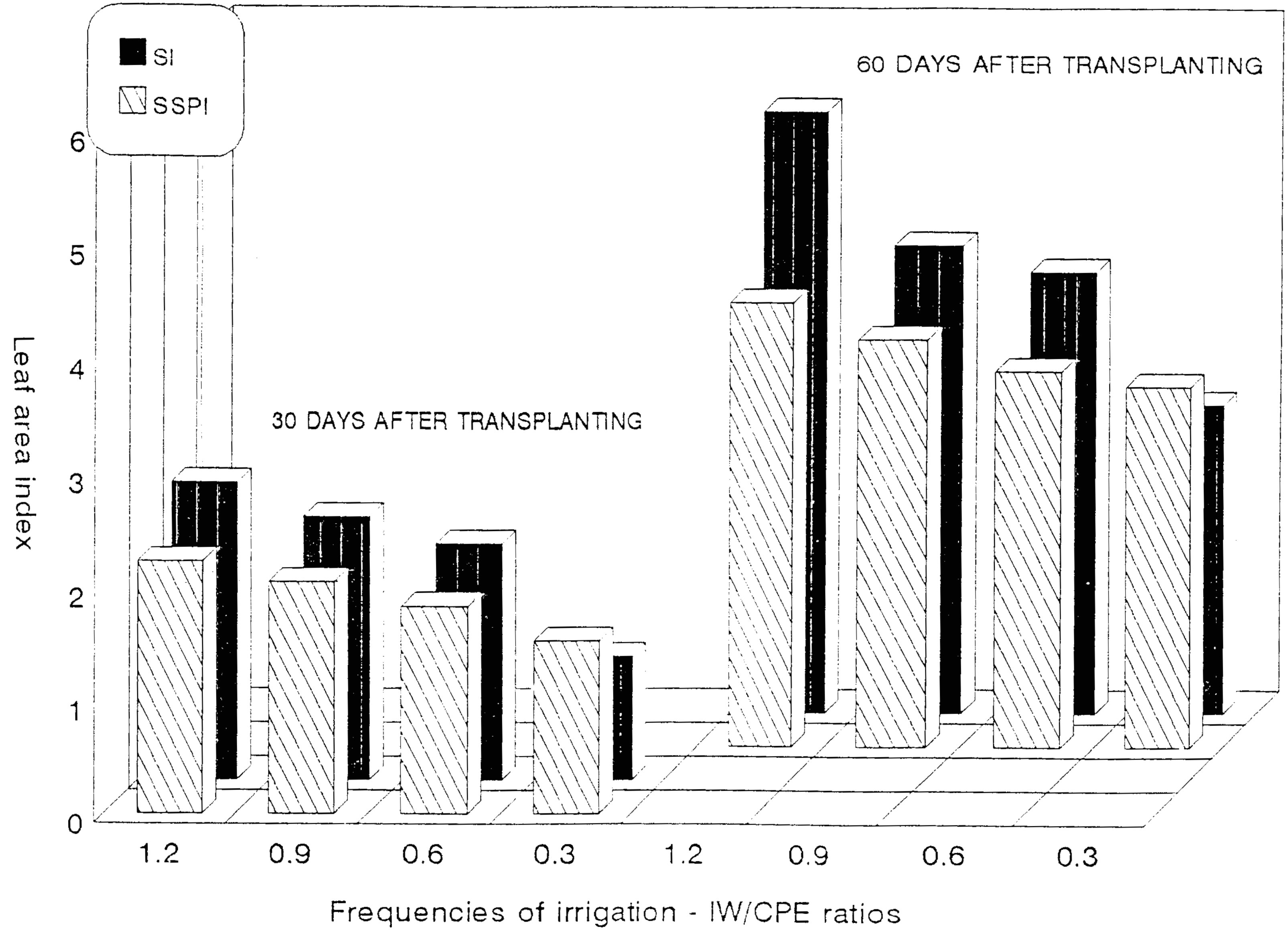


Fig.5 Leaf area index of tomato plants as influenced by systems

Under SSPI though the moisture supply is continuous, it is limited (Table 14). This limited moisture supply to the root zone of the plant restricted absorption and utilisation of moisture for the leaf area expansion. Though the plant is able to put up vertical growth, the depleted level of moisture availability might have restricted leaf area expansion (Rudich *et al.,* 1981). Plants produced similar number of branches irrespective of methods and frequencies of irrigation (Table 6) . This meant that branching was not hindered by the moisture supplied under various treatments.

The surface method of irrigation provided a uniform soil moisture distribution throughout the surface layer upto 30 cm irrespective of irrigation levels (Fig. 10 to 13). Whereas in SSPI the moisture availability reduced with respect to radial distance from the source. The plants closer to the source got moisture supply similar to the surface irrigated crop, while the plants at farthest end had a limited access to moisture. Though moisture supply was sustained for a sufficiently longer period in the SSPI, it was at a lower range ie., between the range of 25 to 60 per cent of the available water capacity and seldom above 75 per cent of available water capacity (Table 14). In case of surface irrigation the moisture supply was recouped to 100 per cent of field capacity within 48 hours after irrigation and the plant was able to utilise the moisture available between the range of 75 to 100 per cent available water capacity. The storage pad in case of subsurface irrigation was kept in the region of 45 to 50 cm vertical depth from the soil surface. The moisture content recouped to 100 per cent of field capacity in the immediate vicinity. But as the radial distance increased from the source, recoupment of moisture level was only to the tune of 50 to 75 per cent of the available water capacity and never attained 100 per cent at the farthest end. The soil moisture distribution curve assumed a parabolic shape around the pad (Fig. 10 to 13). This means that the linear depth of the placement of pad may be reduced to a level that even at the farthest zone moisture is supplied by the pad to the 100 per cent available water capacity. According to Dastane *et al.* (1963) the growth of the tomato crop is reduced drastically when the soil moisture supply is reduced from 50 per cent of available water capacity. The present observation recorded from the experiment also agree to this inference.

Yield attributes and yield of tomato as influenced by methods and frequencies of irrigation.

Number of flowers and fruits produced per plant as well as total weight of fruits plant^{-1} or hectare^{-1} were more with higher levels and surface method of irrigation compared to the respective levels under SSPI system (Table 8 to 11). The crop irrigated at the IW/CPE ratios of 1.2, 0.9 and 0.6 by surface method produced 82, 61 and 82 per cent more flowers compared to the respective levels under SSPI. Similarly 92, 129 and 162 per cent more number of fruits plant^{-1} were produced under surface method of irrigation (Fig. 6). Reflecting the same trend, 108, 129 and 166 per cent more total weight of fruits plant^{-1} was obtained under surface method of irrigating at IW/CPE ratios of 1.2, 0.9 and 0.6 compared to the respective levels

