WATER AND NUTRIENT MANAGEMENT STUDIES ON CAULIFLOWER (*BRASSICA OLERACEA VAR. BOTRYTIS* L.) UNDER DRIP ENVIRONMENT

M.Tech. (Agril. Engg.) Thesis

by

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Thesis

Submitted to the

Indira Gandhi Krishi Vishwavidyalaya, Raipur

by

Khilendra Kumar

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in

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CERTIFICATE - I

This is to certify that the thesis entitled "**Water and nutrient management studies on cauliflower (*brassica oleracea var. botrytis* l.) under drip environment**" submitted in partial fulfillment of the requirements for the degree of **Master of Technology** in **Agricultural Engineering** of the Indira Gandhi Krishi Vishwavidyalaya, Raipur, is a record of the bonafide research work carried out by **Khilendra Kumar** under my guidance and supervision. The subject of the thesis has been approved by the Student's Advisory Committee and the Director of Instructions.

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

Chairman

Date: 14/9/2017

THESIS APPROVED BY THE STUDENT'S ADVISORY COMMITTEE

Chairman	(Dr. Devesh Pandey)	____________
Member	(Er. Prafull Katre)	____________
Member	(Dr. S. V. Jogdand)	____________
Member	(Dr. N. K. Chaure)	____________
Member	(Dr. Vinay K. Pandey)	____________

CERTIFICATE - II

This is to certify that the thesis entitled "**Water and nutrient management studies on cauliflower (*brassica oleracea var. botrytis* l.) under drip environment**" submitted by **Khilendra Kumar** to the Indira Gandhi Krishi Vishwavidyalaya, Raipur, in partial fulfilment of the requirements for the degree of **Master of Technology** in **Agricultural Engineering** in the Department of **Soil and Water Engineering** has been approved by the external examiner and Student's Advisory Committee after oral examination.

14-09-2017

Signature External Examiner

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Date: 14/9/17

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Head of the Department ______________________

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Approved/Not approved

Director of Instructions ______________________

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(Khilendra Kumar)

Place: Raipur

Date: 14.09.17

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Symbols	Description
%	Per cent
@	At the rate
=	Equal to
+	Plus
-	Minus
*	Multiplication
/	Division

LIST OF ABBREVIATIONS

Abbreviations	**Meanings**
Agril.	Agricultural
Agril. Engg.	Agricultural Engineering
CD	Critical difference
cm	Centimeter
CPE	Cumulative pan evaporation
cv.	Crop variety
DAT	Days after transplanting
Dept.	Department
^0C	Degree Celsius
^{0}	Degree
D.F.	Degrees of freedom
dS/m	Deci-Siemen per meter
ETo	Reference evapo-transpiration
ETc	Crop evapo-transpiration
et al.	And others
etc.	Etcetera
FAO	Food Agriculture Organization
Fig.	Figure
g	Gram
g lit^{-1}	Gram per liter
ha	Hectare
hr	Hour
i.e.	That is
K	Potassium
Kc	Crop coefficient
kg ha^{-1} mm^{-1}	Kilogram per hectare-millimeter
kg ha^{-1} cm^{-1}	Kilogram per hectare-centimeter
kg	Kilogram
kPa	Kilo Pascal
Ltd.	Limited
Lit	Liter
ℓph	Liter per hour
Mha	Million hectare
Mha-m	Million hectare meter
MT	Metric tones
MT ha^{-1}	Metric tons per hectare
mm ha^{-1}	Millimeter per hectare
m	Meter
m^2	Meter square
mm day^{-1}	Millimeter per day
mg	Milligram
MC	Moisture content
mm	Millimeter
M. Tech.	Master of Technology

N	Nitrogen
P	Phosphorus
Pvt.	Private
q $ha.^{-1}cm^{-1}$	Quintal per hectare centimeter
q ha^{-1}	Quintal per hectare
Rs.	Rupees
RDF	Recommended dose of fertilizer

THESIS ABSTRACT

a) Title of Thesis:	Water and Nutrient Management Studies on Cauliflower (*Brassica Oleracea Var. Botrytis* L.) under Drip Environment
b) Full Name of the Student:	Khilendra Kumar
c) Major Subject:	Soil and Water Engineering
d) Name and Address of the: Major Advisor	Dr. Devesh Pandey (IWM) ICAR BTC CARS, Bilaspur
e) Degree to be Awarded:	Master of Technology in Agricultural Engineering

Signature of the Student

Signature of Major Advisor

Date: 14/9/17

Signature of the Head of the Department

ABSTRACT

Water is one of the crucial inputs in farming. Its availability is tending to become increasingly scare and costly. Crops suffer greatly due to insufficient water availability and improper scheduling of water application resulting in low yields. Hence, conservation of water and its efficient use has assumed much importance in recent times. The major goal of water management is to meticulously harness the available quantities of water and put them to efficient use to realize higher productivity per unit of water. Drip irrigation which is also known as *micro-irrigation* is a form of irrigation that saves water and fertilizer by allowing water to drip slowly to the roots of individual plants, either onto the soil surface or directly onto the root zone, through a network of valves, pipes, tubing, and emitters. It is done through narrow tubes that deliver water directly to the base of the plant. Drip irrigation can help to use water efficiently. Fertigation is the application of water soluble solid or liquid fertilizer through drip irrigation system. Water and nutrient are the main factors of production in irrigated agriculture and are the major inputs in contributing higher productivity. In intensive agriculture, both fertilizer and irrigation management have contributed immensely in increasing the yield and quality of crops. A field experiment entitled "water and nutrient management studies on cauliflower (*Brassica Oleracea Var. Botrytis* L.) under drip environment" was conducted at Dau Kalayan Singh College of Agriculture and Research Station, IGKV, Bhatapara (C.G.). The experimental site of soil was tested in the laboratory and found Sandy loam soil. Soil moisture content at 15, 30, and 45 cm depth were measured 30.25, 32.56 and 30.10 respectively by gravimetric method. The performance of drip irrigation was measured on the basis of wetting pattern and uniformity coefficient for inline drippers (2 lph) at the pressure of 1.2 kg/cm^2. Horizontal and vertical wetting front advance were recorded for elapsed time of 30, 60, 90 120 and 150 minutes and found 6.2, 10.5, 14.3, 17.8 cm and 13.2, 17.0, 22.3, 25.8, 28.7 cm, respectively. The uniformity coefficient was estimated 95.32%.

Growth and yield of cauliflower was analysed under randomized block design with three levels of irrigation 60, 80, 100% CPE and three levels of fertigation 80, 100 120% and control (Furrow irrigation with 100% RDF). Water requirement of cauliflower has been quantified as 188.36, 251.15, 313.96 and 556.18 mm for irrigation 60, 80, 100% CPE and control, respectively. The experiment results revealed that drip irrigation at 80% CPE with 80% RDF performed the best for all the parameters viz. water use efficiency (1.14 $qha^{-1}mm^{-1}$) fertilizer use efficiency (0.50 q kg^{-1}), yield of cauliflower (28.58 t ha^{-1}), plant height (62.76 cm), number of leaves per plant (24.93), length of the largest leaf (49.33 cm), width of the largest leaf (26.30 cm), plant spread area (1966.50 cm^2), number of days after transplanting elapsed to curd maturity (75.82), weight of curd (771.36 gm/plant) and curd circumference (52.61 cm).

The cultivation of cauliflower with irrigation at 80% CPE with fertigation 80% RDF has given the highest gross returns Rs. 308739.6, and net returns Rs. 226646 with Benefit Cost ratio 2.76 amongst all the treatments.

शोध सारांश

थीसिस का शीर्षक:	फूलगोभी (ब्रासिका ओलेरैसा वार बोट्रीटीस एल.) पर टपक सिंचाई पर्यावरण के तहत पानी और पोषक तत्व प्रबंधन का अध्ययन
छात्र का पूरा नाम:	खिलेंद्र कुमार
प्रमुख विषय:	मृदा एवं जल अभियांत्रिकी
प्रमुख परामर्शदाता का नाम और पता:	डॉ देवेश पांडेय प्रमुख वैज्ञानिक सिंचाई जल प्रबंधन कृषि महाविद्यालय, बिलासपुर
पुरस्कृत होने की उपाधि:	कृषि अभियांत्रिकी में स्नातकोत्तर

छात्र के हस्ताक्षर

प्रमुख सलाहकार के हस्ताक्षर

विभाग के प्रमुख के हस्ताक्षर

दिनांक: 14/9/17

सारांश

खेती में पानी महत्वपूर्ण संसाधनो में से एक है। इसकी उपलब्धता तेजी से कम और महंगी होती जा रही हैं। पानी की अपर्याप्त उपलब्धता और अनुचित प्रबंधन के कारण फसलों को काफी नुकसान होता है, जिससे कम पैदावार होती है। इसलिए अभी के समय में पानी का उचित उपयोग एवं संरक्षण बहुत महत्वपूर्ण विषय है। पानी के प्रबंधन का प्रमुख लक्ष्य सावधानीपूर्वक पानी की उपलब्ध मात्रा का उपयोग करना और पानी की प्रति यूनिट के दर से न्यूनतम उपयोग के व्दारा उच्चतम उत्पादकता प्राप्त करना है। ड्रिप सिंचाई जिसे सूक्ष्म सिंचाई के रूप में भी जाना जाता है। यह सिंचाई की एक विधि है, जो पानी को अलग–अलग पौधों की जड़ों तक धीमी गति से पानी की आपूर्ति करके पानी और उर्वरक बचाता है, या तो मिट्टी की सतह पर या सीधे जड़ पर पाइप, टयूबिंग, वाल्व और मीटर के एक नेटवर्क के माध्यम से पहुंचाता है। यह संकीर्ण ट्यूबों के माध्यम से किया जाता है जो पौधे के आधार पर सीधे पानी वितरित करता है। ड्रिप सिंचाई पानी का उचित उपयोग करने में मदद कर सकती है। फर्टिगेशन ड्रिप सिंचाई प्रणाली के माध्यम से पानी में घुलनशील

ठोस या तरल उर्वरक का अनुप्रयोग है। जल और पोषक तत्व सिंचित कृषि में उत्पादन का मुख्य कारक हैं और उच्च उत्पादकता में योगदान करने के लिए प्रमुख घटक हैं। गहन कृषि में उर्वरक और सिंचाई प्रबंधन दोनों ने फसलों की पैदावार और गुणवत्ता बढ़ाने में काफी योगदान दिया है। एक क्षेत्र प्रयोग फूलगोभी (ब्रासिका ओलेरैसा वार बोट्रीटीस एल.) पर टपक सिंचाई पर्यावरण के तहत पानी और पोषक प्रबंधन का अध्ययन दाऊ कल्याण सिंह कॉलेज ऑफ एग्रीकल्चर और रिसर्च स्टेशन, आई. जी. के. वी., भाटापारा (सी.जी.) में किया गया। प्रयोगशाला मे प्रायोगिक क्षेत्र के मिट्टी का परीक्षण करने पर सैंडी लोम मिट्टी प्राप्त हुई। 15, 30, और 45 से. मी. की गहराई पर मिट्टी की नमी की मात्रा को ग्राविमेत्रिक विधि व्दारा मापने पर क्रमशः 30.25, 32.56 और 30.10 प्रतिशत प्राप्त हुई। ड्रिप सिंचाई के प्रदर्शन को 1.2 केजी/सेमी^{2} के दबाव में इनलाइन ड्रिपर्स (2 लीटर प्रति घंटा) के लिए गीली आकृति और एकरूपता गुणांक के आधार पर मापा गया था। क्षैतिज और ऊर्ध्वाधर गीली आकृति 30, 60, 90, 120 और 150 मिनट के समय के लिए दर्ज किए गए थे और क्रमशः 6.2, 10.5, 14.3, 17.8, से. मी. और 13.2, 17.0, 22.3, 25.8, 28.7 से. मी. प्राप्त हुई। एकरूपता गुणांक का अनुमान 95.32 था।

फूलगोभी की वृद्धि और उत्पादकता का विश्लेषण तीन स्तरों के सिंचाई 0.60 0.80 1.00 सी. पी. ई. और तीन स्तरों के फर्टिगेशन 80, 100, 120 प्रतिशत और नियंत्रण (फरो सिंचाई के साथ 100 प्रतिशत आर. डी. एफ.) के साथ रै.डमाइज्ड ब्लॉक डिजाइन के तहत किया गया था। फूलगोभी की जल आवश्यकता को टपक सिंचाई 0.60, 0.80, 1.00 सी. पी. ई. और नियंत्रण के लिए क्रमशः 188.36, 251.15, 313.96, और 556.18 मि. मी. के रूप में मापा गया है। प्रयोग के परिणाम बताते हैं कि 0.80 सी. पी. ई. पर ड्रिप सिंचाई 80 प्रतिशत आर. डी. एफ. के साथ सभी मापदंडों के लिए सर्वश्रेष्ठ प्रदर्शन करती है पानी का उपयोग दक्षता (1.14 क्विं. हे$^{-1}$ एमएम$^{-1}$), उर्वरक उपयोग दक्षता (0.50 क्विं. केजी.$^{-1}$), फूलगोभी की उपज (28.58 टन. हे.$^{-1}$), पौधे की ऊंचाई (62.76 से. मी.) , पौधे की पत्तीयो की संख्या (24.93) , सबसे बड़ी पत्ती की लम्बाई (49.33 से. मी.), सबसे बड़ी पत्ती की चौड़ाई (26.30 से. मी.) , पौधे फैलाव क्षेत्र (1966.50 से. मी.2) फूलगोभी की परिपक्वता अवधि (75.82), फूलगोभी का वजन (771.36 ग्राम / पौधे) और फूलगोभी का परिधि (52.61 से. मी.)

फूलगोभी की खेती सभी उपचार में से सबसे अधिक 0.80 सी. पी. ई. और 80 प्रतिशत आर. डी. एफ. में सिंचाई के साथ सकल वापसी 308739.6 रु. और शुद्ध वापसी 226646 रु. लाभ लागत अनुपात 2.76 प्राप्त हुआ ।

CHAPTER – I

INTRODUCTION

Water is one of the crucial inputs in farming and its availability tending to become increasingly scare and costly. Crops suffer greatly in terms of low yields due to insufficient water availability and improper scheduling of water application. Hence, conservation of water and its efficient use has assumed much importance in recent times. The major goal of water management is to meticulously harness the available quantities of water and put them to efficient use to realize higher productivity per unit of water per unit of area. Therefore cautious, planning and utilization of available water resources is the need of hour, which includes identification of right place, mode of application time and quantity by adopting the best water management technique.

Drip irrigation was introduced in large scale in Israel during 1960's and presently it is the only irrigation method practiced there. More than 2 mha areas are under drip irrigation in the entire world. The major countries using this system for sustainable agricultural production includes U.S.A., Israel, Taiwan, Thailand, Italy, Cyprus, Australia, Egypt, India, China and Brazil for about sixty different crops.

Micro irrigation in India has seen a steady growth over the years. Since 2005, area covered under micro irrigation systems has grown at a 'Compound Annual Growth Rate - (CAGR)' of 9.6 percent. Geographically, states with the largest area under micro-irrigation include: Rajasthan (1.68 mha), Maharashtra (1.27 mha), Andhra Pradesh (1.16 mha), Karnataka (0.85 mha), Gujarat (0.83 mha) and Haryana (0.57 mha). Majority of the area covered under micro irrigation systems comes under sprinkler irrigation with 56.4 percent, while 43.6 percent comes under drip irrigation**.** Area under drip irrigation has shown stronger growth in recent years, growing at a CAGR of 9.85 percent in the 2012-2015 periods while sprinkler irrigation has grown at a pace of 6.60 percent in the same time period.

Overall, the area under micro-irrigation has grown at a CAGR of 7.97 percent in this time.

In the state of Chhattisgarh, government is now encouraging for growing second crop after rice in order to increase the cropping intensity with limited water resources. This can be accomplished by using, Hi-tech irrigation such as drip irrigation system for growing vegetables in the protected area to achieve highest possible water use efficiency including the fertigation with attractive remunerations.

Drip irrigation which is also known as *micro-irrigation* is a form of irrigation that saves water and fertilizer by allowing water to drip slowly to the roots of many different plants, either onto the soil surface or directly onto the root zone, through a network of valves, pipes, tubing, and emitters. It is done through narrow tubes that deliver water directly to the base of the plant. Drip irrigation can help you use water efficiently. A well-designed drip irrigation system loses, practically, no water to runoff, deep percolation or evaporation. Drip irrigation can be used for crops with high or low water demands. Water seeps into the soil and moves laterally by capillary action beneath the soil's surface. An adequate section of the root zone of the plant is maintained with moisture close to soil capacity, providing a soil-to-water-to-plant relationship which is conductive to better plant growth.

Drip or trickle irrigation has assumed considerable importance in recent years in view of the general need for water economy. (Sivanappan, 1974) attempted successfully to fabricate the small drip irrigation set by locally available PVC pipes, tank and gate valve etc. to irrigate banana and vegetable crops. This device used only ¼th water to that of the basin irrigation, for the same amount of produce. In Chhattisgarh also, drip irrigation set was designed, developed and used for growing vegetables in farmer's field. The results were quite encouraging: It resulted in higher produce (25-30%), savings in water (45-48%), labour (45%) and fertilizer cost (50%). Drip irrigation saves irrigation water to the extent of 30-80%

and enhances the crop yield by 30 to 100% (Sivanappan, 1998). These can reduce the consumption by 30 to 50% as compared to the conventional methods of irrigation. (Narayanmoorty, 1992). The overall application efficiency around 90% can be achieved by drip irrigation whereas the same was found to be 25 to 30% while using surface irrigation. All these emphasize the need for water conservation and improvement in water-use efficiency to achieve “More Crop per Drop of water”.

Fertigation is the application of water soluble solid or liquid fertilizer through drip irrigation system. The factors that governs the fertigation are soil types, crops, methods of irrigation used, water quality, types of fertilizers available, economic feasibility etc. Fertigation has become an attractive method of fertilisation in modern intensive agriculture systems. Water and nutrient are the main factors of production in irrigated agriculture and are the major inputs in contributing higher productivity. In intensive agriculture, both fertiliser and irrigation management have contributed immensely in increasing the yield and quality of crops. Fertigation permits improved efficiency of irrigation and nutrient use and reduces application costs. It improves plant growth and nutrient uptake and limits nutrient losses.

Cauliflower (*Brassica Oleracea var. botrytis* L.) is the crucifer family is grown extensively in India for its high nutritional value. The origin of the name is from the Latin word *caulis* (cabbage) and flower. While it is closely related to broccoli and cabbage. Cauliflower is more exacting in its environmental requirements than other Cole crops. Cauliflower is very sensitive to unusually hot weather and drought. Cauliflower is one of popular vegetable and known as “Ghobi or Gobi” in India and this Flower belongs to “Cruciferaceae” family often overshadowed by its green cousin broccoli. This edible portion of the cauliflower is called ‘Curd’ surrounded by leaves narrower than those of cabbage. There are two main seasonal types of cauliflower is cultivated in India they are 1) Early season crop 2) Late season crop. The seed are sown in nursery bed in May-June for early, July – August for mid season (main crop) and September–October for late varieties. In cauliflower seed rate for early crop is 600 to 750 gm/ha and for late crop 400 to 500 gm /ha. 100 sq. m nursery area is sufficient for raising one hectare. Before that seedlings are prepared in nursery bed (Raised bed) and transplanted in main field after 3-4 weeks. Ridges and furrow type of layout is used for crop. Spacing for early crop is 45×45 cm and late crop it is 60×60 cm. The temperature range of 15°C to 20°C is required for its optimum growth. Sandy loamy soils are recommended for early crops and for late crops, clay loams and loam soils are preferred. Cauliflower grows best on a neutral to slightly acid soils i.e. at pH 6.0 to 7.0. If pH of soil is below 5.5 liming at the rate of 5 to 10 q/ha. It may be given to the crop every 5-6 days to the early planting and 10-15 days for late crop. At the time of head formation, there should be enough moisture in the field, so irrigate at this time. For best result 15 to 20 tons of FYM or compost should be incorporated into the soil about 4 weeks before transplanting. In cauliflower 100 kg N, 50 kg P_2O_5/ha, should be given. In case of early cauliflower crop 200 to 250 q/ha yield is obtained. While in case of later crop it is 250 to 300 q/ha.

