# RESPONSE OF OKRA (*Abelmoschus esculentus* L.) TO DIFFERENT IRRIGATION LEVELS AND MULCHING METHODS UNDER DRIP IRRIGATION

A Thesis

Submitted in partial fulfillment of the requirements for the award of the degree of

## DOCTOR OF PHILOSOPHY

**in**

**Soil Science**


**By**

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Transforming Education Transforming India


**LOVELY PROFESSIONAL UNIVERSITY**

**PUNJAB**


**2021**

**Department of Soil Science and Agriculture Chemistry**

**School of Agriculture**

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## DECELRATION

I hereby declare that the research work presented in the thesis entitled, "**Response of okra (*Abelmoschus esculentus* L.) to different irrigation levels and mulching methods under drip irrigation**" is my own original. The work has been carried out by me in School of Agriculture, Lovely Professional University, Phagwara, Punjab (India) under the guidance of Dr. Raj Kumar, HOD and Professor (Department of Soil Science and Agriculture Chemistry) of School of Agriculture, Lovely Professional University, Phagwara, Punjab (India), for the award of the degree of **Doctor of Philosophy** in **Soil Science**.

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## CERTIFICATE I

This is to certify that Nitin Madan Changade (Registration No: 41600342) has personally completed the thesis entitled, "**Response of okra (*Abelmoschus esculentus* L.) to different irrigation levels and mulching methods under drip irrigation**" under my guidance and supervision. To the best of knowledge and belief, the present work is the results of his original investigation and study. No part of the dissertation has ever submitted for any purpose at any university.

The project report is appropriate for the submission and partial fulfilment of the condition for the evaluation leading to the award of degree of **Doctor of Philosophy** in **Soil Science.**

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# CERTIFICATE II

This is to certify that thesis entitled, "**Response of okra (*Abelmoschus esculentus L.*) to different irrigation levels and mulching methods under drip irrigation**" submitted in partial fulfilment of the requirement for the award of degree **Doctor of Philosophy** in **Soil Science** to Lovely Professional University, Phagwara ( Punjab) is a bonafied research work conducted by **Nitin Madan Changade** (Registration No: 41600342) under our guidance and supervision. No part of the thesis has been submitted for any other degree or diploma. The assistance and help received during the course of investigation have been fully acknowledged.

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# RESPONSE OF OKRA (*Abelmoschus esculentus* L.) TO DIFFERENT IRRIGATION LEVELS AND MULCHING METHODS UNDER DRIP IRRIGATION


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## ABSTRACT


Water plays a vital role in agriculture, domestic and for industrial purposes. As agriculture uses about 70 percent of fresh water, its judicious and economical use is envisaged. Introduction of micro irrigation is a boon to the farmers which helps to use the water precisely and economically to enhance the yield and water use efficiency. Awareness of micro irrigation techniques among the farmers is still a challenge for the research workers. For solving the food and water scarcity conflicts, either water saving technology should be included in the agriculture or deficit irrigation techniques need to be introduced. Present study was carried out to enhance micro irrigation techniques coupled with mulching and exact water requirement concept. The research work was carried out in year 2019 and 2020 at research farm of School of Agriculture to evaluate the response of okra (*Abelmoschus esculentus L.*) to different irrigation levels and mulching methods under drip irrigation. The objectives of the study were to determine the water distribution pattern under different irrigation methods and the water requirement of okra, to find out the effect of irrigation

and mulching on growth and yield of okra and techno-economic feasibility of okra over the irrigation level and mulching. Three irrigation levels, i.e $I_1$, $I_2$, $I_3$ (1.0ETc, 0.8ETc, 0.6ETc) and five mulching methods, i.e. $M_1$, $M_2$, $M_3$, $M_4$ $M_5$ (black plastic mulch, silver plastic mulch, paddy straw mulch, soil mulch (20 cm depth of soil) and no mulch) were replicated thrice with 15 treatments laid in split plot design. The observation recorded during the experiment was statically analyzed at 95 per cent probability level ($p<0.05$). Soil water movement was determined by measuring the moisture content at 5, 10, 15, and 20 cm horizontal and vertical direction from the emitter in each mulching treatment. The good moisture content at field capacity was recorded near to the emitter (10 -15 cm) in all mulching methods except the soil mulch, in soil mulch good moisture was recorded at 15-20 cm below the ground surface. Lateral movement of water was poor in paddy straw mulch and no mulch where as in plastic mulch good moisture content was observed. The reference evapotranspiration ($ET_0$) was determined by the Cropwat 8.0 model by feeding required location and meteorological data. The maximum total monthly crop evapotranspiration recorded as 188.38 mm and 185.07 mm in the months of July and August in the year 2019 and 2020 respectively. Maximum $ET_0$ (182.65 and 190.70 mm) and ETc (184.48 and 188.91) were recorded in mid-season (31 days) and development stages (30 days) in the year 2019 and 2020, respectively. The maximum plant population, plant height and no of branches was recorded in black plastic mulch interacted with $I_2$ in both the year. The $I_2$ irrigation treatment and black plastic mulching took minimum days to emergence of the first flower in both the year. The irrigation level and mulching individually shows the significant effect on no of pods per plant, irrigation level $I_1$ recorded higher number of pods per plant (17.11 and 18.35) in both the year 2019 and 2020 which was significantly superior to irrigation level $I_3$. The interaction of irrigation and mulching showed the significant effect on yield per plant in both the year. In the year 2019, $I_2M_2$ ($0.8ET_C$ + silver plastic mulch) recorded superior yield (20.18 t/ha) followed by treatment $I_2M_1$, $I_1M_1$ and $I_1M_2$. In year 2020, the $I_2M_1$ (0.8ETc + black plastic mulch) significantly influenced the crop yield and was significantly superior compared to other treatments. The treatment $I_3M_1$ (569.42 and 526.32) and $I_3M_2$ (555.27 and 504.31) showed a higher WUE