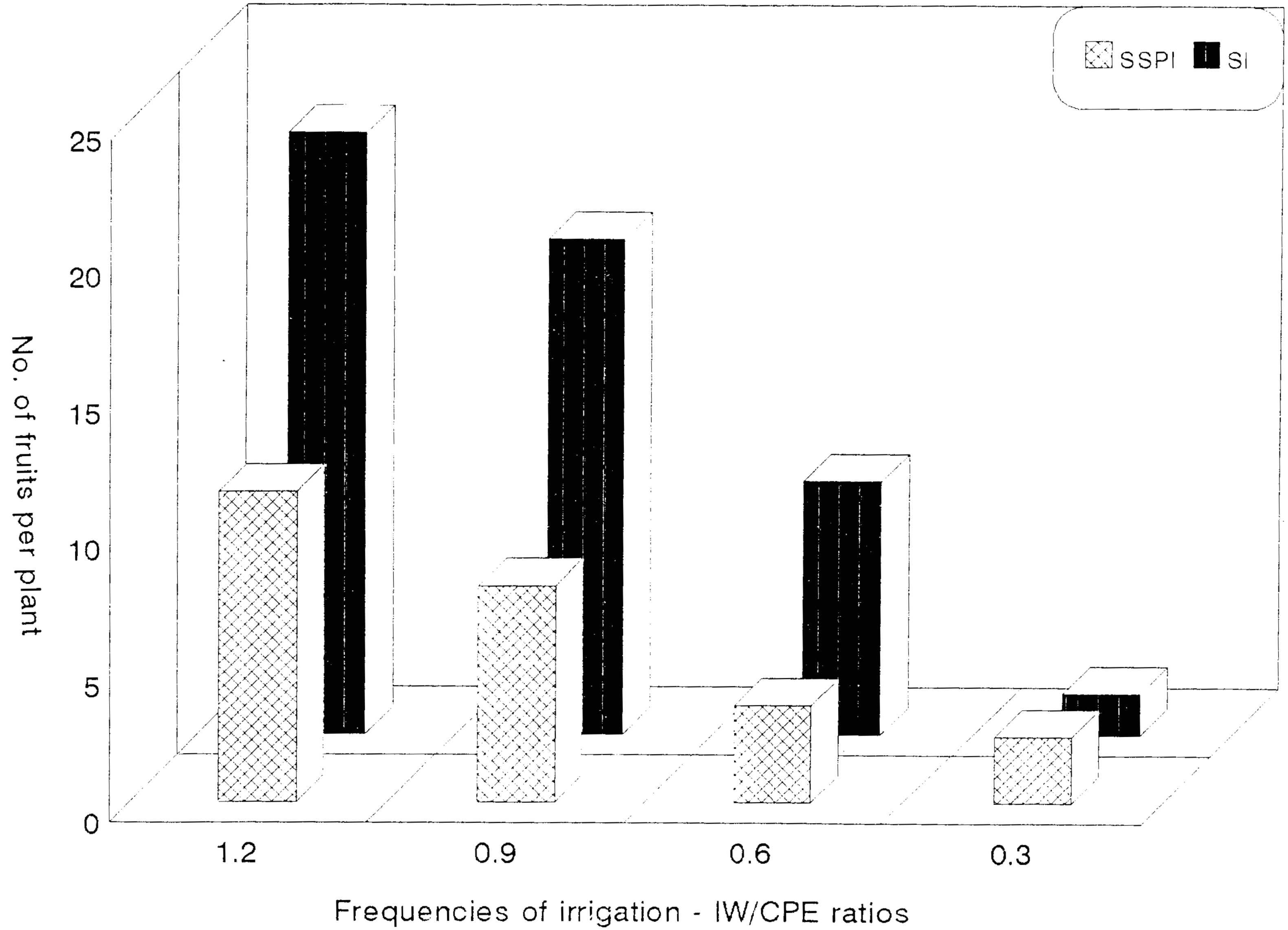


Fig.6 Number of fruits of of tomato plants as influenced by systems and frequencies of irrigation

under SSPI (Fig. 7). This clearly indicated the superiority of surface irrigation at these levels compared to SSPI. But at the lowest level of 0.3 both methods performed equally in the production of flowers and fruits . According to Vittum and Flocker (1967) tomatoes are long season deep rooted plants with less water requirement as observed in North East USA. But in Kerala tomato is a shallow rooted crop with 85 per cent of its roots confining to the upper 30 cm layer under the irrigated condition (Markose and Peter, 1993). Surface method of irrigation provided complete wetting of the root zone uniformly upto a depth of 30 cm as indicated in Table 14 and Fig. 10 to 13. Hence at the higher levels of irrigation there was an assured and uniform supply of moisture to the crop by surface method. This enhanced the reproductive activity of the plant without hampering floral production and fruiting processes. Irrigation increased number of flowers that set fruit, average weight per fruit and number of fruits (Vittum *et al.,* 1963 and Moore *et al.,* 1958).

According to Vittum and Flocker (1967), when irrigation was resorted to tomato at 0.7 atm, it produced lower yields compared to irrigation at 2 atm. This meant the crop needed a drying cycle to putforth higher yields.

In case of SSPI system even at higher levels of irrigation, moisture supply to the effective root zone was not adequate (Table 14 and Fig.10 to 13). The wetting of the root zone was also not even. As the pads are placed (45 cm) below the active root zone (30 cm) and the capillarity of the soil was low, the moisture supply to the root zone was not sufficient to produce the

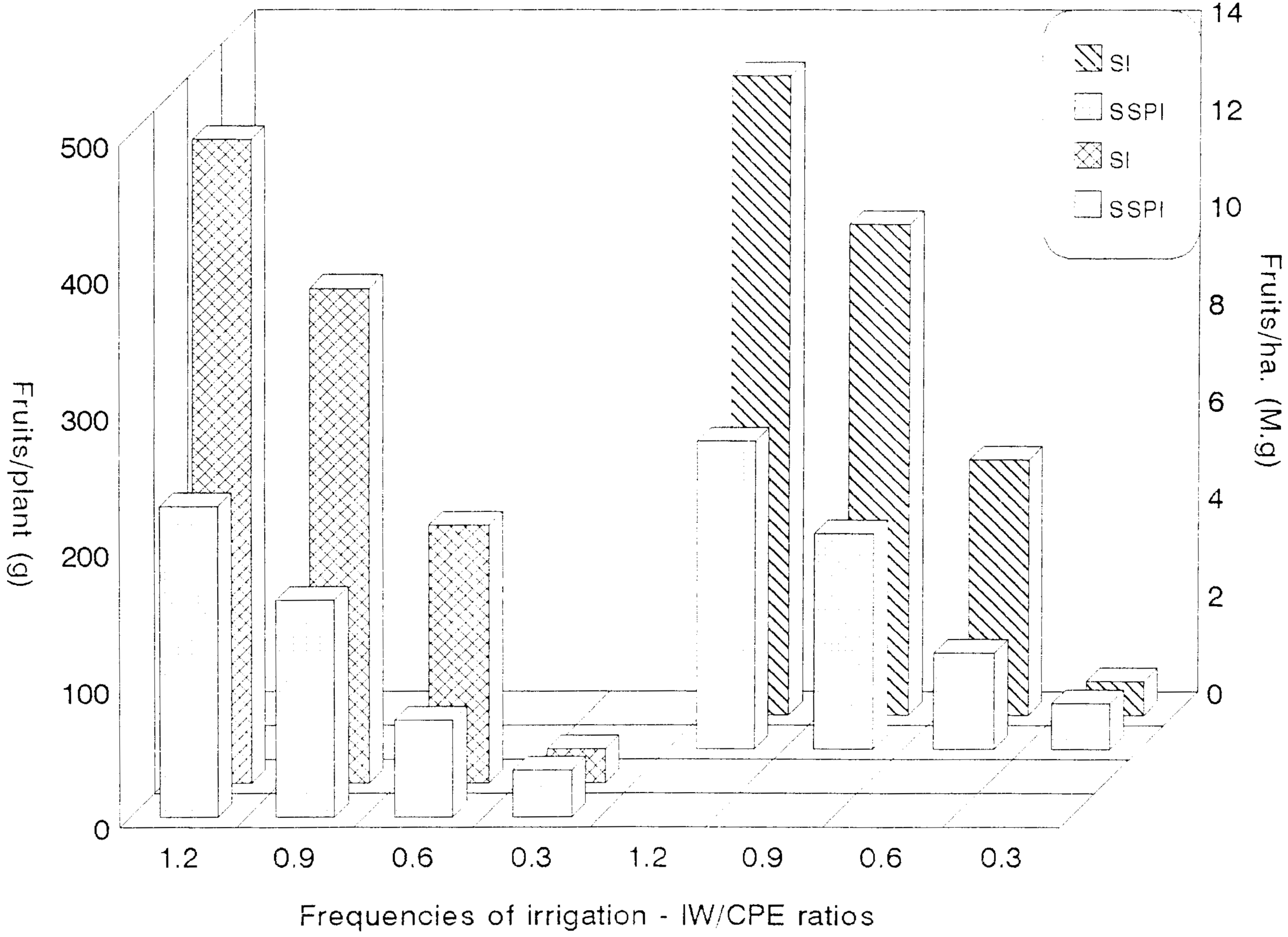


Fig.7 Total weight of tomato fruits per plant (g) and per ha (M.g) as influenced by systems and frequencies of irrigation

flowers and fruits as achieved by surface method at the higher level of irrigation. The continuous supply of moisture assured by SSPI might have led to an anoxic condition and evaded the 'drying cycle' of the crop helping aeration received in surface irrigation. This observation is further strengthened with the fact that at the lower levels of irrigation ie., IW/CPE ratio of 0.3, a favourable crop growth is achieved under SSPI and hence the crop performed better under SSPI than under surface method.

