

P 3783 -TH 6436

**COMPARATIVE PERFORMANCE OF SURFACE
AND SUBSURFACE DRIP FERTIGATION FOR
CAULIFLOWER**

DISSERTATION

submitted to

***Marathwada Krishi Vidyapeeth
in partial fulfillment of the
requirement for the degree of***

T 6436

MASTER OF TECHNOLOGY

(Agril. Engineering)

IN

IRRIGATION AND DRAINAGE ENGINEERING

By

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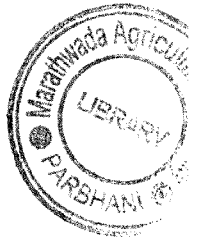
UNDER THE GUIDANCE OF

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MAY - 2011



Ms
T 6436

Affectionately Dedicated To

My Beloved Family

Aai, Pappa,

and Friends



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***I, Hereby Declare that the
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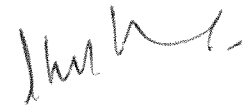


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CERTIFICATE-I

This is to certify that the dissertation entitled “**COMPARATIVE PERFORMANCE OF SURFACE AND SUBSURFACE DRIP FERTIGATION FOR CAULIFLOWER** ” submitted to Marathwada Krishi Vidyapeeth, Parbhani in partial fulfillment of the requirement for the award of the degree of **Master of Technology (Agril. Engineering)** in **Irrigation and Drainage Engineering** embodied the results of the bonafied study carried by **Mr. PATIL DATTOPANT PARSHURAM** under my guidance and supervision. I also certify that the dissertation has not previously submitted by him for the award of Degree or Diploma of any University or Institute.



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CERTIFICATE-II

This is to certify that the dissertation entitled "COMPARATIVE PERFORMANCE OF SURFACE AND SUBSURFACE DRIP FERTIGATION FOR CAULIFLOWER " submitted by Mr. PATIL DATTOPANT PARSHURAM to the Marathwada Krishi Vidyapeeth, Parbhani in partial fulfillment of the requirement for the degree of MASTER OF TECHNOLOGY (Agril. Engg.) in the subject of Irrigation and Drainage Engineering has been approved by the students advisory committee after oral examination in collaboration with external examiner.

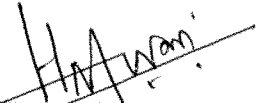


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ACKNOWLEDGEMENT

Before giving way to my feelings, I cordinally want to salute that supreme cosmic consciousness from which everything originates in the beginning and to which everything goes to end, my Gurudeva and the memories of my parents. Though formal and deed words cannot carry the fragrance of emotions with them still they are the available way of expressing emotions such formal acknowledgements.

I express my esteemed and profound sense of gratitude to my guide Dr. U.M. Khodke, chief scientist, AICRP on Water Management, M.K.V., Parbhani for his proper and continue guidance and relevant suggestions in my project work and dissertation writing with immense pleasure. It is my proud privilege to record a deep sense of gratitude Prof. H.W. Awari, Head, Dept. of Irrigation and Drainage Engineering, CAET, M.K.V., Parbhani for valuable suggestions, consistent efforts and strives to keep the progress of work genuine by providing the necessary facilities throughout the research work.

I am highly thankful to Dr. S. B. Soni, Associate Dean and Principal, College of Agricultural Engineering, M.K.V., Parbhani for his encouragement and help during the course of study.

I am thankful to Dr. G. N. Ingle, Junior Vegetable Breeder, M.K.V., Parbhani for his valuable guidance and suggestions.

I am also grateful to thanks to Dr. G. P. Jagtap, Assistant Prof. Dept. of Plant Pathology, College of Agriculture, M.K.V., Parbhani for his guidance and suggestions during the experimental work.

I extend my sincere thanks to Prof. S.B. Jadhav, Assistant Prof. Dept. of Irrigation and Drainage Engineering and Mrs. Dr. S.U. Khodke, Head, Dept. of Agriculture process Engineering, College of Agriculture Engineering, M.K.V., Parbhani for their valuable guidance and suggestions.

I am also thankful to Mr. Shivankar, Agril. Asstt. Dept. of IDE, C.A.E.T., M.K.V., Parbhani for providing the required materials during my research work.

I am also thankful to Shri Y. A. Khan, Agricultural supervisor, AICRP on Water Management M.K.V., Parbhani and Shri B. N. Maske, Agricultural Assistant, AICRP on Water Management M.K.V., parbhani for their valuable help and co-operation.

I am also thankful to shri A. B. Poul, Shri Prakash Mote, Shri Bhrose and all Labours of Water Management Centre, M.K.V., Parbhani for their valuable help and co-operation during the work.

"There are always some persons in this world whome acquaintance is beyond price". They are my father Shri Parshuram Dattu Patil and Mother Sow Anjana Parshuram Patil and my kind inspiration my uncle Shri Suryakant Pandurang Chougule, there are no words indeed inadequate to express my feelings for them.

I am extremely thankful to my friend Datta, Pramod, Vaibhav, Nitin, Sneha, Shraddha, Sukayna, Sunil and Amol who helped me in project work.

No words are enough to express heartiest gratitude to my M.Tech. And B. Tech. friends, Haridas, Durgadas, Gajendra, Manik, Vinayak, Prasad, Akshay, Ravi, Yogesh and Sagar. Also M.Tech. Seniors Kedar, Sagar, Amol, Shyam, Jawahar and Rahul who helped me during my research work and always inspired towards success and gave me moral strength. I am lucky enough to receive constant inspiration from my friends.

My loving thanks are also to my dear closely relatives and my friends of B.Tech. (Mandki-Palvan) and B.Tech. (CAET, M.K.V., Parbhani) and other forever friends for their evergreen affection, encouragement and kind blessing during my whole educational career.

The acknowledgement cannot be completed without mentioning my cordial gratitude thanks to all those, who helped me knowingly or unknowingly in this study.

Place : Parbhani.

Date : 13 / 12 / 2011


(Mr. Patil D. P.)

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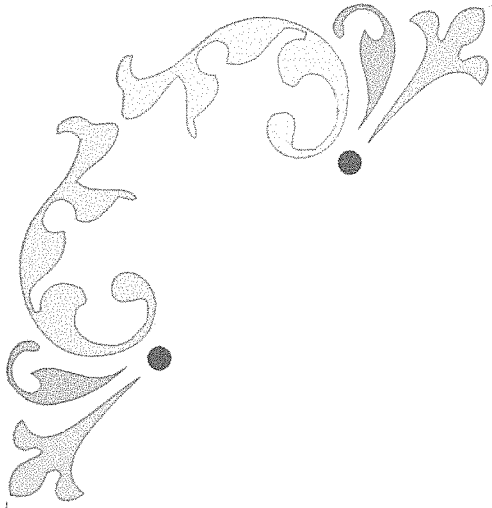
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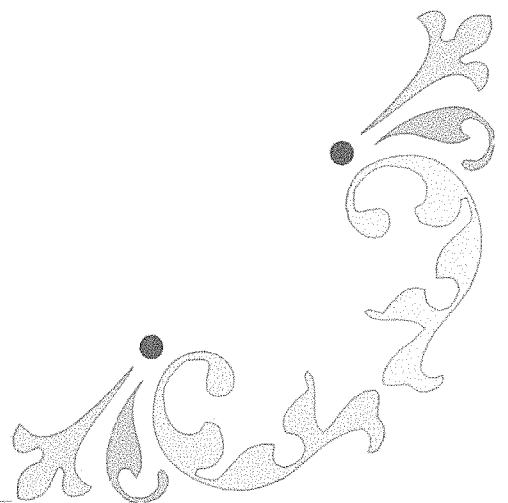
ABBREVIATIONS

Agril. Engg.	:	Agricultural Engineering
Agril.	:	Agricultural
AICRP	:	All India Coordinated Research Project
ASAE	:	American Society of Agricultural Engineers
avg.	:	Average
CAET	:	College of Agricultural Engineering and Technology
CD	:	Critical Difference
cm.	:	Centimeter
CPE	:	Cumulative Pan Evaporation
DAP	:	Days after planting
Deptt.	:	Department
EC	:	Electrical conductivity
Engg.	:	Engineering
<i>et al.</i>	:	Ei alibi and other
Fig.	:	Figure
FUE	:	Fertilizer Use Efficiency
ha	:	Hectare
Hort.	:	Horticulture
hrs	:	Hour
i.e.	:	That is
Ind. J. agric. Sci	:	Indian Journal of Agricultural Science
IMD	:	Indian Meteorological Department
Irrig.	:	Irrigation
J	:	Journal
kg	:	Kilogram
km	:	Kilometer
lps	:	Liter per second
Ltd.	:	Limited

m	:	meter
M.P.K.V.	:	Mahatma Phule Krushi Vidyapeeth
M.K.V.	:	Marathwada Krushi Vidyapeeth
mm	:	millimeter
MT	:	Million tones
N.S.	:	Non Significant
NMR	:	Net Monetary Return
No.	:	Number
PE	:	Pan Evaporation
q	:	Quintal
RDF	:	Recommended dose of fertilizer
SE	:	Standard Error
t/ha	:	Ton per hector
VI	:	Relative Vegetative Index
viz.	:	namely
WUE	:	Water use efficiency
%	:	Per cent
@	:	At the rate
°C	:	Degree Celsius



INTRODUCTION



CHAPTER I

INTRODUCTION

Most of the countries in the world are gifted with varied agro-climatic environments for growing an array of vegetable crops to combat the present ill-balanced diet of a vast population of the world, particularly in the developing countries. Production of vegetables in developed countries is much higher. Vegetables are being considered as an asset providing a good source of income to the growers and they form a vital part of human diet. Vegetable cultivation is mainly centered near towns and cities due to their perishable nature and also have heavy demand from urban population. Recently vegetable growing has been taken up on an intensive scale in many countries. It needs special skill, knowledge and labour throughout the growing season.

Vegetables are rich and comparatively cheaper source of vitamins and minerals and their importance in human nutrition is well known. Consumption of vegetables in sufficient amount provides vitamins, minerals, proteins, carbohydrates and fibers in the diet besides having medicinal value and providing nutritional security. India is the second largest producer of vegetables next to China. Area under vegetable crops in India is 7,981 thousand ha with their annual production of 129077 thousand MT with productivity of 16.22 MT/ha. In Maharashtra the area under vegetables is 448 thousand ha with total production of 6368 MT with an average productivity of 14.20 MT/ha (<http://faostat.fao.org>).

Among the vegetables, cauliflower (*Brassica Oleracea L.*) has gained importance as one of the important and popular vegetable in various parts of the world. Cauliflower plays an important role in human diet due to its attractive appearance, good taste and rich nutritive value. Cauliflower is rich source of protein, carbohydrates, vitamin-B and C as well as various minerals which are necessary for the human health. Cauliflower is grown for its edible flowering head and consumed as a vegetable in curries, soups and pickles. It is one of the important winter vegetables of India. India produces 6532MT of cauliflower per year from 349 thousand ha area with an average productivity of about 18.7

MT/ha. The area under cauliflower crop in Maharashtra during 2008-09 was 13.1 thousand ha with 330.7 MT of production and 25.5 MT/ha productivity (Indian Horticultural Database, 2009(<http://faostat.fao.org>)).

Cauliflower produces the best curds in the cool and slightly moist climate. The optimum monthly average temperature ranges from 15 to 20⁰C. The early varieties require higher temperatures and longer day length. The cauliflower varieties are grouped under three categories viz. early season, main season and late season varieties. Early season varieties are sown during May to August and ready to harvest from September to December. Main season varieties are sown during September to October and are ready for harvest during December to January while late season varieties are sown during October to December and harvested from mid January to April end.

Cauliflower can be grown on any good soil from clay to loamy, but fairly deep loamy soil is most desirable. Soils with a high moisture- holding capacity are preferred in late season/summer since water stress adversely affects curd development. In rainy season, soils that dry rapidly are preferred so that the cultural and harvesting operations can be done easily. It is sensitive to high acidity and the optimum soil pH for maximum production is 5.5 to 6.0. Cauliflower is considered moderately sensitive to salinity in soil and water. Although no salinity threshold for yield reduction has been established for cauliflower, it is considered more tolerant to salinity than lettuce but somewhat less tolerant to salinity than broccoli, hence water with E_{Ce} of 1.3 or less can be used for irrigation (Martin et al., 2009). Although efforts have been made by developing number of high yielding, quality, and disease resistant varieties with higher and better production technologies, much importance has not been given to irrigation and fertilizer management in cauliflower. The need of water to cauliflower crop varies from place to place depending upon the climatic conditions. Therefore it is essential to find out the exact water requirement of this crop.

The National Water Policy of India described water as a prime natural resource, a basic human need and precious asset. The demand for water is increasing both in agriculture and municipal sector at significant rates. To meet

the requirements of growing population, Indian agriculture in future has to produce increased quantities of food, fiber and fuel with the minimum quantity of available water for irrigation. Water is in excess during the monsoon season (June–September) and absent or scarce in the remaining months of the year. Lack of water in arid and semiarid areas limits crop production to single or possibly two crops per year. Access to irrigation, which provides the means to cultivate an additional crop, is viewed as one of the best ways to boost the productivity of small-scale, dry-land farming systems (Postel, 2000). Since the productivity of irrigated agriculture is more than twice the rain fed agriculture, it is essential to bring the maximum area under irrigation.

Irrigation is the application of water to soil, supplementing natural precipitation, to provide water essential for plant growth. Water plays a vital role in transporting mineral nutrients and translocation of materials in the plants through solution. There is liquid phase continuity from the water in the soil through the plant to the liquid gas interface at evaporation sites in the leaves of all actively growing plants (Slatyer, 1967). The root system provides an extensive absorbing surface through which virtually all the water and mineral nutrients utilized by plants pass. In a crop-soil-climate system, maintaining the soil water level within an optimum range is essential to avoid adverse effects on plant growth and crop production.

Surface irrigation methods are utilized for more than 80% of the world's irrigated lands; yet its field-level application efficiency is often only 40–50%. In this context optimum and efficient utilization of water in agriculture for irrigation assumes great significance. This can be achieved by precise and judicious use and maximum possible water use efficiency through modern water saving techniques like micro-irrigation system. The traditional surface irrigation method poses numerous problems of soil, water and environmental degradation. Being a supply driven rather than the crop demand driven, surface methods cause mismatch between the need of crop and quantity supplied with low water application efficiency (Singh and Rajput, 2007), loss of applied water in deep percolation,

fixed depth of water disregarding crop growth stage and water stress conditions for some period during two successive irrigations..

Drip irrigation is one of the efficient micro irrigation methods providing irrigation water directly into soil at the root zone of crop and permits irrigation to limit the watering close to the consumptive use of plants. It keeps soil moisture within the desired range of plant growth and minimizes the losses of water by deep percolation below the root zone or by evaporation, and runoff water from the soil surface. Drip irrigation has field-level application efficiencies of 70–90% as surface runoff and deep percolation losses are minimized (Heermann et al., 1990), hence drip irrigation has proved to produce more crop per unit of applied water (Postel, 2000). Drip irrigation usually saves 30-60 per cent water depending upon crop and weather conditions (Ashwani Kumar, 2001), and increases the yield by providing daily requirement of water and nutrient. Drip is found advantageous in soil with high infiltration rate and land with steep slope avoiding runoff, seepage etc. It has added advantages like reduction in the cost of intercultural operations by 30-40 per cent, minimizing the expenditure on weedicides and pesticides, hastening the maturity by 30-60 days and improvement in quality of fruits (Pawar et al., 2001). The main disadvantage inherent in drip irrigation system are their susceptibility to clogging, there tendency to build up local salinity and maintenance. Thus, drip irrigation may allow crop cultivation in areas where insufficient water exists to irrigate by surface irrigation methods. Other advantage of drip irrigation is uniform distribution of fertilizers, herbicides and fungicides with water.

Surface drip irrigation system with lateral lines laid on soil surface is the most popular method in India. However, it can be made more applicable for irrigating a wide range of agronomic, horticultural and fruit crops by installing laterals below soil surface. Subsurface drip irrigation has a higher capability for minimizing the loss of water by evaporation, runoff and deep percolation in comparison to other irrigation methods that supply water to the soil surface (Camp, 1998; Alizadeh, 2001; ASAE, 2005). Subsurface drip irrigation offers many other advantages over surface drip such as precise placement and

management of water, nutrient and pesticides, greater application uniformity, enhanced plant growth, higher crop yield and better quality produce (Camp, 1998). In addition, the high cost of surface drip irrigation system is substantially reduced when sub surface components are permanently installed below the soil tillage zone (Camp et al., 1997). Water is applied directly to the root zone of the crop and not the soil surface hence germination of annual weed seed is greatly reduced lowering weed pressure on beneficial crops (Reich, 2009). Hence there is a need to study the response of important vegetable like cauliflower to surface and subsurface drip irrigation system.

Drip irrigation for vegetable production will be helpful in semi arid regions like Marathwada where the water scarcity with conditions of dry and warm seasons and high evapotranspiration rates exists. The yield of cauliflower can be increased by adopting improved irrigation, fertilizer and cultural practices. Among improved irrigation and fertigation practices, application of manures and fertilizer through drip irrigation plays an important role to increase the yield of crop (Aziz et al., 1971). Application of fertilizers in bulk by traditional method may increase its concentration in soil near the root zone of crop which may be hazardous to plant and soil health. Such type of drawbacks can be eliminated by fertigation. As controlled amount of water is applied at required time in root zone, fertilizers losses can be avoided along with deep percolation.

Under drip irrigation, only a portion of soil volume around each plant is wetted and thus traditional methods of fertilizer application in conjunction with drip irrigation are ineffective. Fertigation is the simultaneous and efficient application of water and nutrients in the vicinity of effective crop root zone through irrigation water at appropriate times and with desired concentration. This avoids nutrient losses due to seepage ensuing increased fertilizer use efficiency and reduction in quantity of fertilizers to the extent of 25 to 50 per cent. Frequent application of fertilizer as per the requirement of crop growth stages through fertigation results in increased yields (Rolston et al., 1986) and also provides balanced nutrition at appropriate time. Fertilizer is costlier input in agriculture

hence it is also essential to study the effect of varying levels of fertilizer on crop growth and designing of efficient fertigation schedule based on crop growth stage.

Many scientists have worked independently on simply water requirement, fertilizer requirement and planting densities. However, very few studies are reported on integrated practice. Therefore it was felt necessary to conduct research trial on drip irrigation and fertigation in integration. With these considerations in view, the present experiment entitled “Comparative performance of surface and subsurface drip fertigation for cauliflower” was planned during winter season at AICRP on Water Management, M.K.V. Parbhani with the following specific objectives:

Objectives

1. To study the soil moisture distribution under surface and subsurface drip irrigation of cauliflower.
2. To compare growth and yield response of cauliflower under surface and subsurface drip irrigation.
3. To assess the effect of different drip irrigation depths and fertigation levels on cauliflower.



**REVIEW OF
LITERATURE**

CHAPTER II

REVIEW OF LITERATURE

Water is the most important input essential for crop production. Application of precise amount of water and fertilizers may improve crop growth and yield, and also the quality of produce. Drip irrigation with fertigation optimizes the use of water and fertilizers and results in higher yields with increasing water and fertilizer use efficiency. Proper irrigation and fertigation scheduling have to be planned to provide water and nutrients as and when plants need them.

Past studies indicated that the subsurface drip irrigation can be a promising irrigation method for several horticultural and vegetable crops as compared to surface drip. Their comparison in vegetable crop like cauliflower along with conventional furrow irrigation has to be made. The available literature on research carried out by different investigators related to the effect of various irrigation methods, schedule and fertilizer levels on growth, yield and quality of produce in general with particular reference to cauliflower has been reviewed and presented in this chapter. The effect of irrigation methods on moisture distribution pattern and root growth has also been included in this chapter under following sub heads.

2.1 Drip irrigation

2.2 Subsurface drip irrigation

2.3 Irrigation scheduling

2.4 Moisture distribution pattern

2.5 Root distribution

2.6 Effect of fertilizer level on crop response.

2.1 Drip Irrigation

The water shortage is one of the main constraints for economic development in the major part of the world. Agriculture is the core user of freshwater and hence there is no option rather than to adopt the new irrigation technology for efficient and judicious use of water. Hence innovations are

required to increase water use efficiency and adoption of water saving methods like micro irrigation. The flow irrigation has some inherent limitation like mismatch between water delivered and crop water requirement.

2.1.1 Advantages of drip irrigation

The spectacular advantages of drip irrigation compared to surface irrigation have been reported by several workers, such as increase in water use efficiency (50-95 per cent), fertilizer use efficiency (fertilizer saving to 30 per cent) and yields (40-100 per cent); and better quality products as well as reduction in tillage requirements, weed growth, reduction in occurrence of pest and diseases and low labour requirement (Bucks et al., 1982). The efficient use of saline or poor quality water is also possible through drip irrigation (Singh et al., 1978; Goldberg and Shmueli, 1970). With drip irrigation system, water and nutrients can be applied directly to the crop at root level, having positive effects on yield and water saving and increasing the irrigation performance (Phene and Howell, 1984).

2.1.2 Water saving and yield under drip irrigation

In most of the vegetables furrow irrigation is the common surface irrigation method. Many studies have reported water saving, and increase in yield and water use efficiency of different crops under drip as compared to conventional surface irrigation. Drip irrigation provides more efficient water use for crops than furrow irrigation because of frequent and localized water application to the potential root zone and reducing the adverse effects of over-irrigation and water stress commonly occurred in furrow irrigation.

Under drip irrigation, Aziz et al. (1971) observed increase in yield and water saving in cabbage (11 and 43%) and potato (16 and 47%) whereas Agrawal and Singh (1973) reported 46 percent higher yield, and 25 percent water saving in potato as compared to surface method. Drip irrigation saves water and gives better plant yield and quality as it reduces the humidity build up inside greenhouse after irrigation due to precise application of water to the crop root zone (Papadopoulos, 1992).

Under drip irrigated tomato, increase in yield (43%), water saving and higher water use efficiency were recorded (Sivanappan et al., 1974; Bhell, 1988;

Tekinel et al., 1989; Tan 1995) as compared to ridges and furrow method of irrigation. Kadam (1993) compared the effect of furrow, sprinkler and drip irrigation methods on the growth of tomatoes and observed higher plant leaf area index and early flowering which resulted in increased fruit yields under drip irrigation than in surface irrigation.

Increase in yields of different crops were also reported in some crops like sugarcane (32%) (Selvaraj *et al.* 1997b), banana (100%), sugarcane and pomegranate (40 to 50%) and grapes and cotton (25%) (Bhardwaj, 2001). In drip irrigated cauliflower water saving of 29 percent and water use efficiency of 76 and 40 per cent, respectively against furrow is reported (Kadale *et al.*, 1990). Many studies and reports have addressed the improvement in yield and quality of crops like potato, onion, lettuce, tomato and cotton with drip irrigation (Singh et al, 1977; Sammis, 1980; Wood, 1988; Saggu and Kaushal, 1991; Sener et al., 1994; Weatherhead and Knox, 1997; Hansona et al, 1997; Yohannes Tadesse, 1998; Al-Jamal et al., 2001; Daleshwer et al., 2006; Erdem et al., 2006). Nagaz et al. (2008) also reported significantly higher tuber yield and water saving (20%) in drip irrigated potato than those irrigated through furrows.

Drip irrigation improves the quality of produce such as fruit size and marketable yield and brings early harvest in sandy soils (Shumulei and Goldberg; 1971; Bhella, 1985; Warriner and Henderson, 1989; Coelho et al., 1999; Sousa et al, 1999; Leskovar et al, 2001). Increase in yield under drip irrigation might be due to better water utilization (Manfrinato, 1971); higher uptake of nutrients (Bafana et al., 1993) and excellent soil-water-air relationship with higher oxygen concentration in the root zone (Gornat et al., 1973).

Mateos *et al.*, (2003) observed that water application efficiency was 30% higher in the drip irrigation treatments indicating a definitive advantage of this method under limited water supply for irrigated cotton and midday leaf water potential fluctuated along the season in both drip and furrow irrigation due to irrigation events but not due to the soil water deficit.

Malash *et al.* (2005) reported enhanced tomato growth in early growing season under drip irrigation but at later stages there was little difference between the two irrigation systems.

2.1.3 Water use efficiency

The rate of water loss through evaporation from soil surface is much lower under drip irrigation; hence water use efficiency is higher as compared to surface irrigation. In Brinjal water saving (29 to 58%) and higher water use efficiency (4.10 q/ha-cm) was observed as compared to furrow method (Baldota and Bhatane, 1983; Mane *et al.* 1986). The water use efficiency at optimum irrigation schedule can be considerably higher in main and ratoon crop of banana under drip irrigation (644 and 540 kg ha⁻¹ mm⁻¹) than under basin irrigation (537 and 401 kg ha⁻¹), respectively (Hedge and Srinivas, 1990). Malik and Kumar (1996) and Bafana *et al.* (1993) also made similar observations on water-use efficiency of drip irrigation in pea and tomato, respectively.

Cetin and Bilgal (2002) observed that application of irrigation water in the vicinity of root through drippers provides better soil moisture in the root zone resulting in higher yield. Kang *et al.* (2004), Erdem *et al.* (2006), Onder *et al.*, (2005) and Nagaz (2008) registered higher water use efficiency for potato under drip irrigation. Higher water use efficiency in case of drip obviously was due to higher yields accompanied by saving of irrigation water as compared to furrow irrigation. Kumar *et al.*, (2007) compared microsprinkler irrigation system with 0.6, 0.8, 1.0 and 1.2 ratio of irrigation water and cumulative pan evaporation and observed that the water use efficiency was highest in 0.80 CPE treatments and then declined with the increase in IW/CPE ratio.

2.2 Subsurface Drip Irrigation

Subsurface drip offers many advantages over surface drip irrigation such as reduced evaporation loss, precise placement and management of water, nutrient and pesticides leading to more efficient water use, greater water application uniformity, enhanced plant growth, crop yield and quantity (Camp, 1998). Sub surface drip has high potential for efficient and economical productivity to an

accepted method of irrigation for both perennial and annual crops (Ayars et al., 1999). It has been used for irrigating many crops including vegetables, horticultural and agronomic crops under different soil and climatic conditions (Camp, 1998). The discharge rates generally are in the same range as surface drip irrigation (ASAE Std. 1999).

Other advantages of subsurface drip system include less interference with cultural operations, allows field operations even during irrigation, less nutrient and chemical leaching and deep percolation, reduced weed germination and their growth, reduced pest and diseases, avoid damage due to drier and less humid crop canopies, warmer soils, reduced exposure of irrigation equipment to damage, no soil crusting due to irrigation, well suited to widely spaced crops and longer economic life (Phene, 2000).

2.2.1 Growth and yield under subsurface drip irrigation

Many investigators observed the same or more yield for several horticultural crops under sub surface drip irrigation (SDI) system as compared to surface drip irrigation (Hutmacher et al., 1985; Phene et al., 1987; Camp et al., 1993; Davis et al., 1985; Ayars et al., 1999; Machado et al., 2003).

Martinez *et al.* (1991) found that marketable and total ear yield of corn under subsurface trickle were higher than for surface trickle. Total fresh weight, dry matter production and plant height during the growing season were greater for subsurface than surface at the centre of the root zone. Phene and Howell (1984) and Thompson et al. (2002) reported that the subsurface placement of both water and nutrients at the root system resulted in their increased availability and thereby better plant growth than surface placement of both water and nutrients. The increased P and K uptake rates resulted in higher dry matter production and commercial yield relative to surface trickle placement.

Oron *et al.* (1999) observed considerable increases in crop yield under subsurface drip irrigation and reported that crops responded positively to SDI system under different depths of laterals placement when compared with other methods of irrigation.

Sorensen *et al.* (2001) found that sub surface drip irrigation resulted in 38 percent more pod yield of peanut compared to non- irrigated treatments but found that there was no difference in pod yield due to drip tube spacing, emitter spacing and amount of irrigation water applied over several treatments.

Al-Rahwahy *et al.* (2004) showed that subsurface line application of water to cabbage at 15 cm depth gave significantly higher leaf number and weight. For all the three depths of irrigation with 6 mm per day, porous tube-irrigated plots had significantly higher cabbage wrapper leaf number than the drip-irrigated plots. Both the irrigation rates resulted in higher wrapper weight in the porous tube-irrigated than the drip-irrigated plots at 15 cm depth of application.

Al-Omran *et al.* (2005) observed significant differences in the growth and yield of squash under sub-surface and surface drip irrigation. They reported the most important advantage of subsurface irrigation as decreasing the accumulation of salt in the root distribution zone and increasing the moisture level since the roots of the plants were in active status.

Al-Harbi *et al.* (2008) showed that subsurface drip irrigation gave better results than surface drip irrigation on the vegetative characters (plant height, number of leaves, shoot fresh weight) whereas shoot dry weight percentage was higher under the surface drip irrigation.

2.2.2 Water use and water use efficiency

Subsurface drip irrigation is an efficient means of applying water and nutrients to annual row crops. In general, at least 10 to 30% water saving can be realized compared to conventional surface irrigation system.

Bar-Yosef *et.al.* (1989) found that subsurface drip fertigation resulted in higher corn ear yield than surface drip fertigation. In comparing buried drip (point) application with seepage (line) application for tomatoes, Clark et al. (1991) found that maintaining the soil water tension between 5 to 10 kPa gave both methods of applications greater yields than at soil water tension of 10 to 15 kPa during the spring crop.

Phene (1991) and Phene *et al.* (1992) reported that sub irrigation system reduced the amount of irrigation water especially in the early development stages of plants. Whereas, Lamm *et al.*, (1995) reported that the careful management of subsurface drip irrigation system can reduce net irrigation needs by nearly 25%, while still maintaining top yields of 12.5 Mg/ha. Most of these water savings can be attributable to minimizing non-beneficial water balance components such as soil evaporation and long term drainage. Hence subsurface drip irrigation system can make significant improvements in water use efficiency by better managing the water balance components.

El-Gindy and El-Araby (1996) found slightly higher crop yield and water use efficiency (WUE) under subsurface drip than surface drip. Others Studies on irrigation and fertilization management demonstrated significant increase in yield and water use efficiency under subsurface method in vegetable crop (Ayars *et al.*, 1999). Ruskin (2000) observed that SDI could be applied in small frequent amounts, hence in medium and heavy textured soils the water movement into the soil is mainly due to capillary forces. So applying the same water amount 46% of water saving can be achieved using SDI.

Smajstrda and Locascio (2000) demonstrated the use of float level switch to automate a subsurface drip and a seepage irrigation system used for potato production. They found that both systems produced similar yields. However, the subsurface drip system used approximately 36 percent less irrigation water as compared to the seepage system.

Lamm and Trooien (2002) reviewed 10 years of subsurface drip irrigation research on corn in the Great Plains and reported that water savings of 35 to 55 percent were possible compared to traditional forms of irrigation such as sprinkler and furrow. They reported that the automation of subsurface drip irrigation system based on soil moisture sensors may further improve water use efficiency.