Cauliflower is one of the most promising vegetable crops which consumes as vegetable, curries, soups and pickle. Sale price of the cauliflower is always comparable to other high value vegetables available in the market. The improve technology will enhance the productivity as well as quality of the produce which ultimately enhance the socio-economic status of the producer (farmer). The proposed studies which determine the engineering measures helpful to precise cultivation of cauliflower.

The specific objectives of the present study are:

1. To evaluate performance of drip irrigation on the basis of wetting pattern and uniformity coefficient.
2. To determine crop water requirement, water use efficiency and fertilizer use efficiency on different levels of irrigation and fertilizer.
3. To observe the effect of different irrigation and fertigation levels on productivity of Cauliflower.
4. To workout economics of Cauliflower cultivation under drip.

CHAPTER – II

REVIEW OF LITERATURE

This chapter represents the brief review of research work done on different aspect of Water and Nutrient Management Studies on Cauliflower (*Brassica Oleracea var. botrytis* L.) under Drip Environment.

2.1 Current Status and Growth of Micro Irrigation

2.1.1 Country wise Analysis

Status of micro irrigation in India is 5.5% which is much lesser compared to countries like Israel (90%), Russia (78%), Spain (65%), United States (55%), Brazil (52%) and China (10%). India now has close to 8 mha under micro irrigation. In terms of total area, the United States has huge area under micro irrigation. Israel has just 0.23 mha under micro irrigation, but this represents a penetration of over 90 percent.

2.1.2 State wise Situation in India

Status of micro irrigation in states of India is variant. In which Haryana (16.3%), Sikkim (10.8%), A.P (10.4%), Rajasthan (9.3%), Karnataka (8.5%), Gujarat (8.1%), Maharashtra (7.3%), Tamil Nadu (6.4%), Chhattisgarh (5.5%), M.P (2.3%), Odisha (2.3%), Mizoram (2.2%), Bihar (1.9%), Jharkhand (1.5%), Kerala (1.4%), Goa (1.4%), Nagaland (1.4%), Punjab (1.0%), West Bengal (1.0%), Arunachal (0.3%), U.P (0.2%), Tripura (0.2%), H.P (0.2%), Uttarakhand (0.1%), Manipur (0.0%), Assam (0.0%) and the average penetration of micro irrigation in India is 5.5%.

2.2 Water Requirement of Vegetables

Patel and Rajput (2002) irrigation water requirement of vegetables is quit high as compared to grain crops. It requires maintenance of high level of moisture particularly during reproductive phase, usually between field capacity and saturation. Irrigation water requirement depends on consumptive use, crop coefficient, canopy factor, and potential evapotranspiration.

2.2.1 Study of Evapotranspiration

Penman (1948) first derived the combination equation. He combined the components to account for energy required to sustain evaporation and a mechanism required to remove the vapour. The energy source involved an estimate of net radiation from extraterrestrial radiation, percentage of sunshine and relative humidity.

Blaney and Criddle (1960) observed that the consumptive use of crops during growing season was closely correlated with mean monthly temperature and daylight hours. They developed a simplified formula for estimating consumptive use in the arid western regions of the United States.

Christiansen and Hargreaves (1969) developed an equation for estimating crop evapotranspiration (ETc) from United States Weather Bureau (USWB) Class A pan evaporation and several weather parameters.

Wright and Jensen (1972) conducted studies at Kimberly Idaho and developed an alfalfa-reference combination equation for evapotranspiration. They recommended two wind functions for coastal and humid climates and for arid and semi arid areas. This was known as 1972 Kimberly Penman equation.

Doorenbos and Pritt (1975 and 1977) proposed a modified Penman method for estimating reference crop ET accurately and gave tables to facilitate the necessary computations. The major modifications involved a more sensitive wind function that was used by Penman, and an adjustment factor, c that is based on local climatic conditions and the assumption that of zero soil heat flux for daily periods. This is called as FAO-24 Penman method and in ASCE manual it was referred as FAO-24 corrected Penman method and FAO-24 Penman (c=l) method when the value of c is taken one.

Monteith (1981) developed a combination method for estimating evapotranspiration known as Penman-Monteith method. Penman did not included surface resistance function for water vapour transfer in his original equation. This Penman-Monteith equation not only includes the aerodynamic resistance to sensible heat and vapour transfer and but also surface resistance to vapour transfer.

Rajagopalan *et al.* (1983) monthly and yearly ET was estimated by using some of the more popular empirical equations for an inter comparison of various results based on daily meteorological records from experimental watershed established by Central Water and Power Research Station at Khandala. It was seen that pan evaporation estimates and Hargreaves method followed each other closely.

2.2.2 Study of Crop and Pan Coefficients

Guled *et al*. (1997) reported that the crop coefficient (Kc) value for vegetables and commercial field crops varied form 1.0-1.3. The variations may be largely due to the resistance to transpiration of different crops, difference in height, crop roughness, reflection and ground cover. Variation in Kc value results in the differences in crop water requirements. Agro climatic condition has a considerable effect on reference crop evapotranspiration, ETo. Higher evaporative conditions, i.e. hot and strong winds and low humidity increase the value of ETo. Lower and mild wind velocity and higher relative humidity reduces the value of ETo. Increase in ETo value correspondingly increased the crop ET and finally the crop water requirement at the same level or varying levels of area of effective root zone, fraction of effective rot zone and Kc value. Crop water requirement varies from year to year and from season to season within a year for a given locality. Water requirement of field crop gradually increased from initial stage until peak period of their growth was reached and then declined at maturity, but water requirement at maturity was little higher than the initial stage in all the crops. This might be due to gradual increase in the Kc value up to grand growth period and gradually declined towards maturity. Crop factor was affected by the rate of crop development and climatic condition of a growing season to achieve full ground cover. The decrease in the Kc value toward maturity might be attributed to the gradual reduction in the activity of leaf and decrease in the canopy due to senescence. The changing crop ET value from stage to stage also affected the crop water requirement. Crop ET was the sum of transpiration by the crop and evaporation from the soul surface. Crop water requirement exhibited wider variations due to climate, season, crop factor (Kc), and area of effective root zone and stage of crop development.

Sahin *et al.* (2009) determining crop and pan coefficients for cauliflower and red cabbage crops under cool season semiarid climatic conditions The aim of this study was to estimate the evapotranspiration of cauliflower and red cabbage crops grown under cool season semiarid climatic conditions from Class A pan evaporation. Actual evapotranspiration (*ETc*) of cauliflower and red cabbage crops was calculated according to the water balance approach. Reference evapotranspiration (*ETo*) was calculated with FAO Penman-Monteith equation. Pan evaporation (*Epan*) was measured by using Class A pan. Seasonal *ETc* was determined as 475 mm for cauliflower and 556 mm for red cabbage. Seasonal pan coefficient (*kp*=*ETo*/*Epan*) was determined as 0.82, and the seasonal crop coefficient (*kc*=*ETc*/*ETo*) was determined as 0.84 for cauliflower and 0.83 for red cabbage. So the evapotranspiration of cauliflower and red cabbage crops was estimated as 70% Class A pan evaporation.

2.3 Performance of Drip Irrigation

2.3.1 Irrigation Scheduling

Yanglem and Tumbare (2014) scheduling of irrigation at 1.2 ETc irrigation regimes recorded significantly maximum curd yield (37.58 t ha^{-1}) than 0.6, 0.8 and 1.0 ETc irrigation regimes. The higher fertigation level i.e., 100 per cent RD of N and K at every week up to 60 DAT and phosphorus as basal dose registered maximum curd yield (38.94 q ha^{-1}). The Maximum photosynthetic rate, stomatal conductance and transpiration rate and minimum leaf temperature and stomatal resistance were observed due to 1.2 ETc irrigation regimes and 100 % RDF at all crop growth stages of cauliflower. The positive and highly significant correlation was observed between growth and yield attributes and physiological parameters (photosynthetic rate, stomatal conductance and transpiration rate) whereas negative correlation was observed with leaf temperature and stomatal resistance at all the growth period.

2.3.2 Pressure and Discharge Relationship

Ahmed and Hachum (1976) the mathematical relationship between average discharge of emitters (Q in L h^{-1}) and pressure (H in Kg cm^{-2}) was developed as: $Q = 2.54\ H^{0.759}$ ($R^2 = 0.93$). At low operating heads and at corresponding low discharge the vertical advance was higher. With increase in discharge, spread in vertical direction reduced but radial spread in horizontal plane increased. This may be owing to sandy clay loam texture of soil where the higher moisture status was noticed near the soil surface when the emitters were discharging at higher rates corresponding to higher operating pressure. The variation in average discharge values (Q) through micro tubes at different pressure heads (H) showed that Q through micro tube of 1mm diameter increased with increase in H. The same trend was observed at head, middle and tail end of the lateral of 50 m length. But it was also noticed that the Q decreased with increase in length of lateral by 5.1 percent on an average, which was due to the frictional head losses in the lateral. In general it was observed that H increased from 5 to 20 m (75 % increase) on an average, the Q of micro tube also increased from 5.00 to 12.56 Lh^{-1} (60.2 % increase). The correlation developed between the average discharge of micro-tube (Q) in Lh^{-1} and pressure head (H) in m, was: $Q = 1.61\ H^{0.681}$.

2.3.3 Uniformity of Water Applications

Karmeli and Keller (1975) were the first to define an empirical design emission uniformity percentage EU for the evaluation of the performance of drip irrigation system.Based on it the following equation is commonly used to estimate the design emission uniformity in point source and line source of drip irrigation system.

Peng and Yue (1988) conducted a study on pressure distribution along 2 types of drip irrigation lines to determine how the uniformity of irrigation water application varied with the hydraulic head applied. When the flow regime in the drip emitter was the same as that of the lateral, water application uniformity was not affected by pressure change. When it was above or below this critical condition, application uniformity was effected by pressure.

2.3.4 Study of Wetting Patterns of Emitters in Drip System

Peries *et al.* (2007) a research study was conducted to introduce two water saving emitters for surface and subsurface irrigation systems using low cost and freely available materials. Subsurface emitter has a special feature named textile interface which was used to increase the potential gradient between the textile interface and the soil matrix. Present study was conducted to estimate the soil volume wetted by each emitter. In order to compare the performances, commercially available surface drip emitter was also tested. Laboratory experiment was designed using a box having a transparent sheet of glass fixed to one side of the box to observe the wetting patterns. The design box was filled with soil to maintain the bulk density within the box at 1.3 g cm^{-3} for each and every test. Achievable minimum flow rates of the newly developed surface and sub surface emitters were maintained as 11 cm^3 min^{-1}. Flow rate of commercially available emitter was measured and achievable minimum flow rate was about 26.13 cm^3 min^{-1}. Time of irrigation was fixed as 30 minutes for the three experiments. Applied amount of water was measured in each irrigation and it was about 330 cm^3 for surface and sub surface emitters. Amount of water applied by the commercial emitter was about 783.9 cm^3 during 30 minutes irrigation time period.

Skaggs *et al.* (2010) drip irrigation is more effective and less expensive if a large amount of soil can be wetted with each emitter without losing water or nutrients below the root zone. The distance that water spreads horizontally from a drip line and the volume of soil wetted are limiting factors that determine the spacing and number of drip lines and emitters, the frequency of irrigation, and thus the cost of irrigation. We used numerical simulations and field trials to investigate the effects of application rate, pulsed water application, and antecedent water content on the spreading of water from drip emitters. Simulation results showed that pulsing and lower application rates produced minor increases in horizontal spreading at the end of water application. The small increases were primarily due to longer irrigation times, however, and not to flow phenomena associated with pulsing or low application rates. Moreover, the small increases mostly disappeared after the infiltrated water had redistributed for a period of 24 hr field trials confirmed the simulation findings, with no statistically significant difference in wetting being found among five water application treatments involving pulsed applications and varying application rates. The simulations showed that higher antecedent water content increases water spreading from drip irrigation systems, but the increases were greater in the vertical direction than in the horizontal, an undesirable outcome if crop roots are shallow or groundwater contamination is a concern. Overall, soil texture (hydraulic properties) and antecedent water content largely determine the spreading and distribution of a given water application, with pulsing and flow rate having very little impact.

Mondal *et al.* (2007) the present investigation has been carried out to determine soil wetting pattern of four Low Cost Drip Irrigation System (LCDIS), namely traditional dripper, surgical tube, perforation, perforation (coir winded), under 2.5 and 3.5 m water heads for sandy clay loam soil. The study revealed that under 2.5 and 3.5 m water head and 0.65 to 1.22 L hr^{-1} discharge rate, these four types of LCDIS produced average 28 to 33 cm radial influence area with an average influence depth of 25 to 35 cm. It has been found that in most of the cases, small discharge rate with more application time resulted more wetting area in vertical axis and high discharge rate with less application time resulted wider wetted area in lateral axis. So from the vertical and lateral wetting pattern of the LCDISs, it can be stated that these LCDISs are suitable for only shallow rooted crop like cauliflower, cabbage, lettuce, onion, potato etc.

2.3.5 Distribution of Moisture from Drip Irrigation System

Kaul (1979) studied the hydraulics of soil moisture front in drip irrigation. He reported that the soil moisture in the wetted zone, resulting from a point source of water application, manifested itself by a rapid increase in the soil moisture content in the soil layer close to the point of water application. This zone was identified to extend to about 15 cm depth and 20 cm diameter.

Kheper *et al.* (1983) reported that the vertical and radial distribution of applied water was affected by the application rate, initial soil moisture content and volume of water applied. They were observed that, at higher rates of application, the vertical component of water movement was more than the radial component especially in case of initially dry soil. When the water applied to a soil of higher initial moisture content, the moisture moved more both in the radial as well as in the vertical directions. When amount of water applied was increased, the wetted volume of soil was increased. The wetting front also moved to a greater radial distance.

Rema Devi (1983) compared both horizontal and vertical components of the wetting fronts in drip irrigation with saline water. The gravitational force was played a dominant role in the distribution of soil moisture and hence the advance of the moisture front. The soil moisture profile resulting from point source of water application closely approximated a semielliptical shape and represented the equation of the ellipse.

2.4 Study of Water Use Efficiency and Fertilizer Use Efficiency on Different Levels of Irrigation and Fertilizer

Kadam *et al.* (2006) thirty day old seedlings of cauliflower (cv. Golden 80) were subjected to fertigation with 60, 80, 100, 120 and 140% recommended NPK rates in a field experiment conducted in Rahuri, Maharashtra, India. Fertigation with 80% of the recommended NPK rates resulted in the highest average plant survival (98.03%), average plant height (95.9 cm), crop yield (554 q/ha), water use efficiency (18.95 q/ha-cm) and fertilizer use efficiency (230.9 kg/ha), and the lowest number of days required to harvest curds after initiation (13 days).

Kumar *et al.* (2006) field experiments were conducted in sandy loam soil to study the effect of variable irrigation and fertigation on yield, irrigation production efficiency and economic return of potato during 2001-03 in semi-arid environment. The treatments consisted of four irrigation levels viz., I_1 (IW/CPE = 1.20); I_2 (IW/CPE = 1.00); I_3 (IW/CPE = 0.80) and I_4 (IW/CPE= 0.60) and three fertigation ($N:P_2O_5:K_2O$) levels i.e. F_1 (187:63:125), F_2 (141:47:93) and F_3 (93:32:63) kg/ha. Irrigation level I_1 produced significantly higher fresh tuber yield (28.04 t/ha) which was at par with I_2 (26.52 t/ha). The maximum fresh tuber yield of 25.96 t/ha was obtained in fertigation level F_1, which was 3.71 and 17.82% higher than F_2 and F_3, respectively. Irrigation level I_3 had maximum production efficiency (12.78 kg/ha), whereas the highest nutrient use efficiency was observed in fertigation level F_3 (115.65 kg/ha). The gross return and net return were higher at irrigation level I_1 and fertigation level $F_{1.}$

Khodke and Patil (2010) the experiments were conducted in winter season to optimize the irrigation and fertilizer management schedule for cauliflower. Irrigation consisted of surface and subsurface drip methods with irrigation levels of 40%, 60% and 80% of CPE (Cumulative Pan Evaporation) at alternate day irrigation. For the ease in farmers practice the percentage of CPE used in the treatments was the average compounding factor of 40%, 60% and 80% considering crop coefficient and pan coefficient. Both drip systems were compared with control surface irrigation of 60 mm depth through furrow irrigation after CPE reaches 50 mm. Fertilizers were applied with different proportions of 50, 75 and 100% of 120: 60: 60 N, P_2O_5 and K_2O kg ha^{-1} almost at an interval of 10 days in 8, 6 and 6 splits, respectively. The results of two years study indicated that growth and yield parameters of cauliflower parameters were significantly higher under subsurface drip irrigation system and the irrigation applications met the 80% and 60% of the CPE as compared to surface drip and conventional furrow irrigation. Irrigation applications of 80% and 60% of CPE, gave higher cauliflower curd yields that did not differ significantly for both systems (subsurface and surface drip). Among irrigation applications subsurface drip with 60% of CPE was better than 40% of CPE and 80% of CPE. The lower fertilizer dose of 60:30:30 kg ha^{-1};

N: P_2O_5: K_2O through fertigation with 8, 6 and 6 splits proved to be beneficial without much reduction in the curd yield with 50% of fertilizer saving. Water use efficiency was higher under lower irrigation applications and also higher under subsurface though not significantly. Significantly higher root length density was observed in all irrigation applications with subsurface drip and the root length density was highest in subsurface drip followed by surface drip and control furrow irrigation method. During crop growth period soil moisture distribution was more uniform and slightly higher under subsurface drip irrigation.

Singla *et al.* (2011) a field study on fertigation in cauliflower (Brassica oleracea var. botrytis Linn.) using drip irrigation system was undertaken with three rates of nitrogen application (100%, 75% and 50%) of recommended dose applied in three splits i.e. 50% of the dose at planting time, 25% at 30 days after planting and remaining 25% at 60 days after planting with three levels of irrigation at (irrigation water to cumulative pan evaporation ratio) IW/CPE= 0.5, 0.75 and 1.0 in fan pad cooled greenhouse and naturally ventilated greenhouse respectively. Various predication models viz. linear, quadratic, square root and three halves governing the relationship between irrigation water, nitrogen fertilizer and the yield in respect of off-season cauliflower were developed. The studies reveal that the yield 120.7 q/ha and 105q/ha of early cauliflower were maximum under irrigation schedule based on IW/CPE=0.5 and 100% of recommended nitrogen dose in both the greenhouses. Square root model was the best prediction model for assessing the impact of irrigation water and nitrogen dose on crop yield, with higher R^2 value (0.956) in fan pad cooled greenhouse (RMSE=4.18) and quadratic model with higher R^2 value (0.901) in naturally ventilated greenhouse (RMSE=5.72). The prediction model indicates that cauliflower shows a declining response to amount of irrigation water having negative regression coefficient. The crop response was positive to nitrogen application in its square root terms indicating its favorable influence on crop yield at higher doses.

Biswas *et al.* (2011) field trials are carried out for two consecutive years, 2008 and 2009 during *Rabi* season in the adopted farmers filed in Cooch Behar district of West Bengal, India with the objective of effect of potassium fertilization and some plant protection measures on pest incidence and yield of cauliflower (Brassica oleracea var. botrytis L.) In this present study, the increment of potassium doses reduced the infestation of insect pest. Among the different doses of potassium, 50kg K_2O 1ha exhibited the lowest infestation and highest yields of cauliflower.

Devaranavadgi *et al.* (2011) conducted a field experiment to study the effect of different drip irrigation levels on growth and yield of bitter gourd in semi arid conditions of Raichur during *Rabi* / summer 2009-10. The different drip irrigation levels included T_1 - 60 % ET, T_2 - 80 % ET, T_3 - 100 % ET, T_4 - 120 % ET and T_5-furrow irrigation (control). The data revealed that 100 percent ET level with drip irrigation produced superior values for plant height, number of branches, days taken for initiation of male and female flowers, number of fruits per plant, average fruit weight, fruit length, fruit girth and yield per hectare. The yield and yield parameters on either side of 100 percent ET level and with furrow irrigation showed a decreasing pattern.