Increase in the production of flowers, number of fruits and fruits yield with increase in levels of irrigation is common in tomato (Fapohunda, 1992 and Muller, 1993). When moisture supply is adequate or unlimited, surface methods of irrigation are of greater importance to exploit productivity of the crop (Hamdy, 1992). But when the moisture supply is limited, then localised irrigation or micro system of irrigation assumes importance and application of moisture should be carefully carried out to tap the utilisation of all the inputs. The present study reveals that SSPI system tended to dominate at lower levels of irrigation. The effect would have been more pronounced if the pads are kept in the root zone or just above it. Since the present study is a preliminary one and elsewhere reports indicated that tomato is a deep rooted vegetable and the roots go up to 180 cm (Shanmughavelu, 1989), the pads were placed at the depth of 45 cm. The study also indicates that there is a continuous wetting of the soil by SSPI system. Hence the crops which has its total biomass edible (leafy vegetables) and which do not require any drying cycle in the soil will be more benefited by SSPI system.

The systems and frequencies of irrigation has profoundly influenced the consumptive use of water by the crop (Table 12 and Fig. 8). Although the quantity of total water applied at each frequency of irrigation in the two different methods remained the same, the consumption of water by the crop differed remarkably. Under SSPI system the water consumed by the crop through ET was lesser by 22, 30, 40 and 18 per cent than under surface method at the respective frequencies of irrigation viz. IW/CPE ratios of 1.2, 0.9, 0.6 and 0.3. However under both methods of irrigation the consumptive use of water by the crop increased with the frequencies of irrigation.

The consumptive use of water by a crop increased with the levels or frequency or number of irrigations. When the supply of water is more without interfering soil aeration the crop absorbs more water and utilises the resources effectively. The same trend is observed in tomato also (Waister and Hudson, 1970). Under SSPI system the moisture supply to the root zone was not adequate at each frequencies comparably to the corresponding frequency under surface method. The upward movement of water from the source to the root zone is mainly controlled by hydrostatic pressure in the soil, capillarity of the soil medium and the soil moisture tension created in the root zone by the transpiration pull of the crop. The soil moisture movement through diffusive forces are rather very slow especially in a soil type of lateritic medium (Hillel, 1971). In the present study, pads are located at 45 cm below the soil surface and the root zone which is mainly restricted to 30 cm, the root zone has never come to the field capacity under SSPI (Table 13). Hence it is evident that hydrostatic pressure is not there to facilitate the upward movement of moisture to the root zone. Due to open structure of the soil as well as deep placement of pads capillary forces are not sufficient to bring the root zone to the field capacity. Moreover remoteness of the root zone from the source of moisture might have caused a reduced effect of transpirational pull in the absorption of water.

When the soil moisture supply is highly limited as in the case of irrigation scheduled at the IW/CPE ratio of 0.3, the consumptive use of moisture under SSPI still remains lower, but yield of the crop tended to be similar (Table 11) and water use efficiency was more than under surface method (Table 15). This is an indication of the usefulness of this technique, probably can be adopted with precised techniques under limited supply of water. Under limited supply of water, surface methods of irrigation is mostly constrained with limited quantity of water and enormous losses associated with application. But when the subsurface method is adopted, the very little available water can be effectively applied to the root zone with little losses. Similar advantages of subsurface irrigation has been reported by several workers (Davis, 1967 and Phene *et al.*, 1987). The soil moisture extraction pattern is given in Table 12 and Fig. 9. As the data indicate, nearly 2/3 of the moisture use by the crop as ET was drawn from 0-15 cm layer and about 85-90 per cent of the total ET was drawn from the 0-30 cm layer. This trend was identical in both methods of irrigation. As the effective root zone is mainly confined to 0-30 cm (Markose and Peter, 1993) it is quite natural that most of

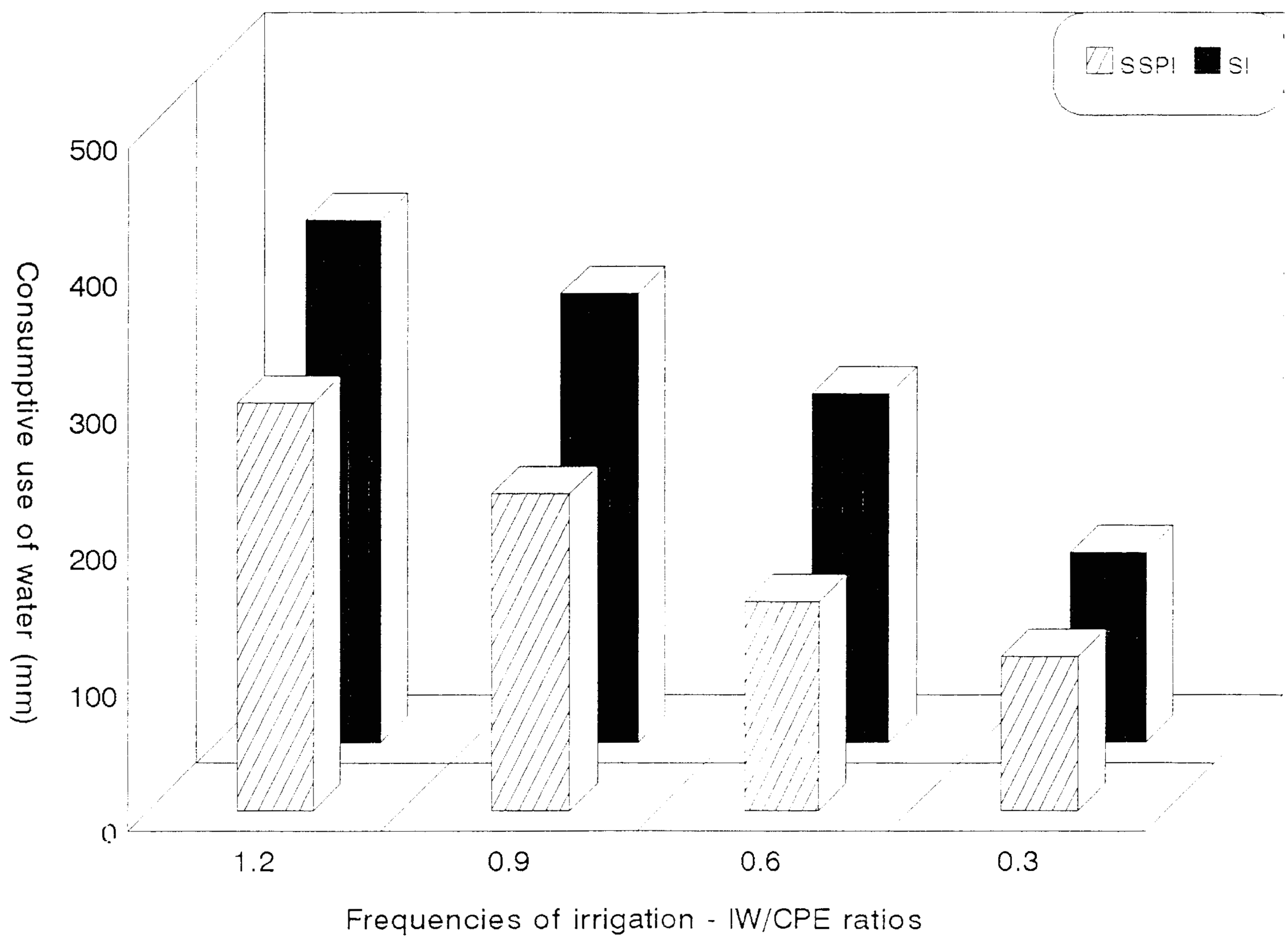
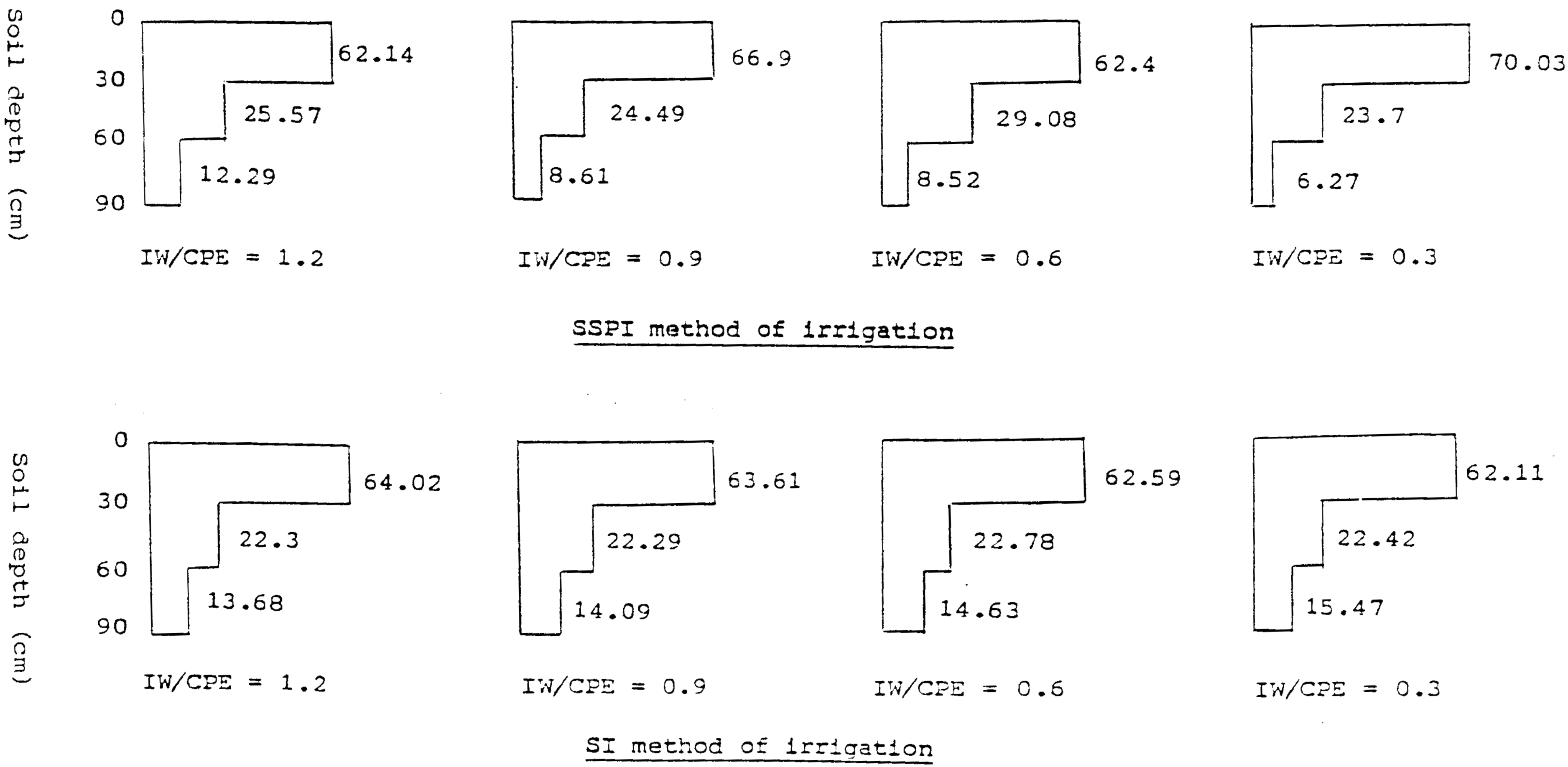