Makrantonaki *et al.* (2002) observed higher root yield under subsurface drip irrigation. The 80 percent and 100 percent SDI treatments produced a similar root yield, but the first saved 16.6 percent irrigation water. Similarly 83.3 percent

of applied water may produce 22.2 percent more yield if water is applied through SDI rather than surface drip.

2.2.3 Depth of placement of drip lateral

In SDI the top 15-20 cm of soil, have lower moisture when the laterals are buried in 45 cm depth, resulting to reduced evaporation (Phene et al., 1983; Solomon, 1993) whereas Ayars et al., 1999 reported 10-28% increase in the earliness and marketable yield when sub-drip irrigation was installed at the depth of 0.45 m. Bryla *et al.* (2003) observed improved yield and water use efficiency under the sub-surface irrigation at depths of 0.30 and 0.40 m but decreased at the depth of 0.60 m.

Singh et al. (2007) found that plant height, yield and water use efficiency of okra increased due to sub-surface placement of laterals. The maximum increase in okra yield was found to be 5.22, 13.48 and 11.56 percent under 0.05, 0.10 and 0.15m depths of lateral placement respectively, as compared to that under surface drip.

Patel *et al.* (2009) reported studies on three different irrigation levels of 60, 80 and 100% of the crop evapotranspiration and six placement depths of drip laterals (on surface, 5, 10, 15, 20 and 30 cm) and observed that the onion yield was significantly affected by the placement depth of the drip lateral. Maximum yield (25.7 t ha^{-1}) and irrigation water use efficiency ($0.55 \text{ t ha}^{-1} \text{ cm}^{-1}$) was obtained by applying the 60.7 cm of irrigation water and by placing the drip lateral at 10 cm soil depth. The greater vertical movement of water in the sandy-loam soil took place because of the predominant role of gravity rather than that of the capillary forces and hence they recommended placement of drip lateral at shallow depths in onion crop to get higher yield.

2.3 Irrigation Scheduling

Irrigation scheduling is based either on cumulative pan evaporation or on the basis of soil moisture depletion. It was observed that frequent irrigation causes cracks in fruits whereas less frequent irrigation limits root and shoot development, and also the fruit size and the yield (Flocker et al., 1965; Pew and Gardner, 1983).

Smaller and frequent applications of water in surface irrigation are not possible. On the other hand there is an ease in drip irrigation for frequent and smaller application. This becomes important for vegetable crops which are very sensitive to even smaller moisture stress. Because of this advantage, drip irrigation enhances quality and quantity of produce besides saving in water (Sonune and Palaskar, 1998).

High-frequency water management by drip irrigation can provide at least daily requirement of water to a portion of the root zone of each plant, and maintain a high soil water potential in the rhizosphere to reduce plant water stress (Nakayama and Bucks, 1986). Due to the differences in soil water potential and soil water distribution with depth, grain yield and WUE might differ when the same quantity of water is applied under different irrigation frequencies. Therefore, it is essential to develop the most suitable irrigation schedule for different ecological regions, especially as plant water consumption during plant growth depends mostly on soil and climatic conditions (Nath *et al.*, 2001).

In irrigation scheduling the amount of water to be given through irrigation depends on crop evapotranspiration or crop water requirement. Doorenbos and Pruitt (1977) reported that the crop water requirement is equivalent to the rate of evapotranspiration necessary to sustain optimum plant growth; the accuracy of the determination of crop water requirement will be largely dependent on the type of climatic data available. The evapotranspiration at the time of irrigation can also be estimated from cumulative class A- Pan Evaporation, pan coefficient and crop factor.

Pan evaporation incorporates the climatic factors influencing evaporation into a single measurement (Hansen *et al.*, 1980) and has been used to schedule irrigation for several crops (Jensen and Middleton, 1970). Irrigation scheduling methods based on pan evaporation are widely used because of their easy applications (Elliades, 1988). Shmueli and Goldberg (1972) compared different pan coefficients under arid conditions of Israel and concluded that a pan coefficient of 1.33 resulted in greater yield than pan coefficients of 0.83, 0.95 and 1.75 for trickle irrigated bell pepper.

Tensiometers are being used for irrigation scheduling with a preset timed irrigation event and irrigation event stopped after programmed time rather than actual soil moisture conditions (Phene and Howell, 1984). The tomato yields with the automated system using soil matric potential sensor were similar to yields from pan evaporation scheduled treatment, however less water can be used in automated sensor based scheduling (Phene and Howell, 1984).

Singh (1987) reported an increase in vegetative growth of okra with increase in irrigation amounts ranging from 40% to 100% of pan evaporation (PE). However irrigation of 60% of PE produced maximum yield and significant decrease in yields were noted with either an increase or decrease in the amount of irrigation than 60% of PE.

Ustun (1993) studied the effect of irrigation methods, irrigation frequency and pan coefficients on bell pepper under Ankara conditions. The highest yield of 27861 kg ha⁻¹ was obtained with trickle irrigation at 6 day interval and pan coefficient of 0.50. Drip irrigation resulted in similar yield with surface irrigation but reduced 2.4 times the amount of irrigation water as compared to furrow method.

Khodke *et al.* (1993) reported 4 to 10 percent more yields and saved 17 to 54 percent of water when Tinda (summer squash) was grown for two successive years under drip irrigation with 2 and 4 days interval and irrigation depth of 40%, 60%, and 80% of pan evaporation produced over surface method. The irrigation interval of two days was significantly superior over 4 days producing 16 percent more yields and higher water use efficiency under 80 percent depth.

Rehman *et al.* (1994) found significant increase in cabbage head diameter, head weight and leaf weight with increase in water application rate from 3 to 6 mm to maintain the soil moisture tension within 80 kPa whereas Selvaraj *et al.* (1997a) reported higher fresh rhizome yield of turmeric under drip irrigation scheduled at 80 percent of surface irrigation over surface irrigation scheduled at 0.90 IW/CPE ratio.

Xie *et al.* (1999) compared three irrigation methods, daily drip, 3-day drip and alternate row furrow irrigation in chilly pepper. They observed that the drip

irrigation (either daily or 3-day) created higher marketable green chilly yields than the alternate row furrow irrigation whereas the yields between the daily and 3-day drip irrigation were statistically similar. The effect of irrigation on marketable combined yields was similar to that on green chilly yields. However, root rot disease infestation was higher under alternate furrow irrigation than for daily and 3-day drip irrigation which showed that drip irrigation increases Chile yield through providing either favourable soil moisture conditions or unfavourable conditions for disease propagation.

Bao-Zhong *et al.*, (2000) studied the water consumption of tomato and the relationship between evapotranspiration and water surface evaporation measured with 20cm-pan. They did not observed significant water flux at 0.75m depth when soil water potential is kept higher than -20 kPa at 15 cm, and around -20 kPa at 60 cm. The accumulative value of evapotranspiration (ET) at any time approximate equal to accumulative value of water surface evaporation measured using 20cm-pan and found that 20cm-pan can be used to determine the tomato water requirement for drip irrigation scheduling.

Orta *et al.* (2001) analysed the response of onion to irrigation scheduling based on available soil water depletion of 0.3, 0.5, 0.7 and no irrigation under drip irrigation. The highest yield was obtained from the plots in which irrigation water was applied at soil water fraction level of 0.3 and the maintenance of soil moisture depletion level at 0.30 required 339.4mm and 227.2mm of irrigation water during two years of study.

Increase in sugarcane yield (9%) and water use efficiency (25.8 %) under drip irrigation at 0.8 cumulative pan evaporation as compared to surface flooding have been reported by Malvia et al.(2001).

Thompson *et al.* (2002a) worked on subsurface drip irrigation and fertigation of broccoli and reported that the optimum soil water tension, with respect to marketable crop yield, was ~ 10 kPa at 30 cm depth and maximum marketable broccoli yield occurred at N rate of 300 to 500 kg ha⁻¹.

Irrigation interval have an impact on the agronomic practices of the region where water is very limited but soils are medium to fine textured, since low

frequency irrigation allows farmers more flexibility with farm operations, as well as avoiding the additional expense of automating their microirrigation systems (Enciso *et al.*, 2003). Dukes *et al.* (2005) reported that soil moisture based irrigation scheduling regime resulted in high frequency short duration (30-min) irrigation events to meet crop water needs. The water use is reduced by 11 percent with similar yields compared to sprinkler irrigation.

Yadav (2006) observed highest yield of onion bulb when drip irrigation was scheduled at 1.25 ET_c mm depth and 100 percent recommended dose of nitrogen was applied.

Nagaz *et al.* (2007) compared drip irrigation scheduling based on daily compensation of calculated crop consumption (ET_c) and the methods of soil water balance by compensating cumulated ET_c with farmers' practice of applying fixed amount of water. They observed that fresh tuber yield of potato was highest for the soil water balance scheduling technique, although no significant differences were observed with the daily irrigation method. The producer method not only caused significant reductions in yield but also resulted in using 20 to 25% more water and increased soil salinity. The highest water use efficiency was obtained with soil water balance method and hence recommended soil water balance method as a tool to use saline water for irrigation in arid zone.

Dan Wang *et al.* (2007) compared drip irrigation scheduling based on soil matric potential measured at 0.2 m depth immediately below emitter with five levels viz., -10, -20, -30, -40 and -50 kPa. They reported that soil matric potential did not affect the tomato yield significantly, for the range of soil matric potential investigated. Both WUE and IWUE increased as soil matric potential decreased. The maximum WUE and IWUE (620 and 406 kg/ ha mm) were for -50 kPa treatment, whereas the minimum WUE and IWUE were for -10 kPa treatment. They recommended controlling soil matric potential higher than 50 kPa at 0.2m depth immediately under drip emitter as an indicator for drip irrigation scheduling during tomato growth period.

Nagaz *et al.*, (2009) studied the effect of deficit irrigation regimes based on water replacements of accumulated ET_c at 100, 80, 60 and 40% with saline water

on soil salinity, growth and yield of millet when the readily available water in control treatment is depleted. Results showed that the yields almost decreased linearly with decrease in applied water and practicality of using the 100% of Etc methodology to optimize irrigation with saline water for millet production and to control soil salinity.

Yildirim *et al.*(2009) conducted studies on melon irrigated with drip at different growth stages with 100, 75 and 50% of full irrigation. They suggested that irrigation be kept on going until the beginning of fruit setting, not during the ripening period, and the application of 75% of full irrigation water amount in fruit ripening is the most convenient irrigation program.

2.4 Moisture Distribution Pattern

Soil moisture distribution has greater significance in drip irrigation as water application is done mostly in restricted area. The soil moisture distribution may vary with the surface and subsurface drip irrigation system. In subsurface drip the depth of lateral placement and type of soil plays an important role in soil moisture distribution pattern.

Yaragattikar and Itnal (2003) observed highest soil moisture near the emitter point in subsurface drip which progressively decreased with the increase in the radial distance. Similarly the soil moisture decreased from surface soil layer to deeper soil depths for the lower application rates. In contrast, the soil moisture increased uniformly from surface to deeper layers at higher application rates. For higher application rate the moisture content at the emitting point was uniform throughout the soil depth and with the lower application rate it decreased progressively with depth.

In subsurface drip Nagle *et al.* (2008) also reported higher moisture content at the point below the dripper which decreased with the depth from 41.7 percent at a 5 cm depth to 33.2 percent at 30 cm depth. They also observed the decrease in moisture content in lateral direction.

Singh *et al.*,(2007) observed uniform soil moisture content in subsurface drip (0.05,0.10 and 0.15 m depth) as compared to surface drip whereas Bhanu Rekha *et al.* (2009) observed higher moisture extraction in surface drip fertigated

crop (40-48%) from top 0-15 cm soil depth as compared to furrow irrigated crop (33-34%).

Douglas *et al.* (2009) monitored soil moisture variability using portable wave reflectometer in a turf lawn irrigated with SDI since traditional irrigation audit techniques of catch cans can not be used for SDI. They observed that pattern of soil soil moisture variability is better described by water extraction of rootzone. The distribution uniformity of soil moisture was found to improve from 57 to 80% when SDI was installed.

2.5 Root Distribution

Crop water uptake and subsequent root distribution within the soil profile is the fundamental concept for irrigation scheduling. Similarly rooting depth is essential to know what should be the adequate water supply through irrigation system. In drip irrigation the root water distribution is different than the sprinkler and surface irrigation. Root distribution remains among the most challenging inputs influencing root water uptake (Skaggs *et al.*, 2006) whereas great variability of the root water uptake was observed in space and time scales (Salgado *et al.*, 2009; Zotarelli *et al.*, 2009).

Phene *et al.*(1991) studied the distribution of root under sweet corn as a function of drip placement and fertilization treatment. They reported differences on sweet corn rooting system between surface and subsurface drip irrigation in the top 45 cm. High root length density was observed below 30 cm in subsurface drip irrigation than in surface drip irrigation.

Subsurface drip irrigation reduced evaporation, deep percolation and runoff loss from the soil (Camp, 1998; Alizadeh, 2001; ASAE 2005) and increased the wetted soil volume and surface area more than surface systems allowing a deeper rooting pattern (Oliveria *et al.*, 1996). Oliveria *et al.* (1996) also reported that in subsurface drip more than 90 percent of the root growth is concentrated in the upper soil layer (up to 30 cm). This may be attributed to the better balance of moisture and aeration in the root zone. Increasing the emitter depth enhanced the growth of root system compared to the surface drip where increase in the moisture level was observed in the upper surface. They also reported that the roots growth

around the emitters under subsurface drip system leads to increase in water use efficiency.

Thompson (1996) observed that the maximum density of cauliflower roots under subsurface drip irrigation is at depth of 15 to 40 cm surrounding the tubing . On the contrary according to Keller and Bliesner(1990) and Dalvi et al. (1999) more roots penetration and further production may be obtained if an acceptable water stress is imposed.

Xiao *et al.* (2000) observed that root length density at 5 and 25 cm from plant was significantly higher in subsurface drip than in furrow irrigation. Similarly root length density was significantly higher in excessive irrigation regime than in the other regimes. Concomitantly, there was higher wilt incidence and severity in excessive and moderate regimes than deficit regime regardless of the irrigation method.

Machado and Oliveria (2003) studied the effect of three emitter depths (0, 0.30 and 0.40 m) in sub-irrigation system on the root distribution of tomato plants. They found that most of the root system was concentrated in the upper 0.40 m of the soil. Vamerali *et al.* (2003) observed that fertilization with 100 kg ha⁻¹ of nitrogen led to higher root length density in shallow layers with respect to unfertilized controls , whereas thicker roots where found deeper than 80 cm of soil without nitrogen.

Wan and Kang (2005) studied the effect of irrigation frequency on radish growth and water use under drip daily, every 2, 3, 4, 6 and 8 days. There was no significant difference among the treatments on radish development and yield, but significant differences in radish roots distribution and marketable quality were found. Radish irrigated once every 3 days had well-developed roots throughout the crop period, the lowest cracking rate and better quality radishes. They reported that radish evapotranspiration decreased as irrigation frequency decreased, and the general changing tendency of 2-day ET of high irrigation frequency was related to that of 2- day evaporation. It is recommended that radish irrigation frequency should be once every 3 days and the irrigation amount should be estimated according to the evaporation of 20 cm diameter pan in the North China Plain.

Al-Harbi et al. (2008) showed that the subsurface drip irrigation significantly increased the root weight, root length, root width and root shoot ratio as compared to surface drip in okra. Guohua *et al.* (2009) observed that the main root distribution zone moved upward under sprinkler and surface drip irrigation when compared to the traditional border irrigation. Profile root distribution pattern changed with irrigation methods. Soil profile water uptake was correlated to the root system and soil water dynamics. Due to the appropriate soil water and higher root density in the surface soil layer under sprinkler and surface drip irrigation, the main water uptake zone was concentrated in the upper layer. Because of the water deficit in the surface layer under border irrigation, water uptake in 50–100 cm depth was stimulated, which caused the main uptake zone downward. The amount and pattern of root water uptake varied with irrigation methods.

Moncef and Khemaies (2009) observed that the rooting depth in trickle irrigated tomato remained confined within 10 cm of the topsoil with approximately similar root length densities (0.40 cm cm^{-3}). Thereafter roots expanded in all directions during the growing season. They reported that the infrequent water supplies generate deeper and deeply denser roots and root expansion along the row was lower than across the row.

Moncef *et al.* (2009) observed similar rooted soil volumes and root length densities with rooting depth confined within the 10 cm of the topsoil for all the treatments during the first growing stages of tomato whereas in the later growth stages roots expanded in all the directions. They reported that infrequent water supplies generate deeper denser roots.

Searles *et al.* (2009) compared different drip emitter arrangements on root length density of orchard of *Manzanilla fina* or *Manzanilla reina* in sandy soils with (1) emitters spaced continuously at 1-m intervals along the drip line (CE-4; 4 emitters per tree); (2) 4 emitters per tree spaced at 1-m intervals, but with a space of 2 m between emitters of neighbouring trees (E-4); or (3) 2 emitters per tree with 4 m between emitters of neighbouring trees (E-2).. Root length density values ($2.5\text{--}3.5 \text{ cm/cm}^3$) in the upper soil depth (0–0.5 m) were fairly uniform along the drip line in the continuous emitter (CE-4) orchard. In contrast, roots

were more concentrated in the E-4 and E-2 orchards with maximum RLD values of 7 cm/cm^3 . Approximately 70% of the root system was located in the upper 0.5 m of soil depth, and most of the roots were within 0.5 m of the drip line. For each of the three orchards, significant linear relationships between soil water content and RLD were detected based on 42 sampling positions that included various distances from the trunk and soil depths. These results should reduce the uncertainty associated with the magnitude of RLD values under drip irrigation as intensively managed olive orchards continue to expand in established and new growing regions. However, Research is still needed to understand how irrigation and roots distribution affect the water use efficiency (Zotarelli et al., 2009).

2.6 Response of Crop to Fertilizers

Welch *et al.*(1987) reported that cauliflower is an initially slow growing crop that takes up little N in its first 60 days of growth, 90% or more of its total N accumulation may occur during the final 50 to 60 days preceding harvest.

Balyan *et al.* (1988) studied the growth and yield of cauliflower variety *Showball-16* in winter as influenced by nitrogen, phosphorus and zinc with the application of N, P_2O_5 and ZnSO_4 ranging from 0-160 kg ha^{-1} , 0-50 kg ha^{-1} and 0-30 kg ha^{-1} , respectively. All P and Zn and one third N were applied before transplanting and the remaining N was top dressed at 30 and 45 days after transplanting. Maximum yield of 238 q ha^{-1} was obtained with 160 kg N + 50 kg P_2O_5 + 20 kg ZnSO_4/ha .

Solomon (1993) reported that in SDI irrigation water and injected chemicals like fertilizers are supplied directly to the roots which is a special advantage for nutrients that have low mobility into the soil. Locascio and Smajstrala (1995) found that tomato yields with daily fertigation were not increased over weekly fertigation events on a fine sand soil. Similarly, yields of drip irrigated peppers were not affected by fertigation interval (11 or 22 days) on a loamy sand soil. Subsurface drip irrigation and fertigation with fluid N can result in optimum crop yield, quality, and economic returns without polluting losses of N to ground water (Pier and Doerge, 1995; Thompson and Doerge, 1996).

Fertigation which combines irrigation with fertilizers is well recognized as the most effective and convenient means of maintaining optimum fertility level and moisture regime to the specific requirement of soil and development phases of the crop (Satisha, 1997).

Bangar and Chaudhari (2001) concluded that for suru sugarcane (CO-86032) the cane yield (28 percent) and the quality parameters, viz. reducing sugar (0.38 per cent), non-reducing sugar (16-27 percent), N (92.01 mg/100g) and P (37.98mg/100g) contents in cane juice were significantly higher in treatments with water soluble fertilizers compared to straight fertilizer. It was also found that application of 100 percent recommended dose (250:115:115 kg ha⁻¹ NPK) of fertilizer through drip irrigation was optimum in cane production. However, Jadhav and Raut (2001) suggested to use 80 percent recommended dose of fertilizers through fertigation than other treatments of 100 and 120 per cent of recommended dose for sugarcane.

In an experiment Chawla and Narda (2001) studied the effect of fertilizer application rate (30,60,100 percent of RD of N), wetted volume of soil (50,75,100 percent) and frequency of fertigation (8,12,16 days) on yield attributes and water use efficiency of potatoes under fertigation. They observed highest fresh tuber yield under application of 100 percent dose on N at 12 days interval (4 splits) with 100 percent wetted area.

Malavia *et al.* (2001) reported a series of field experiments conducted at Junagardh in medium black soil on groundnut, castor and cotton. They observed that for ground nut drip irrigation at 0.8 CPE with fertigation of 25 kg N and 50 kg P₂O₅ ha⁻¹ was superior over soil application of fertilizers. In case of castor, drip irrigation at 0.6 CPE with fertigation of 75 kg N ha⁻¹ (RD) was superior over surface methods whereas for cotton, fertigation at the rate of 160 kg N ha⁻¹ out of which 40 kg N ha⁻¹ (25 %) in soil at sowing and 120 kg ha⁻¹ (75 percent) in 4 splits through ammonium sulphate at an interval of one month gave higher yield and net returns as compared to total soil applications.

Patel and Rajput (2001) recorded same level of onion bulb production with fertigation at 40 percent RDF as compared to drip irrigation with conventional

method of fertilizer application (100 percent RDF) thereby fertilizer saving of 60 percent.

Pawar *et al.* (2001) reported significantly highest fruit yield of banana under water-soluble fertilizers as compared to only N by straight fertilizer through drip and conventional application of water and fertilizers. Shinde *et al.* (2001) observed almost identical seed cotton yield (var.NHH 44) with application of 50 percent recommended dose through drip compared to that of 100 percent recommended dose of fertilizer with surface irrigation. .

Thompson *et al.* (2003) observed that on finer-textured soils, response to fertigation was not as consistent as on coarse ones, although N, and sometimes K are most usually applied through fertigation to increase nutrient use efficiency of Broccoli with subsurface drip irrigation. Broccoli yields were similar with fertigation at 1,7,14 and 28 days intervals.

Use of high chemical N rate (267 kg N ha^{-1}) resulted in higher ear yields at least 20% greater than sweet maize fertilized with reduced N rates of 200 kg N ha^{-1} or less in sandy soils (Cherr *et al.*, 2007)

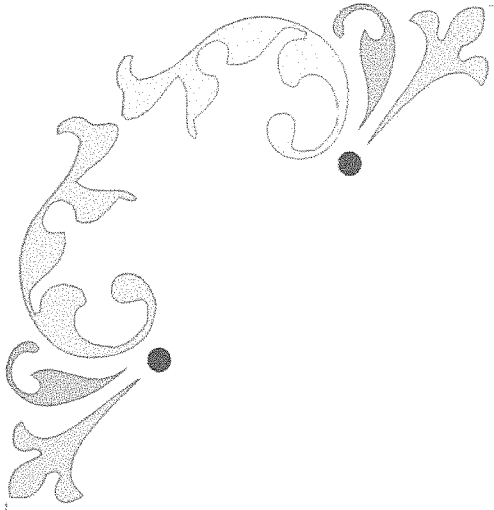
Bhanu Rekha *et al.* (2009) observed highest okra pod yield through drip fertigation with 120 kg N ha^{-1} and irrigation at 1.00 Epan. Furrow irrigated crop recorded 54 and 57 percent lower yields than crop irrigated through drip at 1.00 Epan and fertigated with 120 kg N ha^{-1} . Drip fertigated crop has extracted higher moisture (48-48%) from top 0-15 cm soil depth than furrow irrigated crop (33-34%).

Ali *et al.*(2009) applied different combinations of chemical and organic fertilizers in the cauliflower-stem amaranth-jute cropping pattern and observed higher marketable weight, length and breadth of a cauliflower curd with 50% CF + 50% PM, which was statistically similar to other combinations except control. Cumulative effect of the yield attributes had resulted in increased curd yield for the fertilizer manure treatments.

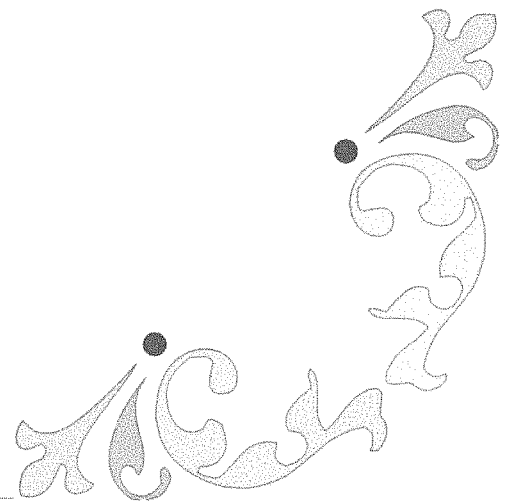
Critiques on the Literature Reviewed

The literature reviewed in the previous sections clearly demonstrate the better performance of crop under drip irrigation with improvement in yield,

quality of produce and water and fertilizer use efficiency. However, the studies on response of the important crop like cauliflower in semi arid region like Marathwada are missing. Although subsurface drip irrigation has showed beneficial effects as regards the moisture and nutrient distribution in some places in the world, such studies are not conducted rigorously in the Indian conditions. In view of the water scarcity and necessity of increasing nutrient use efficiency of crops the subsurface drip irrigation study on short duration crop like cauliflower will surely highlight these aspects. Hence the comparative performance of surface and subsurface drip irrigation systems along with the conventional surface irrigation on crop like cauliflower is the necessity. The literature demonstrates that irrigation scheduling based on pan evaporation seems to be more practical in the field conditions. Hence this concept needs to be used for irrigation scheduling both in surface and subsurface drip.



MATERIAL AND METHODS



CHAPTER III

MATERIAL AND METHODS

To meet the objectives of present research project a field experiment entitled “Comparative performance of surface and subsurface drip fertigation for cauliflower” was conducted during winter season of 2010-2011. The experimental details, material used and methods and techniques followed during the course of investigation are described in this chapter.

3.1 Experimental Site

The field investigation was conducted at the experimental field of AICRP on Water Management, Marathwada Krishi Vidyapeeth, Parbhani. Geographically Parbhani is situated at an altitude of 409 m above mean sea level in the central India and intersected by 76° 47' East longitude and 19° 26' North latitude.

3.2 General Climate and Weather Conditions

The weather prevailing at Parbhani can be categorized as tropical and semi-arid on annual basis whereas within the seasons it can be classified as sub-humid to humid in monsoon, semiarid in winter and arid in summer season. The region falls in an assured rainfall agro-climatic zone with average annual precipitation of 889 mm concentrated mainly in the months of June to September. More than 85 percent annual rainfall in the region is usually received in these months from South West monsoon.

The daily mean maximum temperature varies between 30⁰C in winter (December) to 41⁰C in summer (May). The mean minimum temperature varies from 12⁰C to 25⁰C during winter (January) and summer (May), respectively. The minimum and maximum relative humidity varies between 15 to 51 and 49 to 88 per cent, respectively. Thus Parbhani has hot and dry summer and cold winter. Generally the winter is comparatively very short extending from mid November to beginning of February during which cauliflower crop can be cultivated.

The weather data regarding air temperature, relative humidity, wind velocity, rainfall, and pan evaporation were collected during the experimental period (October 2010 to March 2011) from the IMD recognized MKV

Meteorological observatory situated adjacent to the experimental plot. A summary of the major values of meteorological parameters during the experimental period after transplanting (Nov 11, 2010 to March 3, 2011) is shown in Table 3.1 and their temporal variations are depicted in Fig 3.1 through Fig 3.5. Daily metrological data pertaining to the period of experimentation are presented in Appendix-A.

Table 3.1 Ranges of micro weather parameters during experimental period

Parameters		Experimental Period (Nov2010-March 2011)
Air temperature (°C)	Max	34.2
	Min	3.9
	Mean	21.5
Relative humidity (°C)	Max	100.0
	Min	16.0
	Mean	55.5
Wind speed (ms ⁻¹)	Max	1.89
	Min	0.39
	Mean	0.88
Actual Sunshine (h)	Max	11.2
	Min	0.5
	Mean	9.4
Precipitation (mm)	Total	50.8

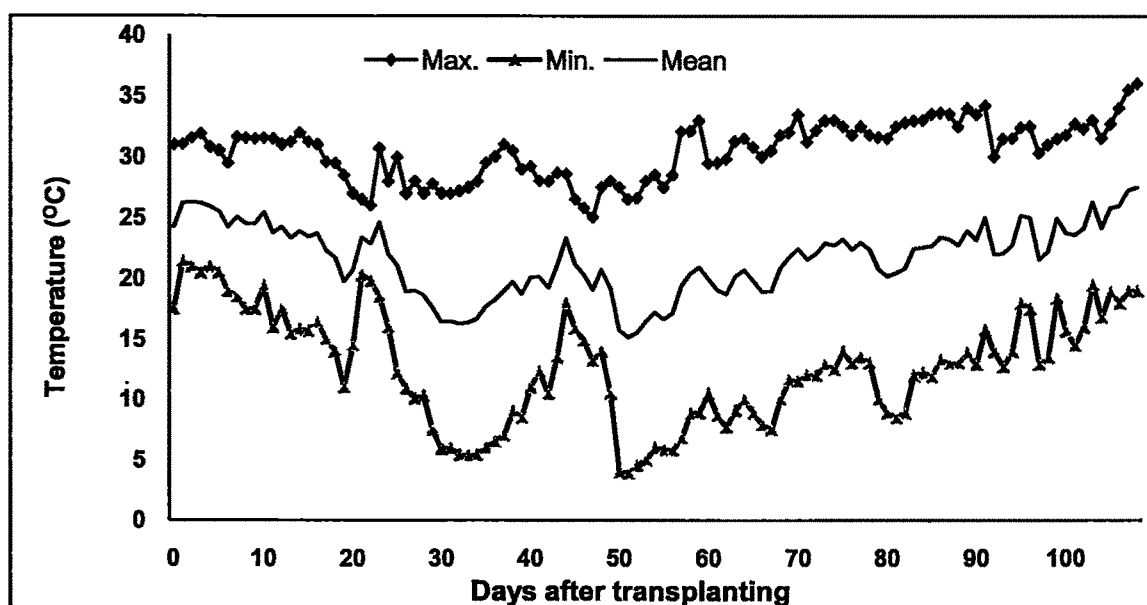


Fig. 3.1 Variation of daily air temperature during the experimental period

For adequate growth of cauliflower the mean temperature should be between 22-28.5⁰C (Doorenbos et al., 1979). During the experimental period the temperatures generally were low to moderate suitable for the growth of cauliflower till 57 DAP. However thereafter the temperature increases around 30⁰ C and reaches maximum on 91 DAP (16th Feb 2011). During the third harvest the temperatures were slightly higher. The exceptionally high difference in maximum and minimum daily temperatures was observed during 22-44, 49-60 and 78-83 DAP. However, the mean temperature varied between 16 to 24⁰C during mid season growth, whereas the mean temperatures were slightly higher during early (24 DAP) and last growth period (91 DAP onwards) (Fig. 3.1).