Popale *et al.* (2012) response of cauliflower to irrigation schedules and fertilizer levels under drip irrigation the present investigation was conducted during *Rabi* season of December 2008 to March 2009 at the farm of Irrigation and Drainage Engineering, Marathwada Agricultural University, Parbhani. The experimental design was split plot with drip irrigation schedules as main treatments and fertigation levels as sub treatments. The treatments were also compared with control. The gross as well as net plot size was 4.8m×3.6m and 4.2m×3.0m, respectively. The plant to plant and row to row spacing was 60cm×60cm. Drip Irrigation schedules comprised of I_1 (0.4 CPE), I_2 (0.6 CPE), I_3 (0.8 CPE) and fertigation levels included F_1 (50% RDF), F_2 (75% RDF) and F_3 (100 %RDF). The control I_4 was furrow irrigation scheduled at 1.2 IW/CPW with 60 mm depth of irrigation. Thus ten treatment combinations were studied with three replications. The drip irrigation (I_1, I_2 and I_3) was scheduled at an alternate day as desired by the treatments and depending on pan evaporation. For control (I_4) furrow irrigation was 60 mm depth of water was applied when CPE reached to 60 mm (IW/CPW ratio of 1.2). The fertilizer dose of N: P: K (120:60:60 kg/ha) was considered for the irrigated cauliflower. The study revealed that percentage of average water saving under drip irrigation system over surface irrigation was 43.45% and it was 75.54%, 63.87% and 50.95% under I_1, I_2 and I_3 irrigation schedules, respectively. The mean water use efficiencies under surface irrigation and irrigation schedules were 22.03 kg/ha-mm and 73.48 kg/ha-mm, respectively. Under drip irrigation system, higher water use efficiency was recorded at I_1 (92.67 kg/ha-mm), I_2 (73.88kg/ha-mm) and I_3 (58.57kg/ha-mm).

Kashyap (2013) the study was carried out at the College of Forestry & Hill Agriculture, Hill Campus, Ranichauri, Uttarakhand. Soil moisture content was measured using gravimetric method periodically in 0-15, 15-30, 30-45 and 45-60 cm soil profiles. Field experiments were conducted on cauliflower (*Brassica oleracea*) crop during 2007-08 and 2008-09. The treatments were 15% (T_1), 30% (T_2), 45% (T_3) and 60% (T_4) maximum allowable depletion of available soil water. It was found that for scheduling of irrigation for cauliflower crop 0-30 cm soil profile should be considered as most of the water was found to be extracted from this layer by the plant.

Ilakyanila *et al.* (2013) field experiments were conducted to find out the "Effect of spacing and fertigation on yield and quality of cauliflower (*Brassica oleracea* L. var. *botrytis*)" at Horticultural College and Research Institute, Tamil Nadu Agricultural University, Coimbatore during July-November 2011, December 2011 and April 2012. Tropical cauliflower hybrid Pawas using. The experiment consisted of three different spacings (60×60, 60×45 and 60×30 cm) and four fertigation levels of straight fertilizers (125, 100, 75 and 50 percent of 200:125:125 kg NPK ha^{-1}) and four levels of water soluble fertilizers (125, 100, 75 and 50 percent of 200:125:125kg NPK ha^{-1}) and conventional method were compared. The treatments were replicated thrice in split plot design. The results revealed that the spacing of 60×45 cm with the application of 100 percent RDF through water soluble fertilizer recorded better growth, yield and quality characters in both the seasons. However, higher BC ratio was recorded with the application of 75 percent RDF through straight fertilizers at a spacing of 60×60 cm.

Kumar and Sahu (2013) conducted experiment on effect of irrigation and fertigation level on Cabbage in *Rabi* season during the year 2007-08 at Horticultural Research Farm, IGKV, Raipur (C.G.). There were 25 treatment combinations involving 5 irrigation levels (Furrow irrigation at 1.2 IW/CPE, drip irrigation at 100, 80, 60 and 40 % PE) and 5 nitrogen levels (50, 75, 100, 125 and 150 % of recommended dose of nitrogen) through fertigation. Results indicate that all the growth parameters were significantly influenced by irrigation and fertigation with nitrogen levels. Higher plant height and more number of leaves plant^{-1} were observed with drip irrigation at 100% PE and fertigation applied 150% of recommended dose of nitrogen. Increasing the irrigation and nitrogen levels increased the yield significantly and highest yield (30.60 ton ha^{-1}) was obtained with drip irrigation at 100% PE and fertigation with 150% of recommended dose of nitrogen (29.71 ton ha^{-1}). Water use efficiency (WUE) was found higher under drip irrigation at 40% PE (9.80 q ha^{-1} cm^{-1}) over furrow irrigation at 1.2 IW/CPE (8.08 q ha^{-1} cm^{-1}).

Kapoor *et al.* (2014) effect of varying drip irrigation levels and NPK fertigation on soil water dynamics, productivity and water use efficiency of cauliflower in wet temperate zone of Himachal Pradesh. The study was conducted at experimental farm of CSK HPKV, Palampur, during the years 2010-11 and 2011-12 with the objectives of evaluating the effects of drip irrigation levels applied at 1.2, 1.0 and 0.8 CPE and NPK fertigation on soil water retention, water use efficiency, growth and productivity of cauliflower. The treatments comprised of (a) Three drip irrigation levels *viz.*, $I_{1.2}$ (1.2 CPE) *i.e.* drip at 120% CPE, $I_{1.0}$ (1.0 CPE) *i.e.* drip at 100% CPE and $I_{0.8}$ (0.8 CPE) *i.e.* drip at 80% CPE, (b) Three fertigation levels F_{100} *i.e.*100% RDF, $F_{66.6}$ *i.e.* 66.6% RDF and $F_{33.3}$ *i.e.*33.3% RDF and (c) Control (I_c) *i.e.* flood Irrigation of 4 cm at 8-10 days interval and 100% recommended dose of fertilizer. The cauliflower variety cv. PSB K-1 was transplanted on October 12, 2010 in the first year and on October 30, 2011 in the second year of experiment. The study concluded that drip based irrigation scheduling resulted in higher water use efficiency (44.94 to 54.34%) and saving in irrigation water (35.85 to 50%) in comparison to conventional method of irrigation.

Yanglem *et al.* (2014) scheduling of irrigation at 1.2 ETc irrigation regimes recorded significantly maximum curd yield (37.58 t ha) than 0.6, 0.8 and 1.0 ETc irrigation regimes. The higher fertigation level i.e., 100 percent RD of N and K at every week up to 60 DAT and phosphorus as basal dose registered maximum curd yield (38.94 q ha). The Maximum photosynthetic rate, stomatal conductance and transpiration rate and minimum leaf temperature and stomatal resistance were observed due to 1.2 ETc irrigation regimes and 100% RDF at all crop growth stages of cauliflower. The positive and highly significant correlation was observed between growth and yield attributes and physiological parameters (photosynthetic rate, stomatal conductance and transpiration rate) whereas negative correlation was observed with leaf temperature and stomatal resistance at all the growth period.

Gupta *et al.* (2014) the experiment consisted of sixteen treatment combinations and replicated four times in a factorial randomized block design. The treatments include four levels of irrigation and fertilizer application. The growth and yield characteristics of knolkhol cv. Early White Vienna was significantly influenced by drip irrigation and fertigation levels. However, the treatment combination of 80% ET through drip (40.04 cm)+80% recommended NPK (100:48:64 kg ha^{-1}) through fertigation proved significantly superior over rest of the treatments in terms of growth and yield contributing characteristics with maximum knob yield (281.50 q ha^{-1}), which was found 68.5% higher than that of surface irrigation and manual fertilizer application.

Ughade and Mahdkar (2014) a field experiment was carried out during 2009-2010 at Department of Agronomy, Dr. B.S.K.K.V, Dapoli, Dist. Ratnagiri (M.S.) to study the effect of three drip irrigation levels (I_1 - 100 percent, I_2 - 80 percent and I_3 - 60 percent of crop evapotranspiration) and two fertigation levels (F_1 - 100 percent and F_2 - 80 percent of RDF through drip) on growth and yield of brinjal. While the irrigation scheduled at I_1 - 100 percent ETc noticed higher values of growth parameters, biomass production, yield attributes and maximum fruit yield (40.17 t ha^{-1}). Similarly Fertigation level F_1 - 100 percent RDF through drip registered superior growth parameters, biomass production, yield attributing characters and fruit yield (39.63 t ha^{-1}) as compared to fertigation level F_2 -80 percent RDF through drip.

Salunkhe *et al.* (2015) the experiment was carried out to check the hydraulic performance of drip irrigation and fertigation studies in okra under different drip irrigation schedules based on pan evaporation (40, 60 and 80% of PE) and levels of fertigation *viz.*, 50, 75, 100 percent recommended dose of fertilizers (NPK) through drip. A control treatment of conventional application of water and fertilizer (furrow irrigation at 1.0 IW/CPE with 60 mm depth and 100% RDF) was used for comparison. The uniformity coefficients of drip system under all treatments were above 95% indicating its better design and performance. There were slight numerical variations in the values of uniformity coefficients showing higher in treatment I_2F_1 (96.99 %) and lower in treatment I_2F_2 (95.38%). The average water requirements under drip irrigation scheduled at 0.4 PE, 0.6PE and 0.8PE and under surface irrigation are 394.7, 502.1, 609.4 and 660 mm. Water use efficiency and fertilizer use efficiency increases with decrease in the depth of irrigation water applied and fertilizer level, respectively. In order to have higher WUE and FUE drip irrigation system should be scheduled at alternate day with 0.4 PE depth of irrigation and fertilizer application of 100% RDF. For okra drip irrigation should be scheduled at 0.6 PE with 75% of RDF through water in five equal splits. Drip irrigation increases the okra fruit yield to the tune of 38.33%.

2.5 Yield Response and Economic Feasibility of Cauliflower

Bozkurt *et al.* (2011) this study was conducted to investigate the effects of different irrigation and nitrogen levels on yield, growth components and water use characteristics of cauliflower (Brassica oleracea L. var. Botrytis cv. Tetris-F1) cultivated in a field for three consecutive years from 2005 to 2007 in the Eastern

Mediterranean region of Turkey. Four irrigation (Kcp) levels with a drip irrigation system based on adjustment coefficients (0, 0.75, 1.0 and 1.25) of pan evaporation were used. Nitrogen (N) treatments were consisted of four different nitrogen rates (0, 75, 150 and 225 kg N ha^{-1}). The highest yield was obtained in Kcp1.0 irrigation level which represents full irrigation treatment. The excess water applications had negative effect on yield of cauliflower. Highest yield was obtained at 225 kg N ha^{-1}. The water use efficiency and irrigation water use efficiency values increased with decreasing irrigation rate. However, lower Kcp coefficients resulted in lower total yield. The FUE in irrigation treatments showed linear increases from non irrigation to full irrigation plots. However, excessive irrigation caused a decrease in FUE. It can be recommended that the Kcp1.0 crop-pan coefficient with 225 kg ha^{-1} nitrogen application can be used to achieve the highest yield for field grown cauliflower in the Eastern Mediterranean coastal region of Turkey.

Bhagyawant *et al.* (2012) the experiment was conducted during the year 2008-09 in *Rabi* season at department of Irrigation and Drainage Engineering, Marathwada Krishi Vidyapeeth, Parbhani. The experimental plot was 3.6 m wide and 4.8 m long. The statistical split plot design was used. The treatments constituted the combination of three irrigation levels and three fertilizer levels with two replication. The climatological approach i.e. pan evaporation (PE) is one of the irrigation scheduling criteria. The treatments were (a) Main treatments I_1 - Irrigation of 0.4 PE by drip, I_2 - Irrigation of 0.6 PE by drip, I_3 - Irrigation of 0.8 PE by drip, (b) Sub treatments F_1 - 50 percent RDF, F_2 - 75 percent RDF, F_3 - 100 percent RDF, (c) Control: I_4 - Surface irrigation at IW/CPE=1.2. Irrigation applied at I_3 (0.8 PE) level recorded significantly higher yield than other irrigation levels. I_3 F_3 (0.8PE with 100% RDF) was significantly superior for yield of cauliflower crop (variety-Hunsa) which was 187.07 q/ha for drip irrigation and 157.61 q/ha for surface irrigation. Drip irrigation system recorded higher water use efficiency than surface irrigation method. It was also observed that the benefit cost ratio of drip irrigation system (1.88) was higher than surface irrigation method (1.62).

CHAPTER - III

MATERIALS AND METHODS

The present study entitled "Water and Nutrient Management Studies on Cauliflower (*Brassica Oleracea Var. Botrytis* L.) under Drip Environment" was carried out during *Kharif* season of 2016-17. This chapter deals with a concise description of study area, climatic condition, experimental material used, methodology adopted for analysis of observation and the techniques employed during the course of investigation.

3.1 The Study Area

3.1.1 Experimental Site

The field experiment was conducted at the Borsi Farm of Dau Kalayan Singh College of Agriculture and Research Station, Bhatapara (C.G.). Location of the experiment site is shown in Fig. 3.1.

3.1.2 Geographical Situation

The experimental site is situated at $21^{\circ}44'\,17''$ N latitude and $81^{\circ}59'\,32''$ E longitude. It has an average elevation of 261 metre.

3.1.3 Agro-climatic Conditions

The district Balodabazar-Bhatapara is located at central part of Chhattisgarh under Chhattisgarh plain agro-climatic zone. The average rainfall of the district is 1100 mm but the study area Bhatapara block of the district in the project adopted village Borsi, climatic vulnerability the average minimum and maximum temperatures are 13.66 ℃ to 27.98 ℃ respectively. The average relative humidity 61.43 percent and average wind velocity 2.08 m s^{-1}.

3.1.4 Weather during the Study Period

The weather data recorded during the period of investigation are presented in Appendix - A. The maximum temperature during the experiment varied between

22.8℃ to 32℃ from November 2016 to February 2017, whereas minimum temperature varied between 6.3℃ to 16.5℃. The relative humidity throughout the crop season varied between 38.3 to 84.5 percent. The average values of open pan evaporation ranged from 3.9 to 7.3 mm day^{-1}, whereas average sunshine values varied from 1.1 to 9.7 hr day^{-1}, maximum wind velocity during crop period was 3.1 m s^{-1} and minimum was recorded 1.2 m s^{-1}.

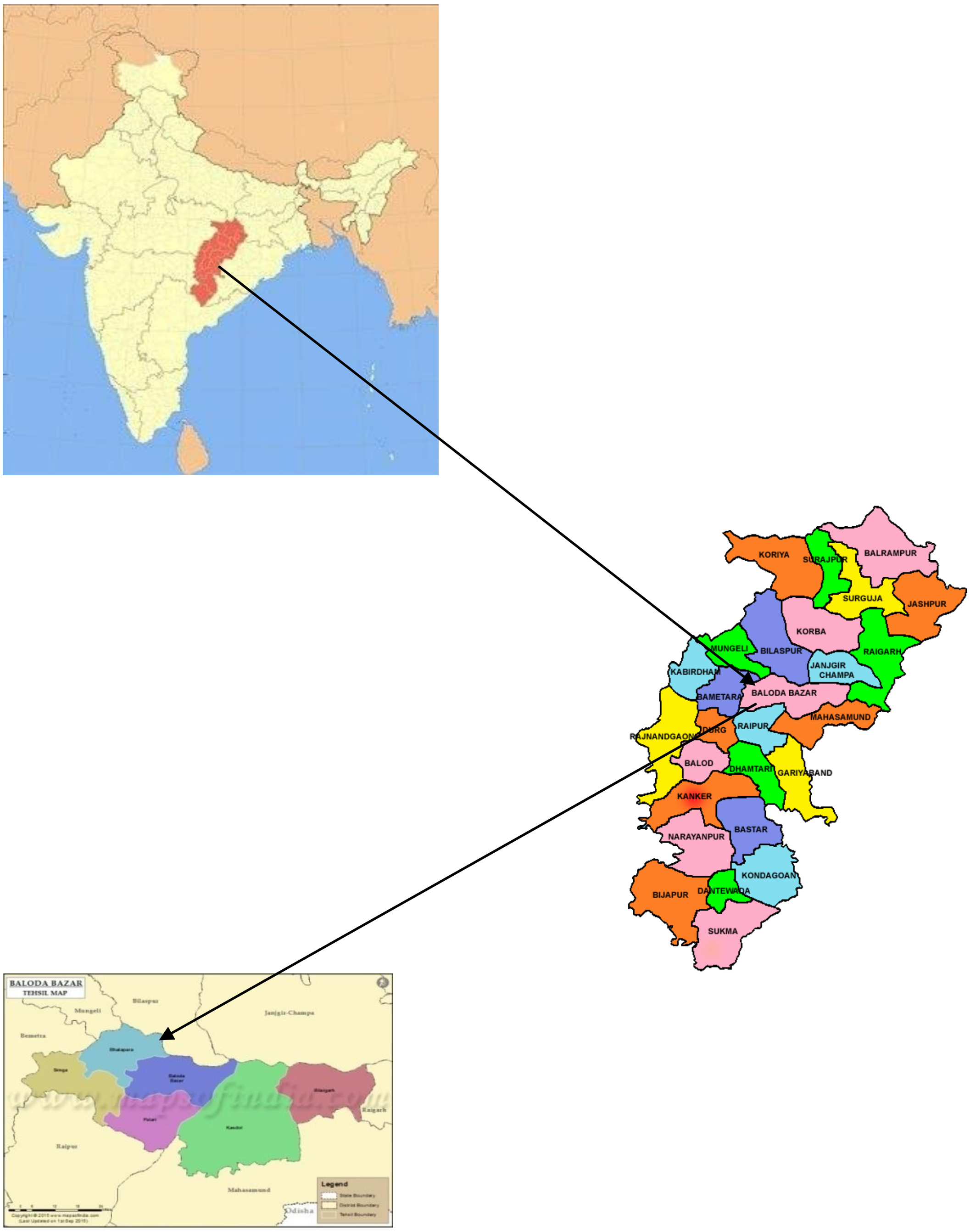

Fig. 3.1: Location map of study area (Chhattisgarh state)

3.1.5 Soil Condition

The topography of the experimental field is uniform and level. The soils are sandy loam. A detailed soil analysis was done to determine soil physical and chemical properties. Soil samples were collected from four corners of the field and another sample was collected from the centre of the field. All collected samples were mixed properly and a composite sample of 1 kg was used for determining physical and chemical properties of the soil. Physical and chemical properties of the soil were determined by adopting standard methods as presented in Table 3.1.

Table 3.1: Physico-chemical characteristics of soil

Particulars		Method used
A. Physical properties		
1.	Soil texture	
	Sand (%)	Soil particle separation by suspension method
	Silt (%)	
	Clay (%)	
2.	Textural class	Triangular diagram of Pursuit
3.	Bulk density (g cm^{-3})	Core sampler method
4.	True density (g cm^{-3})	Pycnometer method
5.	Field capacity (%)	Volume basis method
B. Chemical composition		
1.	pH (1:2.5)	Glass electrode pH meter
2.	EC (dSm^{-1})	Solubridge method
3.	OC (%)	Walkley and Black's rapid titration method
4.	Available N (kg ha^{-1})	Subhiah and Asija method
5.	Available P (kg ha^{-1})	Olsen and Bray method
6.	Available K (kg ha^{-1})	Neutral Normal Ammonium acetate method

3.1.6 Crop Details

Crop: Cauliflower

Scientific name: (*Brassica Oleracea Var. Botrytis* L.)

Family**:** Brassicaceae (Cruciferae)

Variety: Sungro No. 130

Spacing**:** 0.45 m × 0.30 m (r × p)

3.1.7 Drip Irrigation System

The entire experimental drip irrigation system consisted of tube well (water source), pump, control valves, pressure gauge, fertilizer intake assembly, filter, main pipe line, sub-main line and laterals. The drippers and lateral spacing were 0.40 m and 1.2 m, respectively. The details of the drip system are presented in Appendix - B.

3.1.8 Furrow Irrigation (Control)

The plants kept under furrow irrigation were irrigated judiciously and measured quantity of irrigation water was given according to the field capacity. The irrigation was applied once in a week.