Fig.8 Consumptive use of water (mm) by tomato plants as influenced by systems and frequencies of irrigation

Fig.9 Soil moisture extraction pattern (values in per cent) as influenced by systems and frequencies of irrigation



the moisture available at this zone has been absorbed by the crop. According to Kumar (1986) surface 0-30 cm layer contributed to nearly 72 per cent of total moisture use by okra. Further it can be inferred from the results that though SSPI is a point source kept below the root zone, a substantial quantity of moisture is contributed to root zone though may not be adequate. As the source is underneath the soil, the surface evaporative losses are reduced compared to surface method and the weed growth is also hindered (visual observation). Further refinement of the technology is needed to have effective distribution of applied water to the root zone.

The data further indicated that the third layer (30-60 cm) contributed nearly 6-12 per cent of moisture use in case of SSPI against 13-15 per cent in surface method. As there is continuous supply of moisture to this zone under SSPI, probably the computation of moisture use by water balance method might have caused some error. Otherwise, it is really conceivable that more moisture contribution might take place from this layer under SSPI.

The data regarding soil moisture situation before and after each irrigation are given in Table 13 and 14 and represented graphically in Figs.10 to 13. At all irrigation levels except at the IW/CPE ratio of 1.2 the moisture content recorded before each irrigation under SSPI was more by 11 per cent over that under surface irrigation. This meant that under limited soil moisture conditions SSPI system is able to provide a continued supply of moisture compared to the surface method to the crop for the period between

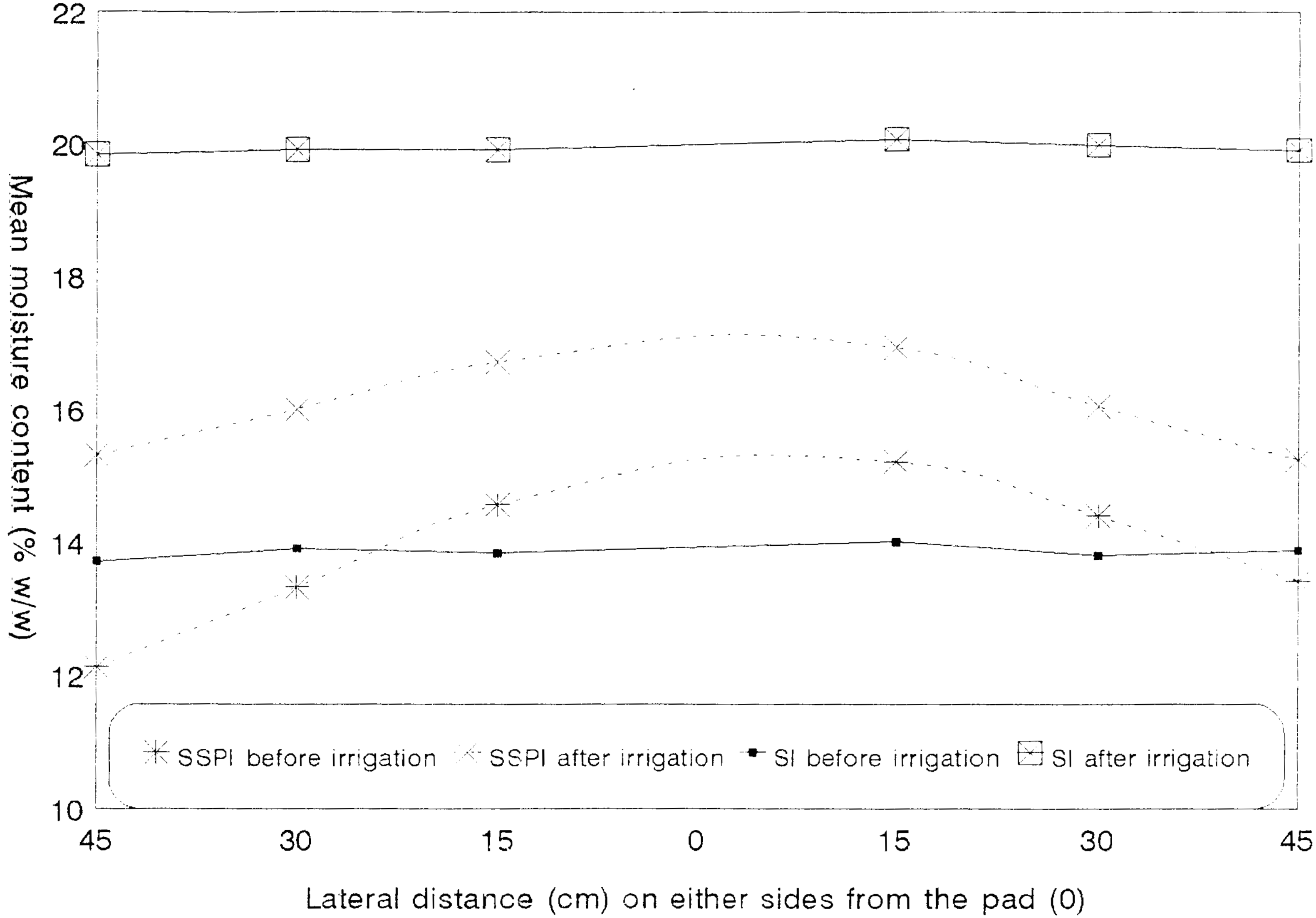


Fig.10 Mean soil moisture content (%) at 15 cm depth before and after irrigations under SSPI and SI systems at the IW/CPE ratio of 1.2 at different lateral distances from the pad/plant