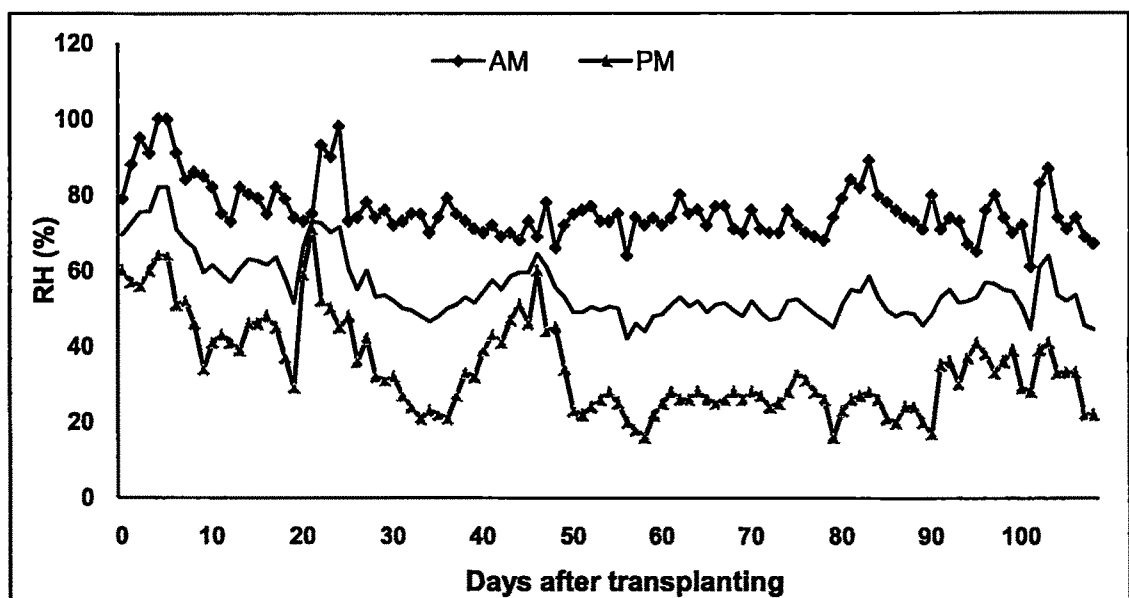


Fig. 3.2 Variation of daily relative humidity during the experimental period

In general, the mean relative humidity was higher at the beginning of the crop period due to rains which is required for the initial growth of crop (Fig. 3.2). Thereafter it decreased progressively and showed minor cyclic variation till the end of season. During mid season growth and curd formation to last harvest (51 DAP onwards) mean relative humidity was lower in the range of 40 to 55%, which might increase the water requirement of crop (Fig. 3.2).

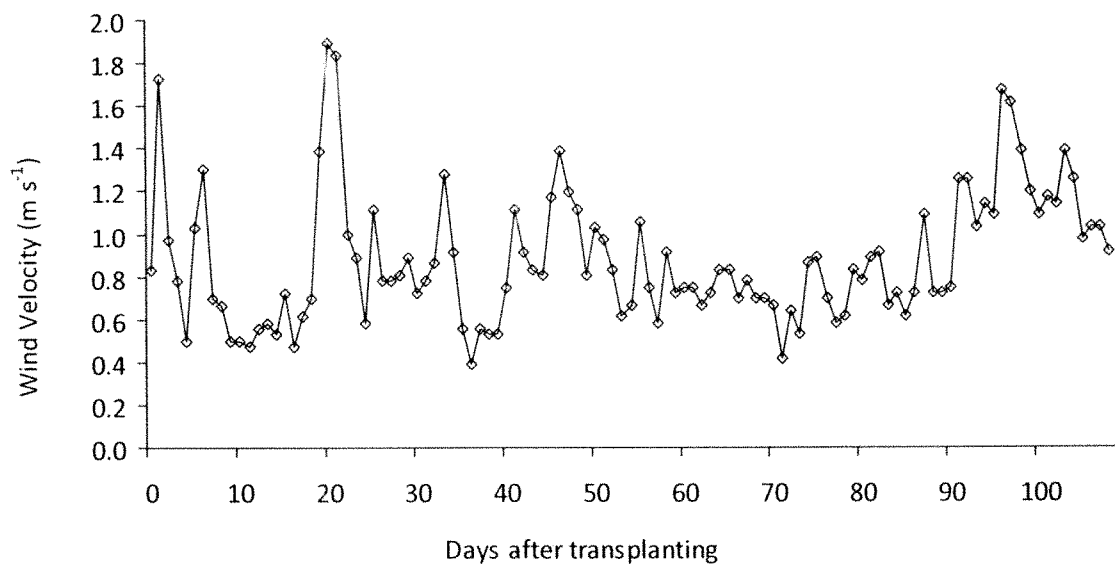


Fig. 3.3 Variation in daily average wind velocity during the experimental period

While the average wind velocity during the experimental period was well within the limit (0.88 ms^{-1}), it varied between 0.39 to 1.89 ms^{-1} and did not reach above 2.0 ms^{-1} (Fig. 3.3). The average value of actual sunshine hours for the experimental period was 9.4 hrs with the maximum value of 11.2 hours (Table 3.1). Except in the first month after transplanting, the actual sunshine hours remained around 10.0, which was sufficient for better growth of crop.

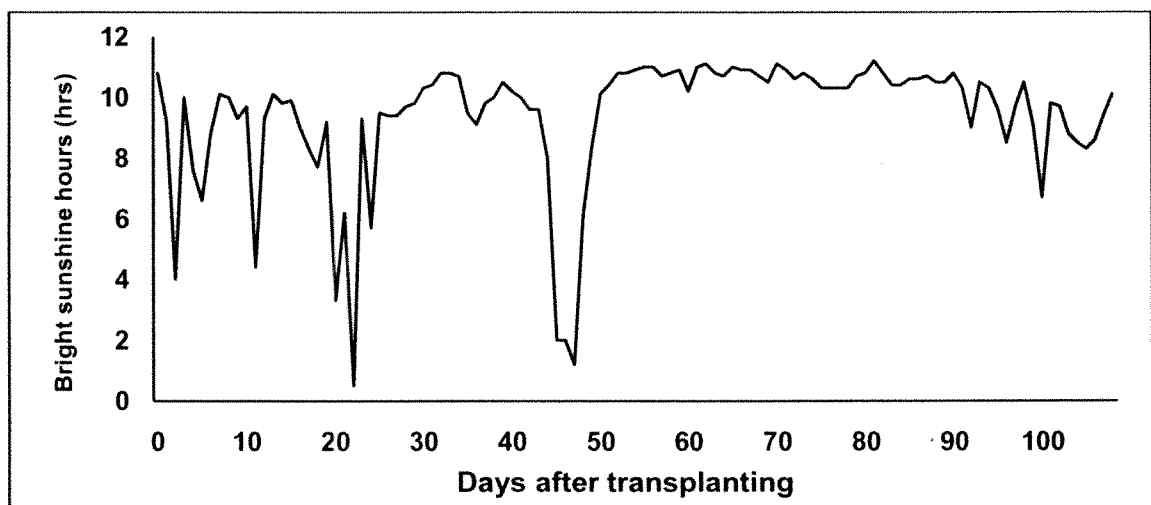


Fig. 3.4 Variation in daily bright sunshine hours during the experimental period

The daily measured evaporation by USWB Class-A pan and rainfall during the experimental period is shown in Fig. 3.5. The two major rainfall events of 50 mm occurred in the first week after transplanting which affected transplanted

seedlings and gaps were again filled in at the places of damaged plants. However thereafter there was not rainfall during rest of the crop growth period. The pan evaporation was well within 4 mm till 54 DAP and increases thereafter in the range of 4 to 7 mm till the end of growth period. The values of pan evaporation were further used for irrigation scheduling of the cauliflower.

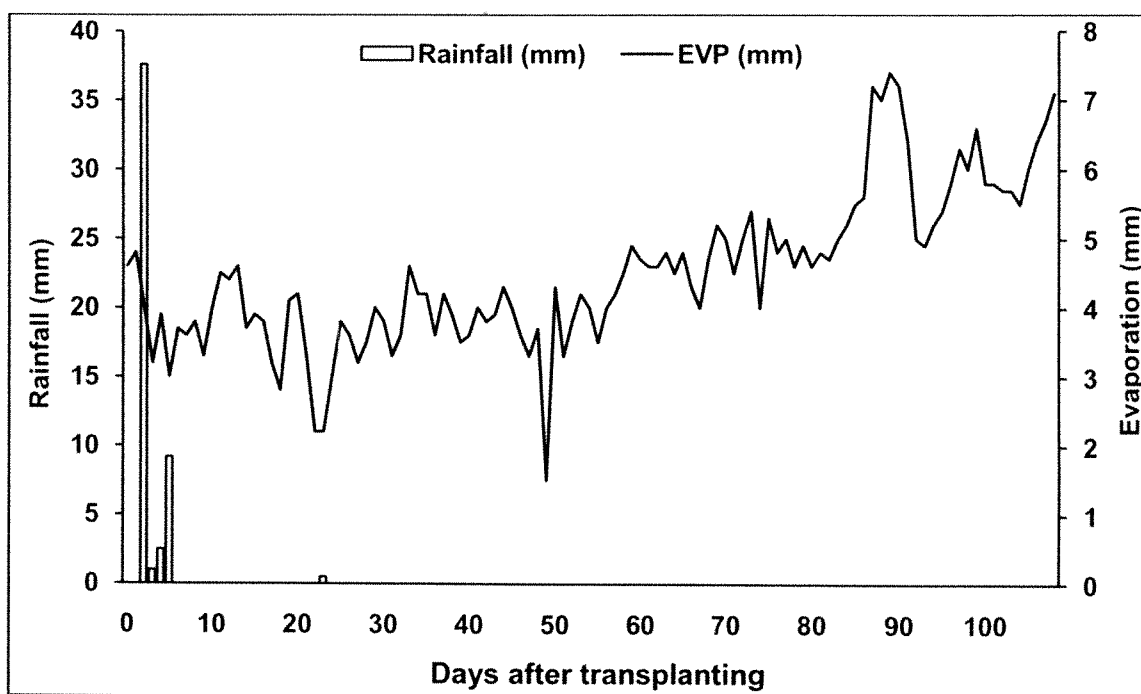


Fig. 3.5 Variation of daily rainfall and evaporation during experimental period

3.3 Soil of the Experimental Plot

The topography of the experimental plot was fairly levelled having 0.2 per cent slope along the lateral (North to South) and 0.5 per cent along the submain (West to East). The soil was medium black (100 cm in depth) clayey in texture dominated by montmorillonite. It has high coefficient of expansion and shrinkage, and is alkaline in reaction with high base saturation. The moisture content at 0.33 and 15 bar was 34.5 and 13.9%, respectively. The bulk density of soil was 1320 kg m^{-3} . The available water storage capacity of surface soil layer (0-60 cm) was 134.64 mm.

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Table 3.2 Methods of finding physical and chemical properties of soil

Sr.No.	Particulars	Methods
1.	Particle size distribution	International pipette method (Piper,1966)
2.	Textural class	Textural triangle (Punmia,1979)
3.	Organic carbon	Walkely and blacks' modified rapid filtration method (Black, 1965)
4.	Available Nitrogen	Alkaline permanganate method (Subbiah & Asija, 1956)
5.	Available phosphorus	Sodium bicarbonate (NaHCO ₃) as an extractant (Olsen et al., 1954)
6.	Available potassium	Normal ammonium acetate as an extractant with flame photometer method (Jackson, 1973)
7.	Soil pH	Glass (electrode) pH meter (Jackson, 1973)
8.	Electrical conductivity	Digital, direct conductivity bridge (Jackson, 1973)
9.	Field capacity	Field method (Michael, 1978)
10.	Permanent wilting point	Pressure plate apparatus
11.	Bulk density	Core sampler method

Before planting the random soil samples at different places from the experimental plot were collected to a depth of 0-15 and 0-30 cm with the help of screw auger using standard procedure (Sacheti, 1985) and composite layer wise representative samples were made. Soil was air dried, pulverized in an agate mortar and pestle and sieved through a 2mm sieve. The physical and chemical properties of soil were determined by adopting the standard procedures (Table 3.2). Cauliflower can be grown on any good soil but fairly deep loamy soil is most desirable. Crop is mostly adapted to well-drained soils with a high moisture holding capacity.

3.4 Crop

Cauliflower (*Brassica Oleracea L.*) a late season hybrid variety Amzing (Beejosheetal) was selected for the present study. The length of growing period of cauliflower varies between 60 to 120 days. Cauliflower generally requires a cool



Plate No. 3.1 Field view of experimental plot under different drip irrigation schedules



Plate No. 3.2 Fertilizer application through Ventury

and slightly moist climate. The optimum temperature range is 15 to 20⁰ C with average maximum and minimum temperature of 25⁰ and 8⁰ C, respectively. In high temperatures cauliflower tends to have small jacket leaves, small curds, solar yellowing and “riceyness” of the curd. At freezing temperatures the curds may get damaged and the secondary decay will occur (Koike et al., 2007 <http://anrcatalog.ucdavis.edu>).

3.5 Raising the Seedling

Cauliflower seeds were sown on nursery beds in order to raise seedlings and later on for transplanting them in the field. Fairly leveled raised beds of 5 m long and 2 m wide were prepared by adding equal proportions of well composted FYM and soil. The seeds were sown on 1st October 2010, cross wise 8 cm apart at the rate of 10 kg ha⁻¹. The nursery beds were first irrigated every alternate day for 25 days and there after at an interval of 3 days. The germination of cauliflower seeds was noticed at 6th day after sowing. Appropriate plant protection schedule and weeding 15 days after germination was followed for preparing the healthy seedlings. The seedlings became ready for transplanting in 41 days.

3.6 Field Layout and Experimental Details

Experimental plot was kept fallow during kharif season for ease of early transplanting. Prior to planting, the soil of the experimental plot was deeply ploughed and well pulverized. Farm Yard Manure (FYM) was mixed with top 10 cm soil at the rate of 25 tones per ha as a common dose to all the plots. The field layout for cauliflower is presented in Fig. 3.6. Field experiment was planned comprising of irrigation methods as the main factor and irrigation depths and fertilizer levels as sub factors in split plot design with three replications. Irrigation depths were based on Pan Evaporation. The control treatment with plots irrigated by furrow irrigation at 1.2 IW/CPE ratio was coampred. Each plot was of 4.8 x 3.6 m with the net plot size of 4.2 x 3.0 m. A buffer strip of 1 m and 2 m was kept between two adjacent plots and within replications, respectively.

The field was irrigated to a ponded depth of 4 cm by surface irrigation before transplanting. Well developed cauliflower seedlings were sorted out and

dipped in the solution of bavistin (0.1%) before transplanting. The transplanting was done on 17th November 2010, simultaneously at 60 cm inter-row and 60 cm intra-row spacing and seedlings were placed at a depth of 3 to 5 cm in the soil. After planting, immediate irrigation was not applied since there was an occurrence of rainfall. However, the plots were irrigated commonly on 28th November to achieve uniform germination of crop. The treatment details are summarized below:

Treatments

a) Main (Irrigation methods)

M₁ – Surface drip irrigation

M₂ – Sub-surface drip irrigation (15 cm below ground)

b) Sub (Irrigation depths) Alternate day drip irrigation

I₁ – Irrigation of 0.4 PE by drip

I₂ – Irrigation of 0.6 PE by drip

I₃ – Irrigation of 0.8 PE by drip

c) Sub (Fertilizer levels)

Recommended dose of fertilizer (RDF) = 120: 60: 60; N: P₂O₅:K₂O kg ha⁻¹

F₁ – 50% RDF

F₂ – 75% RDF

F₃ – 100% RDF

d) Control: Furrow irrigation with irrigation depth of 60 mm at 1.2 IW/CPE

Design: Split plot design

Replications: Three

3.7 Irrigation

As mentioned in treatments cauliflower was irrigated by three irrigation methods. viz., surface drip irrigation, subsurface drip irrigation and control with ridges and furrow under check basin. The field irrigation system layout is shown in Fig. 3.6.

3.7.1 Irrigation scheduling

The daily pan evaporation data measured by USWB Class-A Pan at Instructional Farm Department of Meteorology, MKV Parbhani was collected during the experimental period. The pan evaporation data was used as the base for irrigation scheduling.

For surface irrigated plots, depth of 60 mm per irrigation was applied at 1.2 ratio of irrigation water to cumulative pan evaporation. The water was diverted through furrow to the plots and was allowed to spread in the basin through furrows. The irrigation water was measured and constant discharge was maintained throughout the time of application. Time of water application was calculated by considering the discharge, depth of water to be applied and area to be irrigated.

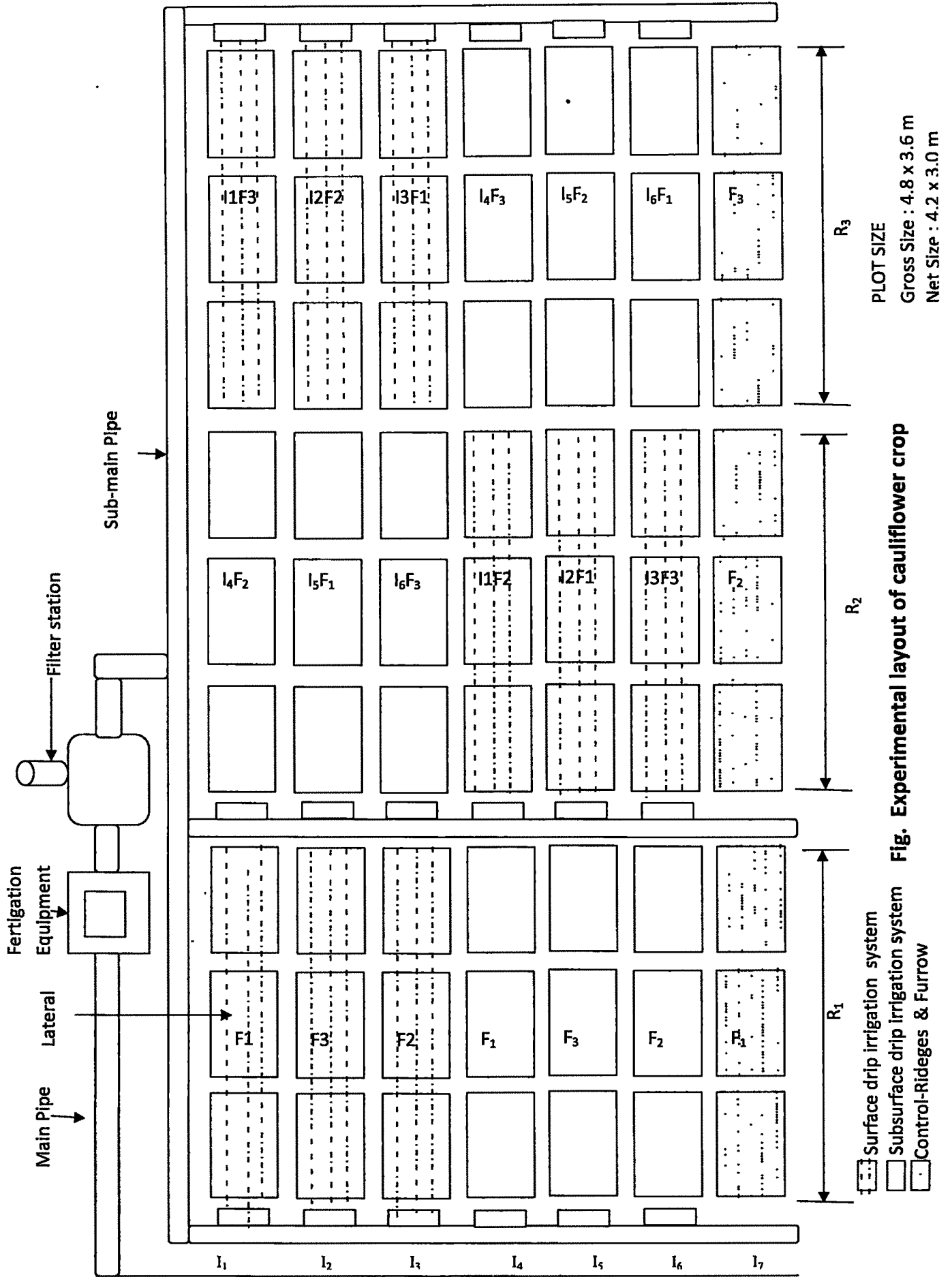
Surface and subsurface drip irrigations were scheduled at an alternate day by computing Cumulative Pan Evaporation (CPE) of two days. The depth of irrigation and volume of water to be applied considering the wetted area and operating time was calculated as per the treatments. During rainfall events, the irrigations were scheduled when evaporation exceeds the effective rainfall during that period. A horizontal open well submersible pump (10 HP) coupled with an electric motor was used for pumping water from the open well. The surface and subsurface drip irrigation system was run at 1.0 kg cm^{-2} .

3.7.2 Drip irrigation setup and installation

Surface and subsurface drip irrigation systems were installed according to the plan of experiment shown (Fig. 3.6) using 12 mm inline laterals with emitters of 2.4 lph discharge spaced at 30 cm. Separate valve arrangement was provided for scheduling irrigation and fertilizers to individual plots. For the subsurface drip system the laterals were buried at 15 cm depth and were covered with the soil. The drip irrigation system consisted of following components:

a) Main, sub mains and manifolds

Irrigation water was diverted from the well to the field through HDPE main of 75 mm diameter. Separate PVC sub mains of 40 mm diameter with control valves were connected to the main in order to distribute water to individual plots. The laterals were connected to 32 mm PVC manifold.



b) Laterals

The inline laterals of 12 mm diameter having 2.4 lph dripper discharge and 0.3 m dripper spacing were connected to submain with the help of take off grommets. The ends of the laterals were closed with end plugs.

c) Control valve

The control valves were fitted at venturi, filtration unit, by pass assembly and at submain to divert the water to respective plots during irrigation and fertigation.

d) Filter

In order to have filtering of irrigation water, screen and disc filter with the capacity $25 \text{ m}^3\text{h}^{-1}$ were installed after pumping and fertigation unit, respectively.

e) Pressure gauges

Pressure gauges were fitted at the control unit for monitoring the fertigation and filtration unit by checking the operating pressures during irrigation and fertigation events.

f) Venturi Manifold

Venturi manifold with 3/4 inches size consisting of gate valve, service saddle and female threaded outlet for venture inlet-outlet connection as fertilizer injection device was connected to the system before filtration unit to apply the fertilizer through drip system. Venturi works on the principle of pressure difference and this pressure difference was created with the help of control valves fitted to the main line.

g) Air valve

For subsurface drip irrigated plots one double action air valve for each plot was fitted to each manifold.

3.8 Fertilizer application

The sources of major nutrients NPK used in the experiment were urea (46 per cent N), single super phosphate (16 per cent P_2O_5), muriate of potash (60 per cent K_2O) for surface irrigated plots. In surface irrigated plots, N was applied in

three splits at planting, 30 DAP and 45 DAP whereas P_2O_5 was applied in two equal splits 30 kg ha^{-1} each at 20 and 30 DAP. The K_2O was applied in three equal splits of 20 kg ha^{-1} at 20, 30 and 40 DAP by ring placement.

In drip fertigation soluble fertilizers of different grades were used (Urea, 19:19:19; 0:0:50; 0:52:34, 13; 0:45) and the nitrogen, phosphorous and potassium were applied in 8, 6 and 6 splits, respectively. The schedule of fertilizer application for the treatment of 100% RDF through drip during crop growth is shown in Table 3.3. The weighted quantity of fertilizers designed for the treatments were dissolved in water by continuous stirring and the fertilizer solution was injected through venturi in the main pipeline by creating the pressure difference.

In addition to major nutrients application of multi-micronutrient (Pawan) was given through drip for drip irrigated plots whereas it was applied through spraying in control plots. One spray of multi-micronutrient (Libreal TM X2) was given to all the plots at the time of curd formation to make up the deficiency of Boron, Sulphur and Zinc.

Table 3.3 Schedule of fertilizer application through drip during crop growth

Sr. No.	Date	Days after planting	N (kg/ha)	P (kg/ha)	K (kg/ha)
1	27/11/2010	10	15	10	-
2	07/12/2010	20	15	10	10
3	18/12/2010	30	15	10	--
4	28/12/2010	40	15	10	10
5	07/01/2011	50	15	10	10
6	17/01/2011	60	15	10	10
7	27/01/2011	70	15	--	10
8	23/02/2010	80	15	--	10
Total application			120	60	60

3.9 Field operations

The schedule of various cultural operations carried out in the experimental field is shown in Table 3.4. The schedule of operations also include gap filling. Due to unseasoned rainfall event after transplanting and very low temperatures the damaged plants were replaced by gap filling to maintain optimum and uniform plant population in each plot. The intercultural operations including two hand weeding at an interval of 20 days and earthing up at 28 DAP were carried out. Proper plant protection schedule was followed to control the attack of insects and pests. One spraying of 0.05 per cent monochrotophos and two sprayings of Rogar were applied to protect crop from attack of larvae of diamond black moth black aphids at the time of curd initiations.

3.10 Harvesting

Fully developed, compact and snow white colored perfect cauliflower curds were harvested with the help of sickle along with small piece of stem of about (1.5 cm). The first harvesting was done on 4th February and harvestings further were continued till 2nd March 2011.

3.11 Field data collection and analyses

In order to study the effect of irrigation methods, irrigation depths and fertigation levels on growth and yield of cauliflower crop, it was necessary to collect data on the plant and growth attributes of the cauliflower. The data regarding growth attributes were collected throughout the experimental period and was analyzed further for interpretations.

The crop growth parameters including plant height, total number of leaves and leaf area per plant (leaf area index) and stem diameter were recorded approximately at 30 days interval after planting till harvest with 3 randomly selected plants from each plot. These plants were properly labeled and growth parameters were monitored on them. The observations at harvest include weight of curd, circumference of curd and curd yield per plot.



Plate No. 3.3 Taking the soil samples from the experimental plot with screw auger for moisture content determination



Plate No. 3.4 Measurement of number of leaves of cauliflower at harvest

Table 3.4 Schedule of cultural operations carried out in the experimental plot

Sr. No.	Operations	Frequency	Date of operation
1	Seedlings		
	a) Preparation of nursery bed	1	30/09/10
	b) Sowing of seed	1	01/10/10
	c) Hand weeding	1	11/11/10
2	Harrowing	1	14/11/10
3	Cleaning	1	15/11/10
4	Field Layout	-	16/11/10
5	Transplanting	1	17/11/10
6	Gap filling	1	24/12/10
7	Hand-hoeing	1	12/12/10
8	Earthing up	1	15/12/10
9	Hand weeding	2	23/12/10
			13/01/10
10	Plant protection: Spraying of Rogor	2	22/01/11 05/02/11
	Endosulphan	1	24/01/11
	Harvesting	9	04/02/11 to 02/03/11

3.11.1 Plant height

The plant height (cm) representing the main shoot was measured from the ground level at the base of growing point to the fully opened top leaf at 30 days interval. After panicle emergence, the height was measured up to the base of panicle.

3.11.2 Number of functional leaves per plant

The progressive change in number of fully opened leaves per plant was counted from selected plants at various stages of crop growth.

3.11.3 Leaf area index

Leaf area per plant (cm^2) was measured with the help of leaf area meter (CID/Inc.USA) at 30 days interval. The leaf area index was calculated using the following equation:

$$LAI = \frac{\text{Total leaf area per plant } (\text{cm}^2)}{\text{Area occupied per plant } (\text{cm}^2)} \quad \dots (1)$$

3.11.4 Stem diameter

Diameter of stem (cm) of the sample plant was measured with the help of thread at three centimeter above the ground level.

3.11.5 Weight of curd per plant

Weight of curd (g) was measured by weighing individual curd of the sample plant in each plot.

3.11.6 Circumference of curd

Circumference of harvested curds (cm) of selected plants was measured by thread from each plot.

3.11.7 Yield per plant

The weight of individual curd (g) in each plot was measured at the time of harvesting.

3.11.8 Yield per hectare

The total weight of curds obtained from each plot in all the harvestings was converted to get the total yield in term of t ha^{-1} per plot and total yield (t ha^{-1})

3.11.9 Root length density

In order to get the root length per unit volume of soil (cm cm^{-3}), soil volume in form of destructive soil samples were collected at different places between the plants with the help of post hole auger from two soil layers viz., 0-15 cm and 15-30 cm at 30 days interval. The volume of post-hole auger was first determined and the soil sample was washed and passed through the screen to get the roots. The roots in each soil samples were immediately cleaned, tagged, and picked up in the plastic trays. The roots were cut in uniform size usually 1 cm length. The root length density was determined by Tenant method (Tenant, 1975; Misra and Ahmed, 1987) using a 1 cm grid.



Plate No. 3.5 Leaf area measurement of cauliflower



Plate No. 3.6 Weight measurement of harvested curd

3.12 Water use efficiency

The water use efficiency for each treatment was determined from the data on corresponding yield and volume of water applied using the following equation:

$$WUE = \frac{\sum Y}{WR} \quad \dots (2)$$

Where,

WUE = Water use efficiency (t/ha-mm)

Y = Yield of cauliflower (t/ha)

WR = Irrigation water applied (mm)

3.13 Soil Moisture Studies

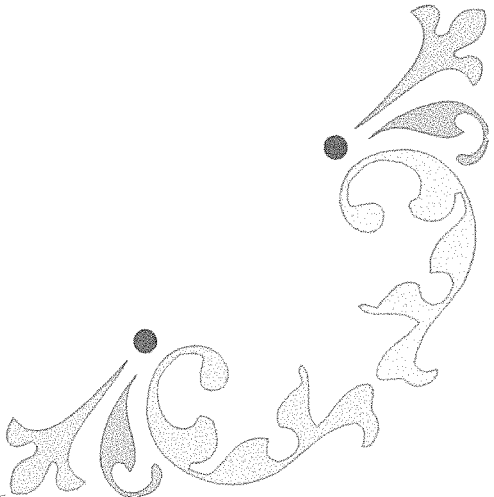
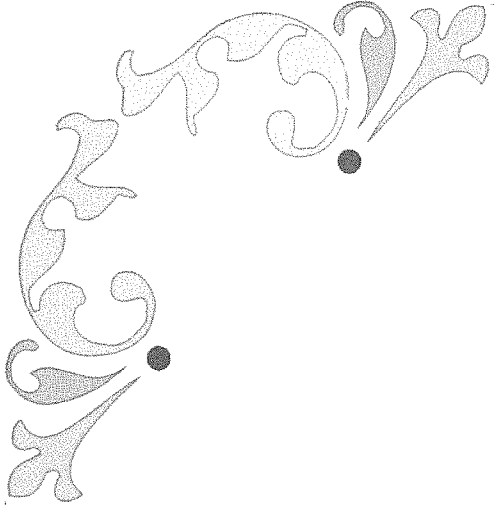
In order to assess the changes in soil water status, soil moisture was measured in 0-15 and 15-30 layers of soil profile at a grid of 15 cm radial (horizontal 0- 30 cm) and vertical (0-30 cm) distances. The moisture content was measured gravimetrically by taking the soil samples from each plot with the help of screw auger at a grid of 15 cm vertically (0 to 30 cm) below emitter and horizontally (0 to 30 cm) distances from the location of emitter. For this moisture contents were measured for an irrigation cycle of 12 days (77 to 87 DAP) during the growth period of cauliflower. Initial and final oven dry weights of soil samples were measured using digital sensitive electronic balance and readings were noted. For drying, the soil samples were kept in hot air oven at 105⁰C for 24 hrs to a constant weight. Soil moisture content was calculated using following formula:

$$\text{Moisture Content} = \frac{\text{Initial Weight} - \text{Final Weight}}{\text{Final Weight}} \times 100 \quad \dots (3)$$

3.14 Statistical Analysis

The field experiment was designed in Split Plot Design with irrigation method as the main factor and irrigation depths and fertilizer levels as the sub factors with three replications. In order to compare the treatments of surface and subsurface drip irrigation with surface irrigation (control) a separate analysis with

two factor split plot design was prepared. The statistical analyses were carried out with MAUSTAT, a standard statistical software for the comparison between the treatment means of growth and yield attributes using F test, standard error of means and the critical differences (CD).