3.2 Methodology

3.2.1 Experimental Details and Layout

The experiment involved ten treatment combinations. It was arranged in randomized block design (RBD) with irrigation and fertigation levels in the plot. Treatments were replicated three times. Including all replications, there were thirty treatments arranged on an area of 40 m × 20 m. The experimental layout is shown in Fig. 3.2.

3.2.2 Treatment Details

Three drip irrigation level *viz.*

I_1 = 0.60 CPE

I_2 = 0.80 CPE

I_3 = 1.00 CPE

(CPE – Cumulative Pan Evaporation)

Three fertigation level *viz.*

F_1 = 80% WSF

F_2 = 100% WSF

F_3 = 120% WSF

Control = Furrow irrigation + 100% recommended dose of fertilizer (RDF)

(WSF – Water Soluble Fertilizer)

3.2.2.1 Treatment Combinations

The ten treatment combinations were as follows:

T_1 = Drip irrigation at 0.60 CPE + 80% RDF through WSF

T_2 = Drip irrigation at 0.60 CPE + 100% RDF through WSF

T_3 = Drip irrigation at 0.60 CPE + 120% RDF through WSF

T_4 = Drip irrigation at 0.80 CPE + 80% RDF through WSF

T_5 = Drip irrigation at 0.80 CPE + 100% RDF through WSF

T_6 = Drip irrigation at 0.80 CPE + 120% RDF through WSF

T_7 = Drip irrigation at 1.00 CPE + 80% RDF through WSF

T_8 = Drip irrigation at 1.00 CPE + 100% RDF through WSF

T_9 = Drip irrigation at 1.00 CPE + 120% RDF through WSF

T_{10} = Control irrigation (Furrow) + 100% recommended dose of fertilizer (RDF)

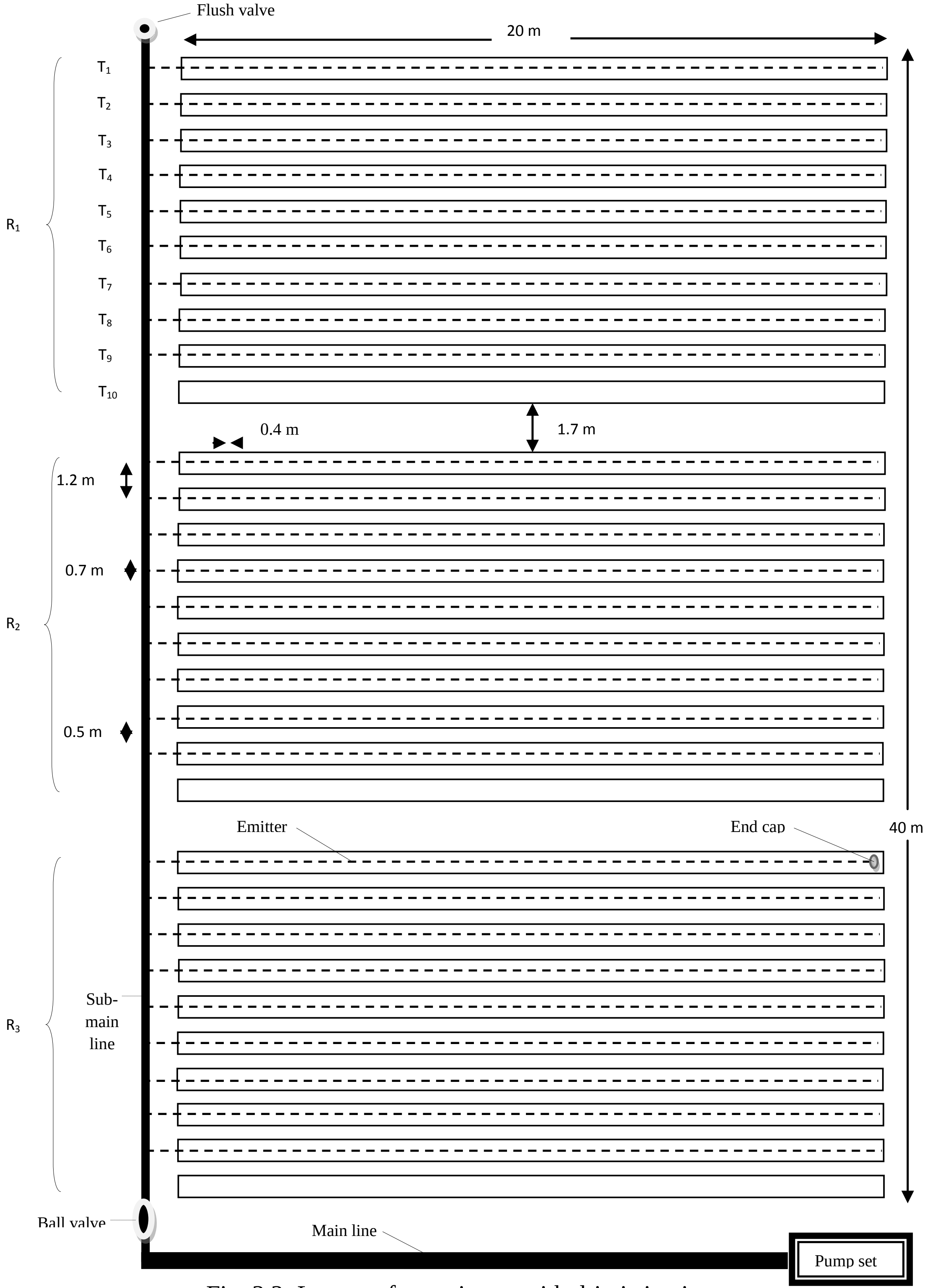

Fig. 3.2: Layout of experiment with drip irrigation system

3.2.3 Cultural Operation

3.2.3.1 Nursery Raising

Nursery was prepared in nursery tray filled with coco peat and then shown on 15 October 2016, @ 500 g/ha. The watering, weeding and plant protection operations were carried out regularly as and when required. Preparation of cauliflower seedling is shown in Fig. 3.3.

Fig. 3.3: Preparation of cauliflower seedling

3.2.3.2 Field Preparation

The experimental site was ploughed by cultivator and rotavator. All grass roots and other unwanted materials were removed from the field. The beds of standard size were prepared as shown in Fig. 3.2. The detailed schedule of field operations is presented in Appendix - C. Preparation of field is shown in Fig. 3.4.

Fig. 3.4: Preparation of field

3.2.3.3 Transplanting

After proper bed preparation and FYM application, the beds were irrigated to field capacity in readiness for transplanting. Cauliflower seedlings of Sungro variety were transplanted on 16th November, 2017. After transplanting, drenching operation was done by applying Bavistine solution at a rate of 2 g ℓ^{-1} to protect the seedlings from fungal infection. Bavistine is a dry flowable systematic fungicide with protestant and eradicant activity. Transplanting of seedling is shown in Fig. 3.5.

Fig. 3.5: Transplanting of cauliflower seedling

3.2.3.4 Gap Filling

In case of failure of some seedling to establish well in the field pits after transplanting, due attention was given to replace the weaker seedlings with the healthier ones from the stock saved in the nursery thus filling the gap. The process of gap filling is shown in Fig. 3.6.

3.2.3.5 Irrigation

The irrigation was applied in the field through the three drip irrigation levels and a furrow irrigation system was used.

Fig. 3.6: The process of gap filling

3.2.3.6 Application of Water Soluble Fertilizer

The water soluble fertilizers were applied based on a recommended dose of fertilizer 200: 125: 125 kg of NPK / ha as recommended by TNAU (2013). The fertilizers were applied through split doses starting from 15 days after transplanting. The recommended dose of water soluble fertilizer (WSF) schedule are presented in Appendix - D respectively. Application of water soluble fertilizer is shown in Fig. 3.7.

Fig. 3.7: Application of water soluble fertilizer

3.2.3.7 Plant Protection

Chemicals were spread on the plants as an effective measure against occurrence of pests and diseases. The plant protection measures are presented in Appendix - E. The spread process of insecticides and pesticides is shown in Fig. 3.8.

Fig. 3.8: The spreading process of insecticides and pesticides

3.2.3.8 Weed Control

The crop was kept weed free throughout the growth period to avoid crop weed competition. Two times hand weeding were done at 25 and 50 DAT.

3.2.3.9 Harvesting

The vegetables were picked at the mature stage and attained maximum size. The process of harvesting is shown in Fig. 3.9.

Fig. 3.9: The process of harvesting

3.2.4 Performance Evaluation of Drip Irrigation

3.2.4.1 Wetting Pattern Measurement

Wetting pattern can be obtained by direct measurement of soil wetting in field. The wetted area in trickle irrigation depends upon the emitter discharge rate, soil type and the infiltration characteristics. Wetting front was observed with emitter of 2 lph at 1.2 kg /cm^2 operating pressure under drip irrigation system. The soil was dug up across the lateral length at the point of emitter location to desired depth to observe cross-sectional view of wetted volume of soil. It appears that a simple procedure for predicting the wetting pattern geometry. The wetting pattern was measured at the end of 30, 60, 90, 120 and 150 minutes of the operation of drip irrigation system.

3.2.4.1.1 Horizontal Wetted Zone

The radius of the horizontal wetted zone was estimated over time during by using the measuring scale, whereas the wetting pattern has almost a circular shape. The measurement of horizontal wetting front is shown in Fig. 3.10.

Fig. 3.10: The measurement of horizontal wetting front

3.2.4.1.2 Vertical Wetted Depth

Immediately after measuring the horizontal wetting front, to record the vertical movement of wetting front after the specified time. The vertical wetted depth was measured exactly below the emitter position. The measurement of vertical wetting front is shown in Fig. 3.11.

Fig. 3.11: The measurement of vertical wetting front

3.2.4.1.3 Moisture Distribution Pattern

The wetting front in horizontal and vertical directions was measured to determine the moisture distribution pattern in the soil profile. The moisture distribution pattern in the soil profile was determined by taking soil samples at different depths on the both sides of the emission points after 24 hours of application. Samples were collected at 0-15, 15-30 and 30-45 cm depths for 0, 15 and 30 cm distances on both sides of the emission point . The undisturbed soil samples were collected using an auger and placed in an oven for 24 hours at 105℃. The oven dried samples were weighed and their volumes determined, finally the moisture content (db) of soil samples was determined. The samples were collected in different depth and width from lateral and dry in oven dryer is shown in Fig. 3.12 and 3.13.

$$MC\ (\%) = \frac{\text{weight of water}}{\text{weight of dry soil}} \times 100 \quad \text{………………..} \ (3.1)$$

Fig. 3.12: Soil samples were collected in different depth and width from lateral

Fig. 3.13: Soil samples placed in oven dryer

3.2.4.2 Uniformity Coefficient

Uniformity coefficients of emitters were tested using the Christiansen's (1942) formula. It gives the information that how efficiently water is distributed in the field.

$$CU = 100\left[1 - \frac{\Sigma X}{MN}\right] \text{ ……………….. (3.2)}$$

Where,

CU = Uniformity coefficient (%) ssss

M = Average value of all observations, mm

N = Total number of observation points

X = Absolute deviation of individual observations from the average application rate, mm

At the constant pressure emitter discharge was measured is shown in Fig. 3.14.

Fig. 3.14: Measurement of the emitter discharge

3.2.5 Crop Water Requirement

Irrigation water was applied at every alternate day based on pan evaporation data. The quantity of irrigation water was calculated by using following formula.

ETo = Epan × Kpan

Where,

ETo = Evapotranspiration of crop (mm)

Epan = Pan evaporation (mm)

Kpan = Pan Coefficient (0.7)

$$V = \frac{ETo \times Kc \times Sl \times Se \times Wa}{E} \quad \text{……………..} \ (3.3)$$

Where,

V = Volume of water (lit day^{-1} $plant^{-1}$)

Kc = Crop coefficient (as per growth stages)

S*l* = Spacing between laterals (m)

Se= Spacing between emitters (m)

Wa = Wetted area (%)

E = Efficiency of system (%)

The operation time of the system (T) was calculated by using the following formula:

$$T = \frac{V}{q \times Ne} \quad \text{………………..} \ (3.4)$$

Where,

T = Operating time of system (hr)

V = Total volume of water (lit)

q = Emitter discharge (lph)

Ne = Number of emitters $plot^{-1}$

Scheduling of irrigation was done by using crop coefficient in drip irrigation (Doorenbos and Pruitt, 1977).

3.2.6 Water Use Efficiency (WUE)

The water use efficiency was determined from the yield data and total depth of water applied. Water use efficiency was computed using following equation:

$$WUE = \frac{\text{Yield of cauliflower (q/ha)}}{\text{Depth of water aapplied (mm)}} \quad \text{………………..} \ (3.5)$$

Where,

WUE = Water use efficiency, q ha^{-1} mm^{-1}

3.2.7 Fertilizer Use Efficiency (FUE)

The fertilizer use efficiency was determined from the yield data and total fertilizer applied. Fertilizer use efficiency was computed using following equation:

$$FUE = \frac{\text{Yield of cauliflower (q/ha)}}{\text{Fertilizer applied (kg/ha)}} \quad \text{………………..} \ (3.6)$$

Where,

FUE = Fertilizer use efficiency, q kg^{-1}

3.2.8 Growth Parameters

The growth observations such as height of the plant, number of leaves per plant, size of the largest leaf, per plant and spread area of the plant were recorded at an interval of 15 days. The growth parameter was measured is shown in Fig. 3.15.

Fig. 3.15: The growth parameter measurement

3.2.8.1 Height of the Cauliflower Plant (cm)

The plant height was recorded with the help of a measuring scale. The plant height was measured from the ground level up to the top of completely open leaf after 15 days from the date of transplanting. Observations were taken at an interval of 15 days.

3.2.8.2 Number of Leaves per Cauliflower Plant

On each randomly selected plant, number of leaves were counted and recorded at 15 days interval from 15 days after transplanting (DAT) up to maturity stage.

3.2.8.3 Length of the Largest Leaf per Cauliflower Plant (cm)

On each randomly selected plant, the size of the largest leaf length was measured and recorded at 15 days interval from 15 (DAT) up to maturity stage.

3.2.8.4 Width of the Largest Leaf per Cauliflower Plant (cm)

On each randomly selected plant, the size of the largest leaf width was measured and recorded at 15 days interval from 15 (DAT) up to maturity stage.

3.2.8.5 Spread Area of the Cauliflower Plant (cm^2)

The spread area of the plant was measured in various directions across the centre of the plant at 15 days interval after 15 (DAT).

3.2.8.6 Number of Days Elapsed to Curd Maturity per Treatment

The number of days elapsed to curd maturity (DAT) of cauliflower plants per treatment was also noted.

3.2.8.7 Average Weight of Cauliflower Curd

The average weight of the curd was recorded after harvesting. This was done with the help of electronic weighing balance.

3.2.8.8 Average Circumference of Cauliflower Curd

The circumference of the curd was measured with the help of thread. Diameter readings were recorded for all curds from randomly selected plants per treatment.

3.2.8.9 Yield of Cauliflower

The yield of cauliflower was recorded on each treatment and then expressed per hectare.

3.2.9 Economics of Drip Irrigation System under Cauliflower Production

3.2.9.1 Cost of Production

The cost of production included the variable cost and fixed cost of product. The variable cost involved paid out cost on hired human labour, ploughing, seeds, fertilizers, plant protection, water, supervision, electricity charges, interest on working capital, and interest on fixed capital, depreciation, repair and maintenance charges for installation of drip irrigation system.

3.2.9.2 Gross Monetary Returns

The gross monetary returns per hectare were worked out by considering the curd yield from different treatments and prevailing market prices.

3.2.9.3 Net Monetary Returns

The net returns were worked out by subtracting the cost of production from gross monetary returns in each treatment.

3.2.9.4 Benefit: Cost Ratio

The benefit: cost ratio was worked out using the formula below:

$$\text{B : C ratio} = \frac{\text{Net monetary returns}}{\text{Cost of production}} \qquad (3.7)$$

3.2.10 Statistical Analysis

Data collected were analysed using OPSTAT software developed by O.P. Sheoran Assoc. Professor, Computer Section CCS HAU, Hisar. Analysis of

Variance (ANOVA) was applied to test for significant differences among the treatment combinations. On each treatment, data from five randomly selected plants were used for statistical analysis. The mean standard error (SEm) as well as critical difference (CD) at 5 percent for each treatment and their interactions were worked out and the significant levels were determined.

The different growth stage on the cultivation of cauliflower is shown in below 3.16 to 3.22 Fig.

Fig. 3.16: Establishment stage of the cauliflower

Fig. 3.17: At development stage of the cauliflower field vigit by the major advisor and advisory committee members

Fig. 3.18: Mid-stage of the cauliflower

Fig. 3.19: Late-stage of the cauliflower

Fig. 3.20: The first cauliflower and harvested from experiment plot

Fig. 3.21: Yield of the cauliflower

Fig. 3.22: Comparison of production of cauliflower in different treatment

CHAPTER - IV

RESULTS AND DISCUSSION

The experiment on "Water and Nutrient Management Studies on Cauliflower (*Brassica Oleracea var. botrytis* L.) under Drip Environment" was carried out at Borsi Farm of Dau Kalayan Singh College of Agricultural and Research Station, Bhatapara (C.G.), during *Kharif* season from 16th November, 2016 to 15th February, 2017.

The effects of different irrigation and fertigation levels were observed by recording data on various parameters as indicated and detailed analysis are illustrated in CHAPTER - III. The results are presented and discussed under the following sections of this chapter.

4.1 Physico-chemical Characteristics of Soil

The physical properties included textural classification, soil type, bulk density, true density and field capacity. Standard procedures were adopted as described in section 3.1.5. The results are presented in Table 4.1.

Table 4.1: Physico-chemical characteristics of soil

Particulars		Value
A. Physical properties		
1.	Soil texture	
	Sand (%)	64.36
	Silt (%)	24.46
	Clay (%)	11.18
2.	Textural class	Sandy loam
3.	Bulk density (g cm^{-3})	1.45
4.	True density (g cm^{-3})	2.6
5.	Field capacity (%)	28.63
B. Chemical composition		

1.	pH (1:2.5)	7.8
2.	EC (dSm^{-1})	0.62
3.	OC (%)	0.23
4.	Available N (kg ha^{-1})	278.8
5.	Available P (kg ha^{-1})	12.45
6.	Available K (kg ha^{-1})	120.7

4.2 Performance Evaluation of Drip Irrigation

4.2.1 Wetting Pattern

The diameter of wetted surface and depth were measured for different times with dripper flow rates of 2 lph operated at 1.2 kg/cm^2 pressure. Increased duration of application also increased the wetted volume. The average flow rate obtained at drippers was 1.95 lph. The vertical wetting front advance was recorded at a distance of “0” cm to maximum depth covered by emitter along the lateral after the end of elapsed time 30, 60, 90, 120 and 150 min. The wetting front advance in the horizontal and vertical direction from the emitter for different elapsed time is shown in Table 4.2.