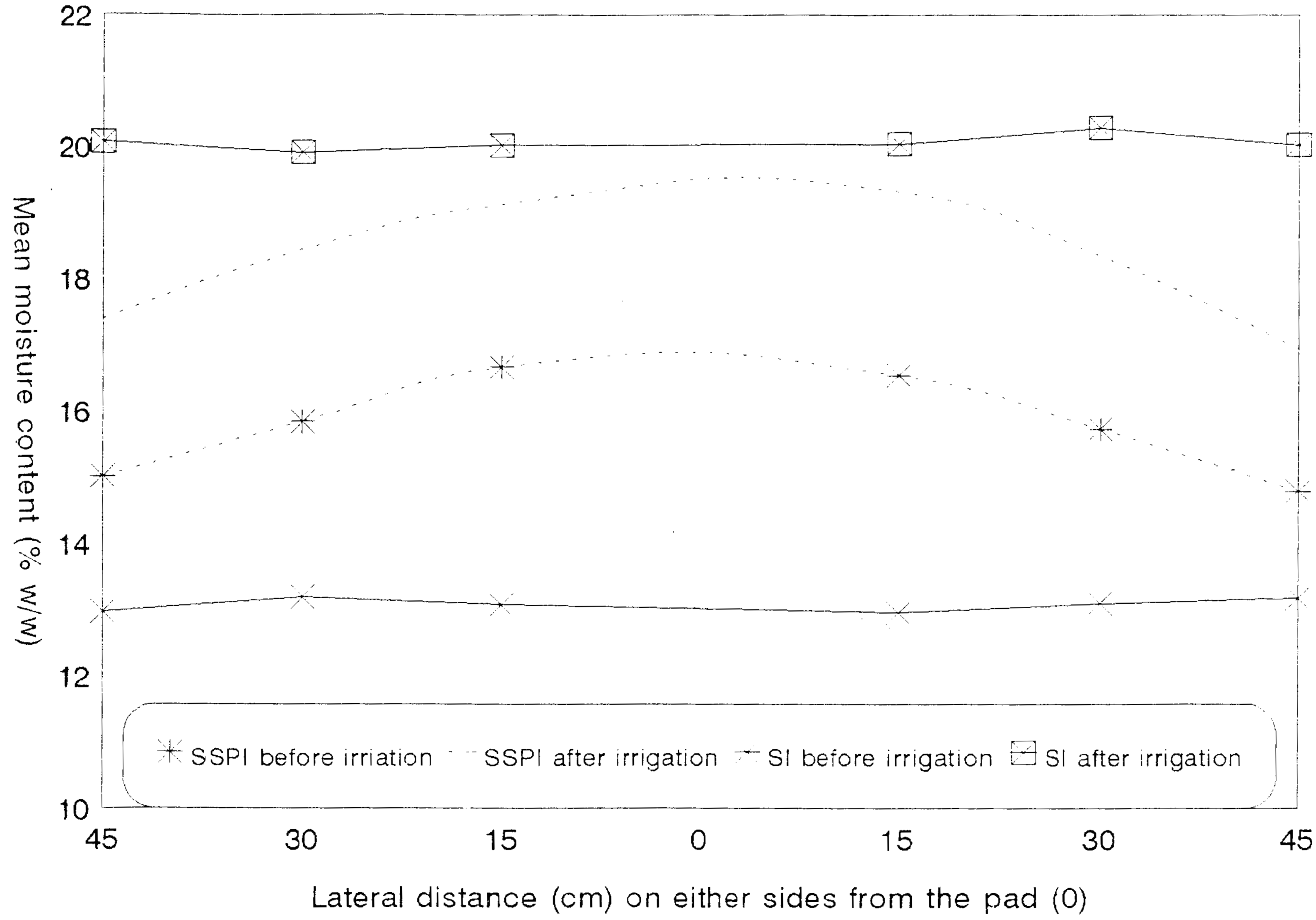


Fig.11 Mean soil moisture content (%) at 15 cm depth before and after irrigations under SSPI and SI systems at the IW/CP ratio of 0.9 at different lateral

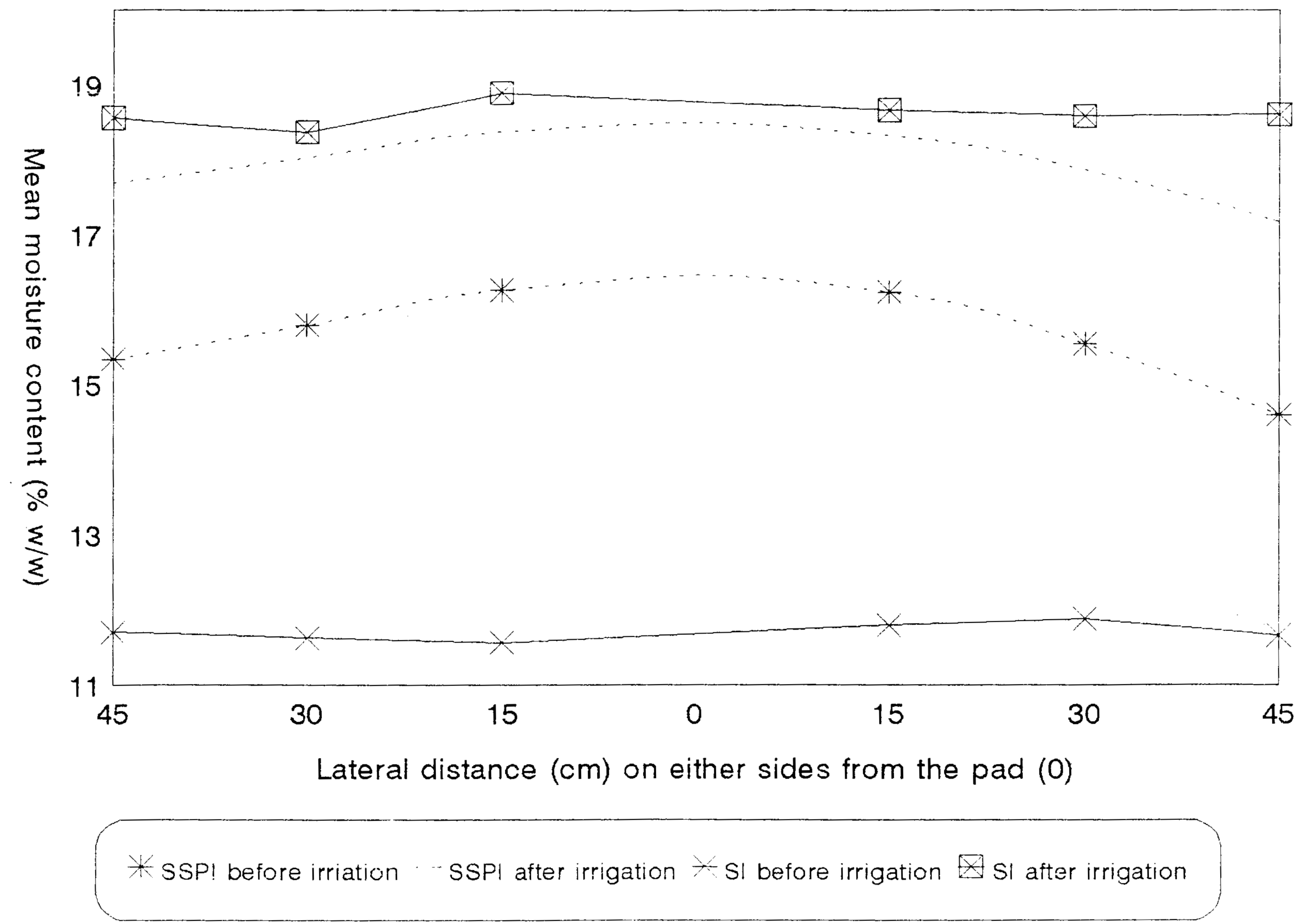


Fig.12 Mean soil moisture content (%) at 15 cm depth before and after irrigations under SSPI and SI systems at the IW/CPE ratio of 0.6 at different lateral distances from the pad/plant