RESULTS AND DISCUSSION

CHAPTER IV

RESULTS AND DISCUSSION

The field investigation was carried out to compare the growth and yield attributes of cauliflower, water saving, water and fertilizer use efficiency under different irrigation methods (surface and sub surface drip), irrigation depths based on pan evaporation (0.4, 0.6 and 0.8 of PE) and levels of fertigation viz. 50, 75, 100 per cent recommended dose of fertilizers (RDF). The growth and yield characteristics of cauliflower were periodically monitored and recorded during the crop growth period. A control treatment of conventional application of water and fertilizer (furrow irrigation at 1.2 IW/CPE with 60 mm depth and 100 per cent RDF; 120:60:60, N:P:K- kg ha⁻¹) was used for comparison. Two types of statistical analysis were carried out for interpretation of results i) Three factor split plot design with irrigation methods (M) as main factor and irrigation depths (I) and fertilizer levels (F) as sub factor and ii) the two factor split plot design with irrigation strategy (S) as main and fertigation levels (F) as sub factors. The second type of analysis was used to compare drip with surface irrigation. The results obtained from the field experiment are discussed in this chapter.

4.1 Properties of Soil

The physical and chemical composition of surface soil (0-30 cm) of the experimental plot is shown in Table 4.1. The soil was uniform in topography and data presented in Table 4.1 shows that the soil of the surface layer (0-30 cm) was clayey in texture, low in nitrogen, rich in phosphorus and potassium. Among the fertility constituents organic carbon was 0.72 per cent. Similarly the soil of experimental plot was slightly alkaline in reaction (pH 8.3) with high base saturation. The moisture content at -0.33 and 15 bar was 34.5 and 13.9 per cent, respectively. The bulk density of soil was 1.32 g cm⁻³. The available water storage capacity of surface soil (0-60 cm) was 163.2 mm.

Table 4.1 Physical and chemical composition of surface soil of experimental plot

Sr. No.	Particulars	Percent (%)
1.	Particle size distribution	
	i) Sand	14.01
	ii) Silt	20.35
	iii) Clay	53.20
	iv) Textural class	Clayey
2.	Chemical composition	
	i) Organic carbon, %	0.72
	ii) Available nitrogen, kg ha ⁻¹	140.80
	iii) Available phosphorus, kg ha ⁻¹	8.40
	iv) Available potassium, kg ha ⁻¹	523.50
	v) Soil pH	8.30
	vi) Electrical conductivity (dS m ⁻¹ at 20 ⁰ C)	0.10
3.	Soil moisture constants	
	i) Field capacity, per cent	34.5
	ii) Permanent wilting point, per cent	13.9
	iii) Bulk density, g cm ⁻³	1.32

4.2 Growth Characteristics

The crop growth characteristics of cauliflower such as plant height, number of leaves, stem diameter and leaf area index was periodically monitored throughout its growth period.

4.2.1 Plant height

Data on height of plant (cm) as influenced by different irrigation methods, irrigation depths and fertilizer levels at different growth stages of cauliflower are presented in Table 4.2 and depicted in Fig. 4.1 and Fig. 4.2.

Data presented in Table 4.2 indicate that plant height increased with the periodical growing period of plant. The increase in plant height during 30 DAP (days after planting) to 60 DAP was higher whereas from 60 DAP to harvest there was slight increase in plant height. This may be because plants have attained almost

full vegetative growth at 60 DAP and harvesting of curd started from 79 DAP onwards.

4.2.1.1 Effect of irrigation method on plant height

The effect of irrigation method on plant height was significant. The plant height under subsurface drip method (M_2) was significantly higher at harvest as compared to surface drip method (M_1) although it was numerically higher at 30 and 60 DAP.

4.2.1.2 Effect of irrigation depth on plant height

The drip irrigation depths significantly influenced plant height at 60 DAP (Table 4.2). Results indicate that plant height of cauliflower under 0.8 PE (I_3) depth was significantly higher (Fig. 4.1) as compared to 0.4 PE (I_1) and was on par with 0.6 PE (I_2).

4.2.1.3 Effect of fertilizer levels on plant height

The effect of fertilizer levels on mean plant height of cauliflower was not significant at 30 and 60 DAP however it was significant at harvest (Table 4.2). Significantly higher plant height was recorded under F_3 (100% RDF) as compared to F_1 (50% RDF) and was on par with F_2 (75% RDF) at harvest.

4.2.1.4 Interaction effects on plant height

The interaction effects of irrigation methods and irrigation depth ($M \times I$) and irrigation method and fertigation level ($M \times F$) were not significant at all the growth stages (Table 4.2).

On the other hand, the interaction effect of irrigation depth and fertigation level ($I \times F$) on cauliflower plant height was significant at 30 DAP and at harvest (Table 4.2). The plant height is significantly highest in treatment I_3F_3 (irrigation depth of 0.8 PE and 100% RDF) as compared to other combinations at 30 DAP, and at harvest. It was at par with treatment I_3F_2 (0.8 PE and 75% RDF), I_1F_2 , I_2F_1 and I_2F_3 at 30 DAP and with treatments I_1F_2 , I_2F_2 and I_3F_2 at harvest (Table 4.3).

Table 4.2 Effect of irrigation methods, irrigation depths and fertilizer levels on plant height

Treatment	Plant height (cm)		
	Days after planting (DAP)		
	30	60	At harvest
Irrigation methods			
M ₁ -Surface Drip	39.39	53.90	65.11
M ₂ -Subsurface drip	40.74	57.24	68.76
S.E. _±	0.480	0.723	0.444
CD at 5%	NS	NS	2.702
Irrigation depths			
I ₁ – (0.4 PE)	39.50	54.26	65.66
I ₂ – (0.6 PE)	40.05	55.70	67.09
I ₃ – (0.8 PE)	40.64	56.75	68.06
S.E. _±	0.879	0.542	0.580
CD at 5%	NS	1.766	NS
Fertilizer levels			
F ₁ - 50% RDF	39.25	54.05	65.07
F ₂ - 75% RDF	39.74	55.92	67.74
F ₃ - 100% RDF	41.20	56.74	68.00
S.E. _±	0.894	0.908	0.808
CD at 5%	NS	NS	2.355
M x I			
S.E. _±	1.243	0.767	0.821
CD at 5%	NS	NS	NS
M x F			
S.E. _±	1.264	1.285	1.142
CD at 5%	NS	NS	NS
I x F			
S.E. _±	1.548	1.574	1.399
CD at 5%	4.513	NS	4.079
M x I x F			
S.E. _±	2.190	2.225	1.979
CD at 5%	6.382	NS	NS

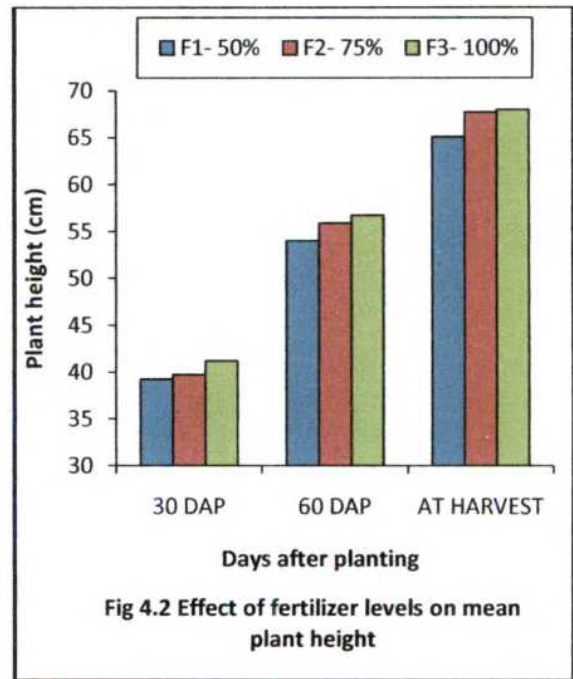
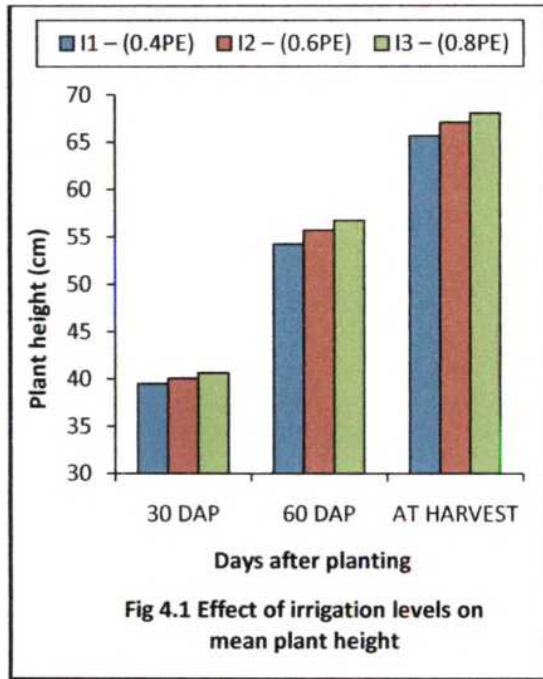


Table 4.3 Interaction effect of (I x F) on plant height

Days after Planting	Treatment	F ₁	F ₂	F ₃
30	I ₁	38.66	41.44	38.39
	I ₂	41.66	36.50	42.00
	I ₃	37.44	41.27	43.22
	S.E.+	1.548	CD at 5%	4.513
At harvest	I ₁	62.27	68.05	66.66
	I ₂	66.94	68.33	66.00
	I ₃	66.00	66.83	71.35
	S.E.+	1.399	CD at 5%	4.079

The interaction effect of irrigation method, depth and fertilizer level (M x I x F) on plant height was significant at 30 DAP (Table 4. 4). Data presented in Table 4.4 show that treatment M₂I₃F₃ was showed significantly higher plant height (44.22 cm) and was at par treatments except M₁I₃F₃, M₁I₂F₂, M₁I₃F₁ and M₂I₁F₁. However, at 60 DAP and at harvest this interaction effect on plant height was non significant.

Table 4.4 Interaction effect of (M x I x F) on plant height

Days After Planting	Treatment	F ₁	F ₂	F ₃
30	M ₁ I ₁	41.33	39.11	35.89
	M ₁ I ₂	39.77	34.11	44.66
	M ₁ I ₃	36.11	41.33	42.22
	M ₂ I ₁	36.00	43.77	40.89
	M ₂ I ₂	43.55	38.89	39.33
	M ₂ I ₃	38.77	41.22	44.22
	S.E.±	2.190		
	CD at 5%	6.382		

Table 4.5 Effect of Irrigation strategy and fertilizer levels on plant height

Factor	Treatment	Plant height (cm)		
		30 DAP	60 DAP	at harvest
Main				
Irrigation strategy (S)	S ₁ - surface drip (0.4 PE)	38.78	52.17	64.26
	S ₂ - surface drip (0.6 PE)	39.51	54.25	65.03
	S ₃ - surface drip (0.8 PE)	39.88	55.27	66.05
	S ₄ - Subsurface drip (0.4 PE)	40.22	56.36	67.07
	S ₅ - Subsurface drip (0.6 PE)	40.59	57.14	69.14
	S ₆ - Subsurface drip (0.8 PE)	41.40	58.22	70.07
	S ₇ - control 1.2 IW/CPE	37.90	50.83	60.18
	S.E. ±	1.378	0.997	0.745
	CD at 5%	NS	2.884	2.154
Sub				
Fertilizer levels (F)	F ₁ – 50% RDF	38.65	53.21	64.19
	F ₂ – 75% RDF	39.83	55.06	66.40
	F ₃ – 100% RDF	40.79	56.42	67.32
	S.E. ±	0.938	0.861	0.844
	CD at 5%	NS	2.492	2.441
Interaction on S x F				
	S.E. ±	2.482	2.280	2.233
	CD at 5%	NS	NS	NS

4.2.1.5 Comparison of surface and drip irrigation with regards to plant height

To assess the effect of different irrigation strategies of irrigation methods and irrigation depth on response of cauliflower and to compare the drip method with the

control surface method, data was analyzed using irrigation strategy as main and fertilizer level as a sub factor.

Effect of different irrigation strategies and fertilizer levels on height of the plants presented is in Table 4.5. All the treatments with drip irrigation showed significantly higher plant height as compared to surface (control) method. Among drip method subsurface drip was superior over surface drip method. Data presented in Table 4.5 also indicate that the effect of fertigation levels on plant height was significant at 60 Dap and at harvest. The F_3 level of fertigation (100% RDF) was superior to F_1 (50% RDF) and was at par with F_2 (75% RDF). The interaction effects were statistically not significant at all growth stages.

4.2.2 Number of leaves

Data on mean number of leaves per plant as influenced by irrigation methods, irrigation depths and fertilizer levels at different growth stages of crop are presented in Table 4.6 and depicted in Fig. 4.3 and Fig. 4.4.

Data reveal that the mean number of leaves per plant increased with the growth of crop. The increase in number of leaves was faster till 60 DAP and thereafter it increased gradually till harvest. Although the number of leaves at harvest was higher than those observed at 60 DAP, some of the leaves turned yellow and about to fall due to senescence of leaves at harvest.

4.2.2.1 Effect of irrigation method on number of leaves

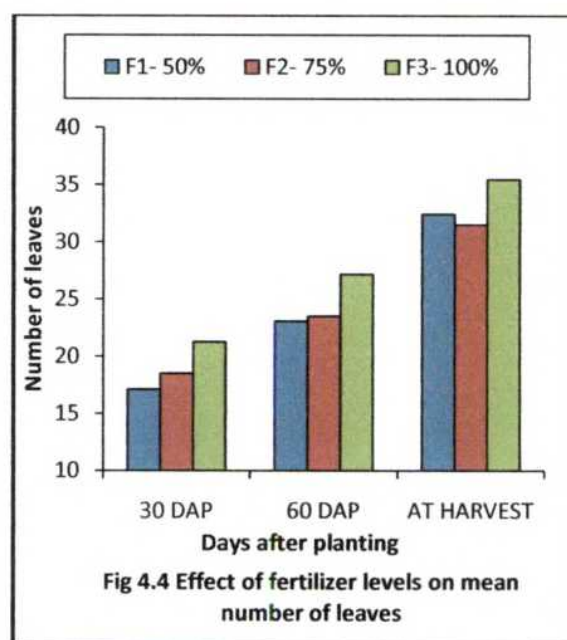
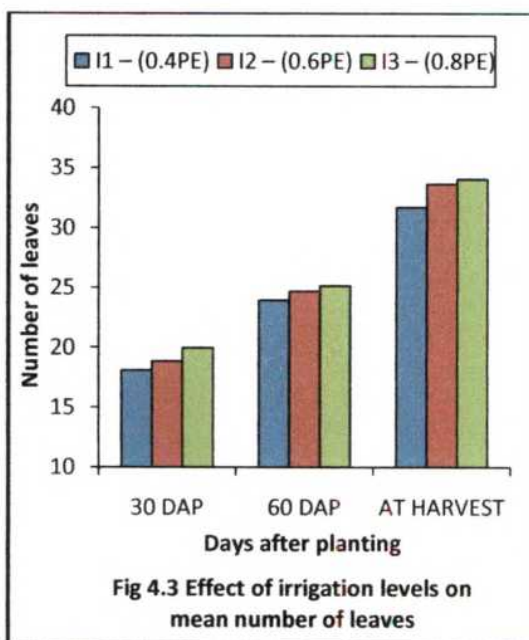
Data presented in Table 4.6 show that the effect of irrigation method on mean number of leaves per plant was significant at all growth stages. Mean number of leaves in the plots irrigated by subsurface drip (M_2) was significantly higher at 30 DAP (20.62), 60 DAP (25.59) and at harvest (34.41) as compared to the surface drip irrigated plots (M_1).

4.2.2.2 Effect of irrigation depths on number of leaves

The effect of irrigation depths on mean number of leaves was significant only at 30 DAP. Mean number of leaves in irrigation depth I_3 (0.8 PE) was significantly higher as compared I_1 depth (0.4 PE) and I_2 depth (0.6 PE). However, at 60 DAP and at harvest were only numerically higher in I_3 (0.8 PE) as compared to 30 DAP irrigation depths (Table 4.5).

Table 4.6 Effect of irrigation methods, irrigation depths and fertilizer levels on mean number of leaves per plant

Treatment	Days After Planting (DAP)		
	30	60	at harvest
Irrigation methods			
M ₁ -Surface Drip	17.32	23.59	31.86
M ₂ -Subsurface drip	20.62	25.59	34.41
S.E. _±	0.329	0.267	0.411
CD at 5%	2.003	1.624	2.498
Irrigation depths			
I ₁ – (0.4 PE)	18.10	23.94	31.72
I ₂ – (0.6 PE)	18.84	24.69	33.64
I ₃ – (0.8 PE)	19.96	25.15	34.06
S.E. _±	0.287	0.494	0.614
CD at 5%	0.935	NS	NS
Fertilizer levels			
F ₁ - 50% RDF	17.12	23.07	32.44
F ₂ - 75% RDF	18.52	23.52	31.51
F ₃ - 100% RDF	21.26	27.18	35.46
S.E. _±	0.359	0.477	0.514
CD at 5%	1.046	1.391	1.498
M x I			
S.E. _±	0.406	0.698	0.868
CD at 5%	NS	NS	NS
M x F			
S.E. _±	0.507	0.675	0.727
CD at 5%	NS	NS	2.119
I x F			
S.E. _±	0.622	0.826	0.890
CD at 5%	NS	NS	NS
M x I x F			
S.E. _±	0.879	1.169	1.259
CD at 5%	NS	NS	3.670



4.2.2.3 Effect of fertilizer levels on number of leaves

At all the growth stages, the fertigation levels significantly influenced the mean number of leaves per plant. Data presented in Table 4.5 and depicted in Fig. 4.4, show that at all the growth stages, the mean number of leaves per plant in F₃ (100% RDF) treatment was significantly highest (21.26, 27.18 and 35.46, respectively) over F₁ (50% RDF) and F₂ (75% RDF).

Table 4.7 Interaction effect of irrigation method and fertilizer levels (M x F) on mean number of leaves at harvest

Days After planting	Treatment	F ₁	F ₂	F ₃
at harvest	M ₁	32.37	30.48	32.74
	M ₂	32.51	32.54	38.18
	S.E.±	0.727	C.D. at 5%	2.119

4.2.2.4 Interaction effect on number of leaves

Data on mean number of leaves per plant as influenced by various interactions at different growth stages of crop is presented in Table 4.6. The interaction effect of irrigation method and irrigation depth (M x I) is non significant at all growth stages.

Table 4.8 Interaction effect of (M x I x F) on mean number of leaves

Days after Planting	Treatment	F ₁	F ₂	F ₃
at harvest	M ₁ I ₁	32.22	28.22	28.33
	M ₁ I ₂	31.88	33.66	33.33
	M ₁ I ₃	33.00	29.55	36.55
	M ₂ I ₁	30.55	32.96	38.02
	M ₂ I ₂	33.00	31.33	38.65
	M ₂ I ₃	34.00	33.34	37.88
	S.E.±	1.259		
	CD at 5%	3.670		

The interaction effect of irrigation method and fertilizer level (M x F) was significant only at harvest and was not significant at 30 and 60 DAP. Hence this interaction effect (M X F) at harvest is separately shown in Table 4.7. Data reveal that at harvest, the treatment M₂F₃ (subsurface drip with 100% RDF) was superior over all other combinations of irrigation method and fertilizer levels.

Table 4.9. Effect of Irrigation strategy and fertilizer levels on number of Leaves

Factor	Treatment	No. of Leaves		
		30 DAP	60 DAP	at harvest
Main				
Irrigation Strategy (S)	S ₁ - surface drip (0.4 PE)	16.62	22.88	29.59
	S ₂ - surface drip (0.6 PE)	17.27	23.82	32.96
	S ₃ - surface drip (0.8 PE)	18.05	24.08	33.03
	S ₄ - Subsurface drip (0.4 PE)	19.58	25.01	33.84
	S ₅ - Subsurface drip (0.6 PE)	20.41	25.56	34.32
	S ₆ -Subsurface drip (0.8 PE)	21.88	26.21	35.07
	S ₇ - control 1.2 IW/CPE	14.37	21.50	27.98
	S.E. ±	0.589	0.604	0.829
	CD at 5%	1.705	1.747	2.973
Sub				
Fertilizer levels (F)	F ₁ – 50% RDF	16.71	22.91	31.86
	F ₂ – 75% RDF	17.97	23.05	30.89
	F ₃ – 100% RDF	20.25	26.49	34.44
	S.E. ±	0.41	0.472	0.461
	CD at 5%	1.185	1.366	1.333
Interaction on S x F				
	S.E. ±	1.084	1.249	1.220
	CD at 5%	NS	NS	3.527

The interaction effect of irrigation depth and fertilizer level (I x F) on mean number of leaves at all growth stages was not significant. However, the interaction effects of irrigation method, depth and fertilizer levels (M x I x F) on number of leaves per plant at harvest was significant and is presented in Table 4.8. Results presented in Table 4.8 reveal that at harvest, treatment combination $M_2I_2F_3$ (subsurface drip, 0.6 PE and 100% RDF) was significantly superior to all other treatments and was at par with $M_2I_1F_3$ and $M_2I_3F_3$.

4.2.2.5. Comparison of surface and drip irrigation with regards to number of leaves

Effects of different irrigation strategies and fertilizer levels on number of leaves are presented in Table 4.9. Results indicated that drip method showed significantly higher number of leaves at all growth stages as compared to surface irrigation (control) method. Subsurface drip with 0.8 PE irrigation depths showed significantly higher number of leaves at all growth stages followed subsurface drip with 0.6 PE and 0.4 PE depths. Similarly the fertilizer level of 100% RDF showed significantly highest number of leaves at all growth stages. However the interaction effects of irrigation strategy and fertilizer level were statistically significant at harvest only.

4.2.3 Stem diameter

Data on mean diameter of plant stem as influenced by different treatments at various crop growth stages are presented in Table 4.10 and depicted in Figs.4.5 and 4.6. Data presented reveal that the mean diameter of stem increased at every stages of crop growth. The increase in stem diameter for initial period from 30 to 60 DAP was higher, although the increase in stem diameter was less from 60 DAP to harvesting stage.

4.2.3.1 Effect of irrigation method on stem diameter

Data presented in Table 4.10 shows that the mean stem diameter of plant in all treatments irrigated by subsurface drip method (M_2) was numerically higher as compared to surface drip irrigation method (M_1) at all growth stages.

Table 4.10 Effect of irrigation methods, irrigation depths and fertilizer levels on diameter of stem

Treatment	Days after Planting (DAP)		
	30	60	At harvest
Irrigation methods			
M ₁ -Surface Drip	5.21	7.32	7.69
M ₂ -Subsurface drip	5.60	7.59	7.86
S.E. _±	0.209	0.0494	0.115
CD at 5%	NS	NS	NS
Irrigation depths			
I ₁ – (0.4 PE)	5.51	7.37	7.72
I ₂ – (0.6 PE)	5.59	7.44	7.77
I ₃ – (0.8 PE)	5.69	7.55	7.84
S.E. _±	0.0802	0.159	0.135
CD at 5%	NS	NS	NS
Fertilizer levels			
F ₁ - 50% RDF	5.10	7.29	7.35
F ₂ - 75% RDF	5.67	7.48	7.82
F ₃ - 100% RDF	6.01	7.59	8.17
S.E. _±	0.132	0.168	0.107
CD at 5%	0.385	NS	0.314
M x I			
S.E. _±	0.113	0.225	0.191
CD at 5%	NS	NS	NS
M x F			
S.E. _±	0.186	0.238	0.152
CD at 5%	0.544	NS	NS
I x F			
S.E. _±	0.228	0.292	0.186
CD at 5%	NS	NS	NS
M x I x F			
S.E. _±	0.323	0.413	0.264
CD at 5%	NS	NS	NS

4.2.3.2 Effect of irrigation depth on steam diameter

Data presented in Table 4.10 indicate that the effect of irrigation depths on mean stem diameter of cauliflower plant was not significant at all growth stages viz., at 30 and 60 DAP, and at harvest. However mean stem diameter of cauliflower in irrigation depth I₃ (0.8 PE) showed numerically higher values at all growth stages.

4.2.3.3 Effect of fertilizer levels on steam diameter of plant

The effect of fertilizer level on mean stem diameter of cauliflower plant was significant at 30 DAP and at harvest. Data presented in Table 4.10 and depicted in Fig. 4.6, show that at 30 DAP and at harvest, the mean stem diameter per plant in F₃ (100% RDF) fertilizer schedule was significantly higher over F₁ (50% RDF) and was at par with F₂ (75% RDF).

4.2.3.4 Interaction effects on steam diameter

All the interaction effects of irrigation method, irrigation depth and fertilizer levels viz. (M x I), (I x F) and (M x I x F) are non significant at every growth stage of cauliflower.

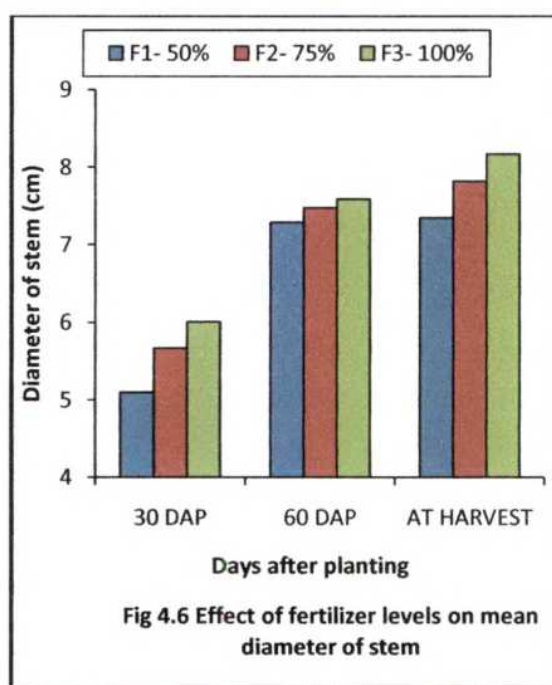
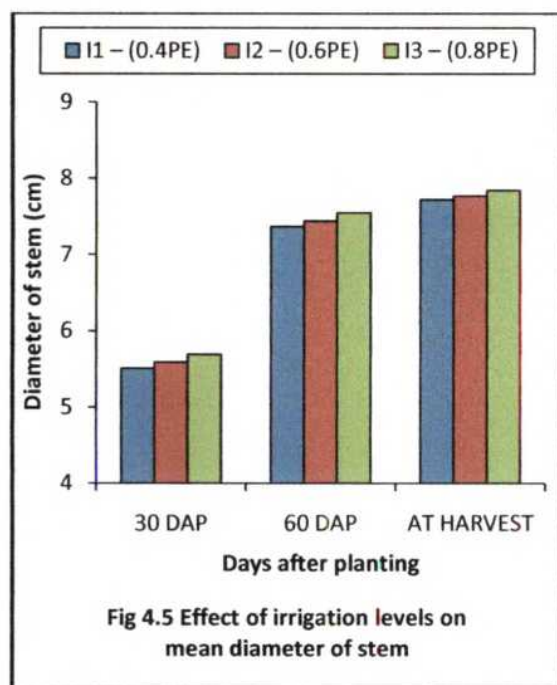


Table 4.11 Interaction effect of (M x F) on stem diameter at 30 DAP

Days After planting	Treatment	F ₁	F ₂	F ₃
30	M ₁	5.07	5.14	5.40
	M ₂	5.13	6.21	6.62
	S.E.±	0.186	C.D. at 5%	0.544

However, the interaction effect of irrigation methods and fertilizer level (I x F) on stem diameter was significant at 30 DAP. Data presented in Table 4.11 indicate that the treatment M₂F₃ (75% RDF) was significantly superior over other treatment combinations and was at par with M₂F₂. On the other hand at 60 DAP and at harvest results were non significant.

Table 4.12 Effect of Irrigation strategy and fertilizer levels on diameter of stem

Factor	Treatment	Diameter of stem (cm)		
		30 DAP	60 DAP	at harvest
Main				
Irrigation Strategy (S)	S ₁ - surface drip (0.4 PE)	5.14	7.22	7.62
	S ₂ - surface drip (0.6 PE)	5.18	7.33	7.70
	S ₃ - surface drip (0.8 PE)	5.29	7.40	7.76
	S ₄ - Subsurface drip (0.4 PE)	5.86	7.51	7.81
	S ₅ - Subsurface drip (0.6 PE)	6.00	7.55	7.85
	S ₆ -Subsurface drip (0.8 PE)	6.10	7.70	7.92
	S ₇ - control 1.2 IW/CPE	4.73	6.96	7.22
	S.E. ±	0.175	0.237	0.187
	CD at 5%	0.506	NS	NS
Sub				
Fertilizer levels (F)	F ₁ – 50% RDF	5.10	7.15	7.28
	F ₂ – 75% RDF	5.51	7.40	7.76
	F ₃ – 100% RDF	5.80	7.59	8.05
	S.E. ±	0.131	0.147	0.099
	CD at 5%	0.379	NS	0.286
Interaction on S x F				
	S.E. ±	0.347	0.39	0.262
	CD at 5%	1.003	NS	NS

4.2.3.5 Comparison of surface and drip irrigation with regards to stem diameter

Effect of different irrigation strategies and fertilizer levels on the stem diameter of cauliflower is presented in Table 4.12 Results indicate that subsurface drip method (S₆) showed significantly higher stem diameter at 30 DAP as

compared to all other strategies. The same strategy showed numerically higher stem diameter as compared to others at 60 DAP and at harvest. Surface as well as subsurface drip method of irrigation was superior over surface method. Similarly at 30 DAP and at harvest, fertilizer level of 100% RDF resulted in higher stem diameter than F_1 and was at par with F_2 .