compared to other treatments in both the years respectively. The highest BC ratio was recorded as 3.72 in treatment $I_1M_3$ followed by $I_2M_2$ in the year 2019, whereas, in year 2020, treatment $I_1M_3$ (3.97) recorded a significantly higher BC ratio compared with other treatments. Black plastic mulch coupled with $I_2$ recorded a significant effect on biological and yield parameters followed by silver plastic mulch. Soil mulch and paddy straw mulch did not differ significantly over each other but as compared to no mulch these differed significantly with respect to yield.

**Keywords:** Irrigation levels, Cropwat model, mulching, okra yield, benefits cost ratio

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**LIST OF ABBREVIATIONS AND ACRONYMS**

| | |
|---|---|
| ANOVA | Analysis of variances |
| B:C | Benefit cost ratio |
| cm | Centimetre |
| CPE | Cumulative pan evaporation |
| CU | Coefficient of uniformity |
| CV | Coefficient of variation |
| CWR | Crop water requirement |
| DI | Drip irrigation |
| DU | Distribution uniformity |
| Ea | Application efficiency |
| EC | Electrical conductivity |
| *et al.* | Et alii (and others) |
| Epan | Pan evaporation |
| ETc | Crop evapotranspiration |
| $ET_0$ | Reference evapotranspiration |
| EU | Emission uniformity |
| FAO | Food and Agriculture Organization |
| FC | Field capacity |
| ha-cm | Hectare centimetre |
| IW | Irrigation water |
| $K_C$ | Crop coefficient |
| Kg | Kilogram |
| lph | liter per hour |
| LSD | Least significant difference |
| Max. | Maximum |
| Min. | Minimum |
| $P_e$ | Effective rainfall |

| | |
|---|---|
| $q_a$ | Average discharge rate |
| $q_{max}$ | Maximum discharge rate |
| $q_{min}$ | Minimum discharge rate |
| SDI | Subsurface drip irrigation |
| viz. | Namely |
| WUE | Water use efficiency |

# Chapter I

# INTRODUCTION

Okra (*Abelmoschus esculentus* L.) locally familiar as bhindi is one of the popular and oldest vegetables in India as well as world, belongs to the *Malvaceae* family. The origin of okra is not certainly recorded but its diversity exists in Ethiopia, Western Africa, India, some part of south East Asia (Fong *et al.* 2011). Okra grows best within the temperature range of 22-35 $^{0}$C especially in tropical, sub-tropical regions and warmer parts of temperate regions too. Germination of okra seed fails when the temperature goes below 20$^{0}$C but gives good yield in warm humid conditions. In India, okra is the first ranked vegetable in consumption and production for the urban, rural and tribal households (Reddy *et al.* 2017). In India, Gujarat, West Bengal, Bihar and Madhya Pradesh are the leading states in okra production and cultivation. As per the report of National Horticulture Board (Anonymous, 2018a), okra is cultivated in 0.52 million hectare which is 5.16 per cent out of total vegetable area (10.07 million hectare) with the total production of 6.18 million metric tons.

Okra is nutritious vegetable which plays a vital role in the human diet, having good source of protein, fiber, carbohydrate along with various minerals. The composition of 100 g edible portion of okra pods is water (88.6 g), energy (36 Kcal), carbohydrate (8.2g) and protein (2.1 g), fat and fiber (0.2 g and 1.7 g respectively), the minerals like calcium (84.0 mg), phosphorus (90.0 mg), ferrous (1.2 mg), βcarotene (185.0 μg), thiamine (0.04 mg), riboflavin (0.08 mg), niacin (0.6 mg) and ascorbic acid is about 47.0 mg (Lamont 1999, Saifullah 2009 and Singh 2014). Okra leaves were often consumed as vegetable in African countries, young pods in Turkey and Sun dried pods in Western Africa. Okra is a versatile vegetable crop due to its uniqueness and substitution for other crops. Okra seeds are the substitute for the coffee and widely used in Central America, Africa and Malaysia. Okra seeds are also used to prepare the curd and oil as well as paper pulp and fuel from its fiber and stems respectively (Lamont 1999).