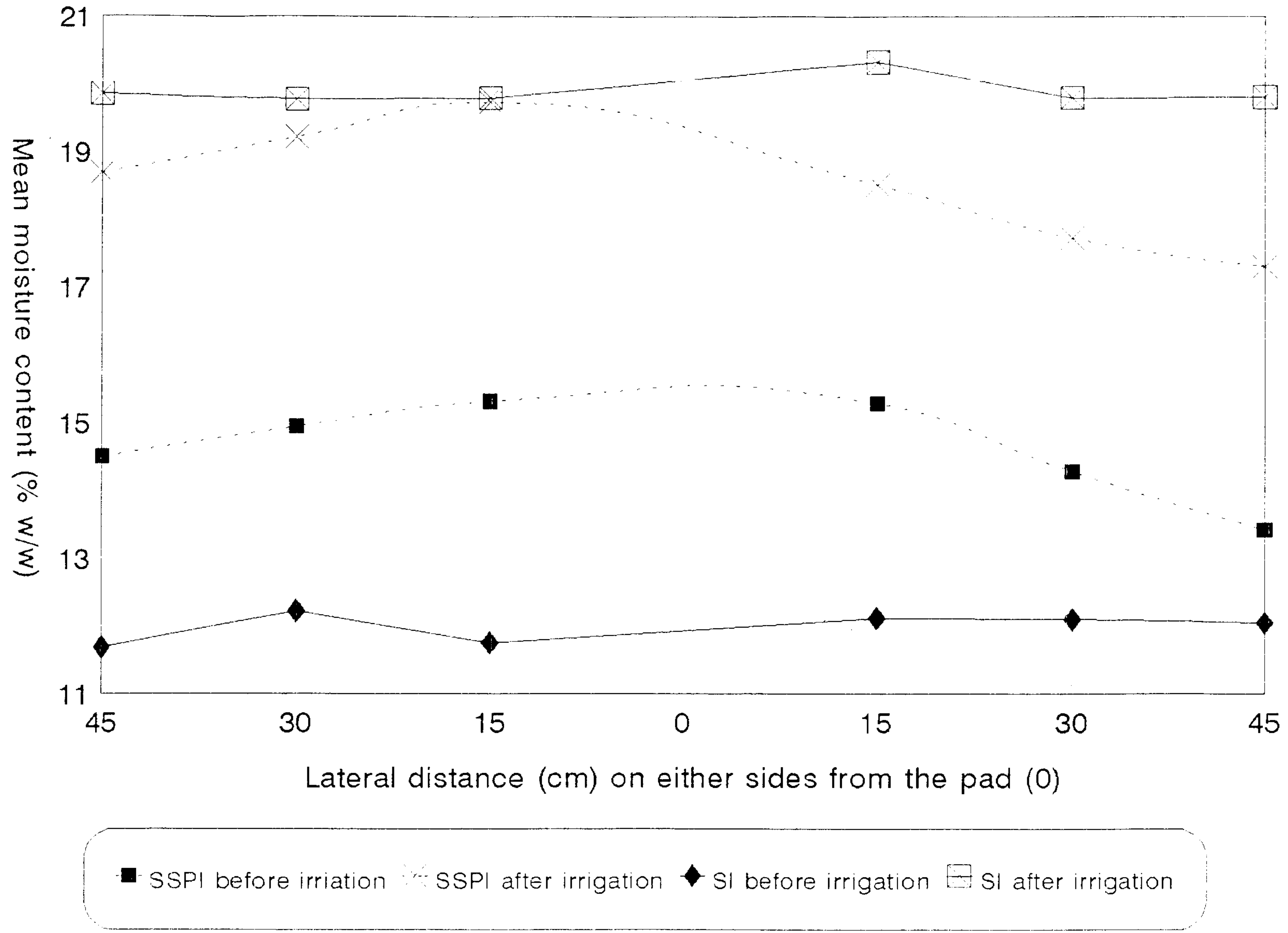


Fig.13 Mean soil moisture content (%) at 15 cm depth before and after irrigations under SSPI and SI systems at the IW/CPE ratio of 0.3 at different lateral distances from the pad/plant

the two successive irrigations. In case of IW/CPE ratio of 1.2, under surface method of irrigation soil at the root zone depth of 0-30 cm retained 7.5 per cent more moisture before each successive irrigation than that under SSPI. Similarly soil moisture content at 48 hours after each irrigation at the root zone depth of 0-30 cm under surface method was more by 29 per cent than that under SSPI.

Under SSPI system, re-distribution of moisture is taking place against the gravitational force and it needs sufficiently longer period for effective re-distribution of soil moisture. In case of surface method, distribution of moisture is taking place in line with the gravitational force. Hence soil moisture distributed rapidly after each irrigation. In the case of IW/CPE ratio of 1.2 irrigation interval on an average was 6 days. Hence the accumulated period for evapotranspiration losses before next irrigation is short and soil moisture content remains higher at this level. These two causes might have attributed to higher moisture content before irrigation in surface method than subsurface method at the IW/CPE ratio of 1.2.

Radial distribution of moisture upto 45 cm on either side from the pad at the depth of 15 and 30 cm in case of SSPI and corresponding point measurements in case of surface method are given in Table 14 and Figs.10 to 13. Soil moisture contents from all the radial distances recorded before each irrigation were considerably higher in case of SSPI compared to surface method. This difference tended to be very prominent as the irrigation frequencies are lowered. It is further inferred that a sustained supply of moisture at the root zone depth of 0-30 cm could be made by the SSPI whereas soil moisture rapidly diminished between successive irrigation in case of surface method. The pad was able to readily distribute moisture upto the measured distance of 45 cm on either side of the pad. A higher level of moisture content can be expected if the pads were placed shallower in the root zone. The moisture distribution curve in case of SSPI assumed an arc shape around the pad meaning that more moisture is available in the immediate radial distance of 15 cm around the pad.

Pelletier and Tan (1993) observed that a distinct cone of more than 50 per cent available water extending from the emitter down to a depth of more than 45 cm existed in drip system. Whereas the 50 per cent available soil water zone in the microjet system was an elongated semicircle from the soil surface to a depth of 35 cm. They further observed that for the 30 cm soil profile, volumetric soil water content was more than 50 per cent of available soil water within a distance of approximately equal to 50 cm from the drip emitters but was only with 20 cm from the microjets.

The soil moisture content in case of surface method at 15 and 30 cm depths did not show any practical variation with respect to radial distance. The moisture content in this case at 30 cm depth was slightly higher than that at 15 cm depth. This meant that under surface method of irrigation moisture is evenly distributed at the root zone depth and the root zone depth is rapidly subjected to evaporative drying cycle.