Interaction effect of irrigation strategy and fertilizer levels was significant only at 30 DAP (Table 4.12).

4.2.4 Leaf area index

Data on mean leaf area index of plant as influenced by different combinations of irrigation methods, irrigation depths and fertilizer levels at various growth stages are presented in Table 4.13 and depicted in Fig. 4.7 and 4.8.

Data presented in Table 4.13 reveal that the mean leaf area index of cauliflower increased at every stages of crop growth. The increase was faster in the early stage from 30 DAP to 60 DAP whereas the increase in leaf area index was gradual from 60 DAP to harvest. The leaf area index indicates the readiness of plant to convert vegetative growth to its reproductive parts. The slower increase during later growth stage of cauliflower indicates the higher conversion of vegetative parts to curd formation and curd development.

4.2.4.1. Effect of irrigation method on leaf area index

The data on effect of irrigation method on leaf area index of cauliflower in Table 4.13 reveal that irrigation method has no significant effect on leaf area index at early growth stage but it was significant at harvest stage. The mean leaf area index of plant in all treatments irrigated by subsurface drip (M_2) was significantly higher as compared to surface drip irrigated plots (M_1) at harvest stage.

4.2.4.2 Effect of irrigation depth on leaf area index

At all the growth stages the irrigation depth significantly influenced the mean leaf area index of plant at harvest. The data is also depicted in Fig. 4.7. Results show that the mean leaf area index in irrigation depth I_3 (0.8 PE) was numerically higher at 30 and 60 DAP and significantly superior to I_1 (0.6 PE) depth and was at par with I_2 (0.6 PE).

Table 4.13 Effect of irrigation methods, irrigation depths and fertilizer levels on mean leaf area index of plant

Treatment	Days After Planting (DAP)		
	30	60	at harvest
Irrigation method			
M ₁ - Surface Drip	0.86	2.02	2.88
M ₂ -Subsurface drip	1.14	2.49	3.49
S.E. _±	0.089	0.108	0.0855
CD at 5%	NS	NS	0.519
Irrigation depths			
I ₁ – (0.4 PE)	0.91	2.15	2.96
I ₂ – (0.6 PE)	0.98	2.24	3.20
I ₃ – (0.8 PE)	1.12	2.38	3.39
S.E. _±	0.082	0.0814	0.0918
CD at 5%	NS	NS	0.298
Fertilizer levels			
F ₁ - 50% RDF	0.815	1.95	2.90
F ₂ - 75% RDF	0.990	2.16	3.04
F ₃ - 100% RDF	1.215	2.66	3.61
S.E. _±	0.076	0.104	0.130
CD at 5%	0.221	0.305	0.381
M x I			
S.E. _±	0.116	0.115	0.129
CD at 5%	NS	NS	NS
M x F			
S.E. _±	0.107	0.148	0.184
CD at 5%	NS	NS	NS
I x F			
S.E. _±	0.131	0.181	0.226
CD at 5%	NS	NS	NS
M x I x F			
S.E. _±	0.186	0.256	0.320
CD at 5%	NS	NS	NS

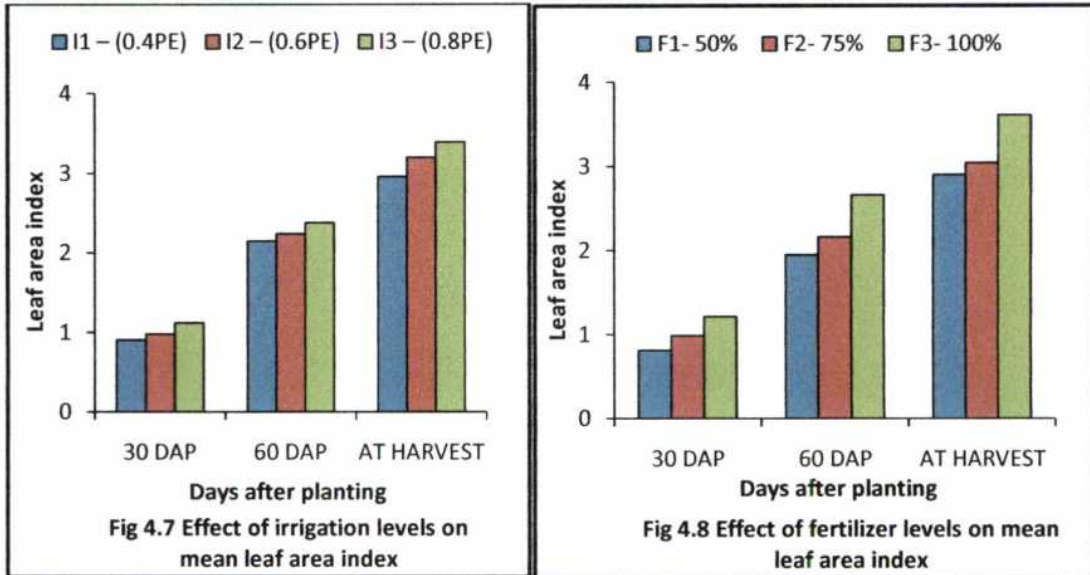
4.2.4.3 Effect of fertilizer levels on leaf area index

Data presented in Table 4.13 reveal that the effect of fertilizer levels on leaf area index was significant at all growth stages. The fertilizer level F₃ (100% RDF)

showed significantly higher leaf area index than F₁ (50% RDF) and F₂ (75% RDF) at all growth stages (Fig. 4.8).

4.2.4.4 Interaction effects on mean leaf area index

Effect of interactions of different factors on mean leaf area index of plant at different crop growth stages are presented in Table 4.13. Data reveal that the effect of (M x I), (M x F), (I x F) and (M x I x F) were non significant at all growth stages.



4.2.4.5 Comparison of surface and drip irrigation with regards to leaf area index

Effect of different irrigation strategies and fertilizer levels on leaf area index of cauliflower is presented in Table 4.14. Results indicate that drip method showed significantly higher leaf area index as compared to surface (control) method. Among drip methods, subsurface drip irrigation showed higher leaf area index as compared to surface drip. The irrigation strategy S₇ (subsurface drip+0.8 PE) showed significantly higher leaf area index among all strategies at all growth stages.

As regards fertilizer levels, F₃ (100% RDF) showed significantly higher leaf area index than F₁ and F₂ fertilizer levels. Data presented in Table 4.14 show that the interaction effects were statistically non significant at all growth stages.

The plant growths at 30 DAP and 60 DAP showing various growth parameters are also illustrated in plate-4.1 and plate-4.2 respectively.



Plate No. 4.1 Plant growth of cauliflower at 30 DAP



Plate No. 4.2 Plant growth of cauliflower at 60 DAP

Table 4.14 Effect of Irrigation strategy and fertilizer levels on leaf area Index

Factor	Treatment	Leaf area index (cm ² /cm ²)		
		30 DAP	60 DAP	at harvest
Main				
Irrigation Strategy (S)	S ₁ - surface drip (0.4 PE)	0.79	1.91	2.57
	S ₂ - surface drip (0.6 PE)	0.87	1.99	2.92
	S ₃ - surface drip (0.8 PE)	0.93	2.15	3.16
	S ₄ - Subsurface drip (0.4 PE)	1.03	2.38	3.36
	S ₅ - Subsurface drip (0.6 PE)	1.09	2.50	3.48
	S ₆ -Subsurface drip (0.8 PE)	1.32	2.60	3.63
	S ₇ - control 1.2 IW/CPE	0.66	1.66	2.32
	S.E. ±	0.119	0.123	0.132
CD at 5%	0.345	0.357	0.382	
Sub				
Fertilizer levels (F)	F ₁ – 50% RDF	0.78	1.88	2.81
	F ₂ – 75% RDF	0.94	2.08	2.92
	F ₃ – 100% RDF	1.14	2.56	3
	S.E. ±	0.067	0.093	0.114
	CD at 5%	0.194	0.270	0.331
Interaction on S x F				
	S.E. ±	0.177	0.247	0.303
	CD at 5%	NS	NS	NS

4.2.4.6 Root length density (cm/cm³)

To assess the effect of different irrigation strategies on growth, yield and moisture distribution of pattern of cauliflower, the root length density was measured at 30 and 60 DAP and at harvest. The data was analyzed as combination of irrigation strategy. The average root length measured in 0-15 and 15-30 cm surface soil layers under different irrigation strategies is presented in Table 4.15.

Data shown in Table 4.15 indicate that the irrigation strategy significantly influenced the root length density at all growth stages in surface soil layer (0-15 cm). The significantly highest root length density was observed in all irrigation depths of subsurface drip method. In all the cases the root length density was highest in subsurface drip followed by surface drip and control furrow irrigation method.

Table 4.15 Effect of Irrigation strategy on root length density (cm/cm³)

Factor	Treatment	Root length density (cm/cm ³)					
		30 DAP		60 DAP		at harvest	
Irrigation strategy (S)	Depth	0-15	15-30	0-15	15-30	0-15	15-30
	S ₁ - Surface drip (0.4 PE)	0.39	0.31	0.72	0.65	0.95	0.80
	S ₂ - Surface drip (0.6 PE)	0.38	0.31	0.74	0.68	0.91	0.76
	S ₃ - Surface drip (0.8 PE)	0.33	0.30	0.70	0.61	0.91	0.75
	S ₄ - Subsurface drip(0.4 PE)	0.43	0.30	0.87	0.58	1.07	0.70
	S ₅ - Subsurface drip(0.6 PE)	0.46	0.32	0.91	0.61	1.07	0.79
	S ₆ - Subsurface drip(0.8 PE)	0.46	0.32	0.89	0.60	1.09	0.74
	S ₇ - Control 1.2 IW/CPE	0.33	0.32	0.69	0.59	0.90	0.72
	S.E. ±	0.015	0.015	0.019	0.017	0.024	0.022
	CD at 5%	0.046	NS	0.060	0.053	0.076	NS

4.3 Profile Soil Moisture Distribution

In order to assess the depth and time variation of soil moisture under different irrigation methods and irrigation depths, a irrigation cycle of 12 days (77 to 87 DAP) was selected and soil moisture was monitored in 0-15 and 15-30 cm soil layers. The soil moisture presented in this section is the average values of measured soil moisture under different irrigation strategy with combination of irrigation methods and scheduling criterion. During this period 1st to 12th February 2011 (77 DAP to 87 DAP), the surface and subsurface drip plots were irrigated six times, whereas the control plots were irrigated 5 days before the moisture measurements and on the last day of irrigation cycle. For surface irrigated plots (C) the moisture content was measured at the centre of furrow and at 15 and 30 cm away from center towards ridge whereas in case of drip irrigated plots moisture content was measured at 0, 15 and 30 cm radial distance away from the position of emitter. The data on measured moisture content at different radial distances from the emitter and vertical distances below soil surface under different irrigation depths and is shown in Appendix C.

The temporal variation of soil moisture in different irrigation depths is presented through Fig. 4.9 to Fig. 4.11. The figures reveal that in general, the soil moisture experienced a cyclic temporal variation following the irrigation event. The amplitude of this cyclic variation was slightly higher in upper (0-15 cm) soil layer than the lower (15-30cm) soil layer.

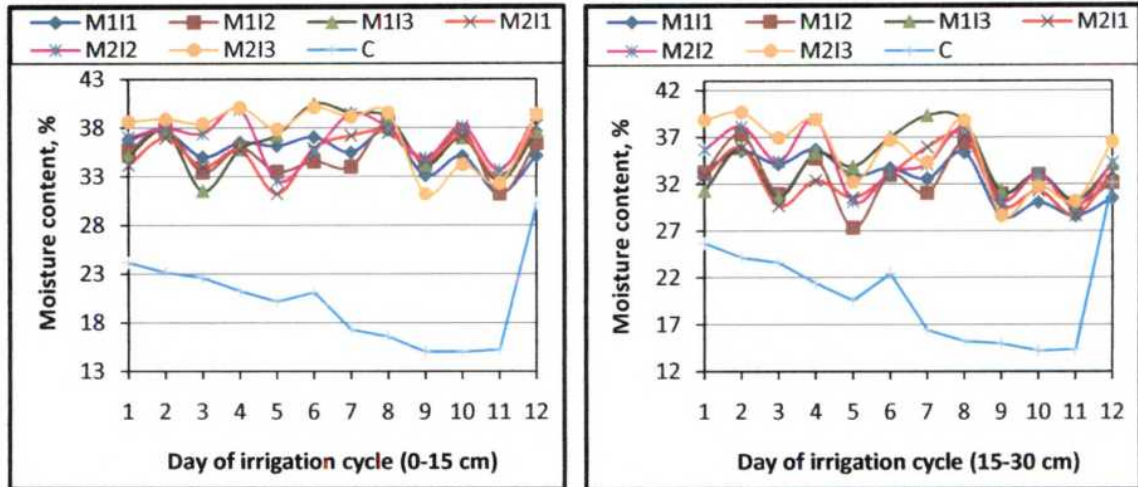


Fig. 4.9 Moisture distribution under different irrigation depths below emitter

Fig. 4.9 shows moisture content under different irrigation depths measured below emitter for drip and in the centre of furrow for control. Under all drip irrigation depths the moisture content in surface soil layer (0-15 cm) lie between 31 to 40% throughout the irrigation cycle whereas the moisture content in 15-30 cm layer is in between 27 to 39%. However, the moisture content in surface irrigated plots remained lower around 15 to 30% in surface soil layer and around 14 to 32% in 15-30 cm layer. With the increase in depth of drip irrigation the moisture content in both the layers increases.



Plate No. 4.3 Initial stage of curd development in surface drip plots (treatment $M_1I_2F_2$)



Plate No.4.4 Initial stage of curd development in subsurface drip plots (treatment $M_2I_2F_2$)

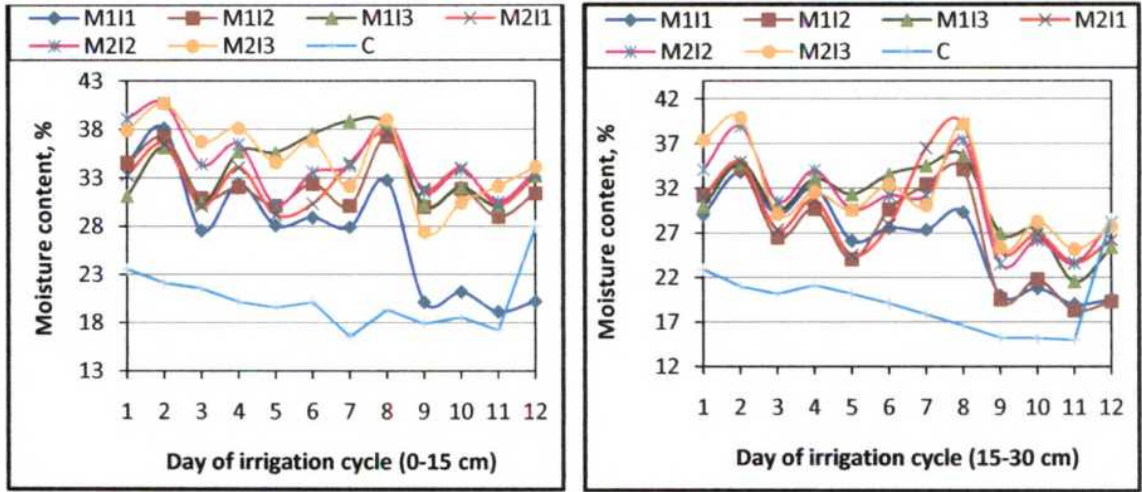


Fig. 4.10 Moisture distributions under different irrigation depths at 15 cm away from emitter

The moisture content under different irrigation strategies measured at 15 cm away from the emitter and 15 cm away from centre of furrow is depicted in Fig. 4.10 shows. Figure shows that, under all drip irrigation strategies the moisture content in surface soil layer (0-15 cm) lie between 19 to 40% whereas the moisture content in 15-30 cm layer is in between 18 to 39%. The moisture contents at 15 cm away from the emitter are slightly lower (Fig. 4.10) as compared to that moisture content below emitter (Fig. 4.9). The cyclic variation of moisture content was more pronounced in upper layer (0-15 cm) than the lower layer (15-30 cm).

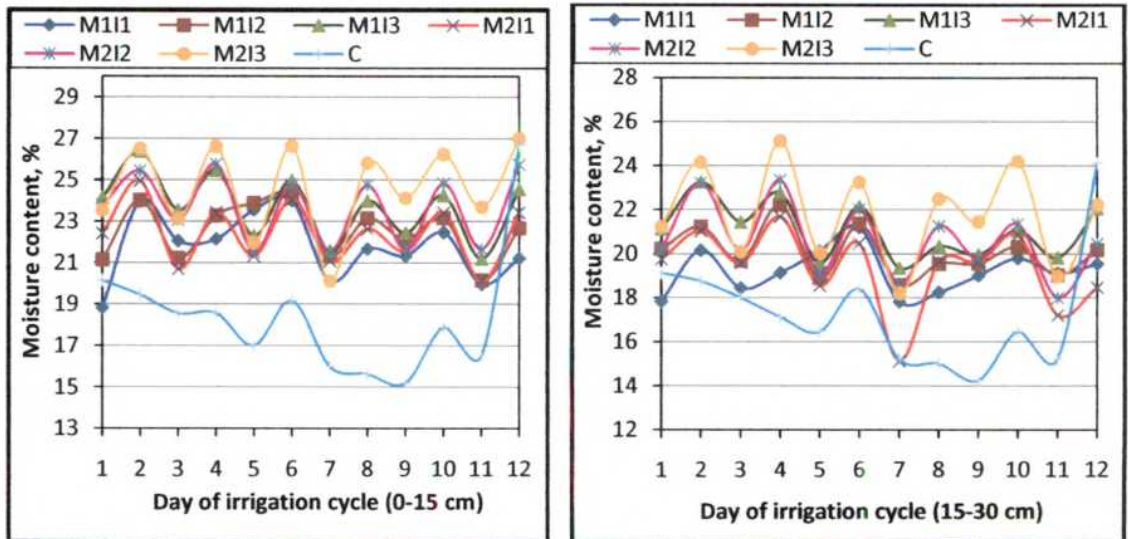


Fig. 4.11 Moisture distributions under different irrigation depths at 30 cm away from emitter

The moisture content under different irrigation strategies measured at 30 cm away from the emitter and 30 cm away from center of furrow in control plot in both the soil layers is depicted in Fig. 4.11. Under all drip irrigation depths the moisture content in surface soil layer (0-15 cm) lie between 21 to 27% whereas the moisture content in 15-30 cm layer is in between 15 to 25%. This indicate that in both the soil layers moisture contents are lower than those shown in Fig. 4.9 and 4.10 measured below emitter and at 15 cm away from emitter. This clearly shows that the moisture content in both soil layers decreases with increase in the horizontal distance from the emitter. The moisture content at 30 cm away from the emitter are around field capacity which is required for better growth of cauliflower.

The figures also show that there is no significant difference in moisture content between surface and subsurface drip irrigation methods. However the moisture content in subsurface drip irrigation was slightly higher in both 0-15 and 15-30 cm layers as compared to corresponding layers in surface drip method. This effect was more pronounced at a distance of 15 cm away from emitter (Fig. 4.10) than at 30 cm away from emitter (Fig. 4.11).

In addition to above figures the soil moisture contours showing spatial distribution of soil moisture under different irrigation treatments for each day of irrigation cycle are presented in Fig. 4.12 to Fig. 4.23.

Fig. 4.12 shows the spatial distribution of soil moisture under different irrigation treatments on first day before irrigation whereas Fig. 4.13 shows spatial distribution of soil moisture on 2nd day of irrigation cycle after irrigation. The moisture content increased due to irrigation in all drip irrigated plots. The moisture distribution under drip irrigated plots is more uniform and higher as compared to surface irrigated plots. No significant difference in spatial distribution of soil moisture was observed between surface and subsurface drip plots throughout the irrigation cycle. However the moisture distribution is more uniform and less varied under subsurface drip plots as compared to surface drip plots. Similar trend was observed throughout the irrigation cycle depicted in Fig. 4.12 through 4.23.

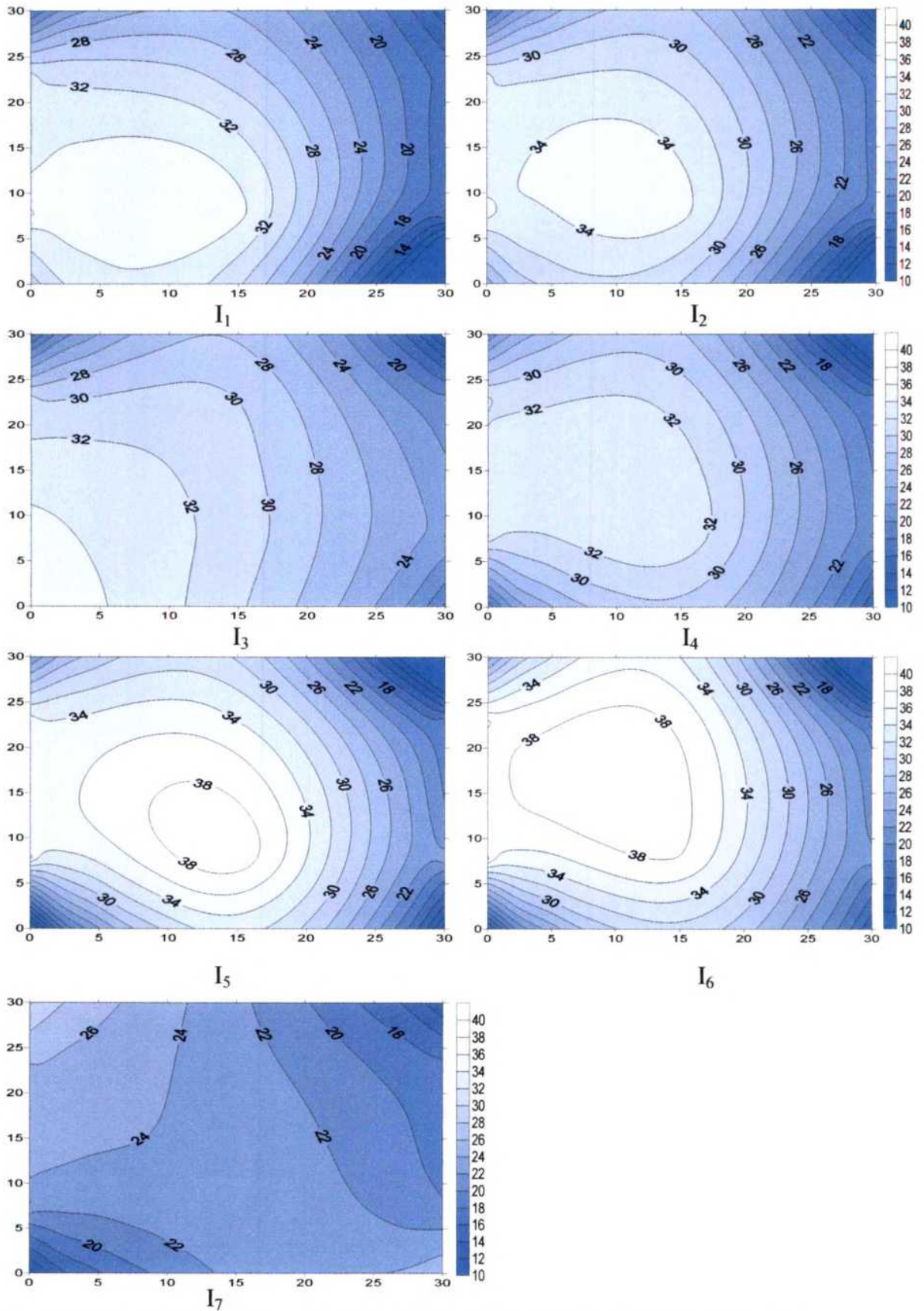


Fig. 4.12 Spatial distribution of soil moisture under different irrigation treatments before irrigation on 1st day of irrigation cycle (1st Feb 2011)

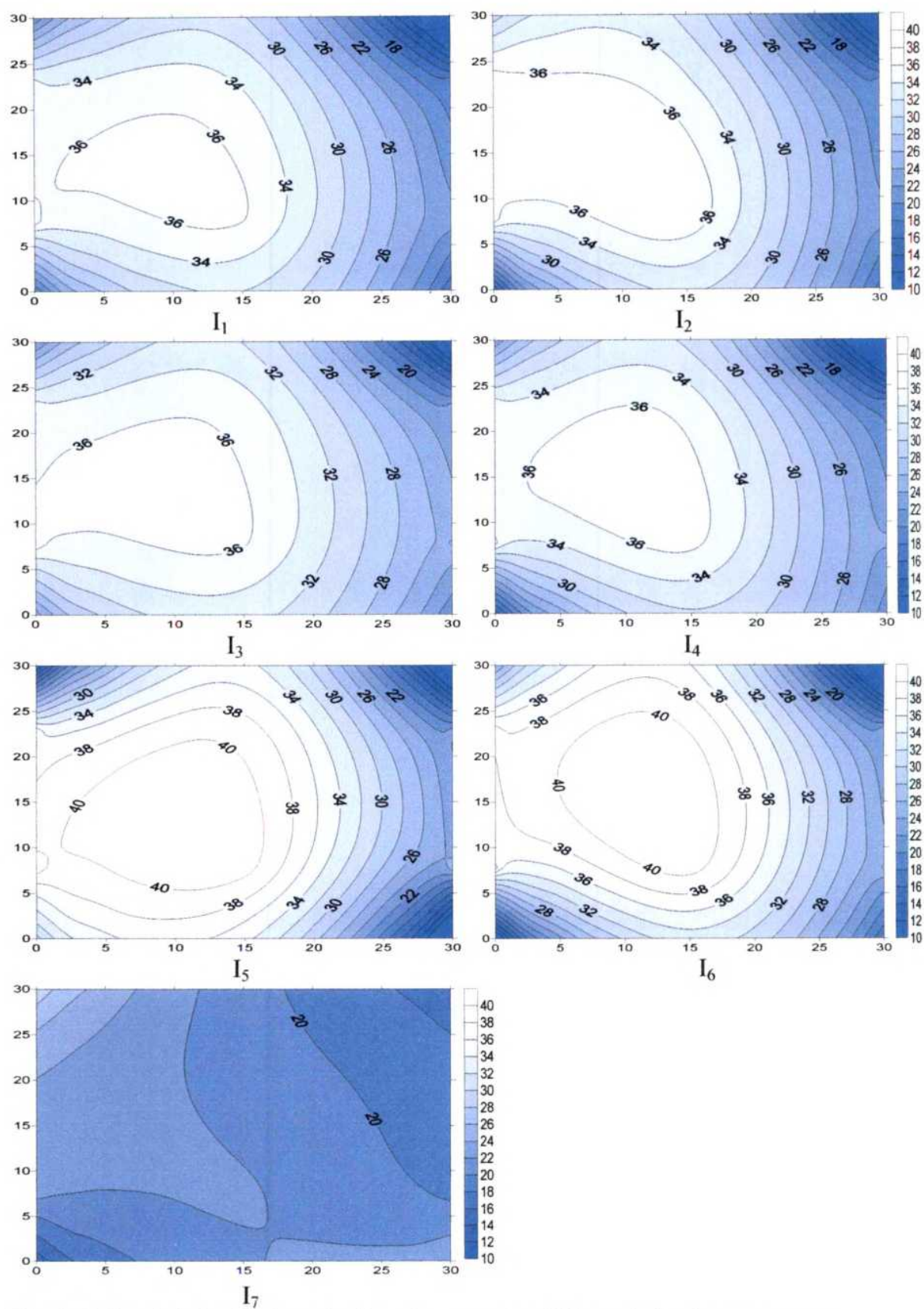


Fig. 4.13 Spatial distribution of soil moisture under different irrigation treatments after irrigation on 2nd day of irrigation cycle (2nd Feb 2011)

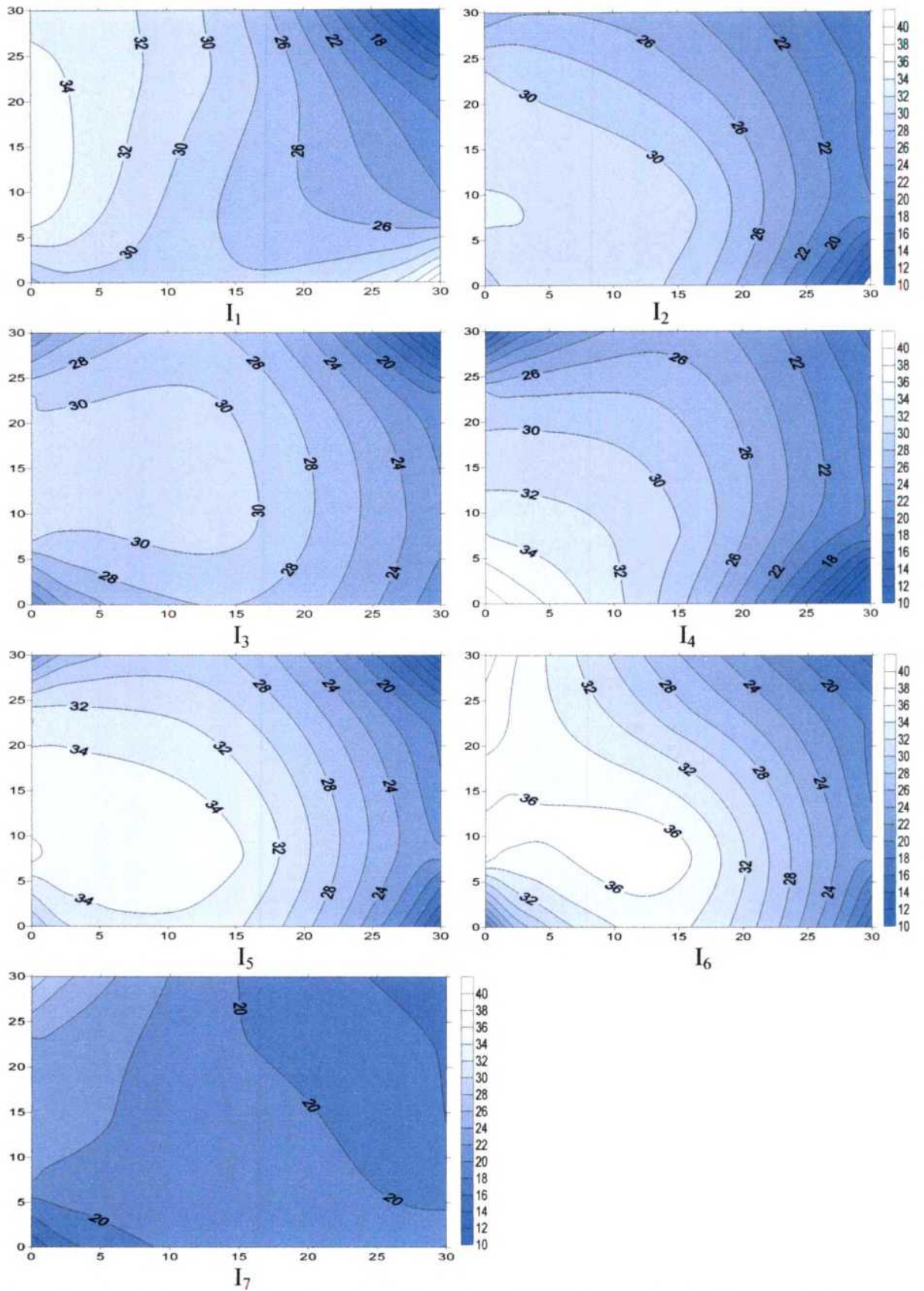


Fig. 4.14 Spatial distribution of soil moisture under different irrigation treatments before irrigation on 3rd day of irrigation cycle (3rd Feb 2011)