The rate of water usage has been increasing more than twice the rate of population increases compared to last century. As per the FAO, eighteen hundred million people would live under complete water paucity areas, whereas two third of world population could face water stress conditions by 2025 (Anonymous, 2016). Water scarcity is the major concern to fulfil the population, industrial and specifically agriculture demand. Due to the impact of climate change, the whole globe is moving towards the water scarcity crisis. Looking at the availability of water, future water scarcity crisis and food security concerns, in the future it will become mandatory for the whole world to use efficient irrigation systems. Micro irrigation was already introduced many years ago, but its lack of application and awareness puts us on the back foot. The Government of India introduced a centrally funded scheme on micro irrigation for the enhancement of efficient use of water in the agriculture sector through trickle irrigation and sprinkler irrigation system (Anonymous, 2006). Jain (2019), interpreted that the area coverage under micro irrigation is about 10.3 mha and the potential is somewhat higher (69.5 mha). It shows the country has achieved only 14.8 per cent of its potential area.

In India, Rajasthan has highest share of area under micro irrigation followed by Andhra Pradesh (15.5 %) and Maharashtra (15.5 %). In micro irrigation, Andhra Pradesh has more area under drip irrigation (1.15 mha) followed by Maharashtra (1.08 mha) and Rajasthan (0.28 mha) whereas Rajasthan is the leading state using sprinkler irrigation (1.60 mha) compared with other states (Anonymous, 2018b). Drip irrigation is an efficient water saving irrigation system that is a boon for the farmers due to its higher water use efficiency (90 %).

From the historical point of view, drip irrigation was first used as a sub irrigation tool in Germany in 1860, based on the basic ideas of underlying irrigation. Later on, the significant breakthrough was made in 1920 by Germany when they introduced the perforated pipe as like as trickle irrigation. In early 1940, Simcha Blass, an Israeli irrigation engineer invented drip irrigation based on the concept of leaking tap near a big tree showed vigorous growth than other tree.

The field research trial conducted by Pruit *et al.* (1984) reported that the water use efficiency increased up to 20 per cent in drip irrigation compared to furrow irrigation. Practically drip irrigation systems perform a vital role in escalating the production of vegetable crops, horticulture crops and some agronomic crops including cash crops like sugarcane and cotton. The data collected from various research studies on okra cultivation under drip irrigation reveals that the drip irrigation shows increased productivity by 20-30 per cent and water saving by 40-60 per cent (Narayanamurthi 2018). Okra crop irrigated with drip irrigation showed remarkable yield of about 70.12 q/ha which was 35.77 per cent more than the furrow irrigation (Gorantiwar *et al.* (1991).

Water saving target can be achieved by maintaining the moisture level in the root zone equal to the crop evapotranspiration. Crop evapotranspiration is the water requirement needed to meet the combined water loss occurring due to evaporation from the soil surface and transpiration from disease free crops when grown in a large field (Doorenbos and Pruitt, 1977). Water requirement of crop also termed as a crop evapotranspiration depends upon weather data. Evaporation multiplied by crop coefficient is the simple technique to determine the crop evapotranspiration but the consideration of all weather data creates the accuracy of water requirement and is widely accepted by scientists. Various temperature and radiation based methods were studied by many scientists to determine the evapotranspiration of vegetable and agronomical crops (Tabari *et al.,* 2013 , Kar *et al.*, 2016, Chowdhury *et al.*, 2017).

Allen *et al.* (1998) systematically elaborated the techniques for the estimation of crop evapotranspiration and represented it as a FAO 56 PM method. Penman-Monteith FAO 56 methods is one the accurate methods and is widely accepted by scientist and growers. Calculation of crop water requirements utilizes input of climatic, crop and rainfall data. This method helps the scientists to determine the reference evapotranspiration by Penman-Monteith methods and is incorporated in the CROPWAT model. Smith *et al.* (1991) presented that the Cropwat model is a practical tool for the meteorologist, agronomist, and irrigation researcher in crop water requirement studies. CROPWAT 8.0 is a computer based tool which needs the meteorological data for the estimation of crop water requirements and irrigation water requirements.

Moisture conservation techniques includes the spreading of the organic and inorganic material near to the crop root zone which increases the quality and quantity yield of crop. Soil mulching is the techniques similar to the subsurface drip irrigation in which drip lateral can be buried at suitable depth. Subsurface drip irrigation (SDI) is superior and advantageous than the surface drip irrigation in various aspects like significant water use, higher water application uniformity, enhancement of crop growth and yield attributes but depend if it is placed at correct depth beneath the soil surface (Camp 1998). Singh and Rajput (2007) stated that yield of okra could be increased if the lateral are placed at 10 to 15 cm depth in SDI methods. Drip irrigation along with mulching increases the productivity and performed a good water saving techniques. Uniformity of application rate of water near to the crop rooting zone depends upon the hydraulic design of drip irrigation system. Water use efficiency could be increased by using moisture conservation techniques and mulching is one of the efficient and widely accepted moisture conservation technique. Mulching is also a boon in water scarcity areas and when combined with drip irrigation methods, then the production and productivity both increases remarkably. Mulching technique is the spreading of organic or inorganic material over the seedbed to conserve the moisture, retard the weed growth, increases the microbial activity and to maintain the proper water air ratio in root zone. Organic mulching i.e crop residue, straw, leaves etc. conserve the moisture and improves fertility after its decomposition whereas inorganic mulching i.e. plastic mulching of various color and thickness maintain the soil temperature, microbial activity and suppress the weed growth.