The data regarding crop and field WUE are given in Table 15 and Fig. 14. High crop WUE is associated with surface method of irrigation than SSPI system at all frequencies of irrigation except at 0.3. The crop was able to utilise all the resources available to it under surface method of irrigation which is reflected in its growth and yield (Tables 5 to 11) under the IW/CPE ratios of 1.2, 0.9 and 0.6. Though there was a continuous supply of moisture under SSPI system as revealed from the Figs.10 to 13, there were constraints in the utilisation of the resources available to the plant which are reflected as poor growth and yield under SSPI even under the higher levels of irrigation. This may be attributed to inadequacy of moisture level in the root zone depth, since the recoupment of soil moisture level to the field capacity was not possible under the present experimental set up (Table 14). If the position of pads were shallower, pad embedded within the root zone, probably soil in the root zone even at the farthest point would have attained field capacity and the crop might have got adequate moisture. Since ET is considerably lowered under SSPI, there is a remarkable reduction in the yield of the crop under SSPI system. The WUE is also reduced under SSPI except at the irrigation level of 0.3. Reduction in yield due to reduced ET and there by reduced WUE is very common in crop plants. The similar situations are also common in tomato (Michelakis and Chartzoulakis, 1988).

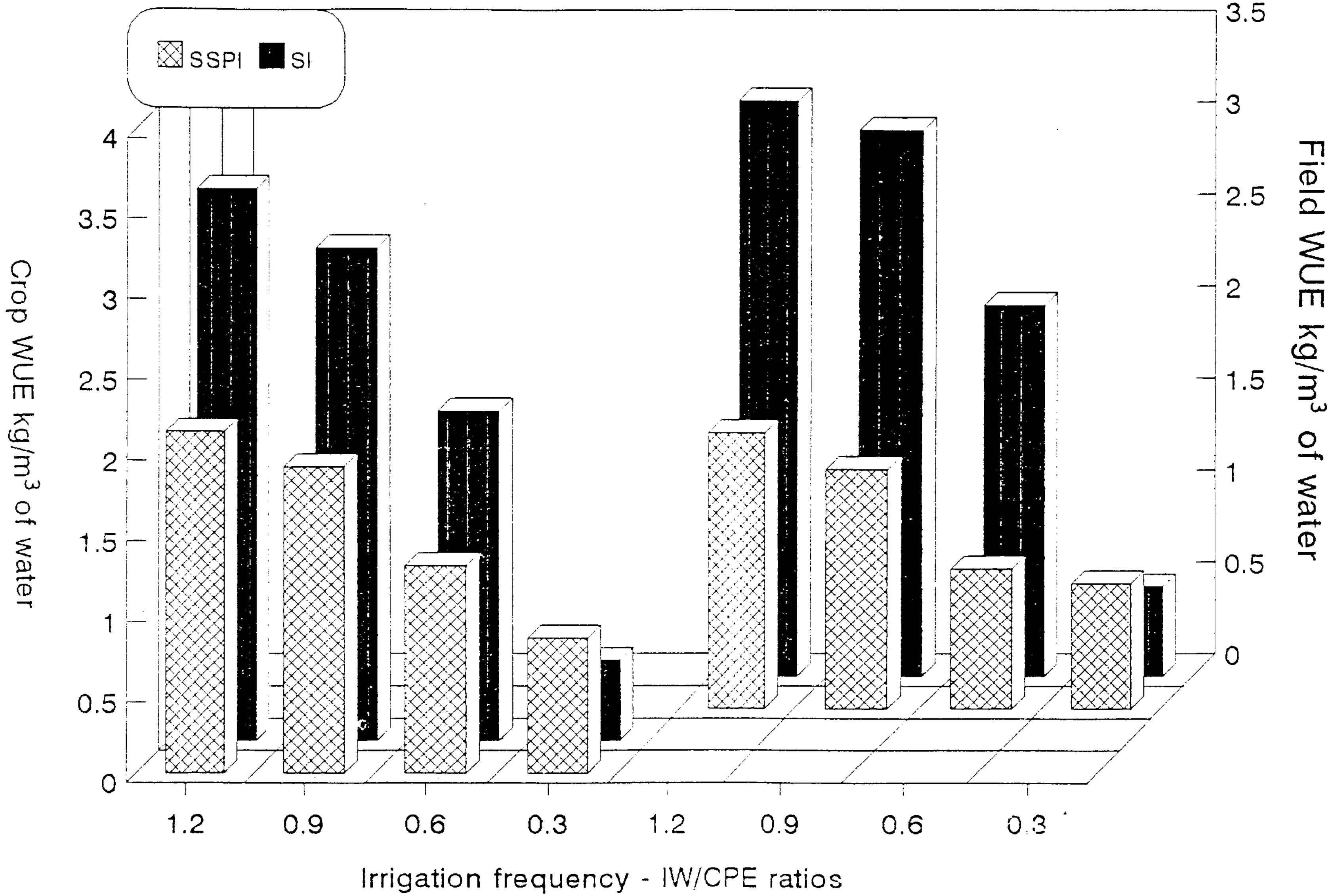


Fig.14 Crop WUE and field WUE (kg/m^3) of tomtato plants as influenced by systems and frequencies of irrigation

Summary and Conclusion

SUMMARY

A field experiment was conducted in the summer rice fallows of the Agricultural Research Station, Mannuthy during 1995 (January to April) to develop and test subsurface pad irrigation system and compare it with surface irrigation system for tomato. The soil of the experimental field was sandy clay loam, bulk density at 0-30 cm depth ranging from 1.50 to 1.52 g cm^{-3}, acidic in reaction, medium in organic carbon and available potassium content and high in available phosphorus. The weather during the cropping period was almost normal with 58.1 mm of rainfall. Eight treatments in the technical programme comprised of combinations of four irrigation frequencies (IW/CPE ratios of 1.2, 0.9, 0.6 and 0.3) and two irrigation systems (subsurface pad irrigation and surface irrigation). Experiment was laid out in randomised block design with three replications. Surface irrigation system followed was the furrow irrigation. The pads in "subsurface pad irrigation" was prepared by filling poly bags with saw dust, sealing and puncturing holes on top. Pads were placed 45 cm below surface and connected to laterals through microtubes. The tomato variety Sakthi (LE-79) was tried as the crop. The salient results obtained during the course of investigation are summarised below.

1. The mean plant height increased with increase in frequency of irrigation and attained maximum values at the IW/CPE ratio of 1.2.

2. Plants irrigated by surface method at the IW/CPE ratios of 1.2, 0.9 and 0.6 and that by SSPI method at the IW/CPE ratio of 1.2 grew taller than the plants irrigated under other treatments.

3. The plants irrigated by surface method at the IW/CPE ratios of 1.2, 0.9 and 0.6 produced significantly more number of green leaves than that irrigated under other treatments.

4. The plants irrigated under SSPI produced similar number of leaves irrespective of frequency of irrigation and this was on par with plants irrigated by surface method at the IW/CPE ratio of 0.3.

5. Methods as well as frequencies of irrigation did not affect branching significantly. However more number of branches were noticed in surface irrigated plants at the IW/CPE ratios of 1.2, 0.9 and 0.6 when compared to plants irrigated by SSPI at the respective levels.

6. The plants when irrigated by surface method at the IW/CPE ratio of 1.2 produced significantly maximum leaf area index (5.29) than the plants under rest of the treatments at 60 DAT.

7. The leaf area index was proportionally reduced with decrease in the frequency of irrigation in each method.

8. At the IW/CPE ratio of 0.3, the plants irrigated by SSPI recorded more leaf area index than the ones irrigated by surface method.

9. The flower production was significantly lowered in each method by the successive decrease in frequency of irrigation.

10. The plants irrigated by surface method at the IW/CPE ratio of 1.2, 0.9 and 0.6 produced significantly more flowers than the one irrigated by SSPI method at the respective levels.

11. The subsurface irrigated plant produced more number of flowers compared to that under surface irrigation at the IW/CPE ratio of 0.3.

12. Plants irrigated by surface method at the IW/CPE ratio of 1.2 produced significantly highest total number of fruits per plant or per ha compared to that under all other treatments.

13. The plants irrigated by surface method produced 94, 129 and 162 per cent more number of fruits at the IW/CPE ratios of 1.2, 0.9 and 0.6 respectively compared to the respective levels under SSPI. These increases on the basis of weight per hectare are 108, 129 and 166 per cent respectively.

14. At the IW/CPE ratio of 0.3, the plants irrigated under SSPI and surface method produced similar number and total weight of fruits.