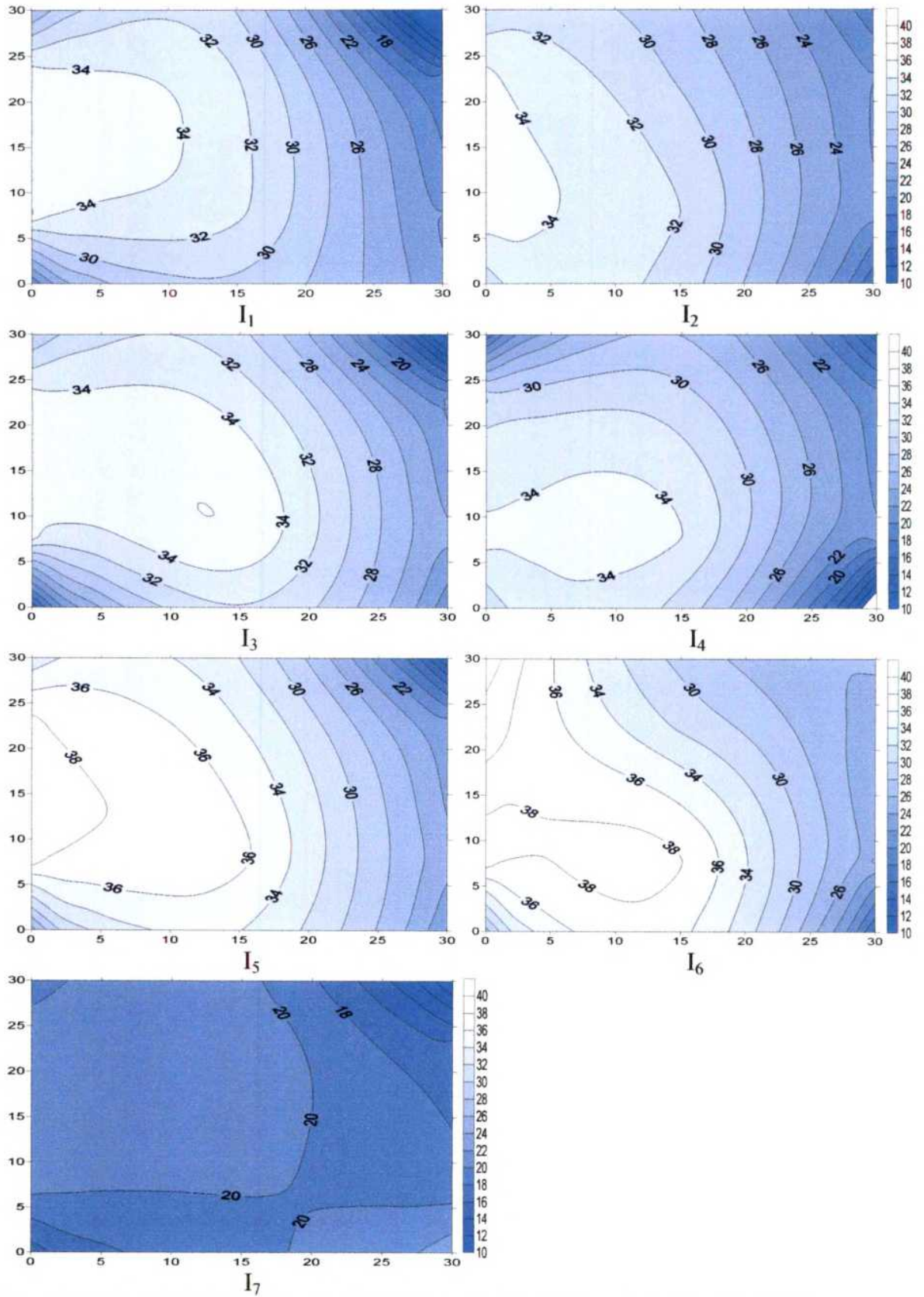


Fig. 4.15 Spatial distribution of soil moisture under different irrigation treatments after irrigation on 4th day of irrigation cycle (4th Feb 2011)

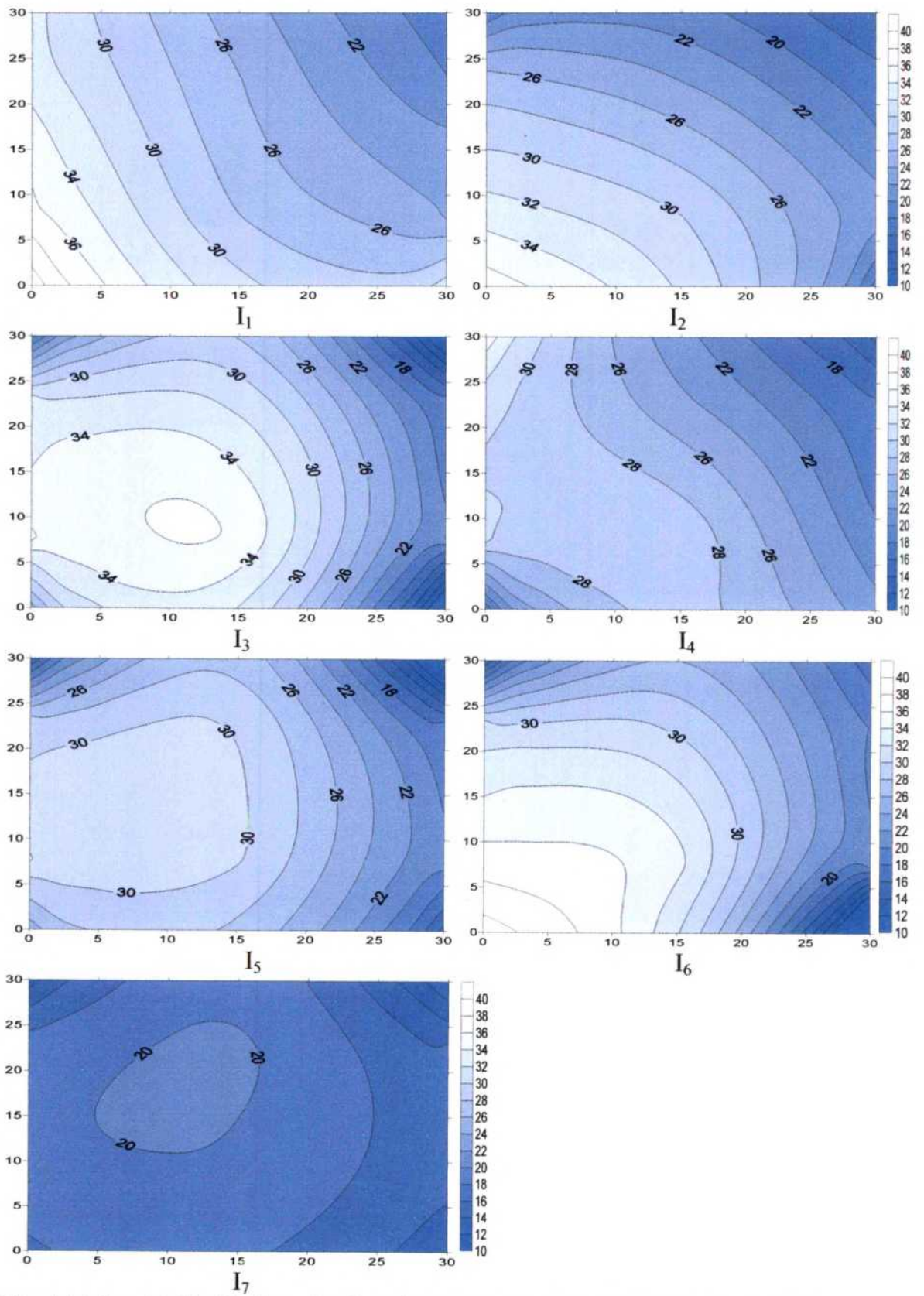


Fig. 4.16 Spatial distribution of soil moisture under different irrigation treatments before irrigation on 5th day of irrigation cycle (5th Feb 2011)

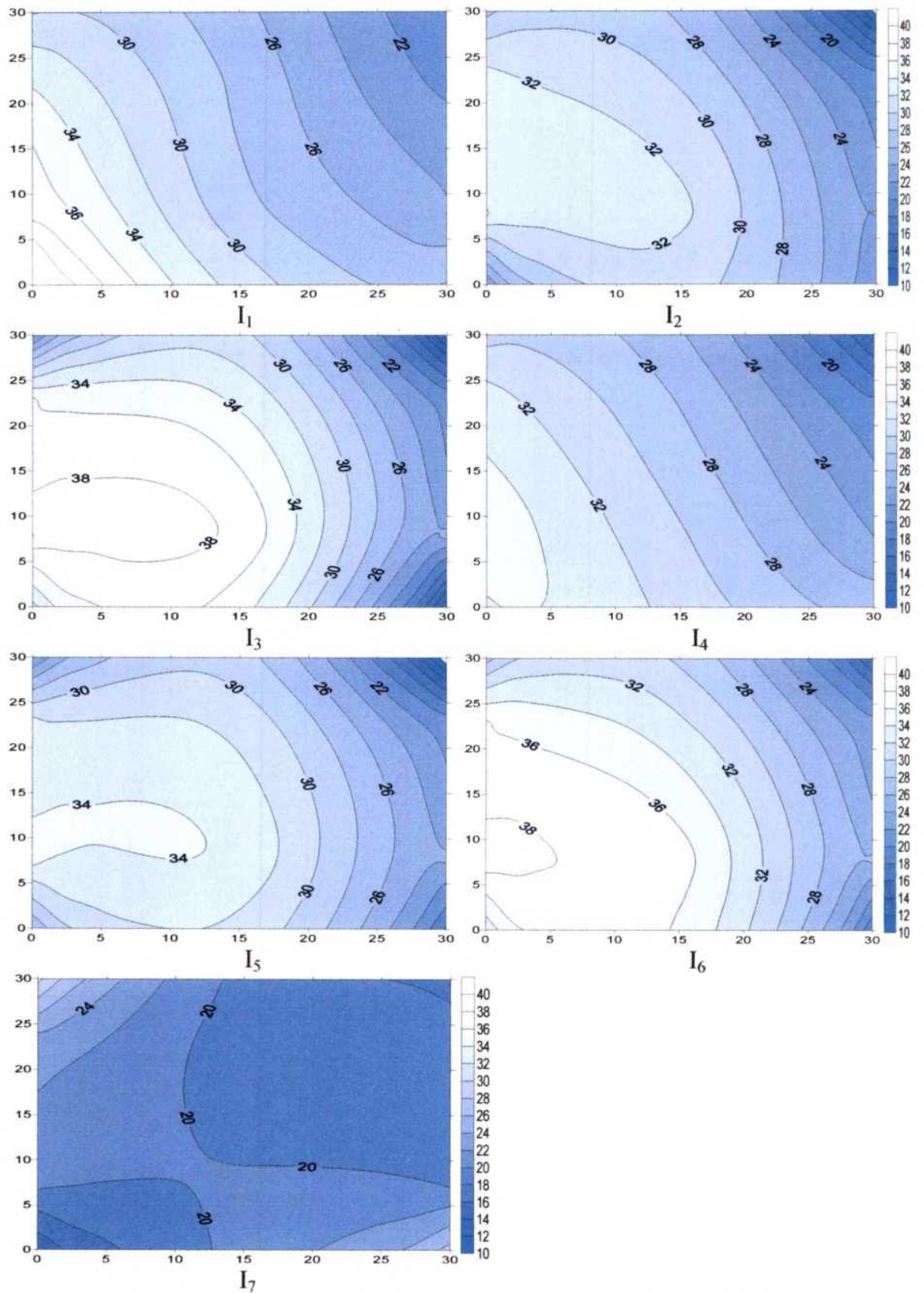


Fig. 4.17 Spatial distribution of soil moisture under different irrigation treatments after irrigation on 6th day of irrigation cycle (6th Feb 2011)

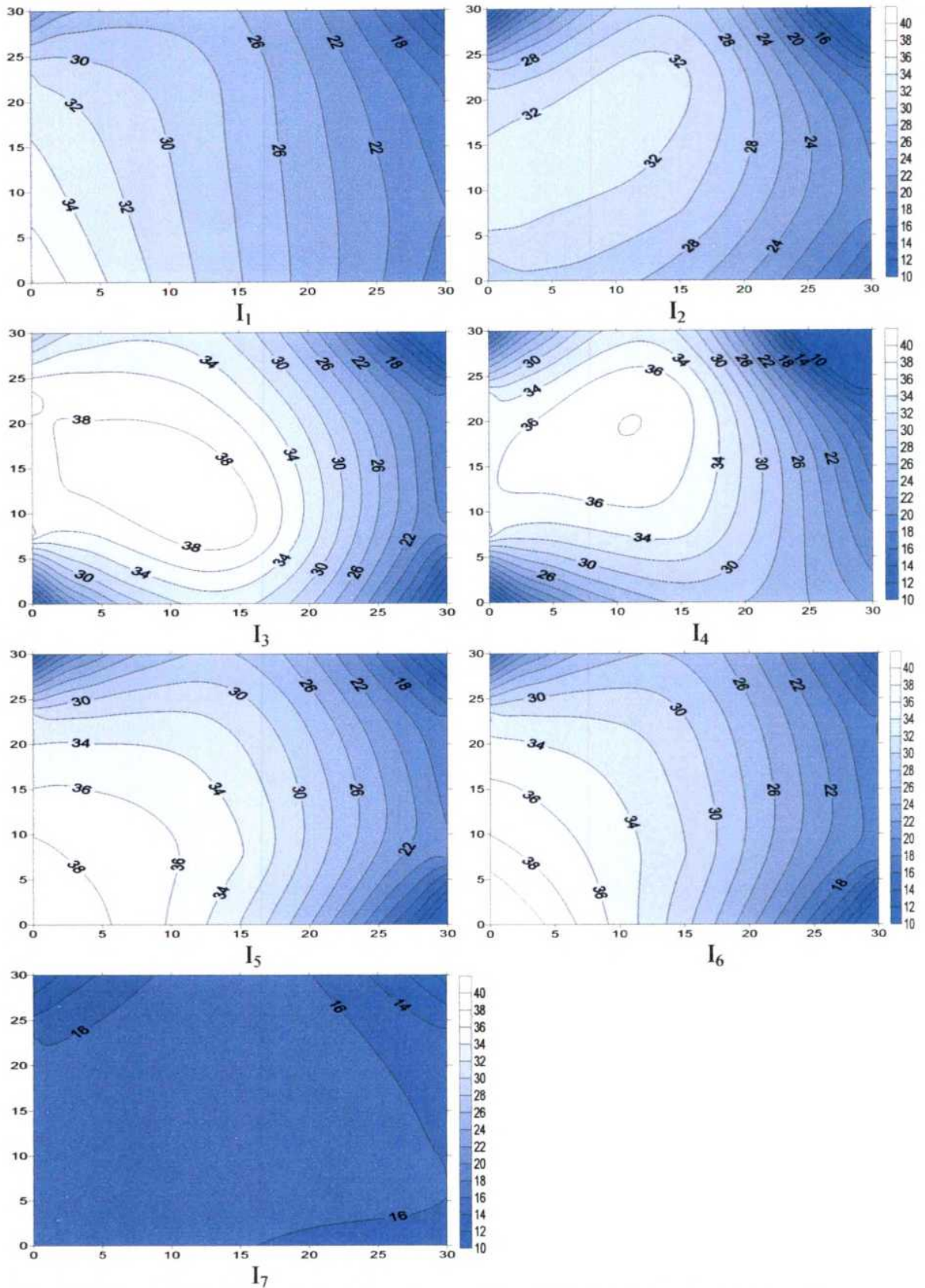


Fig. 4.18 Spatial distribution of soil moisture under different irrigation treatments before irrigation on 7th day of irrigation cycle (7th Feb 2011)

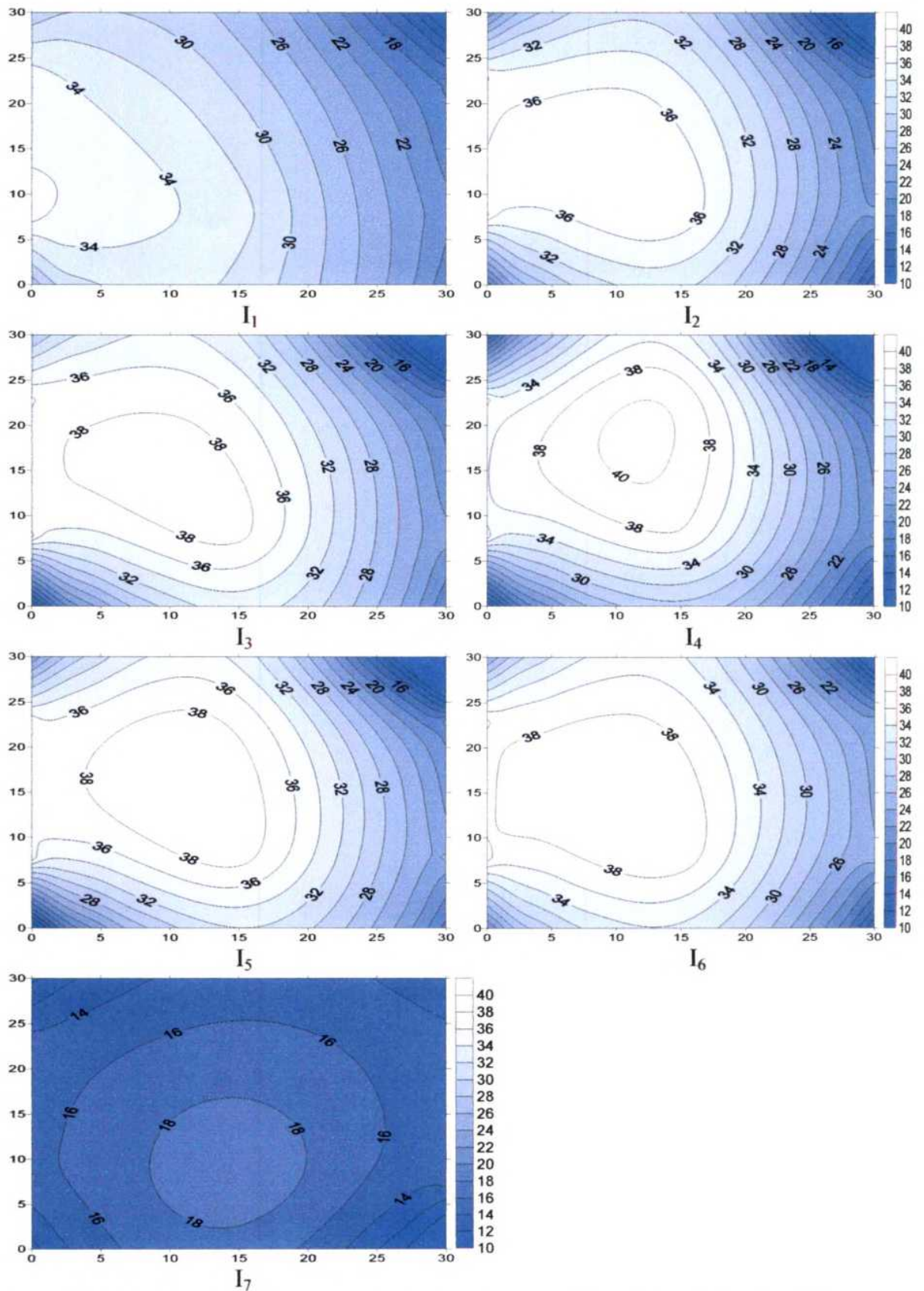


Fig. 4.19 Spatial distribution of soil moisture under different irrigation treatments after irrigation on 8th day of irrigation cycle (8th Feb 2011)

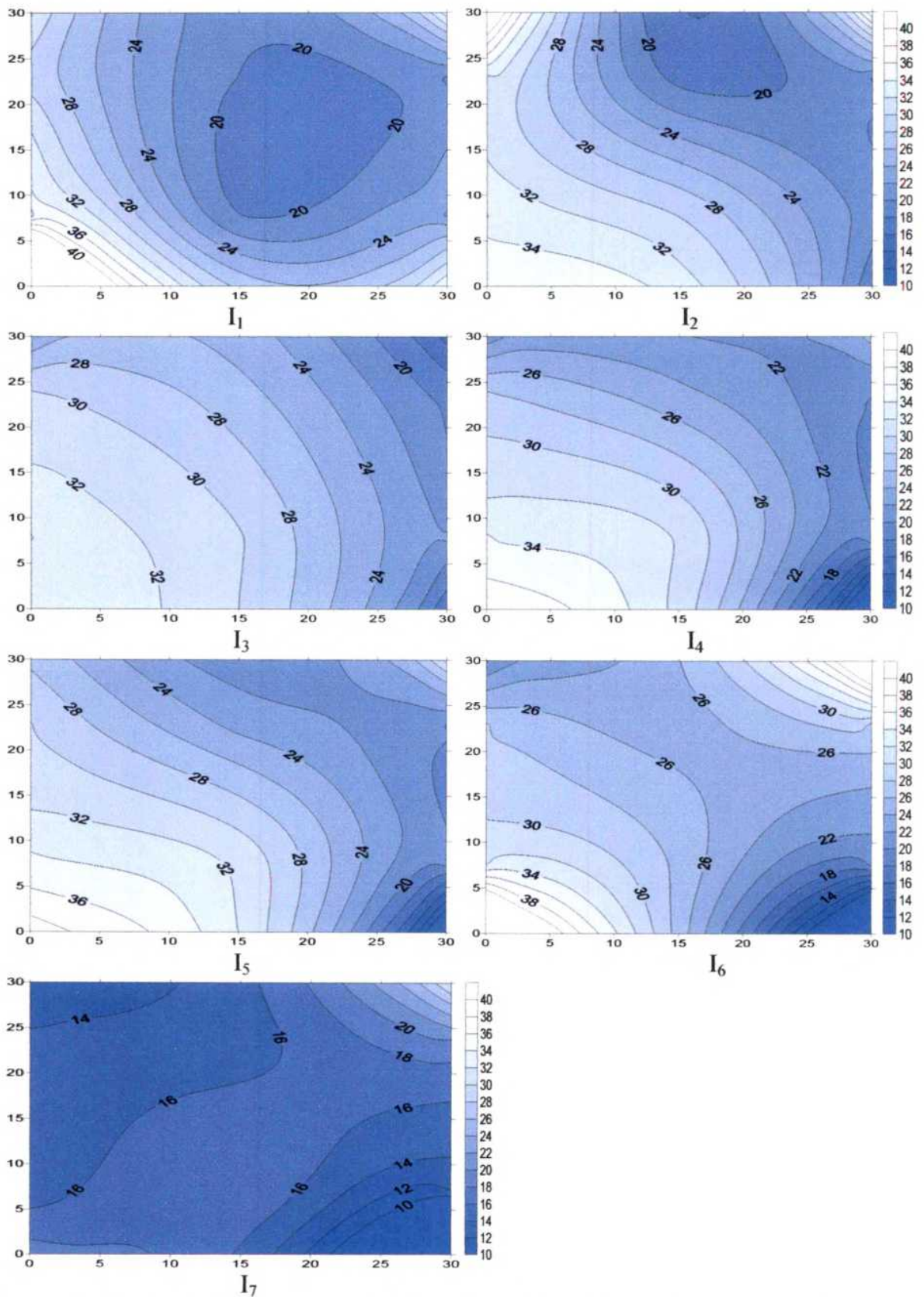


Fig. 4.20 Spatial distribution of soil moisture under different irrigation treatments before irrigation on 9th day of irrigation cycle (9th Feb 2011)

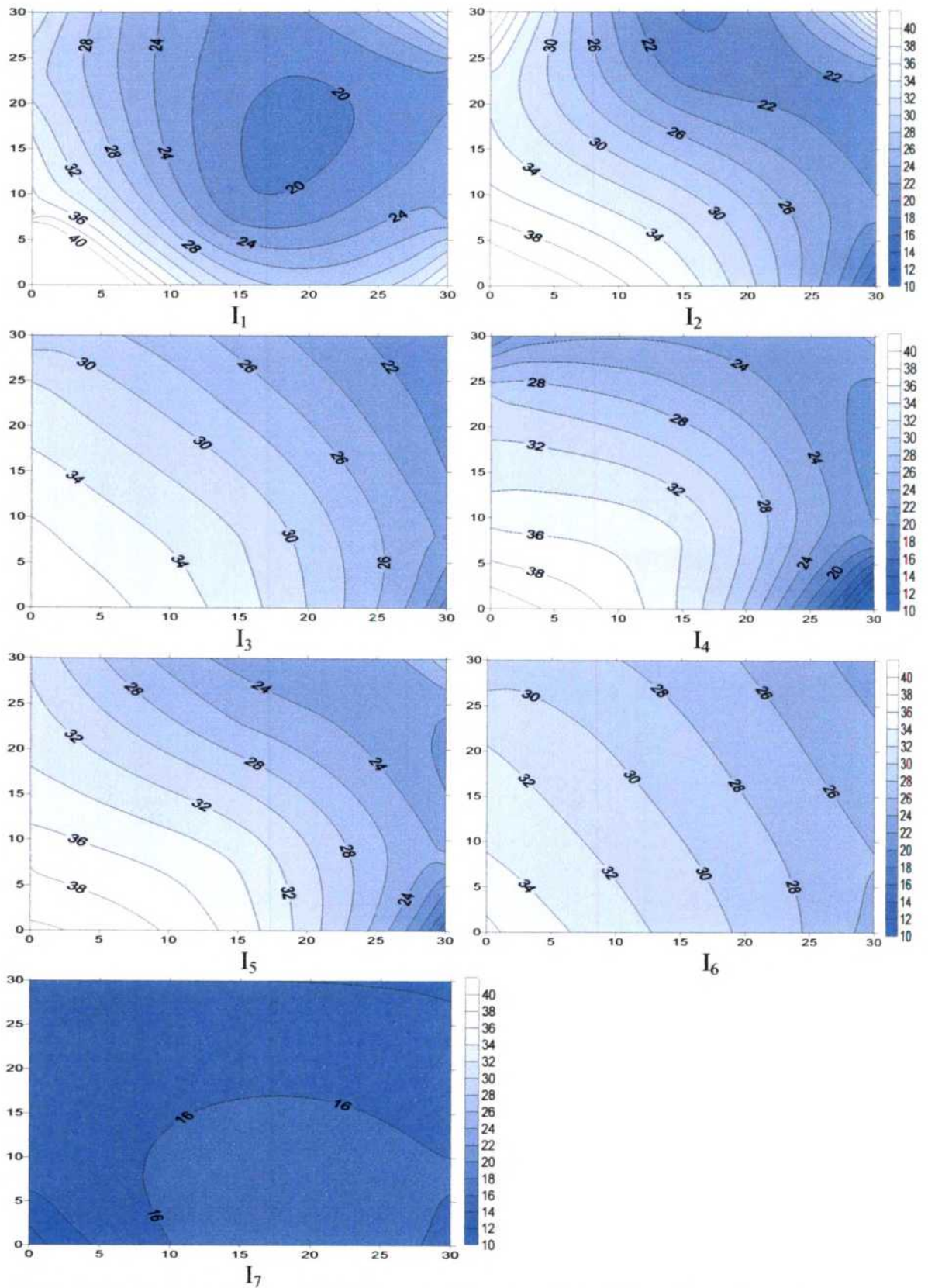


Fig. 4.21 Spatial distribution of soil moisture under different irrigation treatments after irrigation on 10th day of irrigation cycle (10th Feb 2011)