Plastic mulches absorb the large amount of incoming radiation and transmit it to the soil which helps to maintain the required soil temperature for crop germination and growth (Tarara 2000). Transparent polyethylene transmitted 75 per cent of the thermal radiation and black polyethylene transmitted 20 to 40 per cent thermal radiation (Kiss 1972). Different color inorganic mulch showed a remarkable effect on crop growth parameter and soil moisture, among that black plastic mulch boosted the yield of crops due to rise in soil temperature (Bonanno and Lamont, 1987, Soltani *et al.,* 1995, Vos *et al.*, 1995, Ibarra-Jimenez *et al.* (2011). Increase in soil temperature is not favorable for all types of crops and season. In hot climatic regions, rise in soil temperature beneath the black plastic mulch may be unenviable and white color mulches become the good alternatives. In cold climatic regions black plastic maintains the warm soil temperature at night.

By considering the above points and looking the success of the combined effect of mulching and drip irrigation methods, the present study is carried out to evaluate the "**Response of okra (*Abelmoschus esculentus* L.) to different irrigation levels and mulching methods under drip irrigation.** The various irrigation level based on crop evapotranspiration and mulching methods including soil mulch were used and research trials conducted with following objectives:

**OBJECTIVES:**

1. To determine moisture distribution under drip irrigation method.
2. To determine the water requirement of okra crop.
3. To find out the effect of different irrigation levels and mulching methods on the growth and yield attributes of okra.
4. To workout techno-economic feasibility of different irrigation levels and mulching for okra crop.

# Chapter II

# REVIEW OF LITERATURE

To fulfil the objectives of the proposed study "Response of okra (*Abelmoschus esculentus L.*) to different irrigation levels and mulching methods under drip irrigation", various scientific research papers and articles from India and abroad were reviewed. The review of literature presented under the heading as below were studied about the Cropwat model, irrigation interval, mulching, growth and yield parameters of okra which helped in development of methodology and planning of present investigation.

2.1 Soil water distribution pattern
2.2 Hydraulics of emitters
2.3 Crop evapotranspiration and Cropwat Model
2.4 Crop coefficient of crops
2.5 Mulching and irrigation level
2.6 Water use efficiency
2.7 Economics of drip irrigation and mulching

## 2.1 Soil water distribution pattern

Soil moisture distribution beneath the soil surface depends upon the types of soil, its texture and compactness, application rate of irrigation source, time of irrigation and the uniformity of irrigation. The various scientist conducted the field trial on soil moisture distribution pattern, wetting front, water movement with respect to time at different irrigation sources, discharge and pressure of application. Accordingly various research findings were reviewed and elaborated as below.

Shirahatti *et al.* (2007) conducted the study on vertical and horizontal movement of water at various depths during the investigation of the impact of various irrigation methods on the yield levels of cotton in a red soil of Karnataka. Moisture content after 24 hr. of irrigation showed the different trend of water movement in vertical and horizontal direction. The results recorded that moisture content increased near the trickle source (0-10 cm) and declined as the horizontal distance increased from the water source.

The water flow rate in sandy soil under trickle irrigation was investigated by Gaur *et al.* (2008). The trickle irrigation system operated for two hours with emitter discharge 4 lph and measured the wetting front horizontally and vertically. The average lateral water movement increases from 11.20 to 21.25 cm with the increment of the time from 15 minutes to 120 minutes while the downward movement of water incremented from 7.5 to 21.0 cm was recorded at time 15 to 120 minutes. As per the above observation, authors concluded that 4 lph discharge may be used for crops having spacing 45 cm × 45 cm and irrigation requirement up to 8 liter per day per plant.

The two dimensional movement of water in a sandy soil was studied by Kaute and Gaikwad (2011). Two discharges (2 and 4 lph) of the drip irrigation system were selected as a point source and the system ran for different pressure. Researchers observed that at the emitter discharge 2 lph, horizontal movement (30 cm) of water was more than vertical (25.56 cm) but horizontal water front decreases and vertical water front increases with the time increment. In 4 lph emitter discharge, horizontal water movement is less than vertical movement at initial stage and it progresses with respective time. The researcher came to the conclusion that the onion-shaped bulb of moisture content indicates proper moisture distribution near the point source.

Shrivastava *et al.* (2011) conducted the studies on soil moisture distribution in clay soil over layer with clay loam soil irrigated with drip irrigation with different irrigation levels. The soil samples were taken up to 120 cm horizontally and 60 cm vertically in a single row and pair row lateral system. In this study, the authors observed that horizontal and vertical movement of water in soil advances with the increase in time and quantity of irrigation. Investigator concluded that lateral the water front was more than vertical and this may be due to low infiltration rate of clay soil and over layer of clay loam soil.

Water movement patterns in sub soil in the form of soil moisture distribution under drip irrigation and subsurface drip irrigation had been investigated by Al-Ghobari and El-Marazky (2012). Investigator measured the moisture content by gravimetric method at 0, 5, 10, 15, 20 and 25 cm horizontally and 10, 20, 30, 40, 50 and 60 cm depth vertically and prepared the contour map with surfer software. He observed the wetting pattern and concluded that soil moisture vertical motion of water was higher than the soil moisture at horizontal movement of water in both surface drip. He observed that the soil moisture content increased vertically rather than horizontally under different irrigation techniques.