15. The consumptive use of water by the crop receiving irrigation through SSPI was remarkably lower compared to that of by surface method at all frequencies of irrigation.

16. The decline in consumptive use of water by the crop receiving irrigations through SSPI system at the IW/CPE ratios of 1.2, 0.9, 0.6 and 0.3 over that receiving through surface method was to the tune of 22, 30, 40 and 18 per cent respectively.

17. The surface 0-15 cm soil layer contributed nearly 2/3 of the total moisture use by the crop without much variation between the methods of irrigation.

18. In case of SSPI, the 15-30 cm soil layer contributed 24-29 per cent of total consumptive use where as in surface irrigation it was 22-23 per cent.

19. Soil moisture was redistributed rapidly in the case of surface irrigation whereas moisture re-distribution was gradual in case of SSPI.

20. The mean moisture content before irrigation in respect of surface method was 14.04 per cent where as in SSPI it was 15.59 per cent.

21. At surface 0-15 and 15-30 cm soil layers moisture content 48 hours after irrigation was 19.8 and 21.0 per cent respectively in case of surface irrigation whereas the respective values were 15.3 and 16.2 per cent in case of SSPI and the trend was identical in all the IW/CPE ratios.

22. In case of SSPI, the moisture content was maximum at the radial distance of 15 cm from the pad on either sides whereas in surface irrigation there was no remarkable difference in the moisture content with respect to radial distance from the plant.

23. The surface irrigated plants have more crop WUE and field WUE at the IW/CPE ratios of 1.2, 0.9 and 0.6 compared to plants irrigated under SSPI at respective levels.

24. At the IW/CPE ratio of 0.3, the plants irrigated under SSPI have 68 per cent more crop WUE and 39 per cent more field WUE than the respective values recorded for the crop irrigated by surface method.

CONCLUSION

Being a preliminary investigation conclusive results cannot be drawn unless and until detailed investigations are carried out to finalise the protocol for subsurface pad irrigation for vegetables. The present preliminary investigation clearly indicated the possibility of designing a technology by conducting elaborative trials on the movement of soil moisture under subirrigation systems. Hence I suggest that the works in the following line may be taken up in future to gather more informations.

1. Pads of different sizes and filler material may be tried to increase the reservoir efficiency of the pad.

2. The depth and frequency of placement of pads may be changed so that the moisture distribution within the root zone may be continuous and adequate.

3. Technology for developing pre-fabricated pads with hydrophilic properties may be attempted.

4. Ready to use hydrophilic nutrient pads may also be designed and developed by conducting adequate investigation in future.

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Appendices

APPENDIX I

Twelve years (1983-1994) mean monthly weather data for the summer season

Month	Maximum Temperature (°C)	Minimum Temperature (°C)	Mean RH (%)	Bright sunshine hours (h day^{-1})	Wind speed (km h^{-1})	Evaporation per day (mm)	Rainfall (mm)
January	32.9	21.9	56	8.8	10.7	6.8	1.9
February	35.1	22.3	57	9.5	6.7	7.0	3.5
March	36.0	23.7	63	9.1	5.8	6.9	8.7
April	35.7	25.0	69	8.5	4.9	6.2	52.4
May	34.2	25.0	73	7.0	5.0	5.3	158.4

APPENDIX II

Daily evaporation and rainfall data for the cropping period (mm)

Date	Evaporation	Rainfall
07.02.95	8.6	
08.02.95	7.7	
09.02.95	7.4	
10.02.95	5.8	
11.02.95	7.0	
12.02.95	4.2	
13.02.95	7.0	
14.02.95	6.7	
15.02.95	6.0	
16.02.95	4.6	
17.02.95	4.6	
18.02.95	6.1	
19.02.95	4.7	
20.02.95	5.4	
21.02.95	4.2	0.5
22.02.95	5.4	
23.02.95	5.4	
24.02.95	5.4	
25.02.95	4.1	
26.02.95	5.0	
27.02.95	5.5	
28.02.95	6.0	

Contd......

Appendix II Contd.....

Date	Evaporation	Rainfall
01.03.95	4.6	
02.03.95	6.5	
03.03.95	5.2	
04.03.95	6.3	
05.03.95	7.6	
06.03.95	5.6	
07.03.95	5.7	0.8
08.03.95	5.9	
09.03.95	5.2	1.0
10.03.95	5.3	
11.03.95	3.2	
12.03.95	4.4	
13.03.95	3.4	1.0
14.03.95	5.8	
15.03.95	6.8	
16.03.95	6.8	
17.03.95	6.6	
18.03.95	6.7	
19.03.95	7.0	
20.03.95	8.9	
21.03.95	9.9	
22.03.95	9.0	
23.03.95	6.0	

Contd.......

Appendix II Contd.....

Date	Evaporation	Rainfall
24.03.95	6.0	
25.03.95	6.4	
26.03.95	5.1	
27.03.95	5.5	
28.03.95	5.8	
29.03.95	6.0	
30.03.95	6.0	
31.03.95	7.0	
01.03.95	6.1	
02.03.95	6.0	
03.03.95	6.2	
04.03.95	7.3	
05.03.95	7.7	
06.03.95	5.2	54.8
07.03.95	5.0	
08.03.95	4.4	

APPENDIX III

Dates of sowing, transplanting and harvesting of the crop

Dates	Operation done
28.12.1994	Sowing of seeds in the nursery
30.01.1995	Transplanting of the seedlings in the main field
18.03.1995	Harvesting of the crop started - first picking
24.03.1995	Second picking
29.03.1995	Third picking
01.04.1995	Fourth picking
04.04.1995	Fifth picking
06.04.1995	Sixth picking
08.04.1995	Seventh and last picking

DEVELOPMENT OF SUBSURFACE PAD IRRIGATION SYSTEM FOR TOMATO

By

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ABSTRACT OF A THESIS

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ABSTRACT

An experiment was conducted in the summer rice fallows of the Agricultural Research Station, Mannuthy during 1995 to develop and test subsurface pad irrigation system for tomato and to compare it with surface irrigation. The soil was sandy clay loam, medium in organic carbon and available potassium and high in available phosphorus. The eight treatments comprised of combination of four frequencies of irrigation (IW/CPE ratios of 1.2, 0.9, 0.6 and 0.3) and two irrigation systems (subsurface pad irrigation and surface irrigation). The experiment was laid out in randomised block design with three replications. Poly bags filled with saw dust placed 45 cm beneath the surface at the frequency of one pad for every four plants formed SSPI. Water was supplied to pads by laterals supplying 40 mm of water per irrigation.

The study revealed that tomato responded very well to irrigation. Biometric characters like plant height, number of leaves and leaf area index and yield attributing characters like number of flowers, number of fruits and total weight of fruits per plant were favourably influenced by frequent irrigation under both the systems of irrigation. The fruit yield increased with frequency of irrigation and was maximum at the IW/CPE ratio of 1.2.

The plants irrigated by surface method grew taller, had more leaf area index, produced more number of green leaves, flowers, fruits and total fruit weight per plant compared to the plants irrigated under SSPI system at the

irrigation frequencies of IW/CPE ratios 1.2, 0.9 and 0.6. But at the IW/CPE ratio of 0.3, the subsurface irrigated plants performed better than the surface irrigated plants both in terms of growth and yield attributing characters.

The crop receiving irrigations through SSPI systems consumed lesser amount of water at all the frequencies of irrigation compared to surface method. This decline at the IW/CPE ratios of 1.2, 0.9, 0.6 and 0.3 were to the tune of 22, 30, 40 and 18 per cent respectively. The soil moisture extraction from 0-15, 15-30 and 30-60 cm layers in SSPI was 62-70, 24-29 and 6-12 per cent respectively whereas in surface irrigation the respective values were 62-64, 22-23 and 13-15 per cent.

The soil moisture redistribution was rapid in the case of surface irrigation whereas it was gradual in the case of SSPI. Moisture content in the case of SSPI was maximum at the radial distance of 15 cm from the pad on either sides whereas in surface irrigation there was no remarkable difference in the moisture content with respect to radial distance from the plant.