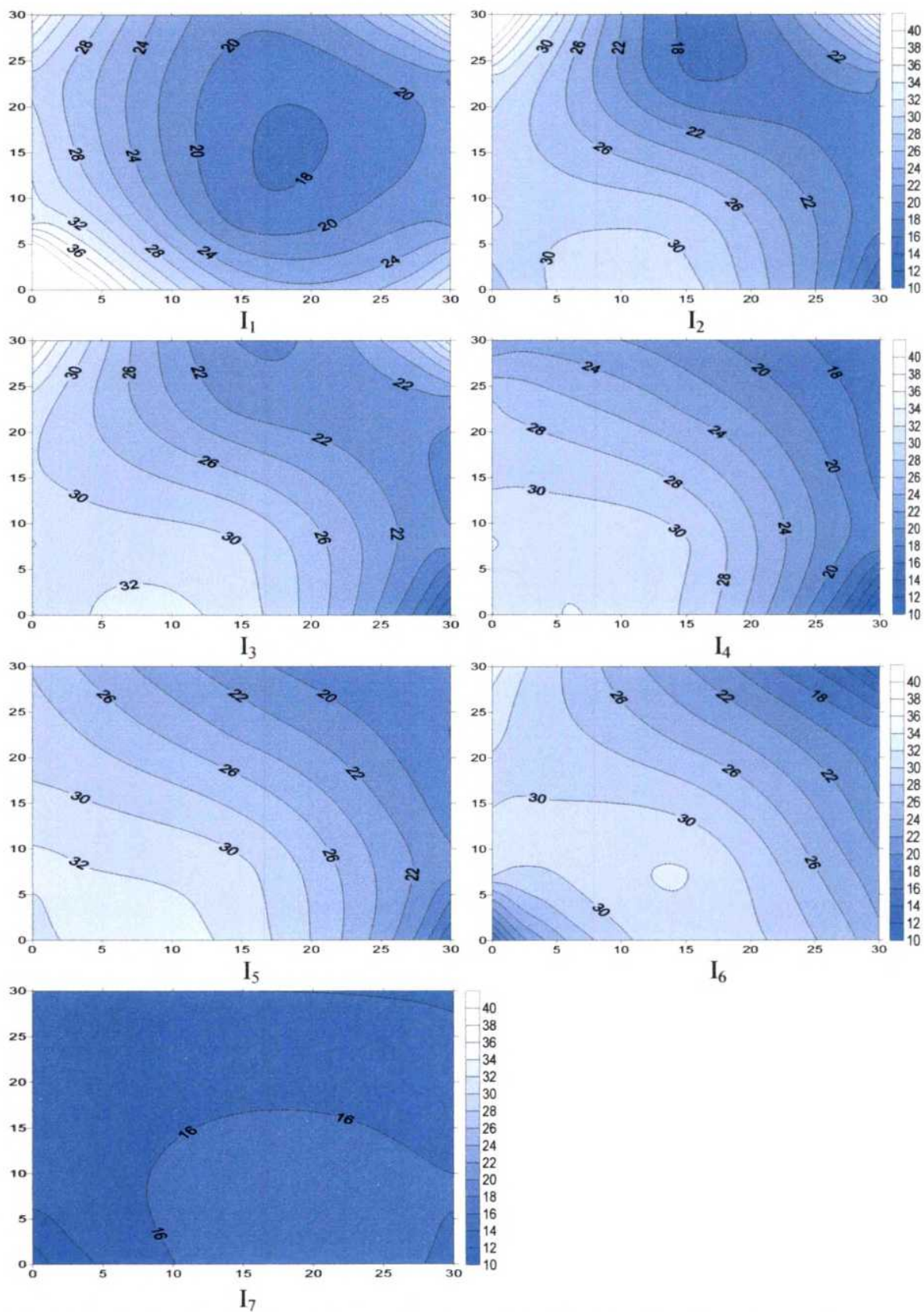


Fig. 4.22 Spatial distribution of soil moisture under different irrigation treatments before irrigation on 11th day of irrigation cycle (11th Feb 2011)

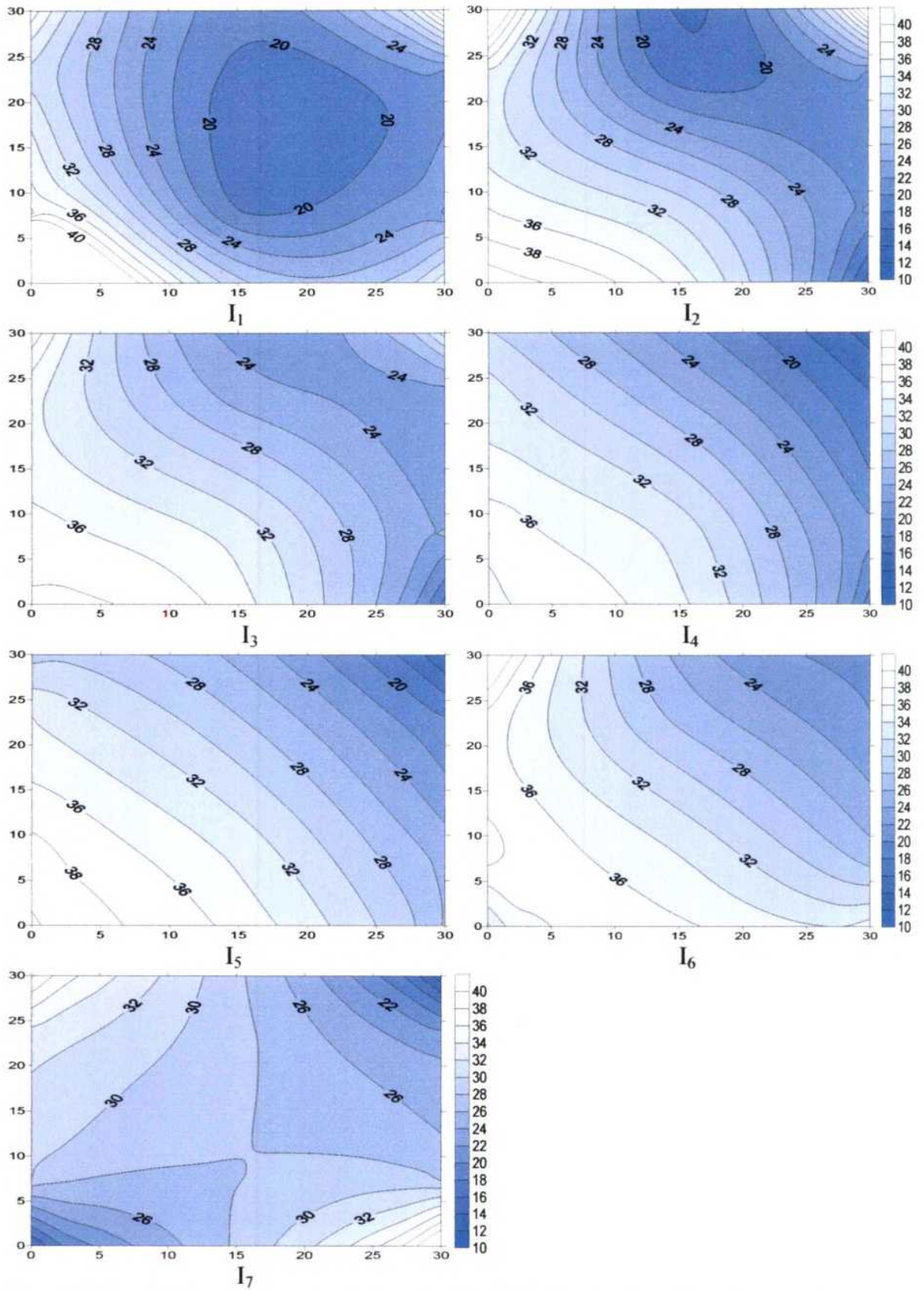


Fig. 4.23 Spatial distribution of soil moisture under different irrigation treatments after irrigation on 12th day of irrigation cycle (12th Feb 2011)

The discussion on preceding sections on growth characteristics viz., plant height, number of leaves, stem diameter, leaf area index and root length density of cauliflower reveal that subsurface drip irrigation resulted in better growth of crop showing higher values of all the growth attributes. The positive effects of subsurface drip system were observed since 30 DAP. The results of the present investigation corroborates with the earlier findings of Al-Harbi *et al.* (2008) who reported better vegetative performance of okra in regards with the plant height, number of leaves, shoot fresh weight under subsurface drip than surface drip system. Their results also indicted that the emitters at a depth of 15 cm resulted in significantly higher growth parameters as compared to emitters placed at 25 and 35 cm. Singh and Rajput (2007) also observed higher plant height of okra under subsurface drip system in which laterals were placed at different soil depths.

As regards the irrigation depth surface and subsurface drip scheduled with 0.8 PE enhanced the plant growth followed with 0.6 PE as compared to 0.4 PE. The irrigation depth of 0.6 PE also was sufficient for crop growth at later growth stages. This indicates that the higher amount of irrigation water significantly increases plant height, number of leaves, stem diameter and leaf area index. The results are in line with those reported by Al-Harbi *et al.* (2008) and Singh and Rajput (2007) for okra. The results on growth characteristics of cauliflower also reveal that the subsurface drip irrigation even with 0.4 PE irrigation depth resulted in better growth characteristics as compared to surface drip with higher amount of irrigation water (0.6 and 0.8 PE). This could be because the subsurface drip with its better water use efficiency can reduce the total water requirement of crop. Similar results were also reported by del Amor and del Amor (2007) for tomato.

Although the fertilizer level of 100% RDF resulted in better growth characters of cauliflower, the effect of fertilizer levels on growth characters was many a times non significant. For some growth parameters the fertilizer levels of 75 and 100% RDF have similar effects. This indicates the possibility of fertilizer saving when they are applied through drip fertigation.

In earlier studies, Al-Harbi *et al.* (2008) reported increased root weight and root length in subsurface drip as compared to surface drip irrigation. This could be

attributed to the better moisture balance and aeration in the root zone in subsurface drip as compared to surface drip method. Surface drip method tends to increase moisture level in the upper surface only.

From the results presented it can be concluded that among the various combinations of treatments subsurface drip with 0.6 PE depth of water and 75% RDF ($M_2I_2F_2$) seems to be the better combination as regards the vegetative growth of cauliflower.

The results on temporal and spatial moisture distribution under various irrigation depths reveal that the moisture content is more uniform in subsurface drip than surface drip method. Although the difference in moisture content is not significant, subsurface drip shows slightly higher moisture content than the surface drip method. Singh and Rajput (2007) observed more uniform soil moisture along soil depth with subsurface drip as compared to surface drip whereas Makrantinaki et al. (2002) observed increased soil moisture at higher depths under subsurface drip method as compared to surface drip irrigation.

4.4 Yield Characteristics

The results on the yield characteristics such as curd yield, and curd circumference are presented in this section.

4.4.1 Mean curd yield of cauliflower

The fresh and fully developed tender curds were harvested from each plot during 4th February to 2nd March 2011. The data on mean curd yield of cauliflower per ha are presented in Table 4.16 and depicted in Fig. 4.24 and Fig. 4.25.

4.4.1.1 Effect of irrigation method on curd yield

The effect of irrigation method on curd yield was not significant. Data presented in Table 4.16 reveal that application of water by subsurface drip method (M_2) recorded numerically higher yield (25.05 t ha^{-1}) than surface drip (M_1) method (22.69 t ha^{-1}).

4.4.1.2 Effect of irrigation depths on curd yield

Data on effect of different irrigation depths on yield of cauliflower head was also not significant. As envisaged from Table 4.16 and depicted in Fig. 4.24, the

irrigation depth I_3 (0.8 PE) recorded highest curd yield (25.98 t ha^{-1}) than I_1 (21.61 t ha^{-1}) and I_2 (24.03 t ha^{-1}) indicating I_3 to be the superior irrigation depths.

4.4.1.3 Effect of fertilizer levels on curd yield

The results presented in Table 4.16 showed that the effect of fertilizer levels on curd yield of cauliflower were statistically non significant. Data in Fig. 4.24 and 4.25 indicate that F_3 fertilizer level is numerically superior to F_1 and F_2 fertilizer levels. However the difference is not significant hence with fertigation there could be saving of fertilizers when the fertilizers are applied even at lower levels viz. 50 and 75 % RDF.

4.4.1.4 Interaction effects on curd yield of cauliflower

The data presented in Table 4.16 show the effect of various interactions of irrigation methods, irrigation depths and fertilizer levels on curd yield of cauliflower.

The interaction effect of irrigation method and irrigation depths (M x I), irrigation method and fertilizer levels (M x F), Irrigation depths and fertilizer levels (I x F), and combined effect of irrigation method, depth and fertilizer levels (M x I x F) were non significant.

4.4.1.5 Comparison of surface and drip irrigation with regards to curd yield

To assess the effect of different irrigation strategies using various irrigation methods on response of cauliflower and to compare the drip method with the surface irrigation method, data on curd yield was analyzed using irrigation strategy as main and fertilizer level as a sub factor. Data presented in Table 4.17 indicate that the effect of different irrigation strategies on curd yield was significant whereas the effect of fertilizer levels on curd yield was non significant. The significantly highest curd yield (26.94 t ha^{-1}) was resulted under S_6 (subsurface drip with 0.8 PE) followed by 25.66 t ha^{-1} in S_6 (subsurface drip with 0.6 PE) and 25.01 t ha^{-1} in S_3 (surface drip with 0.8 PE). Among drip although all the combinations are at par, the subsurface drip gave the highest yields under all irrigation depths as compared to surface drip irrigation. The curd yields obtained under control plots are significantly lower as compared to all irrigation depths of surface and subsurface drip irrigation.

Table 4.16 Effect of various irrigation depths and fertilizer level on yield of cauliflower (t/ha)

Irrigation methods	Yield t/ha
M ₁ -Surface drip	22.69
M ₂ -Subsurface drip	25.05
S. E ± 0.958	C.D at 5% NS
Irrigation depths	
I ₁ – (0.4 PE)	21.61
I ₂ – (0.6 PE)	24.03
I ₃ – (0.8 PE)	25.98
S. E ± 1.250	C.D at 5% NS
Fertilizer levels	
F ₁ - 50% RDF	22.38
F ₂ - 75% RDF	23.67
F ₃ - 100% RDF	25.56
S. E ± 1.027	C.D at 5% NS
Interaction (M x I)	
S. E ±	1.768
C. D at 5%	NS
Interaction (M x F)	
S. E ±	1.559
C. D at 5%	NS
Interaction (I x F)	
S. E ±	1.910
C. D at 5%	NS
Interaction (M x I x F)	
S. E ±	2.701
C. D at 5%	NS

The effect of fertilizer level on curd yield was not significant. This again indicates towards saving of fertilizer by adopting slightly lower fertilizer doses through fertigation without compromising yields.

The interaction effect of irrigation strategies and fertilizer levels on curd yield was non significant.

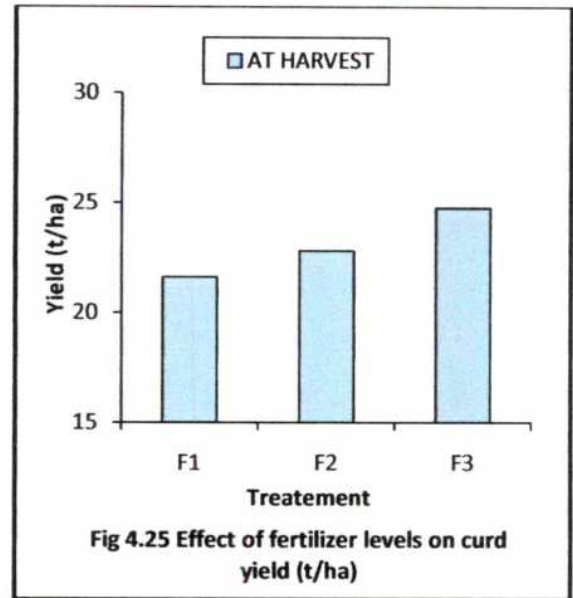
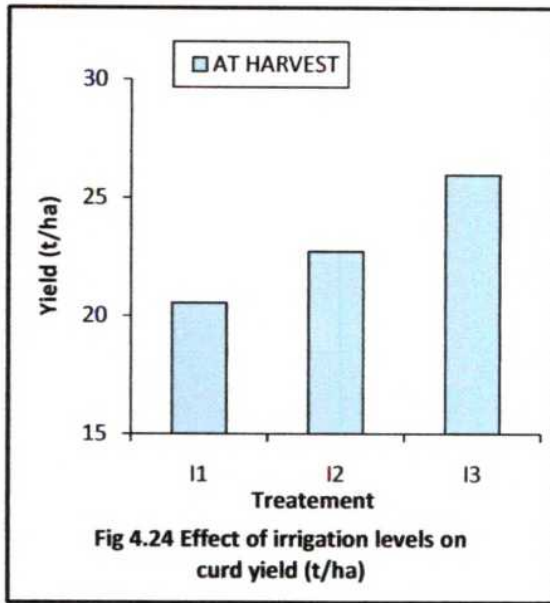


Table 4.17 Effect of Irrigation strategy and fertilizer levels on yield

Factor	Treatment	Yield (t/ha)
Main		at harvest
Irrigation Strategy (S)	S ₁ - surface drip (0.4 PE)	20.66
	S ₂ - surface drip (0.6 PE)	22.39
	S ₃ - surface drip (0.8 PE)	25.01
	S ₄ - Subsurface drip (0.4 PE)	22.55
	S ₅ - Subsurface drip (0.6 PE)	25.66
	S ₆ -Subsurface drip (0.8 PE)	26.94
	S ₇ - control 1.2 IW/CPE	18.24
	S.E. ±	1.609
	CD at 5%	4.654
Fertilizer levels (F)	F ₁ – 50% RDF	21.62
	F ₂ – 75% RDF	23.01
	F ₃ – 100% RDF	24.57
	S.E. ±	1.066
	CD at 5%	NS
Interaction on S X F	S.E. ±	2.821
	CD at 5%	NS

4.4.2 Circumference of curd

The circumference of harvested cauliflower curd was determined by measuring the circumference and diameter of curd. Data on circumference of



Plate No. 4.5 Developed curd of cauliflower under surface drip $M_1I_3F_3$

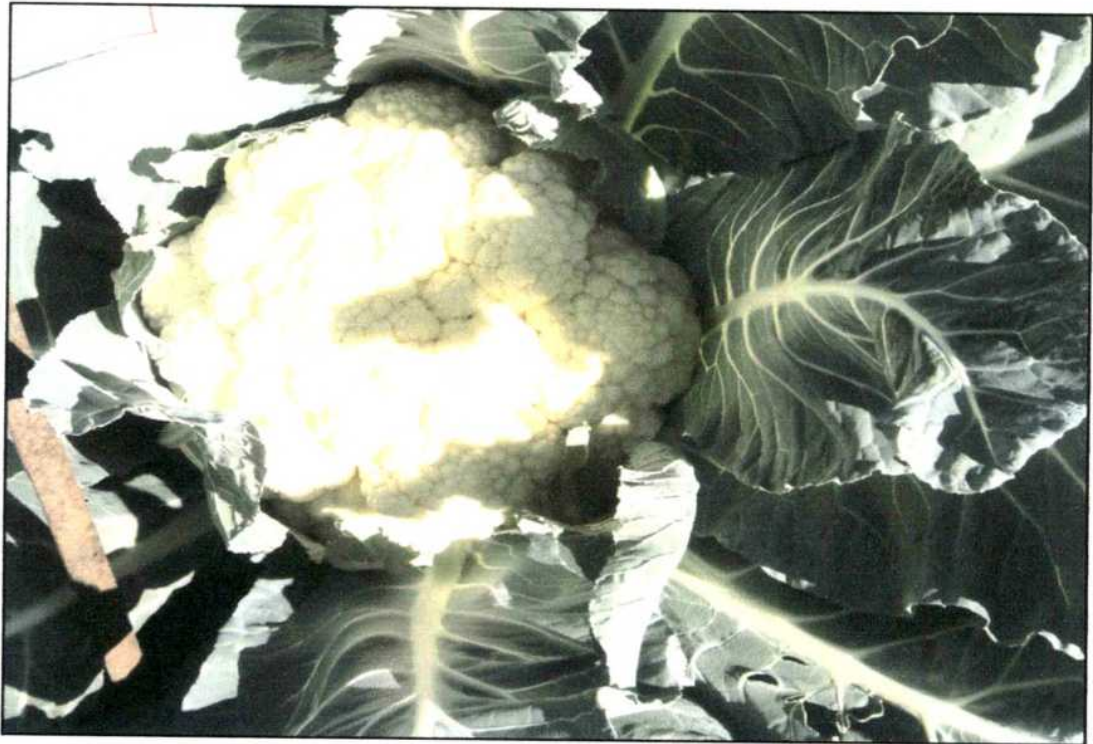


Plate No. 4.6 Developed curd of cauliflower under subsurface drip (treatment $M_2I_3F_3$)

cauliflower curd as influenced by different irrigation methods, irrigation depths and fertilizer levels is presented in Table 4.18 and depicted in Fig. 4.26 and 4.27.

4.4.2.1 Effect of irrigation method on circumference of curd

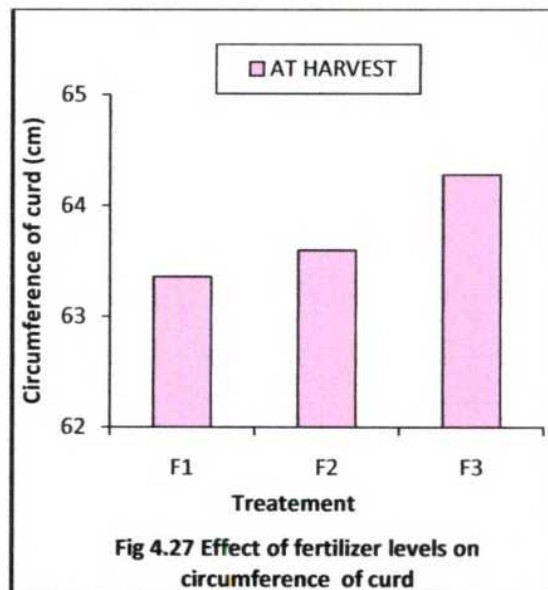
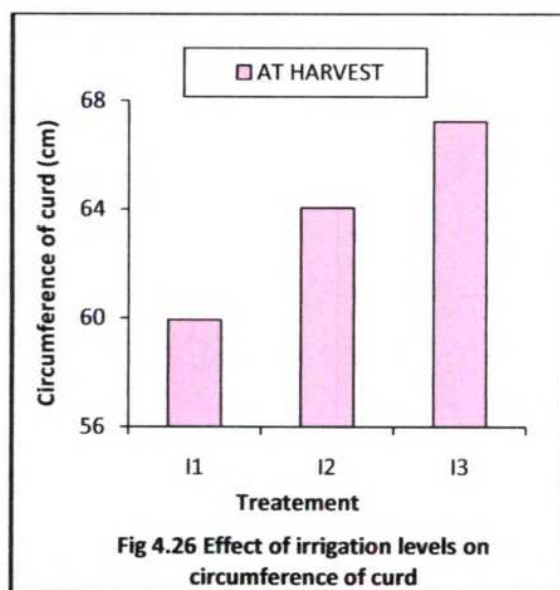
The effect of irrigation method on circumference of cauliflower curd was non significant. However, the data shown in Table 4.18 reveal that the mean circumference of curd was numerically higher in the plots irrigated by subsurface drip method (M_2) than the surface drip (M_1).

4.4.2.2 Effect of irrigation depths on circumference of curd

The irrigation depth could significantly influence the circumference of curd. The irrigation depth I_3 (0.8 PE) gave significantly highest curd circumference (67.24 cm) than I_1 and I_2 treatment (Fig 4.26).

4.4.3.2.3 Effect of fertilizer levels on circumference of curd

The effect of fertilizer levels on the circumference of curd was also not significant (Fig 4.27). However the fertilizer level F_3 (100% RDF) gave slightly higher curd circumference as compared to F_1 and F_2 fertigation levels.



4.4.2.4 Interaction effect on circumference of curd

The circumference of cauliflower curd could not be significantly affected due to any of the interaction effect. All the interaction effects of irrigation method, irrigation depth and fertigation levels on curd circumference were non significant.

Table 4.18 Effect of various irrigation methods, irrigation depths and fertilizer level on circumference of curd

Irrigation methods	Circumference of curd (cm)
M ₁ - Surface drip	61.33
M ₂ -Subsurface drip	66.16
S. E ± 1.255	C.D at 5% NS
Effect of irrigation depths on circumference of curd (cm)	
I ₁ – (0.4 PE)	59.93
I ₂ – (0.6 PE)	64.06
I ₃ – (0.8 PE)	67.24
S. E ± 0.651	C.D at 5% 2.121
Effect of fertilizer levels on circumference of curd (cm)	
F ₁ - 50% RDF	63.36
F ₂ - 75% RDF	63.60
F ₃ - 100% RDF	64.28
S. E ± 0.867	C.D at 5% NS
Interaction (M x I)	
S. E ±	0.921
C. D at 5%	NS
Interaction (M x F)	
S. E ±	1.227
C. D at 5%	NS
Interaction (I x F)	
S. E ±	1.502
C. D at 5%	NS
Interaction (M x I x F)	
S. E ±	2.125
C. D at 5%	NS

4.4.2.5 Comparison of surface and drip irrigation with regards to circumference of curd

Effect of different irrigation strategies and fertilizer levels on circumference of curd in all treatments by drip method was significantly higher as compared to surface (control) method. The irrigation strategy S₆ (subsurface drip with 0.8 PE) gave significantly highest curd circumference (70.12 cm) as compared to all the strategies and was at par with S₆ (subsurface drip with 0.6 PE).

As regards the fertilizer levels, its effect on curd circumference was not significant. Similarly the interaction effects of irrigation strategy and fertilizer levels were also statistically non significant.

Table 4.19 Effect of Irrigation strategy and fertilizer levels on circumference of curd

Factor	Treatment	Circumference of curd
Main		at harvest
Irrigation strategy (S)	S ₁ - Surface drip (0.4 PE)	58.96
	S ₂ - Surface drip (0.6 PE)	60.66
	S ₃ - Surface drip (0.8 PE)	64.37
	S ₄ - Subsurface drip (0.4 PE)	60.90
	S ₅ - Subsurface drip (0.6 PE)	67.46
	S ₆ -Subsurface drip (0.8 PE)	70.12
	S ₇ - control 1.2 IW/CPE	57.12
	S.E. ±	1.325
	CD at 5%	3.834
Fertilizer levels (F)	F ₁ – 50% RDF	62.07
	F ₂ – 75% RDF	62.73
	F ₃ – 100% RDF	63.60
	S.E. ±	0.828
	CD at 5%	NS
Interaction on SX F	S.E. ±	2.191
	CD at 5%	NS

The results obtained in the preceding section on yield attributes of cauliflower are in agreement with those reported by El-Gindy and El-Araby (1996), Al-Omran *et al.* (2005) and Al-Habri *et al.* (2008) also observed higher yields under subsurface drip as compared to surface drip irrigation. Realization of higher yields under sub surface drip over surface drip is also in confirmation with Singh and Rajput (2007) and Camp (1998) who found equal or greater yields of vegetables and row crops in subsurface drip as compared to surface drip. The better yields obtained in subsurface drip irrigation could be attributed to the reduced evaporation from top soil, and better water utilization by crop and uniform moisture distribution in the root zone in subsurface drip irrigation, this has been also revealed in Fig. 4.9 through 4.23.

As regards the fertilizer levels the yields under 50% RDF are also comparable with 75% and 100% RDF. Under subsurface drip the fertilizers applied at 15 cm depth might redistribute differently in the soil profile than surface applied fertilizers which resulted in better yields. These results are in conformity with earlier findings of Lamn *et al.* (2001). Although the results presented on yields of cauliflower indicate non significant difference due to irrigation method, the quality of cauliflower curd was superior under drip irrigated plots especially under subsurface drip. This has been shown in Plate 4.8. The cauliflower curds under subsurface drip plots were white, tender and without cracking and yellowing. This could be the additional benefits obtained with subsurface drip irrigation as regards the quality aspects of produce.

4.5 Water Saving and Water Use Efficiency

The irrigation was scheduled in surface irrigation at 1.2 IW/CPE when the cumulative pan evaporation reaches 50 mm. The depth of water applied was 60 mm. In case of surface and sub surface drip irrigation methods, the irrigation was scheduled at an alternate day with 0.4 PE, 0.6 PE and 0.8 PE. The actual depth of water applied in both the cases was measured. The data regarding actual water applied and the water saving over surface method is presented in Table 4.20.

Table 4.20 Water expense under different irrigation depths

Treatments	Water (ha-mm)		Water saving (%)	Additional area under irrigation (%)
	applied	Saving over control		
Control (Surface)	600.00	--	--	--
Drip irrigation depths				
I ₁	183.68	416.32	69.38	226
I ₂	255.52	344.48	57.41	135
I ₃	327.36	272.64	45.44	83

Data presented in Table 4.20 show that the depth of water applied in surface control was higher as compared to all the depths under drip irrigation. The drip irrigation could save water to the tune of 69.38, 57.41 and 45.44%, respectively under I₁, I₂ and I₃ irrigation depths over surface irrigation. Similarly an additional area of 226, 135 and 83 per cent can be brought under irrigation, if the crop is



Plate No. 4.7 Harvested curds from the plots of surface drip (treatment $M_1I_2F_3$)



Plate No. 4.8 Harvested curds from the plots of subsurface drip (treatment $M_2I_2F_3$)

irrigated under drip irrigation with 0.4 PE, 0.6 PE and 0.8 PE irrigation depths, respectively.

4.5.1 Water use efficiency

Data on water use efficiency (kg/ha-mm) of cauliflower as influenced by different treatments are presented in Table 4.21. The application of irrigation water through surface drip irrigation method (M_1) and subsurface drip irrigation method (M_2) appreciably improved water use efficiency which was two to three times higher than surface irrigation.

Table 4.21 Water use efficiency (kg/ha-mm) of cauliflower as influenced by different irrigation depths

Treatment	Yield (Kg/ha)	Water applied (mm)	Effective Rainfall (mm)	Total water use (mm)	Water use efficiency (kg/ha-mm)
M_1I_1	20,668.08	183.68	39.80	223.48	92.48
M_1I_2	22,393.26	255.52	39.80	295.32	75.83
M_1I_3	25,016.72	327.36	39.80	367.16	68.14
Mean	22,692.69	255.52	39.80	295.32	78.82
M_2I_1	22,548.87	183.68	39.80	223.48	100.90
M_2I_2	25,657.15	255.52	39.80	295.32	86.88
M_2I_3	26,944.44	327.36	39.80	367.16	73.39
Mean	25,050.15	255.52	39.80	295.32	87.05
Control (Surface)	18,244.60	600.00	39.80	639.80	28.52

Among the drip irrigation methods, water use efficiency under subsurface drip was higher (87.05 kg/ha-mm) than the surface drip irrigation (78.82 kg/ha-mm). The minimum water use efficiency was observed in control treatment of surface irrigation (28.52 kg/ha-mm).

It is obvious that among the irrigation depths the irrigation depth of 0.4 PE under surface drip (M_1I_1) gave the highest water use efficiency of 92.48 kg/ha-mm whereas lowest WUE (68.12 kg/ha-mm) was observed under 0.8 PE irrigation depth under surface drip method (M_1I_3).



Plate No.4.9 Harvested cards of surface irrigated control (I_7F_2)



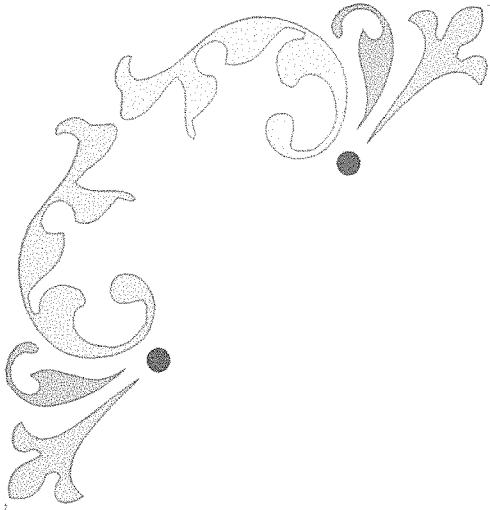
Plate No. 4.10 Harvested cards of cauliflower from surface irrigation plots control
(I_7F_3)

4.6 Fertilizer use efficiency

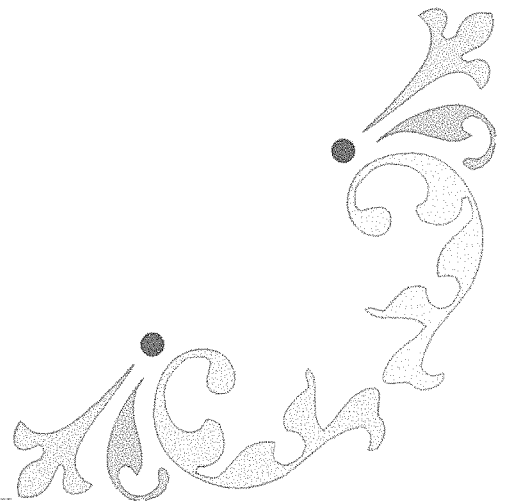
Fertilizer use efficiency of cauliflower under different treatments is presented in Table 4.22. The highest fertilizer use efficiency was observed in $M_2I_3F_1$ and $M_1I_3F_1$ treatments. This is because the yields were comparatively higher and the fertilizers used were lower resulting into higher fertilizer use efficiency. Within the drip system subsurface drip irrigation gave highest fertilizer use efficiency under all irrigation depths as compared to surface drip system. The fertilizer use efficiency under control surface irrigation is significantly lower (108.57 kg/ kg of fertilizer use).