Dough *et al.* (2013) studied soil water distribution under subsurface drip irrigation at different depth and time intervals. Investigators placed the lateral at different depths and soil moisture content were determined at two, four and six hour duration after irrigation. Moisture content was estimated from soil samples taken laterally at 0, 20 and 40 cm away from emitter and downward direction at each 10 cm incremental depth up to 60 cm. Investigator recorded that the soil water distribution at depth 35 cm was uniform compared to 5 and 10 cm and he added that this was due to dry soil at 35 cm depth and lesser evaporation rate.

Changade and Raj Kumar (2019) reviewed on challenges and opportunities of subsurface drip irrigation. They studied the challenges of depth of placement of lateral for proper moisture distribution and to avoid the rodent attack. From the previous study they concluded that the lateral placed at 30 cm depth below the ground surface can distribute the moisture uniformly for most of the crops and also avoid the damages of lateral due to rodent attack. They also suggested that use of anti-rodents material for lateral gives less maintenance and increased the life of subsurface lateral.

Soil water distribution pattern in clay loam soil of Gujarat investigated by Vadar *et al.* (2019) during the study of effect of subsurface and surface drip on summer okra. The good moisture distribution was observed under lateral laid at15 cm and also recorded higher crop yield compared to other treatments.

Soil moisture distribution under drip irrigation and mulching in sandy clay loam soil was studied by Selvaperumal *et al.* (2020). The soil samples were taken on just before, immediately, one day and two day after irrigation at 0, 15, 30 and 45 cm horizontally and 0, 10, 20 and 30 cm vertically and soil moisture content were estimated by gravimetric method. It was observed that the average soil moisture about 40 per cent was found beneath the emitter at depth 10 cm measured just after irrigation. Author concluded that the increase in soil moisture content below the emitter at certain depth was due to minimum evaporation rate.

### 2.2 Hydraulics of emitters

Crop vegetative growth and better yield is proportional to the distribution of moisture and nutrient near to the root zone which could be possible due to good irrigation system and its water uniform distribution efficiency. Pressurised irrigation techniques like drip and sprinkler affect the distribution uniformity by variation in pressure, components dimension, layout and manufacturing techniques. To investigate the various uniformity indexes of the drip system, scientists developed the various formulae and techniques and whose results are discussed briefly as below.

Sahu and Rao (2005) evaluated the hydraulic parameter of drip irrigation in context of uniformity behaviour of emitter at various operating pressure and discharge measured at various stages of lateral. The various head loss and friction loss of different components was estimated and the relationship between the discharge and pressure was studied. The relationship within the average emitter discharge at the respective pressure head was discovered. The coefficient of uniformity (CU) was rated as outstanding (>95 per cent) and the emission of uniformity (EU) was rated as reasonable (>90 per cent).

Design uniformity coefficient of drip irrigation system at two emission devices and at different pressure heads was investigated by Popale *et al*. (2011). Finding showed that uniformity of the system increased with the increase in operating pressure but the coefficient variation decreased.

Deshmukh *et al.* (2014) experimented on a levelled field to determine hydraulics of emitters on two discharge rates and varying pressure. The results showed that for both the emitter discharge (1.3 and 2.4 lph), various hydraulic parameter viz. coefficients of variation and emitter flow variation were recorded as minimum at pressure head 1.5 kg/cm$^2$ and maximum at 0.7 kg/cm$^2$. Similarly, at same pressure, for both emitters discharge and maximum emission uniformity was found to be 94.68 per cent and 96.66 per cent, uniformity coefficient was 95.3 per cent and 97.1 per cent, application efficiency was 92.98 per cent and 96.07 per cent and delivery efficiency was 95.3 per cent and 97.1 per cent respectively.

The hydraulic performance as uniformity coefficient of drip irrigation at different irrigation levels were studied by Salunkhe *et al.* (2015). Authors recorded that the maximum emitter flow was 3.46 lph with average uniformity coefficient of about 95 per cent indicate the better performance. The results revealed that field emission uniformity ($EU_f$) and absolute emission uniformity ($EU_a$) values were lower than the corresponding uniformity coefficients (Cu) and system was well performing within the critical limit of flow variation about 0.088 to 0.158.

Shashikant *et al.* (2016) estimated the hydraulic parameters of drip systems like coefficient of variation and emission uniformity for 1.3 lph inline emitters at selected pressure. They experienced that when the pressure increases, then discharge of the emitter also increases and the coefficient of variation was found to be maximum 0.1 and minimum 0.03 at pressure 0.70 kg/cm$^2$ and 1.50 kg/cm$^2$ respectively. The uniform discharge distribution of each emitters were decided by emission uniformity. The average maximum emission uniformity was recorded as 95.75 per cent at operating pressure 1.5 kg/cm$^2$ followed by

1.2 kg/cm$^2$ (94.25 %), 0.9 kg/cm$^2$ (92.37 %) and 0.7 kg/cm$^2$ (86.02 %), respectively. It was clear from the recorded observation, as the operating pressure increased, the emission uniformity increased.