Table 4.2: Horizontal and vertical movement of water (cm) w.r.t. elapsed time

Elapsed Time (min)									
30		60		90		120		150	
HWW (cm)	VWD (cm)	HWW (cm)	VWD (cm)	HWW (cm)	VWD (cm)	HWW (cm)	VWD (cm)	HWW (cm)	VWD (cm)
0.0	13.2	0.0	17.0	0.0	22.3	0.0	25.8	0.0	28.7
5.0	6.4	5.0	15.1	5.0	20.4	5.0	24.6	5.0	27.4
6.2	3.1	10.0	4.6	10.0	17.6	10.0	23.7	10.0	26.7
		10.5	2.8	11.5	12.8	15.0	13.4	15.0	22.8
				14.3	3.6	16.0	8.7	20.0	8.5
						17.8	3.9	20.8	6.7
								21.1	2.3

HWW = Horizontal wetted width VWD = Vertical wetted depth

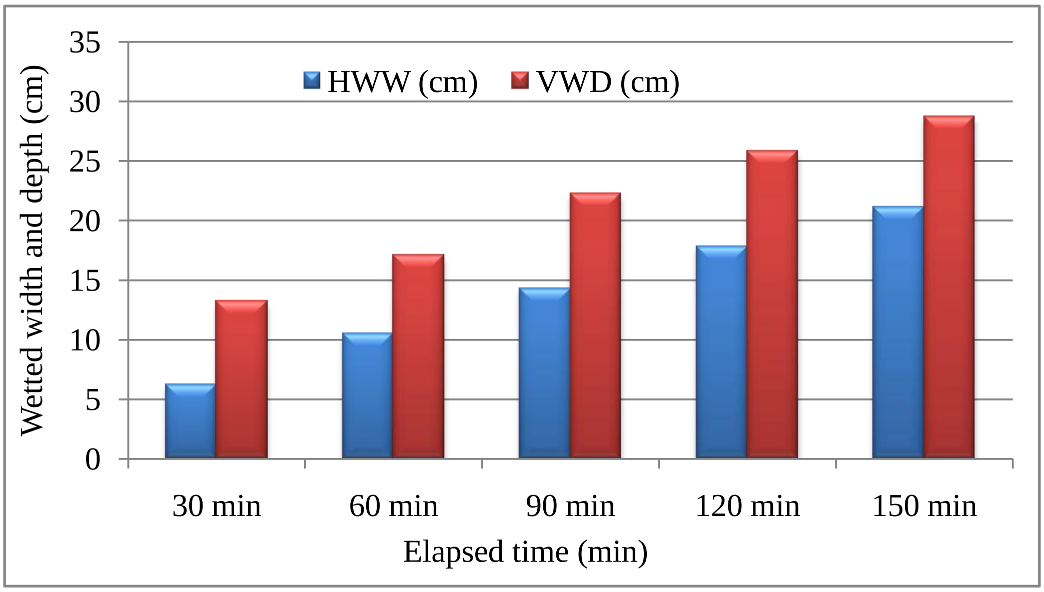

Fig. 4.1: Correlation between horizontal and vertical movement of water

Correlation between maximum wetting front advance (horizontal and vertical direction) and the elapsed time is presented in Fig. 4.1. As the soil is sandy loam texture, initially the moisture moves at faster rate vertically as compared to horizontal movement (Koul, 1979). The maximum horizontal and vertical wetting front advance from emitter were observed as 6.2, 10.5, 14.3, 17.8, 21.1 cm and 13.2, 17.0, 22.3, 25.8, 28.7 cm after elapsed time 30, 60, 90, 120 and 150 min respectively.

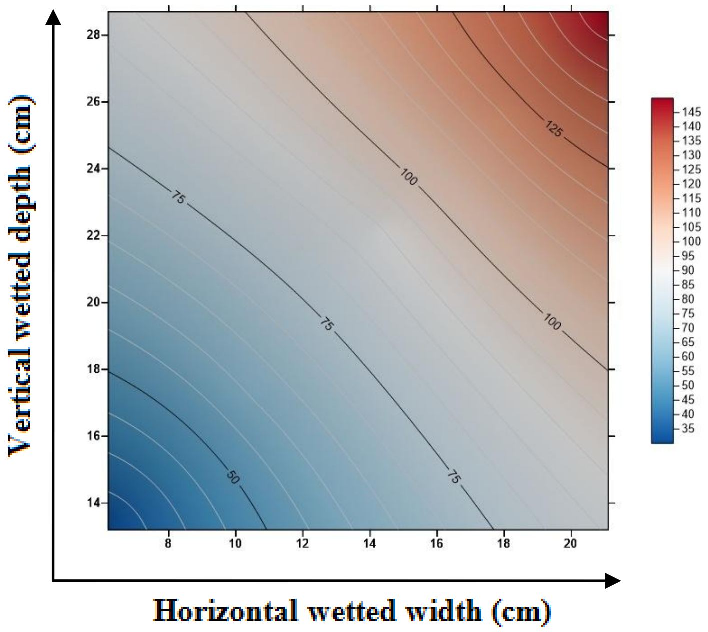

Fig. 4.2: Wetted area Vs Time relationship

The observed and plotted data is indicating nearly uniform distribution between vertically and horizontally in Fig. 4.2. Water movement below the emission point was more pronounced in vertical direction rather than in horizontal direction. The deeper water movement suggests more water available to the roots, which is necessary for plant growth. A horizontal movement of water will generally result in evaporation losses. Almost similar results have been reported in a numerical analysis of the different experiments by Elmaloglou and Diamantopoulos (2009).

4.2.2. Uniformity Coefficient (CU)

The irrigation system under constant pressure volumes were measured from each of 20 emitters was randomly selected in plot. In order to collect a minimal volume of water, a 5 minutes collection time was fixed. The collected volume in a given time was then measured using graduated cylinder.

Table 4.3: The computation of CU are shown in the following tabular form

Observation	**Frequency**	**Application rate × Frequency**	**Numerical deviation**	**Frequency × deviation**
180	1	180	16	16
176	1	176	12	12
172	2	344	8	16
168	4	672	4	16
164	3	492	0	0
160	2	320	4	8
156	3	468	8	24
152	2	304	12	24
148	1	148	16	16
144	1	144	20	20
	20	3248		152

$$\mathrm{CU} = 100\left[1 - \frac{152}{3248}\right]$$

CU = 95.32 %

Uniformity coefficient of drip irrigation was 95.32 % at operating pressure 1.2 kg cm^{-2}. The results are in conformity with the findings of Popale *et al.* (2011), Kumar and Singh (2007).

4.2.3 Moisture Distribution

Observations of soil moisture content were taken after irrigation at depths of 15, 30 and 45 cm were 30.25, 32.56 and 30.10%, respectively. The standard procedure described in section 3.2.4.1.3.

4.3 Water Requirement of Cauliflower

Cauliflower seeds were sown on 15 October and transplanting was done on 16th November, 2016. All treatment plots were irrigated to attain moisture content at field capacity. The amount of water applied during this period was accounted for the total water requirement of the crop.

The detailed estimation of amount of water applied and the time of operation for each treatment is presented in Appendix – F. The monthly water applied for each treatment is presented in Table 4.4 and graphically presented in Fig 4.3.

Table 4.4: Water applied to cauliflower under different treatments for each month

Month	**Depth of water applied (mm)**			
	I_1 0.60 CPE	**I_2 0.80 CPE**	**I_3 1.00 CPE**	**Control (Furrow)**
(16-30) November	21.45	28.61	35.76	79.46
December	50.29	67.05	83.82	175.93
January	74.26	99.01	123.77	204.32
(1-15) February	42.36	56.48	70.61	96.47
Total	**188.36**	**251.15**	**313.96**	**556.18**

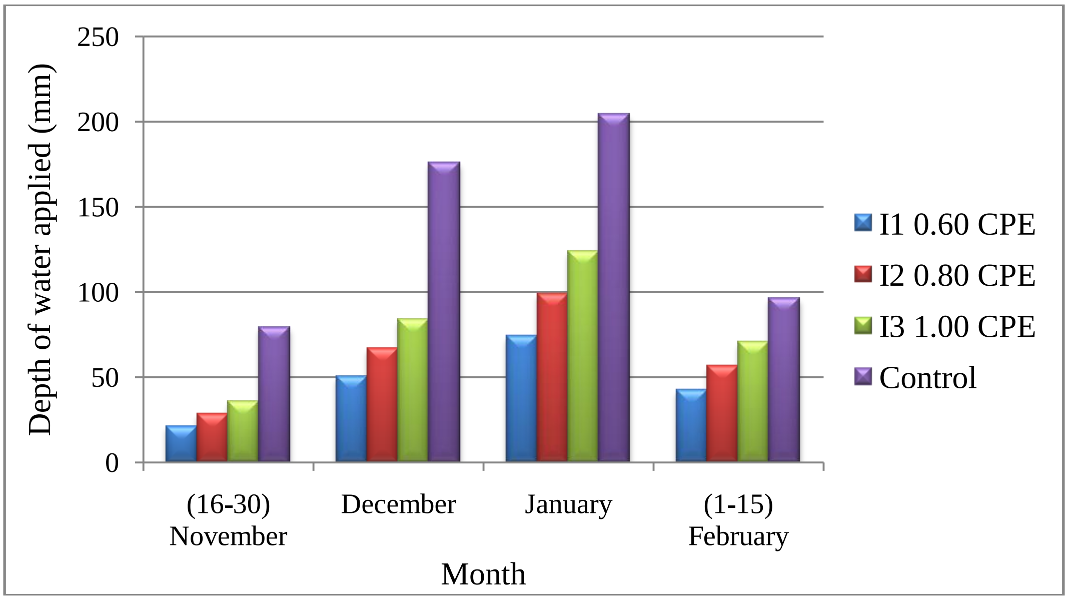

Fig.4.3: Water applied to cauliflower under each irrigation level

On monthly basis, water applied in irrigation level I_1 was 21.45, 50.29, 70.26 and 42.36 mm in the month of November, December, January and February respectively. Water applied in irrigation level I_2 was 28.61, 67.05, 99.01 and 56.48 mm in the month of November, December, January and February, respectively. Water applied in irrigation level I_3 was 35.76, 83.82, 123.77 and 70.61 mm in the month of November, December, January and February, respectively. Water applied in control irrigation was 79.46, 175.93, 204.32 and 96.47 mm in the month of November, December, January and February, respectively. Among all treatments, the maximum seasonal amount of water (188.36 mm) was applied in irrigation level I_1 followed by irrigation level I_2 (251.15 mm), irrigation level I_3 treatment (313.96 mm) and control irrigation (556.18 mm). From Table 4.3 and Fig.4.3, it can be observed that the depths of water applied in November, December and in February are less as compared to depth of water applied in January.

4.3.1 Water saving

For optimization of water requirement for cauliflower under field condition, three levels viz. I_1= 0.6 CPE, I_2= 0.8 CPE, I_3= 1.0 CPE and control irrigation were applied.

Table 4.5: Total depth of irrigation water applied under different irrigation levels

S. No.	Irrigation	Total depth of water applied (cm)	Water saving (%)
1.	I_1 (0.60 CPE)	18.83	66.13
2.	I_2 (0.80 CPE)	25.11	53.98
3.	I_3 (1.00 CPE)	31.39	43.55
4.	Control (Furrow)	55.61	-

4.3.2 Water use Efficiency

The water use efficiency is the ratio of yield obtained in a particular treatment to the depth of water applied. it is observed that the maximum water use efficiency 1.14 q ha^{-1} mm^{-1} was found in treatment combination I_2F_1, followed by 1.10 q ha^{-1} mm^{-1}, 0.94 q ha^{-1} mm^{-1} and 0.86 q ha^{-1} mm^{-1} which were found in treatment combinations I_1F_2, I_2F_2 and I_2F_3, respectively. The minimum water use efficiency 0.21 q ha^{-1} mm^{-1} was observed in treatment of control irrigation due to very low yields in relation to the amount of water applied. Details of the water use efficiency for the rest treatment combinations are presented in Table 4.6.

Table 4.6: Water use efficiency under different treatment combinations

Treatment combinations	Depth of water applied (mm)	Yield (q ha^{-1})	Water use efficiency (q ha^{-1} mm^{-1})
I_1F_1	188.36	146.46	0.78
I_1F_2	188.36	206.73	1.10
I_1F_3	188.36	161.68	0.86
I_2F_1	**251.15**	**285.87**	**1.14**

I_2F_2	251.15	236.30	0.94
I_2F_3	251.15	176.16	0.70
I_3F_1	313.96	191.34	0.61
I_3F_2	313.96	221.53	0.71
I_3F_3	313.96	131.67	0.42
Control	556.18	116.96	0.21

From the data presented in Table 4.6, it is revealed that the water use efficiency ranged from 0.21 q ha^{-1} cm^{-1} to 1.14 q ha^{-1} mm^{-1} under different treatment combinations. The increase in WUE was largely due to reduction in total water applied and attainment of higher yields. From the above results it is clearly observed that, the individual effect of irrigation levels is very important and responsible for growth of cauliflower to get maximum yield and water use efficiency. Fig. 4.4 illustrates the water use efficiency in all treatment combinations.

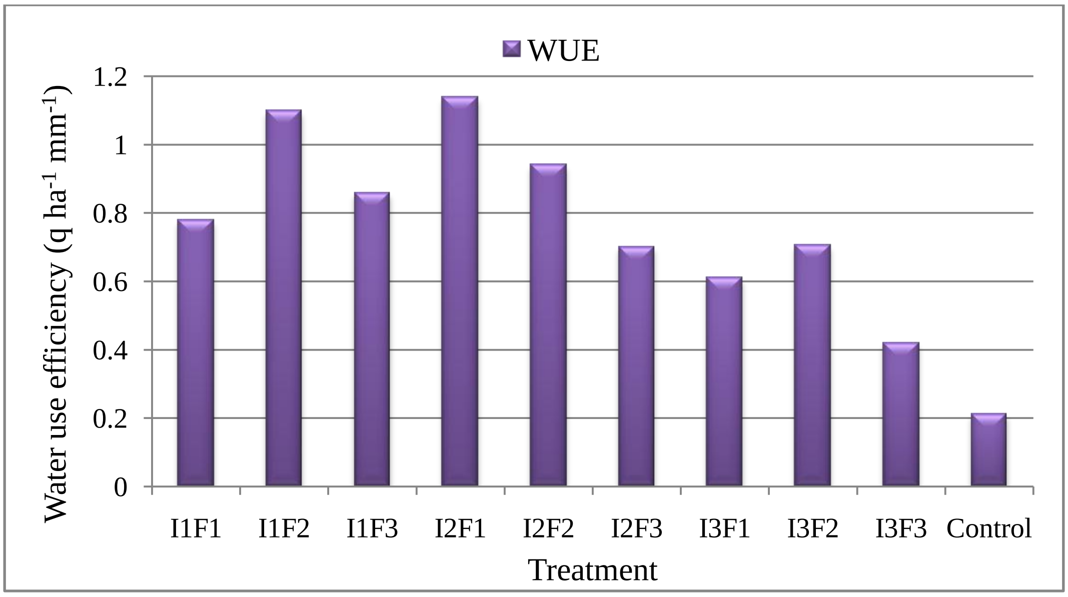

Fig. 4.4: Water use efficiency under different treatment

4.3.3 Fertilizer use Efficiency

The fertilizer use efficiency is the ratio of yield obtained in a particular treatment to the total fertilizer applied. It is observed that the maximum fertilizer use efficiency 0.50 q kg^{-1} was found in treatment combination I_2F_1, followed by 0.34 q kg^{-1}, 0.33 q kg^{-1} and 0.32 q kg^{-1} which were found in treatment combinations I_2F_2, I_3F_1 and I_3F_2, respectively. The minimum fertilizer use efficiency 0.16 q kg^{-1} was observed in treatment combination I_3F_3 due to very low yields in relation to the amount of water applied. Details of the fertilizer use efficiency for the rest treatment combinations are presented in Table 4.7.

Table 4.7: Fertilizer use efficiency under different treatment combinations

Treatment combinations	**Fertilizer applied (kg ha^{-1})**	**Yield (q ha^{-1})**	**Fertilizer use efficiency (q kg^{-1})**
I_1F_1	566.55	146.46	0.26
I_1F_2	700.65	206.73	0.30
I_1F_3	840.78	161.68	0.19
I_2F_1	**566.55**	**285.87**	**0.50**
I_2F_2	700.65	236.30	0.34
I_2F_3	840.78	176.16	0.21
I_3F_1	566.55	191.34	0.33
I_3F_2	700.65	221.53	0.32
I_3F_3	840.78	131.67	0.16
Control	700.65	116.96	0.17

From the data presented in Table 4.7, it is revealed that the fertilizer use efficiency ranged from 0.16 q kg^{-1} to 0.50 q kg^{-1} under different treatment combinations. FUE increase largely due to reduction in total fertilizer applied and attainment of higher yields. From the above results it is clearly observed that, the individual effect of irrigation levels is very important and responsible for growth of cauliflower to get maximum yield and fertilizer use efficiency. Fig. 4.5 illustrates the fertilizer use efficiency in all treatment combinations.

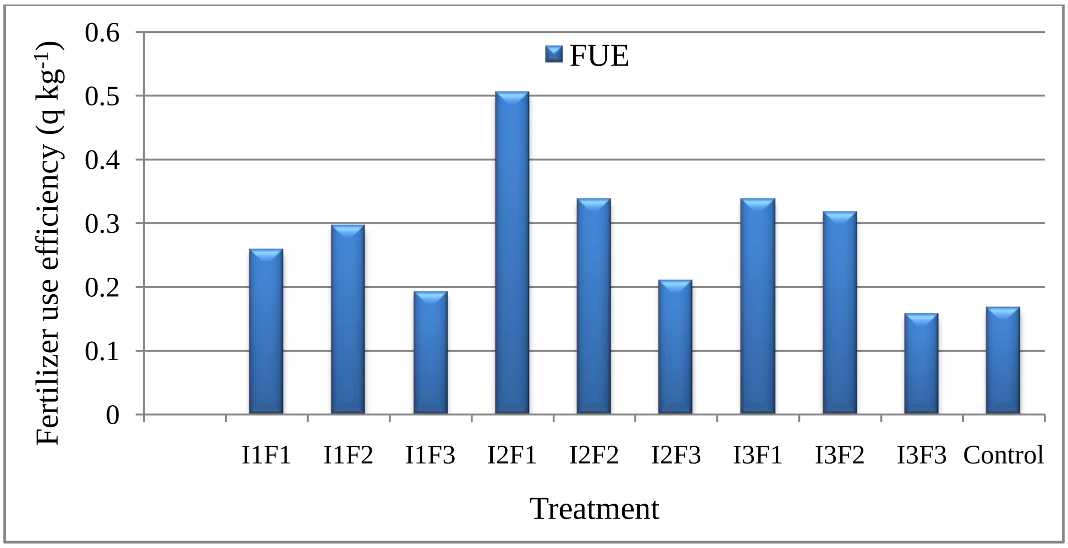

Fig. 4.5: Fertilizer use efficiency under different treatment

4.4 Effect of Different Irrigation and Fertigation Levels on Productivity of Cauliflower

To observe the effect of irrigation and fertigation levels on productivity of cauliflower, different biometric observations and yield contributing parameters were recorded periodically and their results are discussed in the following sections of this chapter.

The effects of irrigation and fertigation levels in all the treatments were tested for different growth parameters of cauliflower. The results of the above mentioned biometric parameters were statistically analysed and are discussed in the following sub sections.

4.4.1 Height of cauliflower plant

Detailed results of statistical analysis of plant height at 15, 30, 45 and 60 DAT are presented in Appendix - G.

The effect of irrigation and fertigation was analysed and results are presented in Table 4.8 and Fig.4.6. Plant height at 15 DAT of cauliflower was found highest in irrigation and fertigation combination I_2F_1 (18.27 cm) is significantly superior over I_3F_3 (17.72 cm) followed by the combination I_3F_2 (17.40 cm). These treatments are obviously significantly superior over control (14.81 cm). Plant height at 30 DAT of cauliflower was found highest in irrigation and fertigation combination I_2F_1 (37.75 cm) is significantly superior over I_2F_3 (36.81 cm) followed by the combination I_1F_3 (35.77 cm). These treatments are obviously significantly superior over control (24.91 cm). Treatment I_2F_1 (57.89 cm) give higher plant height at 45 DAT while at par with I_2F_3 (56.61 cm), I_1F_3 (55.60 cm). These treatments are obviously significantly superior over control (28.28 cm). Treatment I_2F_1 (62.76 cm) give higher plant height at 60 DAT while at par with I_1F_2 (62.64 cm), I_3F_3 (60.77 cm). These treatments are obviously significantly superior over control (48.82 cm). Overall height of the cauliflower plant was observed highest in irrigation and fertigation combination I_2F_1.