Table 4.22 Fertilizer use efficiency of cauliflower under different treatments

Treatments	Fertilizer use efficiency (kg/kg of fertilizer use)			
	F ₁	F ₂	F ₃	Mean
M_1I_1	186.29	119.78	75.37	127.15
M_1I_2	168.85	124.28	102.28	131.80
M_1I_3	199.22	122.99	120.86	147.69
M_2I_1	168.77	122.11	105.89	132.26
M_2I_2	190.65	146.38	115.60	150.88
M_2I_3	205.23	153.58	119.00	159.27
control	142.44	105.76	77.51	108.57
Mean	180.21	127.84	102.36	



SUMMARY AND CONCLUSION



CHAPTER-V

SUMMARY AND CONCLUSIONS

Water and nutrients are the basic needs of any crop. Cauliflower, one of the most important vegetable crops, is very sensitive to moisture and nutrients stress. It requires comparatively more water and nutrients in precise quantity and at appropriate time. Nevertheless water scarcity and high input cost of fertilizer are the major constraints in increasing the area, production and productivity of cauliflower. In order to get rid of these constraints irrigation with fertigation through drip is the most suitable option, which can save water and fertilizer in addition to increase in the area along with increasing productivity. Besides, drip irrigation method provides many other associated benefits like saving in pesticides and labour. Much of work has been done on growth and yield response of various vegetable crops under drip including scheduling. The moisture distribution pattern under drip also has been studied by the researchers. Subsurface drip irrigation has been evolved as a new method for close growing crops because of its capability for minimizing the loss of water by evaporation, runoff and deep percolation in addition to precise placement and management of water, nutrient and pesticides and greater application uniformity. However, the research on subsurface drip irrigation under vegetable crops is scanty. The studies on fertigation scheduling and evaluation of performance of drip irrigation with fertigation are also limited.

In view of the above points, the field experiment entitled " Comparative performance of surface and subsurface drip fertigation for cauliflower" was conducted during October 2010 to March 2011 at research farm of AICRP on Water Management, Marathwada Krishi Vidyapeeth Parbhani.

The initial soil samples from the experimental plot were collected and analyzed for physical and chemical composition of soil adopting usual procedures. The experimental design was split plot with irrigation methods (surface and subsurface drip) as main factor and three irrigation depths (0.4, 0.6

and 0.8 PE) and three fertigation levels (50, 75 and 100 % RDF) as sub factors. The results were then compared with control treatment consisting of furrow irrigation of 60 mm depth scheduled at 1.2 IW/CPE. Thus twenty one treatment combinations were replicated thrice.

Initially the seedlings were prepared and six weeks old seedlings were transplanted on the experimental plots. The gross and net plot size was 4.8 x 3.6 m and 4.2 x 3.0 m, respectively. The plant to plant and row to row spacing of 60 cm was maintained. For subsurface drip plots the laterals were laid 15 cm below the ground and were covered with soil. Subsurface and surface drip irrigation was scheduled with three irrigation depths viz., I_1 , I_2 and I_3 at an alternate day as desired by the treatments and depending on pan evaporation. The recommended dose of fertilizer with N: P: K as 120:60:60 kg/ha was used for the irrigated cauliflower. The fertilizers were applied in splits through irrigation water in drip irrigated control plots using venturi while in surface irrigated plots they were conventionally applied in soil by ring placement. Water soluble fertilizers of grade 19:19:19, Urea, 0:52:34, 0:0:50 and 12:61:0 were used for fertigation whereas for surface irrigated plots urea, MOP and SSP were used as fertilizer source.

The weather data were collected from IMD recognized observatory of Meteorology Department, Marathwada Krishi Vidyapeeth Parbhani. The evaporation was estimated by open pan evaporation method. The amount of water applied at an alternate day by drip irrigation was calculated on the basis previous two days cumulative pan evaporation.

Cultural operations and plant protection measures were taken up as and when required during different stages crop growth. The growth parameters viz. plant height; number of leaves; diameter of stem and leaf area index were periodically recorded at an interval of 30 days. At harvest, the curd circumference and curd yield was measured. In order to assess the moisture distribution under surface and subsurface drip method the moisture content was measured under different irrigation depths for a one week irrigation cycle. For which the soil samples were collected by screw auger at 0-15 and 15-30 cm soil

depth and moisture content in soil profile was determined gravimetrically. The root length density between the crop rows was measured in each plot at 30 DAP, 60 DAP and at harvest.

The measured data was analyzed using MAUSTAT software and the results are interpreted and discussed.

Conclusions

Based on the results of the present investigation following conclusions are drawn:

The vegetative growth of cauliflower in term of plant height, number of leaves, stem diameter and leaf area index is better in subsurface drip than surface drip irrigation. In this regard, better crop growth can be achieved if surface drip irrigation is scheduled at 0.8 PE as compared to 0.4 PE whereas in subsurface irrigation depth of 0.6 PE can be adopted without affecting the crop growth thereby saving in water use. For most of the growth parameters the effect of fertilizer level is non significant indicating use of lower dose as desirable than the recommended dose of 120: 60: 60; N: P₂O₅:K₂O kg ha⁻¹.

As far as yield is concerned subsurface drip irrigation gives higher curd yield (25.05 t ha⁻¹) as compared to surface drip (22.69 t ha⁻¹) and conventional furrow irrigation (18.24 t ha⁻¹). The subsurface drip irrigation with 0.6 PE irrigation depths gives higher curd yield whereas use of lower fertilizer dose of 50% RDF through fertigation can be adopted without much reduction in the curd yield.

The sub surface drip irrigation system should be scheduled at an alternate day with 0.6 PE depth of irrigation. The total water requirement of cauliflower under drip irrigation is 295.32 mm. The combination of subsurface drip with 0.8 PE depth of water and 50% of RDF gives the highest fertilizer use efficiency. Similarly subsurface drip irrigation results in higher root length density and uniform moisture distribution

Although the effect of irrigation method and depth of irrigation are not significant in many cases, the subsurface drips have shown better results with indication of reduction in irrigation depth and fertilizers. The root length

density and moisture distribution pattern can well be studied if the monitoring is done more frequently and also at lower depths.

These results are based on one season trial only; hence they are suggestive and needs repetitions for further confirmations. The cost economics also needs to be worked out which will help in deciding the appropriate strategy for fertigation of short duration crops.



**LITERATURE
CITED**

LITERATURE CITED

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APPENDICES

Appendix - A

Weather data for the experimental period at Parbhani

Date	Rainfall (mm)	Temperature (^o C)		Humidity (%)		EVP (mm)	BSS (Hrs.)	Wind Velocity (Kmph)
		Max.	Min.	AM	PM			
01-Oct-10	0.0	32.0	19.0	80	47	5.2	10.5	4.8
02-Oct-10	0.0	32.5	18.5	91	48	4.6	10.0	3.5
03-Oct-10	0.0	32.0	22.7	79	50	5.4	6.1	2.7
04-Oct-10	1.4	32.5	22.3	84	62	4.4	8.6	3.7
05-Oct-10	0.0	32.6	22.0	83	52	5.0	6.6	2.6
06-Oct-10	0.0	33.2	22.3	76	37	5.0	8.2	4.0
07-Oct-10	0.0	34.8	20.7	77	37	4.7	9.9	3.5
08-Oct-10	0.0	33.5	19.4	74	36	5.2	10.3	3.8
09-Oct-10	0.0	34.2	18.7	72	47	5.6	10.0	3.7
10-Oct-10	0.0	33.5	18.4	75	40	4.6	7.8	2.9
11-Oct-10	0.0	34.5	22.5	74	46	5.0	9.8	5.7
12-Oct-10	0.0	33.5	22.4	70	39	5.6	9.5	4.9
13-Oct-10	0.0	33.5	19.8	71	38	4.7	7.3	2.1
14-Oct-10	0.0	33.8	19.5	77	30	5.4	9.4	2.7
15-Oct-10	0.0	35.2	18.5	78	29	5.5	8.3	3.6
16-Oct-10	0.0	34.5	23.0	72	53	5.7	7.7	5.6
17-Oct-10	4.4	31.0	23.0	100	84	2.7	0.3	4.8
18-Oct-10	3.0	28.5	22.5	90	65	3.0	2.1	4.1
19-Oct-10	0.0	29.5	22.7	83	53	3.5	1.7	4.2
20-Oct-10	15.8	33.0	21.5	100	59	3.8	6.6	1.7
21-Oct-10	0.0	31.9	22.4	83	53	4.6	10.7	2.7
22-Oct-10	3.6	33.5	21.5	91	66	3.8	9.6	3.7
23-Oct-10	3.0	30.5	21.5	100	60	2.0	6.5	2.5
24-Oct-10	0.0	30.0	19.4	82	55	3.2	6.4	2.0

25-Oct-10	0.0	32.5	19.8	75	45	4.0	10.3	2.5
26-Oct-10	0.0	32.5	19.4	77	40	4.4	10.1	1.8
27-Oct-10	0.0	32.5	17.0	72	32	4.9	10.3	3.8
28-Oct-10	0.0	32.3	15.5	76	30	5.4	9.9	3.5
29-Oct-10	0.0	32.5	16.0	73	34	5.4	10.2	3.2
30-Oct-10	0.0	31.3	15.5	72	35	6.1	9.3	4.2
31-Oct-10	0.0	29.8	21.0	71	40	6.2	6.8	6.9
01-Nov-10	0.0	29.5	15.5	70	38	6.6	3.7	6.8
02-Nov-10	0.0	29.0	17.0	72	54	6.2	9.6	6.4
03-Nov-10	0.0	29.3	19.4	66	65	5.1	9.8	6.0
04-Nov-10	0.0	29.0	21.0	88	68	3.8	4.0	4.7
05-Nov-10	36.2	29.7	21.3	91	57	4.4	3.9	2.6
06-Nov-10	0.0	31.4	19.0	91	52	4.2	7.9	2.3
07-Nov-10	0.0	29.8	15.5	82	44	3.7	7.7	2.2
08-Nov-10	0.0	30.2	21.5	73	65	5.6	9.2	8.2
09-Nov-10	4.0	29.5	21.5	88	53	2.8	3.5	11.7
10-Nov-10	0.0	31.0	21.4	75	60	4.6	9.5	7.5
11-Nov-10	0.0	32.2	21.7	81	48	3.4	8.2	2.3
12-Nov-10	1.8	33.2	22.1	95	61	3.8	8.8	1.8
13-Nov-10	0.0	31.6	21.2	83	54	3.6	9.2	1.7
14-Nov-10	1.0	32.0	21.6	91	59	3.3	6.4	2.6
15-Nov-10	0.0	32.2	21.4	77	54	4.2	8.9	2.7
16-Nov-10	0.0	31.3	18.5	84	45	4.3	8.8	3.4
17-Nov-10	0.0	31.0	17.5	79	60	4.6	10.8	3.0
18-Nov-10	0.0	31.0	21.4	88	57	4.8	9.2	6.2
19-Nov-10	37.6	31.5	21.0	95	56	4.0	4.0	3.5
20-Nov-10	1.0	31.9	20.5	91	60	3.2	10.0	2.8
21-Nov-10	2.5	30.8	21.0	100	64	3.9	7.6	1.8
22-Nov-10	9.2	30.5	20.5	100	64	3.0	6.6	3.7
23-Nov-10	0.0	29.5	19.0	91	51	3.7	8.8	4.7
24-Nov-10	0.0	31.6	18.5	84	52	3.6	10.1	2.5
25-Nov-10	0.0	31.5	17.5	86	46	3.8	10.0	2.4

26-Nov-10	0.0	31.5	17.5	85	34	3.3	9.3	1.8
27-Nov-10	0.0	31.5	19.4	82	41	4.0	9.7	1.8
28-Nov-10	0.0	31.5	16.0	75	43	4.5	4.4	1.7
29-Nov-10	0.0	31.0	17.5	73	41	4.4	9.3	2.0
30-Nov-10	0.0	31.2	15.5	82	39	4.6	10.1	2.1
01-Dec-10	0.0	32.0	15.8	80	46	3.7	9.8	1.9
02-Dec-10	0.0	31.2	15.7	79	46	3.9	9.9	2.6
03-Dec-10	0.0	31.0	16.4	75	48	3.8	9.0	1.7
04-Dec-10	0.0	29.6	15.0	82	45	3.2	8.3	2.2
05-Dec-10	0.0	29.5	14.0	79	37	2.8	7.7	2.5
06-Dec-10	0.0	28.5	11.0	74	29	4.1	9.2	5.0
07-Dec-10	0.0	27.0	14.5	73	59	4.2	3.3	6.8
08-Dec-10	0.0	26.5	20.3	75	71	3.3	6.2	6.6
09-Dec-10	0.0	26.0	19.8	93	52	2.2	0.5	3.6
10-Dec-10	0.5	30.7	18.5	90	50	2.2	9.3	3.2
11-Dec-10	0.0	28.0	16.0	98	45	3.0	5.7	2.1
12-Dec-10	0.0	30.0	12.2	73	48	3.8	9.5	4.0
13-Dec-10	0.0	27.0	10.9	74	36	3.6	9.4	2.8
14-Dec-10	0.0	28.0	10.1	78	42	3.2	9.4	2.8
15-Dec-10	0.0	27.0	10.3	74	32	3.5	9.7	2.9
16-Dec-10	0.0	27.8	7.5	76	31	4.0	9.8	3.2
17-Dec-10	0.0	27.0	5.9	72	32	3.8	10.3	2.6
18-Dec-10	0.0	27.0	6.0	73	27	3.3	10.4	2.8
19-Dec-10	0.0	27.2	5.4	75	24	3.6	10.8	3.1
20-Dec-10	0.0	27.5	5.3	75	21	4.6	10.8	4.6
21-Dec-10	0.0	28.0	5.4	70	23	4.2	10.7	3.3
22-Dec-10	0.0	29.5	6.0	74	22	4.2	9.5	2.0
23-Dec-10	0.0	30.0	6.5	79	21	3.6	9.1	1.4
24-Dec-10	0.0	31.0	7.0	75	27	4.2	9.8	2.0
25-Dec-10	0.0	30.5	9.0	73	33	3.9	10.0	1.9
26-Dec-10	0.0	29.0	8.5	71	32	3.5	10.5	1.9

27-Dec-10	0.0	29.2	11.0	70	39	3.6	10.2	2.7
28-Dec-10	0.0	28.0	12.3	72	43	4.0	10.0	4.0
29-Dec-10	0.0	28.0	10.5	69	41	3.8	9.6	3.3
30-Dec-10	0.0	28.7	13.5	70	47	3.9	9.6	3.0
31-Dec-10	0.0	28.6	18.0	68	51	4.3	8.0	2.9
01-Jan-11	0.0	26.5	15.9	73	46	4.0	2.0	4.2
02-Jan-11	0.0	25.8	14.9	69	60	3.6	2.0	5.0
03-Jan-11	0.0	25.0	13.2	78	44	3.3	1.2	4.3
04-Jan-11	0.0	27.5	14.0	66	45	3.7	6.1	4.0
05-Jan-11	0.0	28.0	10.5	72	34	1.5	8.3	2.9
06-Jan-11	0.0	27.5	4.0	75	23	4.3	10.1	3.7
07-Jan-11	0.0	26.5	3.9	76	22	3.3	10.4	3.5
08-Jan-11	0.0	26.6	4.5	77	24	3.8	10.8	3.0
09-Jan-11	0.0	28.0	5.0	73	26	4.2	10.8	2.2
10-Jan-11	0.0	28.5	6.0	73	28	4.0	10.9	2.4
11-Jan-11	0.0	27.5	5.8	75	25	3.5	11.0	3.8
12-Jan-11	0.0	28.5	5.8	64	78	4.0	11.0	2.7
13-Jan-11	0.0	32.1	6.8	74	18	4.2	10.7	2.1
14-Jan-11	0.0	32.1	8.8	72	16	4.5	10.8	3.3
15-Jan-11	0.0	33.0	8.9	74	22	4.9	10.9	2.6
16-Jan-11	0.0	29.5	10.5	72	25	4.7	10.2	2.7
17-Jan-11	0.0	29.5	8.7	74	28	4.6	11.0	2.7
18-Jan-11	0.0	29.8	7.7	80	26	4.6	11.1	2.4
19-Jan-11	0.0	31.3	9.1	75	26	4.8	10.8	2.6
20-Jan-11	0.0	31.5	10.0	76	28	4.5	10.7	3.0
21-Jan-11	0.0	30.8	8.9	72	26	4.8	11.0	3.0
22-Jan-11	0.0	30.0	7.9	77	25	4.3	10.9	2.5
23-Jan-11	0.0	30.5	7.5	77	26	4.0	10.9	2.8
24-Jan-11	0.0	31.8	10.0	71	28	4.7	10.7	2.5
25-Jan-11	0.0	32.0	11.6	70	26	5.2	10.5	2.5
26-Jan-11	0.0	33.5	11.5	76	28	5.0	11.1	2.4
27-Jan-11	0.0	31.2	12.0	71	27	4.5	10.9	1.5

28-Jan-11	0.0	32.2	12.0	70	24	5.0	10.6	2.3
29-Jan-11	0.0	33.0	12.9	70	25	5.4	10.8	1.9
30-Jan-11	0.0	33.0	12.5	76	28	4.0	10.6	3.1
31-Jan-11	0.0	32.5	14.0	72	33	5.3	10.3	3.2
01-Feb-11	0.0	31.8	13.0	70	31	4.8	10.3	2.5
02-Feb-11	0.0	32.5	13.5	69	28	5.0	10.3	2.1
03-Feb-11	0.0	31.8	13.0	68	26	4.6	10.3	2.2
04-Feb-11	0.0	31.6	10.0	74	16	4.9	10.7	3.0
05-Feb-11	0.0	31.5	8.9	79	23	4.6	10.8	2.8
06-Feb-11	0.0	32.5	8.5	84	26	4.8	11.2	3.2
07-Feb-11	0.0	32.8	8.9	82	27	4.7	10.8	3.3
08-Feb-11	0.0	33.0	12.0	89	28	5.0	10.4	2.4
09-Feb-11	0.0	33.0	12.2	80	26	5.2	10.4	2.6
10-Feb-11	0.0	33.5	11.9	78	21	5.5	10.6	2.2
11-Feb-11	0.0	33.6	13.3	76	20	5.6	10.6	2.6
12-Feb-11	0.0	33.5	13.0	74	24	7.2	10.7	3.9
13-Feb-11	0.0	32.5	13.0	73	24	7.0	10.5	2.6
14-Feb-11	0.0	34.0	13.9	71	20	7.4	10.5	2.6
15-Feb-11	0.0	33.5	12.9	80	17	7.2	10.8	2.7
16-Feb-11	0.0	34.2	15.8	71	35	6.4	10.3	4.5
17-Feb-11	0.0	30.0	14.0	74	36	5.0	9.0	4.5
18-Feb-11	0.0	31.5	12.7	73	30	4.9	10.5	3.7
19-Feb-11	0.0	31.5	14.0	67	37	5.2	10.3	4.1
20-Feb-11	0.0	32.4	18.0	65	41	5.4	9.6	3.9
21-Feb-11	0.0	32.5	17.5	76	38	5.8	8.5	6.0
22-Feb-11	0.0	30.3	12.9	80	33	6.3	9.7	5.8
23-Feb-11	0.0	31.0	13.5	74	36	6.0	10.5	5.0
24-Feb-11	0.0	31.5	18.4	70	39	6.6	9.1	4.3
25-Feb-11	0.0	31.8	15.7	72	29	5.8	6.7	3.9
26-Feb-11	0.0	32.7	14.5	61	28	5.8	9.8	4.2
27-Feb-11	0.0	32.3	16.0	83	39	5.7	9.7	4.1
28-Feb-11	0.0	33.0	19.5	87	41	5.7	8.8	5.0

01-Mar-11	0.0	31.5	16.8	74	33	5.5	8.5	4.5
02-Mar-11	0.0	32.7	18.9	71	33	6.0	8.3	3.5
03-Mar-11	0.0	34.0	18.0	74	33	6.4	8.6	3.7
04-Mar-11	0.0	35.5	19.0	69	22	6.7	9.4	3.7
05-Mar-11	0.0	36.0	19.0	67	22	7.1	10.1	3.3

Appendix-B

Details of irrigation schedule under different treatments

Date	DAP	Rainfall	ER	Evaporation	CPE	Depth of irrigation (mm)			Volume of irrigation (lph)			Time of operation (min)						
						I1	I2	I3	Control	I1	I2	I3	I1	I2	I3			
17-Nov	0	0.0		4.6														
18-Nov	1	0.0		4.8														
19-Nov	2	37.6	37.6	4.0														
20-Nov	3	1.0		3.2														
21-Nov	4	2.5		3.9														
22-Nov	5	9.2	9.2	3.0														
23-Nov	6	0.0		3.7														
24-Nov	7	0.0		3.6														
25-Nov	8	0.0		3.8														
26-Nov	9	0.0		3.3														
27-Nov	10	0.0		4.0														
28-Nov	11	0.0		4.5		40	40	40	60									
29-Nov	12	0.0		4.4														
30-Nov	13	0.0		4.6														
01-Dec	14	0.0		3.7														

28-Feb	103	0.0		5.7	11.4	4.56	6.84	9.12	1.73	2.59	3.46	41.04	61.56	82.08
						183.68	255.52	327.36						

* Wetted area of 0.27 and 0.36 m² was consider from 8 to 35 and 36 to 103 DAP, respectively

Appendix-C

Measured soil moisture constants at different location and soil depths

C-I Soil moisture contents measured below the emitter

Day of Irrigation cycle	Depth (cm)	I1	I2	I3	I4	I5	I6	I7
1	15	36.82	35.61	35.14	34.19	37.01	38.63	24.13
	30	33.49	33.29	31.25	32.79	35.67	38.83	25.65
2	15	37.65	37.94	37.73	36.97	41.92	38.92	23.14
	30	35.54	37.30	35.83	35.88	38.15	39.67	24.12
3	15	35.01	33.45	31.54	34.02	37.41	38.45	22.56
	30	34.13	30.89	30.58	29.68	34.40	36.97	23.56
4	15	36.49	35.97	35.81	35.69	39.89	40.06	21.24
	30	35.70	34.73	35.34	32.38	38.88	38.89	21.38
5	15	36.13	33.51	37.26	31.25	32.56	37.87	20.11
	30	32.93	27.29	33.88	30.54	30.12	32.21	19.56
6	15	37.04	34.55	40.46	35.90	35.59	40.09	21.10
	30	33.73	32.96	36.97	33.03	33.19	36.66	22.38
7	15	35.47	34.00	39.55	37.22	39.41	39.12	17.29
	30	32.56	31.04	39.32	35.93	34.12	34.38	16.42
8	15	37.78	38.61	39.04	37.54	38.02	39.57	16.55
	30	35.38	36.48	38.73	37.15	37.87	38.82	15.23
9	15	33.12	34.22	34.25	34.59	34.89	31.22	15.00
	30	28.56	30.98	31.22	29.66	30.21	28.63	14.96
10	15	35.12	37.75	36.98	37.10	38.14	34.23	15.00
	30	30.00	32.98	33.14	31.28	33.12	31.73	14.22
11	15	31.22	31.22	32.54	32.87	33.66	32.31	15.21
	30	28.56	29.89	30.21	28.65	29.49	30.14	14.33
12	15	35.13	36.42	37.64	38.22	39.28	39.38	30.23
	30	30.48	32.13	34.12	33.28	34.27	36.52	32.14

C-II Soil moisture content measured at 15cm horizontal distance from emitter

Day of Irrigation cycle	Depth (cm)	I1	I2	I3	I4	I5	I6	I7
1	15	34.52	34.51	31.12	33.30	39.09	37.91	23.56
	30	29.04	31.22	30.01	31.10	34.12	37.39	22.89
2	15	36.13	37.16	36.16	36.52	40.71	40.66	22.13
	30	33.81	34.29	34.85	34.97	38.92	39.87	21.02
3	15	27.53	30.89	30.46	30.12	34.37	36.72	21.54
	30	29.13	26.48	29.63	27.41	30.54	29.11	20.13
4	15	32.38	32.05	35.70	34.06	36.46	38.13	20.15
	30	32.06	29.72	33.10	30.73	34.02	31.59	21.14
5	15	28.08	30.12	35.63	29.20	30.21	34.56	19.56
	30	26.13	24.02	31.35	24.51	29.65	29.55	20.18
6	15	28.90	32.39	37.51	30.32	33.56	36.81	20.12
	30	27.58	29.63	33.60	27.87	31.21	32.42	19.13
7	15	27.90	30.12	38.87	34.51	34.21	32.12	16.55
	30	27.38	32.42	34.55	36.51	31.22	30.12	17.89
8	15	32.75	37.23	38.44	37.67	38.71	39.02	19.32
	30	29.35	34.12	35.69	39.21	37.41	39.21	16.57
9	15	20.13	29.98	30.21	31.85	31.55	27.42	17.86
	30	20.00	19.55	26.98	25.00	23.55	25.32	15.22
10	15	21.19	31.86	32.08	33.99	33.84	30.42	18.56
	30	20.79	21.78	27.44	26.88	26.18	28.28	15.21
11	15	19.14	28.96	30.10	30.21	30.56	32.12	17.20
	30	19.00	18.33	21.56	23.66	23.57	25.19	14.98
12	15	20.21	31.42	33.22	33.28	33.64	34.13	27.98
	30	19.56	19.33	25.42	26.28	28.27	27.73	28.56

C-III Soil moisture content measured at 30cm horizontal distance from emitter

Day of Irrigation cycle	Depth (cm)	I1	I2	I3	I4	I5	I6	I7
1	15	18.82	21.14	24.15	22.43	23.78	23.55	20.15
	30	17.83	20.21	21.13	19.76	20.18	21.22	19.13
2	15	23.97	24.03	26.39	24.96	25.45	26.53	19.45
	30	20.16	21.22	23.27	21.03	23.21	24.15	18.74
3	15	22.06	21.23	23.55	20.72	23.07	23.15	18.56
	30	18.44	19.67	21.45	19.57	20.14	20.11	18.00
4	15	22.15	23.28	25.46	23.45	25.78	26.61	18.56
	30	19.13	22.22	22.78	21.68	23.35	25.12	17.12
5	15	23.56	23.88	22.31	21.33	21.54	21.97	17.00
	30	20.13	18.88	19.59	18.55	19.13	20.05	16.45
6	15	24.00	24.28	25.00	24.06	24.77	26.65	19.17
	30	21.20	21.35	22.16	20.48	22.00	23.25	18.39
7	15	20.13	21.35	21.55	21.10	21.56	20.13	16.00
	30	17.81	18.56	19.36	15.12	18.65	18.20	15.21
8	15	21.68	23.15	24.00	22.64	24.75	25.82	15.63
	30	18.24	19.53	20.35	19.65	21.26	22.49	15.00
9	15	21.35	22.14	22.45	21.55	21.66	24.12	15.20
	30	19.00	19.55	19.96	19.62	19.78	21.45	14.25
10	15	22.47	23.16	24.26	23.41	24.85	26.24	17.89
	30	19.78	20.31	21.08	20.86	21.35	24.19	16.45
11	15	19.98	20.15	21.22	20.14	21.68	23.69	16.54
	30	19.11	19.02	19.82	17.21	18.00	18.95	15.23
12	15	21.23	22.68	24.56	23.45	25.74	27.01	26.71
	30	19.54	20.17	22.06	18.47	20.47	22.22	24.13

Comparative performance of surface and subsurface drip fertigation for cauliflower

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ABSTRACT

The experiment was conducted to evaluate the effect of surface and subsurface drip irrigation with fertigation on the growth and yield response of cauliflower (*Brassica oleracea* L.) through field experiment. The treatment consisted of two irrigation methods viz., surface and subsurface drip irrigation, three irrigation depths I₁ (0.4 PE), I₂ (0.6 PE) and I₃ (0.8 PE), and three fertigation levels viz. F₁ (50% RDF), F₂ (75% RDF) and F₃ (100% RDF). The results were also compared with conventional surface irrigation with 1.2 IW/CPE and above three fertilizer levels. The surface drip laterals were placed on the surface whereas in subsurface drip the laterals were placed at 15 cm depth below surface and the drip irrigation was scheduled at alternate day. The experimental design was split plot with three replications. The biometric attributes viz., plant height, number of leaves, stem diameter, leaf area index and yield attributes viz., total curd yield and circumference of curd were monitored periodically. The profile soil moisture during irrigation cycle and root length density at harvest also was measured by taking the soil samples.

The results indicated that plant height, number of leaves, stem diameter, leaf area index, and root length density of cauliflower increased due to subsurface placement of laterals. The subsurface drip produced numerically higher curd yield (25.05 t ha⁻¹) as compared to surface drip (22.69 t ha⁻¹) and conventional furrow

irrigation (18.24 t ha^{-1}). Among irrigation depths the curd yields were significantly higher under I_2 (0.6 PE) and I_3 (0.8 PE) depth than I_1 (0.4 PE) depth. The effect of fertilizer levels on curd yield was not significant indicating beneficial use of lower fertilizer dose of 50% RDF ($60:30:30 \text{ kg ha}^{-1}$; N: P_2O_5 : K_2O) through fertigation with 8, 6 and 6 splits for nitrogen, phosphorous and potassium, respectively during the crop growth period (10 to 80 days after planting) without much reduction in the curd yield. The total water requirement of cauliflower under drip irrigation was 295.32 mm. The higher root length was obtained under subsurface drip irrigation. The spatial distribution of soil moisture was more uniform and near to field capacity under subsurface drip irrigation. Hence, for cauliflower subsurface drip irrigation system should be scheduled at an alternate day with irrigation depth of 0.6 of two days Pan Evaporation.

Key words: *Subsurface drip irrigation, fertigation, cauliflower, soil moisture content, root length density, water use efficiency.*



Signature of Student



Signature of Advisor