Elnemr and Amer (2020) compared the drip irrigation parameter with crop yield. The system was operated at four operating pressure heads (5, 10, 15and 20 m) and the uniformity parameters i.e distribution uniformity, manufacturing coefficient of variation, emission uniformity were determined. Two crops lettuce and turnip were selected as study crops. Results revealed that crop yield increased with the increase in uniformity of drip system and emission uniformity showed the strongest effect on crop yield.

Kishore *et al.* (2020) evaluated the performance of drip irrigation systems by using existing drip tape, new drip tale and inline drip lateral. The various hydraulic parameters viz. distribution uniformity, application efficiency, field emission uniformity, absolute emission uniformity were studied. The finding revealed that the inline drip system recorded a more uniform coefficient (98 %) followed by new drip tape (96 %) and existing drip tape (95 %). Maximum absolute emission uniformity was recorded in a new drip tape inline drip which was considered as an excellent water distribution system.

### 2.3 Crop evapotranspiration and Cropwat Model

Significant growth and good yield of crops could be achieved by maintaining the definite water needed for crop development which is termed as the crop evapotranspiration. Evapotranspiration ($ET_0$) is the vaporization of water from the soil surface (evaporation) and the plant tissue (transpiration) which is based on the climatic factors. The evaporation rate is higher and transpiration rate is less when the crop is small and *vice versa* when the crop is at the developed stage. The various researchers and scientists developed methods and models for estimation of evapotranspiration based on the available climatic data. Temperature based model (Blaney-Criddle Method 1952, Thornthwaite 1948, Hargreaves-Samani 1985), radiation based (Turc 1961, Priestley and Taylor 1972, Doorenbos and Pruitt, 1977 ) and combined climatological data Penman-monteith (FAO 56) were studied by various researcher to estimate the evapotranspiration, among them Blaney- Criddle method, Priestley -Taylor methods and Penman-Monteith methods were found more accurate and reliable methods. The FAO-56 Penman-Monteith method was used as a tool for the Cropwat model. The findings and process of various scientists and researchers were reviewed and elaborated as below.

Doorenbos and Pruitt (1977) stated the guideline to estimate the evapotranspiration by various methods, they stated that evapotranspiration is combination of evaporation process on soil surface and transpiration by vegetative part of plant. They also observed that the crop evapotranspiration rate varied as per the stages of crop i.e. crop coefficient (Kc) values which can be measured by lysimeters or field water balance method. Crop evapotranspiration rate solely depended on climatic factors so its rate varied as per the region and can be used for irrigation scheduling.

Smith (1991) studied the Cropwat 8.0 model for estimation of reference evapotranspiration ($ET_0$). Researcher stated that Cropwat 8.0 is a computer based tool used for estimation of crop and irrigation requirements from past or current meteorological and crop data. Crop water requirements can be determined by using the reference evapotranspiration determined by Cropwat. The Cropwat enables users to input the calculated $ET_0$ values or to enter the required weather data which allows Cropwat to estimate $ET_0$ by programmed the Penman-Monteith formulae. He also stated that certain weather variables such as wind speed, sunshine hours and relative humidity are often unavailable at meteorological weather stations, posing a challenge for estimation of $ET_0$ precisely with the Cropwat 8.0 mode.

Allen *et al.* (1998) developed the Penman-Monteith equation for the estimation of reference evapotranspiration in mm/day based upon meteorological data taken on a daily basis. The required meteorological data for the estimating of reference evapotranspiration was temperature, relative humidity, average wind speed, solar radiation, location, and crop details.

Kuo *et al.* (2001) evaluated crop water requirements for rice crop in Taiwan by using the Cropwat model. According to the results obtained by the Cropwat model, the yearly possible evapotranspiration and successful precipitation in Hsueh Chia were 1,444 mm and 897 mm, respectively. Crop water requirements and deep percolation in the paddy fields were 96.2 cm and 29.5 cm for the first and 111.4 cm and 29.6 cm for the second research trial respectively. Experimental study demonstrated that water requirements of crops would be efficiently and accurately estimated by irrigation management model.

Lee *et al.* (2005) tested the eight evapotranspiration estimation methods with thirty years of daily meteorological data of the west coast of peninsular Malaysia. It was observed that samani Hargreaves methods recorded the maximum evapotranspiration values followed by Priestley -Taylor and Hargraves method. It was also recorded that the Penman-Monteith, Blaney-Criddle and pan methods recorded least evapotranspiration with non-significant differences. Statistically, these three methods were observed to be the superior methods for estimation of evapotranspiration in the current research area with correlation coefficients of 0.97, 0.55 and 0.87, respectively.

According to Pereira *et al.* (2006), the issue of forecasting water usage by plants is a complex phenomenon and requires the measurement of various climatological and biological attributes. Evapotranspiration varies with meteorological conditions, and also affected by plant factors and the amount of soil water available to the roots. The leaf area will influence transpiration under unlimited soil water conditions. When foliage fully shades the ground, the transpiring surface is considered to be equal to the covered ground area, even though the leaf area index varies from unity.

Hatfield and Allen (2006) compared the existing ET equation value with different empirical and energy balance equation at different irrigation regimes and reported that the penman-monteith model gave consistent result of evapotranspiration under deficit water supply over the growing season and found best model among other different ET estimation methods, authors also added penman-Monteith method was more reliable model due to requirement of standard meteorological data.