Table 4.8: Effect of irrigation and fertigation levels on height of cauliflower plant

Treatment combination	**Plant height (cm)**			
	15 DAT	**30 DAT**	**45 DAT**	**60 DAT**
I_1F_1	15.42	27.54	43.50	49.69
I_1F_2	15.65	26.47	46.74	**62.64**
I_1F_3	16.66	**35.77**	**55.60**	60.76
I_2F_1	**18.27**	**37.75**	**57.89**	**62.76**
I_2F_2	15.55	30.04	54.43	50.71
I_2F_3	16.47	**36.81**	**56.61**	53.73
I_3F_1	17.01	34.81	43.67	56.82
I_3F_2	**17.40**	29.89	48.65	59.73
I_3F_3	**17.72**	35.24	50.76	**60.77**
Control	14.81	24.91	28.28	48.82
SE(m)	0.12	0.17	3.75	3.15
C.D.	0.36	0.52	11.24	9.43

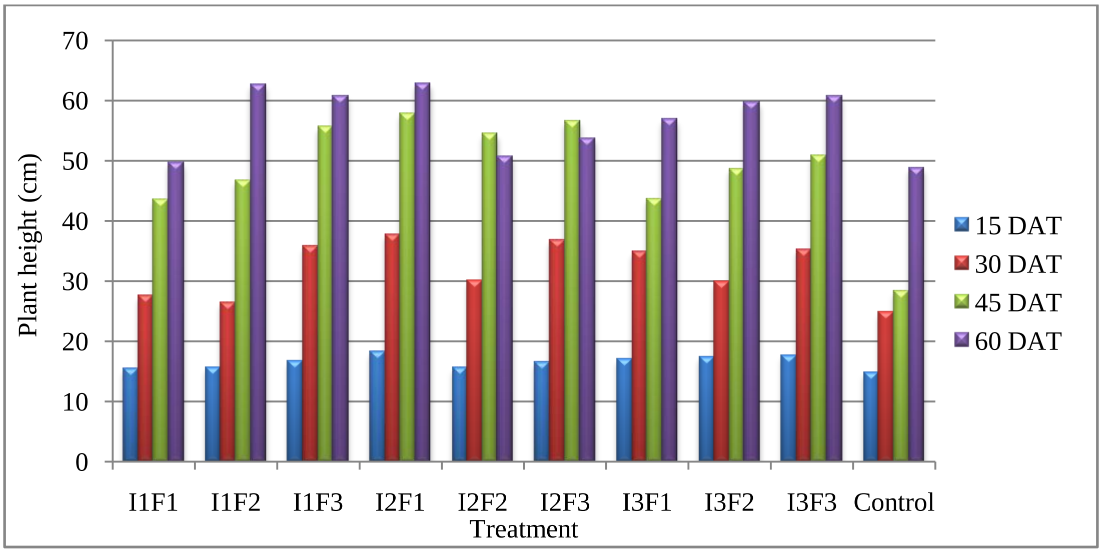

Fig. 4.6: Plant height under different treatment combinations

4.4.2 Number of leaves per cauliflower plant

Detailed results of statistical analysis of number of leaves per plant at 15, 30, 45 and 60 DAT are presented in Appendix - H.

The effect of irrigation and fertigation levels was analysed and results are presented in Table 4.9 and Fig.4.7. Treatment I_2F_1 (7.06) give higher number of leaves per plant at 15 DAT while at par with I_3F_3 (6.46), I_3F_1 (6.23). These treatments are obviously significantly superior over control (3.76). Treatment I_2F_1 (15.23) give higher number of leaves per plant at 30 DAT while at par with I_3F_2 (14.53), I_3F_3 (14.13). These treatments are obviously significantly superior over control (12.53). Treatment I_2F_1 (19.93) give higher number of leaves per plant at 45 DAT while at par with I_3F_1 (19.10), I_1F_2 (18.63). These treatments are obviously significantly superior over control (16.63). Number of leaves per plant at 60 DAT of cauliflower was found highest in irrigation and fertigation combination I_2F_1 (24.93) is significantly superior over I_3F_3 (23.23) followed by the combination I_3F_1 (22.83). These treatments are obviously significantly superior over control (20.86). Overall number of leaves per plant was observed highest in irrigation and fertigation combination I_2F_1.

Table 4.9: Effect of irrigation and fertigation on number of leaves per cauliflower plant

Treatment combination	**Number of leaves per plant**			
	15 DAT	**30 DAT**	**45 DAT**	**60 DAT**
I_1F_1	4.40	12.80	17.66	21.70
I_1F_2	5.43	13.80	**18.63**	21.76
I_1F_3	5.86	13.66	18.43	22.80
I_2F_1	**7.06**	**15.23**	**19.93**	**24.93**
I_2F_2	4.76	13.03	17.73	21.06
I_2F_3	5.83	13.56	18.03	22.20
I_3F_1	**6.23**	14.00	**19.10**	**22.83**
I_3F_2	6.06	**14.53**	17.86	21.30
I_3F_3	**6.46**	**14.13**	18.40	**23.23**
Control	3.76	12.53	16.63	20.86
SE(m)	0.35	0.46	0.41	0.50
C.D.	1.05	1.40	1.23	1.49

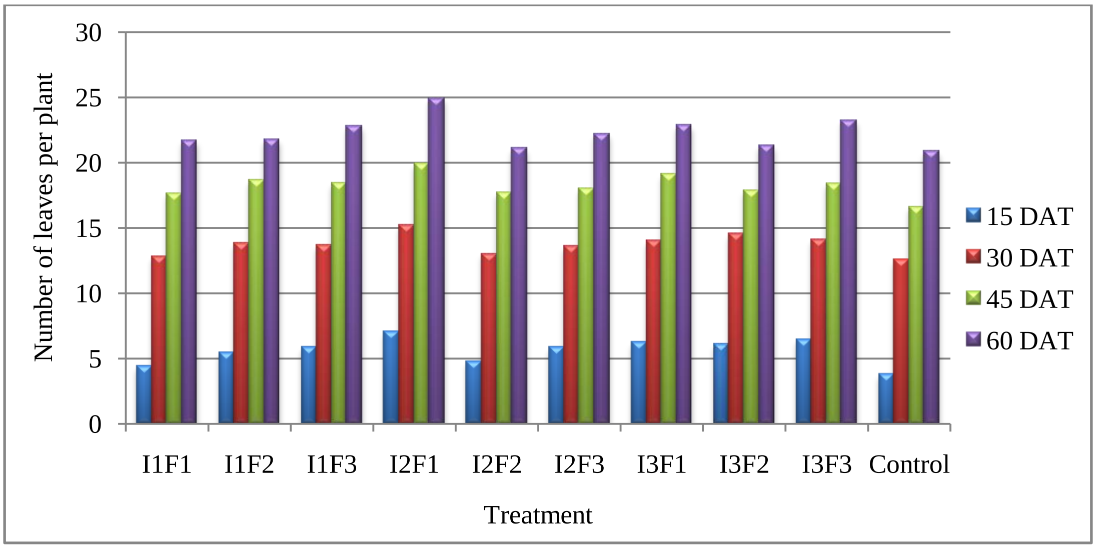

Fig. 4.7: Number of leaves per plant under different treatment combinations

4.4.3 Length of the largest leaf per cauliflower plant

Detailed results of statistical analysis of length of the largest leaf per cauliflower plant at 15, 30, 45 and 60 DAT are presented in Appendix - I.

The effect of irrigation and fertigation levels was analysed and results are presented in Table 4.10 and Fig. 4.8. Treatment I_2F_1 (7.80 cm) give length of largest leaf per cauliflower plant at 15 DAT while at par with I_3F_2 (6.86 cm), I_1F_2 (6.76 cm). These treatments are obviously significantly superior over control (4.90 cm). Treatment I_2F_1 (17.33 cm) give length of largest leaf per cauliflower plant at 30 DAT while at par with I_1F_2 (16.66 cm), I_2F_3 (16.35 cm). These treatments are obviously significantly superior over control (14.33 cm). Treatment I_2F_1 (30.66 cm) give length of largest leaf per cauliflower plant at 45 DAT while at par with I_3F_3 (30.00 cm) and significantly superior over I_2F_2 (29.01 cm). These treatments are obviously significantly superior over control (27.33 cm). Length of largest leaf per cauliflower plant at 60 DAT of cauliflower was found highest in irrigation and fertigation combination I_2F_1 (49.33 cm) is significantly superior over I_3F_3 (49.00 cm) followed by the combination I_3F_1 (48.66 cm). These treatments are obviously significantly superior over control (45.33 cm). Overall length of largest leaf per cauliflower plant was observed highest in irrigation and fertigation combination I_2F_1.

Table 4.10: Effect of irrigation and fertigation on length of largest leaf per plant

Treatment combination	**Length of the largest leaf per cauliflower plant (cm)**			
	15 DAT	**30 DAT**	**45 DAT**	**60 DAT**
I_1F_1	5.63	15.66	28.33	47.00
I_1F_2	**6.77**	**16.66**	29.00	47.67
I_1F_3	6.23	16.00	29.33	48.00
I_2F_1	**7.80**	**17.33**	**30.66**	**49.33**
I_2F_2	5.80	15.66	**29.01**	47.66
I_2F_3	6.00	**16.35**	28.66	46.66
I_3F_1	6.06	15.33	27.66	**48.66**

I_3F_2	**6.86**	16.34	29.00	47.66
I_3F_3	6.76	16.33	**30.00**	**49.00**
Control	4.90	14.33	27.33	45.33
SE(m)	0.38	0.39	0.41	0.49
C.D.	1.13	1.19	1.24	1.48

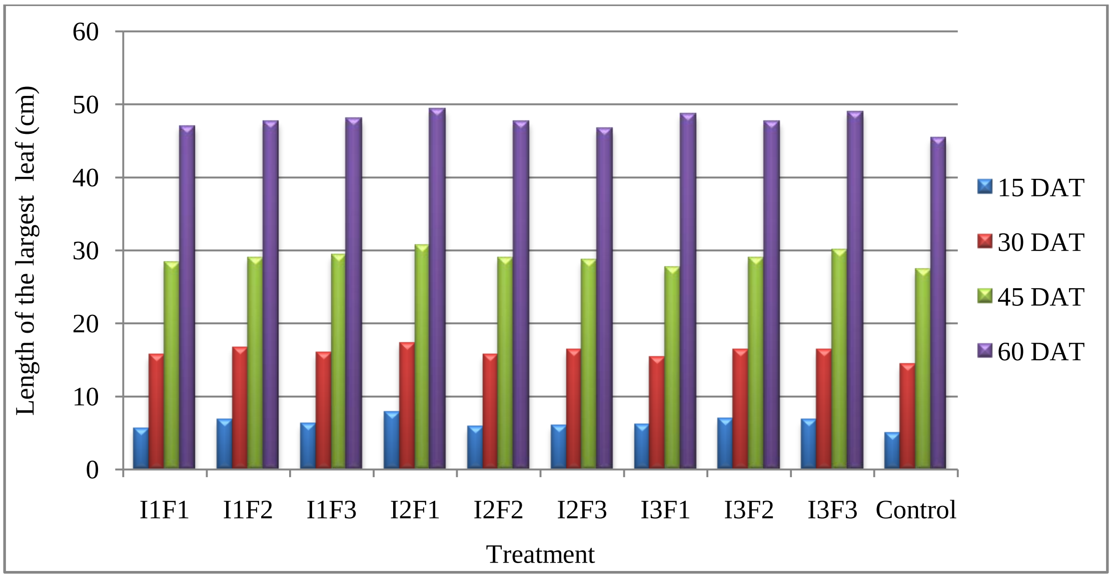

Fig. 4.8: Length of the largest leaf per cauliflower plant under different treatment combinations

4.4.4 Width of the largest leaf per cauliflower plant

Detailed results of statistical analysis of width of the largest leaf per cauliflower plant at 15, 30, 45 and 60 DAT are presented in Appendix - J.

The effect of irrigation fertigation levels was analysed and results are presented in Table 4.11 and Fig.4.9. Width of largest leaf per cauliflower plant at 15 DAT of cauliflower was found highest in irrigation and fertigation combination I_2F_1 (3.86 cm) is significantly superior over I_3F_3 (3.26 cm) followed by the combination I_3F_1 (3.03 cm). These treatments are obviously significantly superior over control (2.53 cm). Width of largest leaf per cauliflower plant at 30 DAT of cauliflower was found highest in irrigation and fertigation combination I_2F_1 (12.06 cm) is significantly superior over I_3F_2 (11.83 cm) followed by the combination I_3F_3 (11.53 cm). These treatments are obviously significantly superior over control (10.23 cm). Treatment I_2F_1 (15.90 cm) give width of largest leaf per cauliflower plant at 45 DAT while at par with I_3F_3 (15.83 cm) and significantly superior over I_2F_2 (15.26 cm). These treatments are obviously significantly superior over control (14.30 cm). Width of largest leaf per cauliflower plant at 60 DAT of cauliflower was found highest in irrigation and fertigation combination I_2F_1 (26.30 cm) is significantly superior over I_3F_3 (25.86 cm) followed by the combination I_1F_3 (25.73 cm). These treatments are obviously significantly superior over control (24.30 cm). Overall width of largest leaf per cauliflower plant was observed highest in irrigation and fertigation combination I_2F_1.

Table 4.11: Effect of irrigation and fertigation on width of largest leaf per plant

Treatment combination	**Width of the largest leaf per cauliflower plant (cm)**			
	15 DAT	**30 DAT**	**45 DAT**	**60 DAT**
I_1F_1	2.56	10.63	14.83	24.73
I_1F_2	2.93	10.83	14.86	25.36
I_1F_3	2.80	11.40	15.03	**25.73**
I_2F_1	**3.86**	**12.06**	**15.90**	**26.30**
I_2F_2	2.70	10.46	14.63	24.83
I_2F_3	2.76	10.70	14.80	24.83
I_3F_1	**3.03**	11.36	14.66	25.56
I_3F_2	2.86	**11.83**	**15.26**	25.26
I_3F_3	**3.26**	**11.53**	**15.83**	**25.86**
Control	2.53	10.23	14.30	24.30
SE(m)	0.22	0.13	0.16	0.10
C.D.	0.66	0.41	0.49	0.32

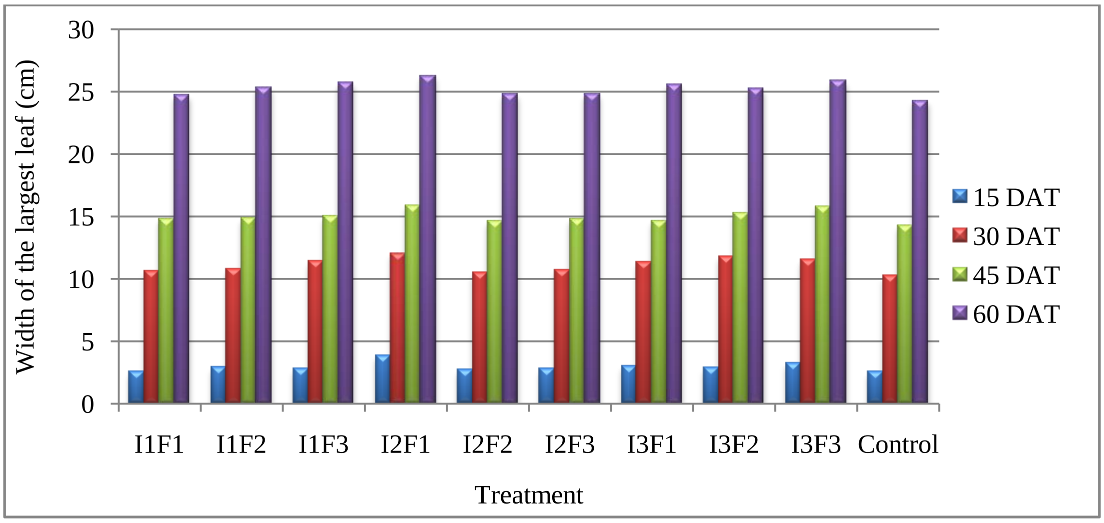

Fig. 4.9: Width of the largest leaf per cauliflower plant under different treatment combinations

4.4.5 Spread area of cauliflower plant

Detailed results of statistical analysis of plant spread area at 15, 30, 45 and 60 DAT are presented in Appendix - K.

The effect of irrigation and fertigation levels was analysed and results are presented in Table 4.12 and Fig.4.10. Plant spread area at 15 DAT of cauliflower was found highest in irrigation and fertigation combination I_2F_1 (171.46 cm^2) is significantly superior over I_3F_3 (166.93 cm^2) followed by the combination I_3F_{12} (162.36 cm^2). These treatments are obviously significantly superior over control (151.56 cm^2). Plant spread area at 30 DAT of cauliflower was found highest in irrigation and fertigation combination I_2F_1 (700.73 cm^2) is significantly superior over I_3F_3 (699.40 cm^2) followed by the combination I_1F_3 (699.00 cm^2). These treatments are obviously significantly superior over control (691.63 cm^2). Plant spread area at 45 DAT of cauliflower was found highest in irrigation and fertigation combination I_2F_1 (1590.50 cm^2) is significantly superior over I_3F_3 (1588.97 cm^2) followed by the combination I_1F_3 (1588.30 cm^2). These treatments are obviously significantly superior over control (1584.70 cm^2). Plant spread area at 60 DAT of cauliflower was found highest in irrigation and fertigation combination I_2F_1 (1966.50 cm^2) is significantly superior over I_3F_3 (1965.40 cm^2)

followed by the combination I_3F_2 (1964.67 cm^2). These treatments are obviously significantly superior over control (1960.70 cm^2). Overall plant spread area was observed highest in irrigation and fertigation combination I_2F_1.

Table 4.12: Effect of irrigation and fertigation on spread area of cauliflower plant.

Treatment combination	**Plant spread area (cm^2)**			
	15 DAT	**30 DAT**	**45 DAT**	**60 DAT**
I_1F_1	153.60	695.16	1,586.30	1,962.37
I_1F_2	155.06	698.10	1,587.40	1,963.57
I_1F_3	161.60	**699.00**	**1,588.30**	1,964.60
I_2F_1	**171.46**	**700.73**	**1,590.50**	**1,966.50**
I_2F_2	157.53	692.46	1,586.30	1,962.53
I_2F_3	158.00	694.36	1,587.63	1,962.50
I_3F_1	159.53	695.23	1,587.73	1,963.60
I_3F_2	**162.36**	698.03	1,587.63	**1,964.67**
I_3F_3	**166.93**	**699.40**	**1,588.97**	**1,965.40**
Control	151.56	691.63	1,584.70	1,960.70
SE(m)	0.51	0.29	0.18	0.27
C.D.	1.52	0.88	0.54	0.81

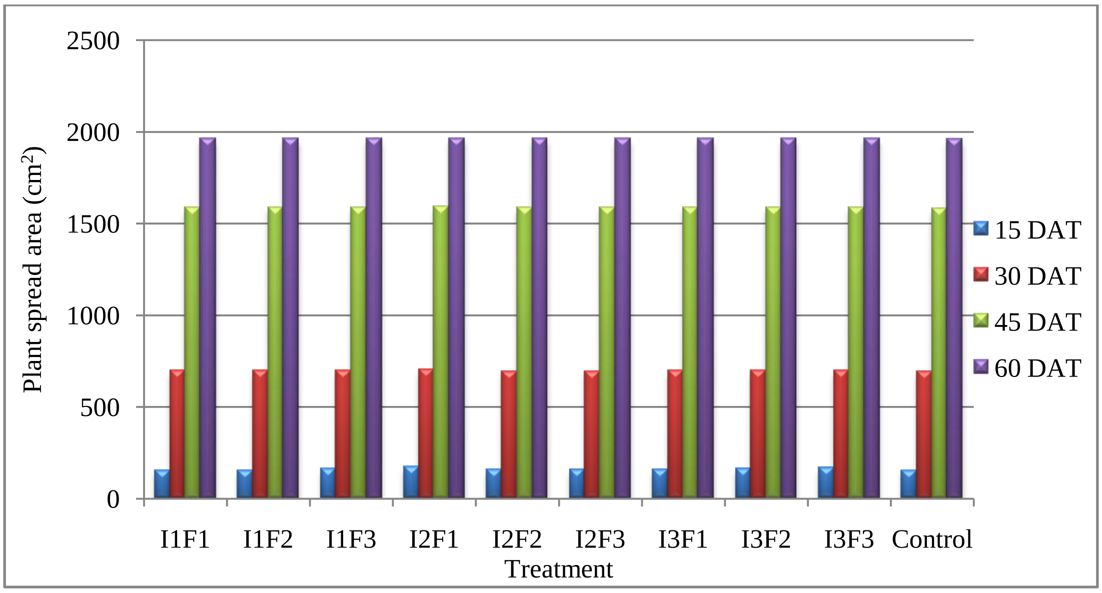

Fig. 4.10: Spread area of cauliflower plant under different treatment combinations

4.4.6 Number of days elapsed to curd maturity per treatment

Detailed results of statistical analysis of number of days elapsed to curd maturity (after transplanting) are presented in Appendix - L.