Tabari (2010) selected the accurate model to estimate the evapotranspiration for four climatic zones of Iran i.e., cold humid, arid, warm arid, semi-arid climate. Turc model was selected as the most appropriate model for cold humid as well as arid climates, whereas, the Hargraves model was incredibly exact model for semi-arid humid and warm humid climates. Investigator reported that Makking and Priestley -Taylor models were less accurate as compared to Turc and Hargraves model for all climatic zones.

Tukimat *et al.* (2012) studied three temperature based ET methods and three radiation based ET methods to estimate the past and future based ET at Kedah region of Malaysia under Muda Irrigation scheme. The performance of these methods were compared with the Penman-Monteith method and it was noticed that radiation based methods performed better than temperature based methods. In view of projecting future ET, radiation based methods were observed in close approximation to Penman-Monteith method. Thus, it was concluded that radiation based methods gave better performance for historical ET and projecting future ET as compared with Penman-Monteith method.

Panigrahi and Sahu (2013) evaluated the response of okra i.e., evapotranspiration (ETc), biometric parameters, yield attributes and nutrient uptake efficiency under partial root zone drying furrow irrigation. Investigators found the maximum yield in partial root zone irrigation. They calculated the ETc and Kc values of a crop, based on growth stages, management practices and environmental factors in a region and concluded that their calculation was more accurate than empirical model estimation.

Tabari *et al.* (2013) evaluated the simple reference evapotranspiration by various methods which were based on the requirement of different meteorological data. He studied eight methods based on pan evaporation data, seven methods based on temperature data, four methods based on radiation data and ten methods based on mass transfer based data and evaluated these methods against Penman-Monteith FAO 56 (PMF-56) method. Among these 29 methods, the five methods i.e., two radiation based, one temperature based (Blaney-Criddle), one Hargraves–M4 and Snyder pan evaporation were found best in comparison to PMF-5.

Laghari *et al.* (2014) conducted the research trial to estimate water requirement of crop based on meteorological data collected from meteorological data of Faisalabad region. He estimated the evapotranspiration by using the Penman-Monteith method within the Cropwat model and reference evapotranspiration was observed higher during April to September months.

Tahashildar *et al*. (2015) carried out the field experiment to estimate the reference evapotranspiration by eight different models which included temperature based, radiation based $ET_0$ estimation methods. The crop coefficient was determined by field lysimeters experiment. The estimated $ET_0$ of all these methods were compared with the $ET_0$ value of Penman-Monteith methods by scatter plot and pair t test tool. Researchers observed that the Blaney Criddle method and penman monteith methods found similar $ET_0$ values. He also observed that highest Kc values was obtained at $8^{th}$ week after transplantation when there was maximum vegetative growth.

Kar *et al.* (2016) studied the eight methods to estimate the reference evapotranspiration ($ET_0$) for the sub humid agro-ecological region. The artificial neural network was used for estimation of $ET_0$ using minimum input. He observed that the annual average evapotranspiration of the Varanasi region was observed to be 144.74 cm by Penman-Monteith methods. Selected eight methods were compared with Penman-Monteith method and it was observed that the FAO-24 and Hargraves-Samani (3) method underestimates the reference evapotranspiration value and Modified Penman-Monteith, Hargreaves-Samani, Valiantzas, Irmak, Hargreaves, over-estimated the reference evapotranspiration.

Chowdhury *et al.* (2017) conducted the study on estimation of reference evapotranspiration by three temperature and three radiation based methods and results compared with FAO - 56 PM. The former study was conducted at the Mohanpur research station West Bengal by using 10 years meteorological data. The results revealed that the radiation based Turc method showed closest $ET_0$ values compared with FAO-56 PM method whereas temperature based Thornthwaite method showed least match with FAO-56 PM method.

Manik *et al.* (2017) studied the six methods to estimate the standard evapotranspiration by using the one year meteorological data of Masgar, Lampung Indonesia. He analysed the ET results as Index Agreement (IA) by using statistical method in error indicator i.e. root mean square error, mean absolute error and logarithmic root mean square error. He concluded that the Makkink model was simple and suitable for the Lampung lowland area, and it worked well when climatic data was limited but the FAO 56 was best and recommended model.

Patil and Tiwari (2018) conducted the field experiment to assess the response of okra under subsurface drip irrigation. He also studied the water balance parameter and regional crop coefficient using lysimeters.  He found that total crop evapotranspiration under subsurface drip irrigation under plastic mulch and without mulch was 512 and 403 mm in year 2016 whereas 363 and 468 in year 2017 respectively. High yield of okra was observed under subsurface drip irrigation with minimum crop evapotranspiration.

Trivedi *et al.* (2018) carried out the experiment to estimate the actual evapotranspiration (AET) in the Shipra river basin area by using the Cropwat model 8.0. Investigators determined the potential evapotranspiration (PET) through Cropwat model and converted it into AET by using crop coefficient.  It was observed that the maximum average AET was 288 mm in the month of May and that was due to maximum temperature recorded in that month whereas minimum AET was observed in November (34 mm). From this study, authors concluded that the PET and AET increased and decreased with change in temperature increases and decreases.