The effect of irrigation and fertigation levels on number of days elapsed to curd maturity per treatment was analysed and results are presented in Table 4.13. It was observed combination of irrigation and fertigation I_2F_1 (75.82 DAT) is significantly superior over I_2F_3 (78.57 DAT) followed by the combination I_3F_3 (79.19 DAT). These treatments are obviously significantly superior over control (91.51 DAT). Overall number of days elapsed to curd maturity per treatment was observed lowest in irrigation and fertigation combination I_2F_1.

Table 4.13: Effect of irrigation and fertigation levels on number of days elapsed to curd maturity per treatment

Treatment combination	Number of days after transplanting
I_1F_1	84.29
I_1F_2	82.55
I_1F_3	81.09
I_2F_1	**75.82**
I_2F_2	81.11
I_2F_3	**78.57**
I_3F_1	85.69
I_3F_2	81.75
I_3F_3	**79.19**
Control	91.51
SE(m)	0.45
C.D.	1.37

4.4.7 Yield and quality parameters of the curd

The effects of irrigation and fertigation in all the treatments were tested for quality parameters of the curd and cauliflower yield. The results of the above mentioned parameters were statistically analysed and are discussed in the following sub sections.

4.4.7.1 Curd weight

Detailed results of statistical analysis of average weight of cauliflower curd are presented in Appendix - M.

The effect of irrigation and fertigation on average weight of the curd was analysed and results are presented in Table 4.14. It was observed combination of irrigation and fertigation I_2F_1 (771.36 g) is significantly superior over I_3F_3 (669.69 g) followed by the combination I_2F_3 (640.52 g). These treatments are obviously significantly superior over control (468.01 g). Overall average weight of curd was observed highest in irrigation and fertigation combination I_2F_1.

Table 4.14: Effect of irrigation and fertigation on average curd weight

Treatment combination	Average weight of curd (g/plant)
I_1F_1	485.78
I_1F_2	541.18
I_1F_3	637.21
I_2F_1	**771.36**
I_2F_2	489.51
I_2F_3	**640.52**
I_3F_1	494.71
I_3F_2	589.14
I_3F_3	**669.69**
Control	468.01
SE(m)	3.37
C.D.	10.11

4.4.7.2 Circumference of the cauliflower curd

Detailed results of statistical analysis of circumference of the cauliflower curd are presented in Appendix - N.

The effect of irrigation and fertigation on average circumference of cauliflower curd was analysed and results are presented in Table 4.15. It was observed combination of irrigation and fertigation I_2F_1 (52.61 cm) is significantly superior over I_3F_3 (49.84 cm) followed by the combination I_1F_3 (47.79 cm). These treatments are obviously significantly superior over control (34.70 cm). Overall average circumference of cauliflower of curd was observed highest in irrigation and fertigation combination I_2F_1.

Table 4.15: Effect of irrigation and fertigation levels on average curd circumference

Treatment combination	**Circumference of cauliflower curd (cm)**
I_1F_1	36.54
I_1F_2	39.58
I_1F_3	**47.79**
I_2F_1	**52.61**
I_2F_2	37.44
I_2F_3	40.46
I_3F_1	42.63
I_3F_2	46.78
I_3F_3	**49.84**
Control	34.70
SE(m)	0.08
C.D.	0.25

4.4.7.3 Yield of cauliflower

Detailed results of statistical analysis of average yield of cauliflower curd are presented in Appendix - O.

The effect of irrigation and fertigation levels on average yield of cauliflower was analysed and results are presented in Table 4.16 and Fig.11. It was observed combination of irrigation and fertigation I_2F_1 (28.58 t ha^{-1}) is significantly superior over I_3F_2 (23.63 t ha^{-1}) followed by the combination I_3F_2 (22.15 t ha^{-1}). These treatments are obviously significantly superior over control (11.69 t ha^{-1}). Overall average circumference of cauliflower of curd was observed highest in irrigation and fertigation combination I_2F_1.

Table 4.16: Effect of irrigation and fertigation on yield of cauliflower

Treatment combination	**yield of cauliflower (t ha^{-1})**
I_1F_1	14.64
I_1F_2	20.67
I_1F_3	16.16
I_2F_1	**28.58**
I_2F_2	23.63
I_2F_3	17.61
I_3F_1	19.13
I_3F_2	22.15
I_3F_3	13.16
Control	11.69
SE(m)	0.054
C.D.	0.161

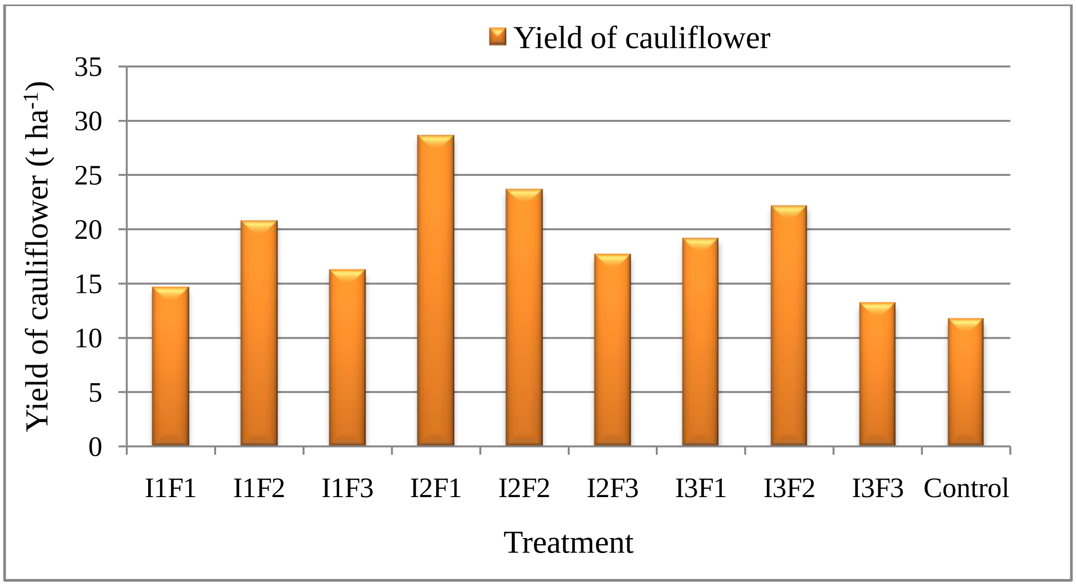

Fig.4.11: Yield of cauliflower under different treatment combinations

4.5 Economics

The detailed cost economics for cauliflower was calculated by considering the cost of production and gross monetary returns obtained. The procedure suggested in section 3.2.9 was applied. The net income and B: C ratios are the indicators used for economic study.

4.5.1 Gross monetary returns

The detailed cost economics is reported in Table 4.17 It is clearly observed that, the maximum gross monetary returns of Rs. 308739.6 per hectare was recorded in treatment combination I_2F_1, followed by Rs. 255204.0 and Rs. 223300.8 in treatment combinations I_2F_2 and I_1F_2 respectively.

4.5.2 Net monetary returns

The detailed cost economics is reported in Table 4.17 It is clearly observed that, the maximum net monetary returns of Rs. 226646 per hectare was recorded in treatment combination I_2F_1, followed by Rs. 172738.4 and Rs. 143475.2 in treatment combinations I_2F_2 and I_1F_2 respectively.

4.5.3 Benefit: Cost ratio

The benefit cost ratio was calculated by taking the ratio of gross monetary returns to cost of production. Table 4.17 the maximum B: C ratio (2.76) was observed in treatment combination I_2F_1, followed by a B: C ratio of 2.09 and 1.79 which was observed in treatment combination I_2F_2 and I_1F_2 respectively.

Table 4.17: Benefit Cost analysis

S. No.	Particulars	I_1F_1	I_1F_2	I_1F_3	I_2F_1	I_2F_2	I_2F_3	I_3F_1	I_3F_1	I_3F_3	Control
1.(a)	**Fixed Cost**	82460	82460	82460	82460	82460	82460	82460	82460	82460	
(b)	**Life (yr.)**	10	10	10	10	10	10	10	10	10	
(c)	**Depreciation (Rs.)**	8246	8246	8246	8246	8246	8246	8246	8246	8246	
(d)	**Interest Cost @ 12%**	9895	9895	9895	9895	9895	9895	9895	9895	9895	
(e)	**Repair & Maintenance @ 1%**	824.6	824.6	824.6	824.6	824.6	824.6	824.6	824.6	824.6	
(f)	**Total operational cost (c+d+e) (Rs.)**	18965.6	18965.6	18965.6	18965.6	18965.6	18965.6	18965.6	18965.6	18965.6	
2	**Cost of cultivation (Fertilizer+Irrigation Water+Labour+Spray material) (Rs.)**	59128	60860	62756	63128	63500	64653	65128	66860	67562	70300
3	**Total Cost (1f+2) in (Rs.)**	78093.6	79825.6	81721.6	82093.6	82465.6	83618.6	84093.6	85825.6	86527.6	70300
4	**Yield (q/ha)**	146.46	206.76	161.68	285.87	236.3	176.16	191.34	221.53	131.67	116.96
5	**Selling price (Rs/q)**	1080	1080	1080	1080	1080	1080	1080	1080	1080	1080
6	**Gross Returns (Rs)**	158176.8	223300.8	174614.4	308739.6	255204.0	190252.8	206647.2	239252.4	142203.6	126316.8
7	**Net Returns (Rs.)**	80083.2	143475.2	92892.8	226646	172738.4	123028.6	122553.6	153426.8	55676	56016.8
8	**Benefit Cost Ratio**	1.02	**1.79**	1.13	**2.76**	**2.09**	1.47	1.45	1.78	0.64	0.79

CHAPTER - V

SUMMARY AND CONCLUSIONS

The experiment on "Water and Nutrient Management Studies on Cauliflower (*Brassica Oleracea var. botrytis* L.) under Drip Environment" was carried out at Borsi Farm of Dau Kalayan Singh College of Agricultural and Research Station, Bhatapara (C.G.), during *Kharif* season from 16^{th} November, 2016 to 15^{th} February, 2017. The research work aimed at the following specific objectives: to evaluate performance of drip irrigation on the basis of wetting pattern and uniformity coefficient, to determine crop water requirement, water use efficiency and fertilizer use efficiency on different levels of irrigation and fertilizer, to observe the effect of different irrigation and fertigation levels on productivity of Cauliflower, to workout economics of Cauliflower cultivation under drip.

5.1 Summary

5.1.1 Physico-chemical properties of soil

The soil of the experimental field was sandy loam in texture having sand, silt and clay percentages as 64.36, 24.46 and 11.18, respectively. The field capacity was 28.63 percent respectively. The bulk density and true density were 1.45 g cm^{-3} and 2.6 1.45 g cm^{-3}. The available nitrogen (N), phosphorus (P), and potassium (K) were 178.8, 12.45 and 120.7 kg ha^{-1}respectively. The pH and EC of the soil were 7.8 and 0.62 dSm^{-1}, respectively.

5.1.2 Effect of irrigation and fertigation levels on height of cauliflower plant

It was observed that, effect of irrigation and fertigation significantly influenced height of cauliflower plant. The maximum plant height (62.76 cm) was observed in treatment combination I_2F_1 and the lowest plant height (48.82 cm) was observed in the control (furrow irrigation with 100 RDF) at the 60 DAT of crop stage. The treatment combination I_2F_1 created optimum soil conditions for growth of cauliflower.

5.1.3 Effect of irrigation and fertigation levels on number of leaves per cauliflower plant

Irrigation and fertigation significantly influenced the number of leaves per cauliflower plant. More leaves per plant (24.93) were observed in treatment combination I_2F_1 and less leaves per plant (20.86) in the control at the 60 DAT of crop stage.

5.1.4 Effect of irrigation and fertigation levels on length of the largest leaf per cauliflower plant

It was observed that effect of irrigation and fertigation significantly influenced length of the largest leaf per plant. In view of the crop stage, at 60 DAT, the largest leaf length per plant (49.33 cm) was observed in treatment combination I_2F_1 and the smallest leaf length (45.33 cm) in the control.

5.1.5 Effect of irrigation and fertigation levels on width of the largest leaf per cauliflower plant

Irrigation and fertigation significantly influenced width of the largest leaf per plant. In view of the crop stage at 60 DAT, the largest leaf width per plant (26.30 cm) was observed in treatment combination I_2F_1 and the smallest leaf width (24.30 cm) was observed in treatment combination of control irrigation.

5.1.6 Effect of irrigation and fertigation levels on spread area of cauliflower plant

Irrigation and fertigation significantly influenced plant spread area. The largest plant spread area (1966.50 cm^2) was observed in treatment combination I_2F_1 and the least plant spread area (1960.70 cm^2) in treatment combination of control at 60 DAT of the crop.

5.1.7 Effect of irrigation and fertigation levels on number of days elapsed to curd maturity per treatment

The treatment combination I_2F_1 significantly showed earliest time (75.82 DAT) for the curd to mature as compared to other treatment combinations. The treatment combination of control irrigation took longer duration (91.51 DAT) for the curd to mature.

5.1.8 Effect of irrigation and fertigation levels on average weight of the cauliflower curd

The maximum average weight of cauliflower curd (771.36 g) was recorded in treatment combination I_2F_1 and the minimum average curd weight (468.01 g) was recorded in treatment combination of control irrigation in which plants experienced water stress and there was also much soil temperature variation.

5.1.9 Effect of irrigation and fertigation levels on average circumference of cauliflower curd

The maximum average circumference of the curd (52.61 cm) was recorded in treatment combination I_2F_1 and the minimum average diameter of the curd (34.70 cm) was recorded in treatment combination I_1M_1. The treatment combination of control irrigation is suitable for production of good quality curds of maximum average curd diameter.

5.1.10 Effect of irrigation and fertigation levels on average yield of cauliflower

The maximum yield of cauliflower (28.58 t ha^{-1}) was recorded in treatment combination I_2F_1 and the minimum average yield of cauliflower (11.69 t ha^{-1}) was recorded in treatment combination of control irrigation. It was concluded that, the treatment combination I_2F_1 is suitable for production of maximum yield of cauliflower.

5.1.11 Performance of drip irrigation

The performance of drip irrigation was measured on the basis of wetting pattern for inline drippers (2 lph) at the pressure of 1.2 kg/cm^2. Horizontal and vertical wetting front advance recorded at elapsed time 30, 60, 90 120 and 150 minute.

5.1.12 Crop water requirement

The maximum depth of water (556.18 mm) was applied in control irrigation and the least amount of water (189.36 mm) was applied in irrigation level I_1. The maximum water saving (66.13 percent) was achieved in irrigation level I_1 and 53.98 percent water saving was achieved in irrigation level I_2.

5.1.13 Water use efficiency

The maximum water use efficiency (1.14 q ha^{-1} mm^{-1}) was found in treatment combination I_2F_1 and the minimum water use efficiency (0.21 q ha^{-1} mm^{-1}) was observed in treatment combination control irrigation due to very low yields in relation to the amount of water applied.

5.1.14 Fertilizer use efficiency

The maximum fertilizer use efficiency (0.50q kg^{-1}) was found in treatment combination I_2F_1 and the minimum (0.17 q kg^{-1}) was observed in treatment combination control irrigation due to very low yields in relation to the amount of fertilizer applied.

5.1.15 Net monetary returns

The maximum net monetary returns (Rs. 226646 ha^{-1}) was found in treatment combination I_2F_1.

5.1.16 B: C ratio

The maximum B: C ratio (2.76) was found in treatment combination I_2F_1 and the B: C ratio (0.79) was found in control irrigation.

5.2 Conclusions

1. Horizontal and vertical wetting front advance recorded at elapsed time 30, 60, 90 120 and 150 minute were found to be 6.2, 10.5, 14.3, 17.8 cm and 13.2, 17.0, 22.3, 25.8, 28.7 cm respectively.

2. Uniformity coefficient was worked out to be 95.32%.

3. The best treatment combination I_2F_1 had total water requirement of cauliflower as 251.15 mm under drip irrigation with fertigation.

4. The maximum water use efficiency (1.14 q ha^{-1} mm^{-1}) and fertilizer use efficiency (0.50 q kg^{-1}) was found in treatment combination I_2F_1.

5. The treatment combination I_2F_1 was found significantly superior in terms of growth and attaining maximum yield of cauliflower (28.58 t ha^{-1}).

6. The maximum net monetary returns (Rs. 226646 ha^{-1}) and maximum B: C ratio (2.76) was found in treatment combination I_2F_1.

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APPENDIX

Appendix - A

Daily weather data during crop period of cauliflower (*Kharif* season, 2016-17) at

Bhatapara.

Date	Tmax (℃)	Tmin (℃)	RH (%)	Epan (mm/day)	WS (m/s)	SS (hr)	Rainfall (mm/day)	ETo (mm/day)
16-Nov	26.1	13.3	74.8	4.9	2.7	9	0.0	3.4
17-Nov	25	11.1	65.4	5	2.3	9.4	0.0	3.5
18-Nov	25.2	10.8	65.5	4.8	1.9	9.3	0.0	3.3
19-Nov	25.6	11.1	64.6	4.5	1.5	9.1	0.0	3.2
20-Nov	26	12.1	66.8	4.5	1.5	8.9	0.0	3.1
21-Nov	25.6	12.4	66.4	4.5	1.5	9.1	0.0	3.1
22-Nov	25.6	11.8	63.9	4.7	1.8	9.2	0.0	3.3
23-Nov	25.6	12.7	61	4.3	1.2	9.1	0.0	3
24-Nov	25.7	12.6	63.3	4.5	1.6	8.8	0.0	3.2
25-Nov	25.6	11	61.1	4.6	1.6	9.1	0.0	3.2
26-Nov	26.5	11.5	61.2	4.9	1.9	8.9	0.0	3.4
27-Nov	27.1	10.7	64.2	5.2	2.4	9	0.0	3.7
28-Nov	26.4	12.1	63.7	4.5	1.6	8.9	0.0	3.2
29-Nov	26.4	12.6	62.6	4.2	1.2	8.8	0.0	3
30-Nov	25.5	11.4	71.2	4.4	2	8.6	0.0	3.1
01-Dec	25.5	11	77.6	3.9	2	7.2	0.0	2.8
02-Dec	25.4	14.5	84.5	3.9	2.2	8.1	0.0	2.7
03-Dec	26.6	14.2	83.5	4.1	2.5	8.2	0.0	2.9
04-Dec	26.4	13.8	78.2	4.4	2.6	8.6	0.0	3.1
05-Dec	25.5	11.7	76.2	4.2	2.1	8.7	0.0	3
06-Dec	25.3	11.2	74	4.3	2.1	8.7	0.0	3
07-Dec	25.3	10.7	70.5	4.1	1.6	8.8	0.0	2.9
08-Dec	24.8	10.5	68.9	4.1	1.6	8.8	0.0	2.9
09-Dec	24.4	9.1	67.9	4.4	2.1	8.9	0.0	3.1
10-Dec	24.8	8.9	70.4	4.6	2.7	8.7	0.0	3.2
11-Dec	25.2	8.6	68.3	4.9	2.9	8.7	0.0	3.4
12-Dec	25	10.6	73.1	4.5	2.8	8.5	0.0	3.2
13-Dec	26.4	12	70.1	4.8	2.9	7.1	0.0	3.3
14-Dec	26.1	10.9	65.4	4.9	2.6	8.1	0.0	3.5
15-Dec	25.7	10.6	64.4	4.8	2.4	8.6	0.0	3.4

16-Dec	25.3	9.8	61.2	4.4	1.7	8.7	0.0	3.1
17-Dec	25.1	9.8	58.8	4.3	1.6	8.7	0.0	3
18-Dec	24.2	9.2	55.9	4.6	1.9	9	0.0	3.2
19-Dec	24.7	8	54	4.5	1.7	9.1	0.0	3.2
20-Dec	25.4	10.1	55.5	4.2	1.3	9	0.0	3
21-Dec	26	9.9	50.3	4.5	1.4	9.1	0.0	3.2
22-Dec	25.3	9.5	49.3	4.6	1.5	9.1	0.0	3.2
23-Dec	24.2	8.1	52.5	4.6	1.8	8.9	0.0	3.2
24-Dec	25.2	10.1	57.8	4.3	1.5	8.8	0.0	3
25-Dec	26.4	10.6	63.2	4.5	1.7	8.6	0.0	3.1
26-Dec	26	10.9	56.3	4.7	1.8	8.8	0.0	3.3
27-Dec	24.5	7.5	58.4	5.1	2.7	8.8	0.0	3.6
28-Dec	24.6	8.6	64.6	4.3	1.9	8.7	0.0	3
29-Dec	25.9	10.3	62.7	4.4	1.6	8.6	0.0	3.1
30-Dec	27	10.6	60.5	4.5	1.5	8.6	0.0	3.1
31-Dec	27.4	10.8	61.3	4.5	1.5	8.5	0.0	3.2
01-Jan	27	12.2	64.5	4.5	1.6	8.4	0.0	3.1
02-Jan	26.6	12.7	70.4	4.5	2.1	8.2	0.0	3.2
03-Jan	24.9	12.1	72.9	4.2	2.2	8.3	0.0	3
04-Jan	24.8	10.6	69.5	4.3	2	8.3	0.0	3
05-Jan	25.3	11.3	62.3	4.5	1.8	8.8	0.0	3.2
06-Jan	26.1	11.4	59.8	4.7	1.8	8.7	0.0	3.3
07-Jan	27.1	11	57.5	5.4	2.4	8.6	0.0	3.8
08-Jan	26.7	12.1	65.5	4.6	1.8	8.5	0.0	3.2
09-Jan	27.6	12.9	62.6	4.9	1.9	8.3	0.0	3.4
10-Jan	25.4	14.5	68	4.1	2	5.6	0.0	2.9
11-Jan	24.2	12.8	65.3	4.5	2	8.3	0.0	3.1
12-Jan	22.8	8.6	60.2	4.6	2.1	9	0.0	3.2
13-Jan	23.2	7.3	60.3	4.7	2.2	8.9	0.0	3.3
14-Jan	23.5	6.3	55.8	4.9	2.2	9	0.0	3.4
15-Jan	25.3	8.2	53.5	5	1.9	9	0.0	3.5
16-Jan	27.1	9.8	52.3	5	1.6	8.9	0.0	3.5
17-Jan	28	12.5	55.8	5.1	1.7	8.6	0.0	3.6
18-Jan	27.6	13.4	62.3	5.3	2.2	8.7	0.0	3.7
19-Jan	27.4	11.6	65.8	5.7	3.1	8.9	0.0	4
20-Jan	27.2	11.4	67.5	5.4	2.8	8.3	0.0	3.8
21-Jan	28	12	64.1	5.6	2.6	8.9	0.0	4
22-Jan	28.6	12.5	62.5	5.6	2.3	8.9	0.0	3.9
23-Jan	29.1	12.7	57.6	5.9	2.3	9	0.0	4.1
24-Jan	28.4	12.3	57	6.1	2.6	9.1	0.0	4.3
25-Jan	28.6	11.1	57.8	5.9	2.3	9.3	0.0	4.1
26-Jan	29	12.3	56.8	5	1.9	5.1	0.0	3.5
27-Jan	30	15	56.6	6	2.2	8.4	0.0	4.2

28-Jan	27.9	14.2	58	6.1	2.6	9.2	0.0	4.3
29-Jan	28.3	10.7	48.6	6	2	9.5	0.0	4.2
30-Jan	29	12.3	45.7	5.9	1.7	9.6	0.0	4.1
31-Jan	30.6	12.8	44.5	6.3	1.8	9.5	0.0	4.4
01-Feb	29.4	12	52	6.7	2.6	9.2	0.0	4.7
02-Feb	29.3	12.6	52.7	6.7	2.6	9.1	0.0	4.7
03-Feb	28.6	11.8	52.5	6.2	2.1	9.5	0.0	4.3
04-Feb	29.5	10.6	47.7	6.7	2.3	9.7	0.0	4.7
05-Feb	30.4	11.6	43.8	6.6	1.9	9.7	0.0	4.6
06-Feb	31.9	14.9	38.8	6.7	1.7	9.4	0.0	4.7
07-Feb	30.2	13.7	47.8	6.7	2.1	9.4	0.0	4.7
08-Feb	31.1	13.8	43.7	6.5	1.7	9.7	0.0	4.6
09-Feb	31.9	15.7	38.3	7	1.8	9.7	0.0	4.9
10-Feb	30.9	15.6	43.7	6.9	2	9.4	0.0	4.9
11-Feb	31.1	14.1	48.8	7.1	2.3	9.2	0.0	5
12-Feb	31.2	15.9	53.9	6	2.8	1.1	0.0	4.2
13-Feb	31.2	16.2	54.3	7.1	2.5	9	0.0	5
14-Feb	31.5	16.5	52.5	7.3	2.5	9	0.0	5.1
15-Feb	32	15.2	43.7	7.1	1.9	9.7	0.0	5

Appendix - B

Details of the drip irrigation system

S. No.	Particulars	Specification
1.	Pump	5 hp
2.	Filter	Screen filter
3.	Main line (PVC)	63 mm× 4 kg/cm^2
4.	Sub-main line (PVC)	50 mm × 6 kg/cm^2
5.	Lateral (LDPE)	12 mm
6.	Lateral with inline drippers	2ℓph, 40 cm
7.	Spacing between laterals	1.2 m
8.	Type of emitters	Inline type
9.	Operating head	1.2 kg cm^{-2}
10.	Poly-joiner	12 mm
11.	End stop	12 mm
12.	Lateral valve	12 mm
13.	Ball valve	50 mm
14.	Flush valve	50 mm

Appendix - C

Cultural Schedule

S. No.	Field operation	Frequency	Date
1.	Field preparation		
	1. Primary tillage (Cultivator)	1	26.10.2016
	2. Secondary tillage (Rotavator)	2	30.10.2016
			03.11.2016
	3. Field layout	1	09.11.2016
	4. Preparation of bed	1	10.11.2016
	5. Installation of drip system	1	12.11.2016
	6. Application of FYM	1	14.11.2016
2.	Transplanting of seedlings		16.11.2016
3.	Fertigation		
	Water soluble fertilizer	3	26.11.2016
			21.12.2016
			26.01.2016
4.	Intercultural operation		
	Hand weeding	2	11.12.2016
			05.01.2017
5.	Harvesting	10	15.01.2017
			18.01.2017
			21.01.2017
			24.01.2017
			27.01.2017
			01.02.2017
			04.02.2017
			08.02.2017
			11.02.2017
			14.02.2017

Appendix - D

Fertigation schedule

RDF through WSF of Cauliflower

Recommended Dose: 200:125:125 kg/ha

S. No.	Crop stage	Duration in days	Fertilizer Grades	Total fertilizer (kg/ha)
1.	Transplanting to establishment stage	10	19:19:19 13:00:45 Urea (46% N)	62.66 7.33 15.33
	Sub total			85.33
2.	Curd initiation stage	25	12:61:00 13:00:45 Urea (46% N)	31.333 111.333 204.00
	Sub total			346.66
3.	Curd development stage	35	00:00:50 Urea (46% N)	120.66 148.00
	Sub total			268.66
Total				700.65

Appendix - E

Plant protection measures

S. No.	Date	Type of chemical	Purpose
1.	16.11.2017	Bavistine solution(2 g/litre)	To protect seedlings from fungal attack
2.	27.11.2017	Dithane M-45 (2.5 g/litre)	To protect plants from fungal infection
3.	02.12.2017	Dichlorovos (DDVP)-(1.5 ml/litre)	To protect plant from insect and pests
4.	17.12.2017	Dithane M-45 (2.5 g/litre)	To protect plant from fungal infection
5.	30.12.2017	Systemic insecticides (Emedachpid)- (1.5 g/litre)	To protect plant from insect and pests
6.	19.01.2017	Dithane M-45 (2.5 g/litre)	To protect plant from fungal infection

Appendix – F

Depth of water applied

Date	Eto (mm/ day)	0.60 ETo l/bed	Irrigation time (Hr)	0.80 ETo l/bed	Irrigation time (Hr)	1.00 ETo l/bed	Irrigation time (Hr)
16-Nov	3.41	67.22	0.69	89.62	0.92	112.03	1.15
17-Nov	3.51	69.19	0.71	92.25	0.95	115.32	1.18
18-Nov	3.33	65.64	0.67	87.52	0.9	109.4	1.12
19-Nov	3.15	62.09	0.64	82.79	0.85	103.49	1.06
20-Nov	3.13	61.7	0.63	82.26	0.84	102.83	1.05
21-Nov	3.13	61.7	0.63	82.26	0.84	102.83	1.05
22-Nov	3.3	65.05	0.67	86.73	0.89	108.42	1.11
23-Nov	3.03	59.73	0.61	79.64	0.82	99.546	1.02
24-Nov	3.18	62.68	0.64	83.58	0.86	104.47	1.07
25-Nov	3.21	63.28	0.65	84.37	0.87	105.46	1.08
26-Nov	3.43	67.61	0.69	90.15	0.92	112.69	1.16
27-Nov	3.66	72.15	0.74	96.19	0.99	120.24	1.23
28-Nov	3.18	62.68	0.64	83.58	0.86	104.47	1.07
29-Nov	2.97	58.54	0.6	78.06	0.8	97.574	1
30-Nov	3.08	60.71	0.62	80.95	0.83	101.19	1.04
01-Dec	2.75	54.21	0.56	72.28	0.74	90.347	0.93
02-Dec	2.7	53.22	0.55	70.96	0.73	88.704	0.91
03-Dec	2.89	56.97	0.58	75.96	0.78	94.946	0.97
04-Dec	3.11	61.3	0.63	81.74	0.84	102.17	1.05

05-Dec	2.95	58.15	0.6	77.53	0.8	96.917	0.99
06-Dec	2.98	58.74	0.6	78.32	0.8	97.903	1
07-Dec	2.89	56.97	0.58	75.96	0.78	94.946	0.97
08-Dec	2.86	56.38	0.58	75.17	0.77	93.961	0.96
09-Dec	3.05	60.12	0.62	80.16	0.82	100.2	1.03
10-Dec	3.24	63.87	0.66	85.16	0.87	106.44	1.09
11-Dec	3.42	67.42	0.69	89.89	0.92	112.36	1.15
12-Dec	3.16	62.29	0.64	83.05	0.85	103.82	1.06
13-Dec	3.33	65.64	0.67	87.52	0.9	109.4	1.12
14-Dec	3.45	68.01	0.7	90.68	0.93	113.34	1.16
15-Dec	3.38	66.63	0.68	88.84	0.91	111.04	1.14
16-Dec	3.08	60.71	0.62	80.95	0.83	101.19	1.04
17-Dec	3.04	59.92	0.61	79.9	0.82	99.874	1.02
18-Dec	3.22	63.47	0.65	84.63	0.87	105.79	1.09
19-Dec	3.18	62.68	0.64	83.58	0.86	104.47	1.07
20-Dec	2.96	58.35	0.6	77.8	0.8	97.246	1
21-Dec	3.15	93.14	0.96	124.2	1.27	155.23	1.59
22-Dec	3.19	94.32	0.97	125.8	1.29	157.2	1.61
23-Dec	3.22	95.21	0.98	126.9	1.3	158.68	1.63
24-Dec	3.02	89.3	0.92	119.1	1.22	148.83	1.53
25-Dec	3.13	92.55	0.95	123.4	1.27	154.25	1.58
26-Dec	3.32	98.17	1.01	130.9	1.34	163.61	1.68
27-Dec	3.6	106.4	1.09	141.9	1.46	177.41	1.82
28-Dec	3.03	89.59	0.92	119.5	1.23	149.32	1.53
29-Dec	3.06	90.48	0.93	120.6	1.24	150.8	1.55

30-Dec	3.13	92.55	0.95	123.4	1.27	154.25	1.58
31-Dec	3.15	93.14	0.96	124.2	1.27	155.23	1.59
01-Jan	3.12	92.25	0.95	123	1.26	153.75	1.58
02-Jan	3.17	93.73	0.96	125	1.28	156.22	1.6
03-Jan	2.97	87.82	0.9	117.1	1.2	146.36	1.5
04-Jan	3	88.7	0.91	118.3	1.21	147.84	1.52
05-Jan	3.18	94.03	0.96	125.4	1.29	156.71	1.61
06-Jan	3.29	97.28	1	129.7	1.33	162.13	1.66
07-Jan	3.8	112.4	1.15	149.8	1.54	187.26	1.92
08-Jan	3.23	95.5	0.98	127.3	1.31	159.17	1.63
09-Jan	3.41	100.8	1.03	134.4	1.38	168.04	1.72
10-Jan	2.9	85.75	0.88	114.3	1.17	142.91	1.47
11-Jan	3.13	92.55	0.95	123.4	1.27	154.25	1.58
12-Jan	3.19	94.32	0.97	125.8	1.29	157.2	1.61
13-Jan	3.27	96.69	0.99	128.9	1.32	161.15	1.65
14-Jan	3.42	101.1	1.04	134.8	1.38	168.54	1.73
15-Jan	3.51	103.8	1.06	138.4	1.42	172.97	1.77
16-Jan	3.49	103.2	1.06	137.6	1.41	171.99	1.76
17-Jan	3.58	105.9	1.09	141.1	1.45	176.42	1.81
18-Jan	3.72	110	1.13	146.7	1.5	183.32	1.88
19-Jan	3.99	118	1.21	157.3	1.61	196.63	2.02
20-Jan	3.76	111.2	1.14	148.2	1.52	185.29	1.9
21-Jan	3.95	116.8	1.2	155.7	1.6	194.66	2
22-Jan	3.94	116.5	1.19	155.3	1.59	194.16	1.99

23-Jan	4.14	122.4	1.26	163.2	1.67	204.02	2.09
24-Jan	4.29	126.8	1.3	169.1	1.73	211.41	2.17
25-Jan	4.13	122.1	1.25	162.8	1.67	203.53	2.09
26-Jan	3.53	104.4	1.07	139.2	1.43	173.96	1.78
27-Jan	4.21	124.5	1.28	166	1.7	207.47	2.13
28-Jan	4.28	126.6	1.3	168.7	1.73	210.92	2.16
29-Jan	4.2	124.2	1.27	165.6	1.7	206.98	2.12
30-Jan	4.14	122.4	1.26	163.2	1.67	204.02	2.09
31-Jan	4.42	130.7	1.34	174.3	1.79	217.82	2.23
01-Feb	4.7	125.7	1.29	167.6	1.72	209.56	2.15
02-Feb	4.66	124.7	1.28	166.2	1.7	207.77	2.13
03-Feb	4.32	115.6	1.19	154.1	1.58	192.61	1.98
04-Feb	4.7	125.7	1.29	167.6	1.72	209.56	2.15
05-Feb	4.59	122.8	1.26	163.7	1.68	204.65	2.1
06-Feb	4.67	124.9	1.28	166.6	1.71	208.22	2.14
07-Feb	4.67	124.9	1.28	166.6	1.71	208.22	2.14
08-Feb	4.56	122	1.25	162.7	1.67	203.32	2.09
09-Feb	4.88	130.5	1.34	174.1	1.79	217.58	2.23
10-Feb	4.85	129.7	1.33	173	1.77	216.25	2.22
11-Feb	4.96	132.7	1.36	176.9	1.81	221.15	2.27
12-Feb	4.2	112.4	1.15	149.8	1.54	187.26	1.92
13-Feb	4.99	133.5	1.37	178	1.83	222.49	2.28
14-Feb	5.12	137	1.4	182.6	1.87	228.28	2.34
15-Feb	4.98	133.2	1.37	177.6	1.82	222.04	2.28

Appendix - G

Anova table of plant height (cm)

15 DAT

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Signficance
Replication	2	0.056			
Treatment	9	34.1	3.789	84.079	0
Error	18	0.811	0.045		
Total	29	34.967			

30 DAT

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Signficance
Replication	2	0.607			
Treatment	9	593.732	65.97	722.514	0
Error	18	1.644	0.091		
Total	29	595.983			

45 DAT

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Signficance
Replication	2	82.318			
Treatment	9	2,113.63	234.848	5.55	0.00101
Error	18	762.252	42.347		
Total	29	2,958.20			

60 DAT

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Signficance
Replication	2	64.758			
Treatment	9	810.602	90.067	3.027	0.02177
Error	18	535.648	29.758		
Total	29	1,411.01			

Appendix - H

Anova table of number of leaves per cauliflower plant

15 DAT

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Signficance
Replication	2	0.504			
Treatment	9	27.507	3.056	8.143	0.00009
Error	18	6.756	0.375		
Total	29	34.767			

30 DAT

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Signficance
Replication	2	0.158			
Treatment	9	17.876	1.986	3.017	0.02206
Error	18	11.849	0.658		
Total	29	29.882			

45 DAT

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Signficance
Replication	2	0.848			
Treatment	9	21.521	2.391	4.717	0.00252
Error	18	9.125	0.507		
Total	29	31.494			

60 DAT

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Signficance
Replication	2	2.207			
Treatment	9	40.687	4.521	6.04	0.00061
Error	18	13.473	0.749		
Total	29	56.367			

Appendix - I

Anova table of length of the largest leaf per cauliflower plant (cm)

15 DAT

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Signficance
Replication	2	0.105			
Treatment	9	17.422	1.936	4.47	0.00336
Error	18	7.795	0.433		
Total	29	25.322			

30 DAT

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Signficance
Replication	2	1.4			
Treatment	9	18	2	4.186	0.00473
Error	18	8.6	0.478		
Total	29	28			

45 DAT

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Signficance
Replication	2	2.6			
Treatment	9	26.7	2.967	5.681	0.00088
Error	18	9.4	0.522		
Total	29	38.7			

60 DAT

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Signficance
Replication	2	1.4			
Treatment	9	37.633	4.181	5.673	0.00089
Error	18	13.267	0.737		
Total	29	52.3			

Appendix – J

Anova table of width of the largest leaf per cauliflower plant (cm)

15 DAT

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Signficance
Replication	2	0.365			
Treatment	9	4.173	0.464	3.128	0.01889
Error	18	2.669	0.148		
Total	29	7.207			

30 DAT

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Signficance
Replication	2	0.217			
Treatment	9	10.265	1.141	19.803	0
Error	18	1.037	0.058		
Total	29	11.518			

45 DAT

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Signficance
Replication	2	0.511			
Treatment	9	7.19	0.799	9.879	0.00002
Error	18	1.456	0.081		
Total	29	9.157			

60 DAT

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Signficance
Replication	2	0.219			
Treatment	9	10.016	1.113	31.578	0
Error	18	0.634	0.035		
Total	29	10.869			

Appendix – K

Anova table of spread area of cauliflower plant (cm^2)

15 DAT

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Signficance
Replication	2	17			
Treatment	9	1,001.82	111.313	142.484	0
Error	18	14.062	0.781		
Total	29	1,032.88			

30 DAT

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Signficance
Replication	2	6.859			
Treatment	9	257.95	28.661	110.208	0
Error	18	4.681	0.26		
Total	29	269.49			

45 DAT

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Signficance
Replication	2	18.319			
Treatment	9	70.87	7.874	79.632	0
Error	18	1.78	0.099		
Total	29	90.969			

60 DAT

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Signficance
Replication	2	22.494			
Treatment	9	76.983	8.554	38.516	0
Error	18	3.997	0.222		
Total	29	103.474			

Appendix – L

Anova table of number of days elapsed to curd maturity per treatment

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Signficance
Replication	2	0.286			
Treatment	9	506.478	56.275	88.899	0
Error	18	11.394	0.633		
Total	29	518.159			

Appendix – M

Average curd weight (gm/plant)

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Signficance
Replication	2	9,972.37			
Treatment	9	601,273.88	66,808.21	367.529	0
Error	18	3,271.98	181.777		
Total	29	614,518.24			

Appendix – N

Anova table of average circumference of cauliflower curd (cm)

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Signficance
Replication	2	26.273			
Treatment	9	1,007.82	111.98	5,344.40	0
Error	18	0.377	0.021		
Total	29	1,034.47			

Appendix – O

Anova table of average yield of cauliflower (t/ha)

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Signficance
Replication	2	0.02			
Treatment	9	725.517	80.613	9,327.82	0
Error	18	0.156	0.009		
Total	29	725.693			

RESUME

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