Ewaid *et al.* (2019) investigated the water requirement and irrigation schedule of major crops in southern Iraq. Investigators used the Cropwat 8.0 model to estimate the reference crop evapotranspiration. The investigators concluded that the Cropwat 8.0 model was useful for estimation of reference evapotranspiration which helped proper water resource management for the major crops in southern Iraq.

Pathak and Shete (2019) studied the Cropwat model, water balance method with selected depth of root zone to estimate the water requirement of tomato. Twelve years of meteorological data utilized in Cropwat 9.0 model to determine the crop evapotranspiration and effective rainfall. Net irrigation requirement was recorded as 456.4 mm by Cropwat 9.0 and 275.89 mm by the water balance method. Authors also concluded that water balance method is superior to that of Cropwat 9.0 methods with respect to water saving.

## 2.4 Crop coefficient of crops

The crop coefficient is the essential parameter for estimation of crop water evapotranspiration which can be determined by lysimeters experiment, water balance method, soil water depletion method and other empirical equations. The ratio of crop evapotranspiration (ETc) to the reference evapotranspiration ($ET_0$) is known as crop coefficient (Kc). The crop coefficient is affected by the vegetative growth and ground cover at different growth stages. Estimation of crop coefficient varies as per the latitude, climatic region and crop stages. Crop coefficient value at different growth stages i.e. initial, development, mid-season and late season is the key value for exact water requirement. Number of research studies have been done to estimate the crop coefficient and comparing the estimated Kc values with standard one. Allen *et al.* (2006) proposed that accuracy is highly concerned when scientists estimate crop coefficient factor using local climatic conditions by observing data using lysimeters. Some of the literature reviewed and presented below:

Jyothy *et al.* (2011) estimated the average weekly crop coefficient value of four crops namely groundnut, paddy, cash crop tobacco and sugarcane in Tirupati, Andhra Pradesh region, and compared them with the recommended procedure of FAO-56. The crop coefficient values of these crops were estimated as ratio ETc measured by lysimeters to

$ET_0$ estimated by Penman Monteith method. It has also been discovered that ETc values calculated using the proposed models are comparable to lysimeters-measured ETc.

Abyaneh *et al.* (2011) estimated the water requirement as well as single and dual crop coefficient of garlic with lysimeter in 2008-09. During the growing season, crop water requirements (ETc) were recorded as 54.65 cm and 51.92 cm, respectively. Odofin *et al.* (2011) estimated the ETc and crop coefficients (Kc) for bush okra during a two year study at a tropical sub-humid area of Nigeria. ETc was calculated using the soil moisture depletion process, and daily pan evapotranspiration (ETp) estimated using the Blaney-Morin-Nigeria (BMN) ET model developed for climatic conditions in Nigeria. Weekly crop coefficient (Kc) values increased from a low of 0.38 at initial growth stage to a high of 1.05 in middle of the season, then fell to 0.40 at late season stage.

The crop coefficient (Kc) value, water requirement of tomato and the influence of deficit irrigation on tomato in Ghana was studied by Owusu-sekyere (2012). They used four irrigation treatments designed by completely randomized design. It was observed that the seasonal water requirement for tomato crop to be 302.98 mm and crop coefficient values lied within 0.62 and 1.61. Irrigation level with 80 % ETc showed negative effect on growth parameters and yield of tomato.

Patil and Tiwari (2018) studied the crop coefficient of okra under subsurface drip irrigation in sub humid climatic conditions in mulching and non-mulching treatment. He observed that the average crop coefficient ranged between 0.31 and 0.77 under subsurface drip irrigation mulched with plastic material and 0.51 to 0.93 in without mulch.

Hommadi, *et al.* (2020) developed the equation for determination of crop coefficient through the dimension analysis. The research used the evapotranspiration, crop coefficient and crop evapotranspiration data as an input and developed the equation. The percent of deviation between the value of crop coefficient which is used by ordinary equations and extracted equation of statistical method was 4.28%. The extracted equations from statistical and dimension analysis represented the value of Kc changes with time (week). These equations are used to loam soil texture and okra crops inside the greenhouse.

### 2.5 Mulching and irrigation level

Soil cover by spreading the organic and inorganic material, reduce the soil moisture loss and enhance the water use efficiency. The various soil covering material termed as a mulching material conserves the soil moisture and maintains the optimum temperature for significant crop growth and yield results. Organic mulch including the rice straw, paddy straw, plant leaves, sugar cane baggage, agriculture residue play a vital role in moisture conservation as well as to increase the organic content in the soil due to the time being decomposition process. Inorganic mulching i.e. various grade and colour plastic paper is the alternatives to the organic mulch and trending as a boon for the farmers to increase crop yield and control weed. Plastic mulch improved weed control, increased water and fertilizer efficiency (Lamount, 1993), maintained the microclimate to the plant by modifying soil energy balance (Liakatas *et al.* 1986), increased optimum soil temperature near to the root zone (Cooper, 1973 and Tarara, 2000) and enhanced the crop yield. Among the various colour plastic mulches, black plastic mulch was found suitable for vegetable crops to increase the yield, suppress the weed and improve the soil health. The research work on different mulching method along with different irrigation level, crops, and tillage practices in different climatic region are briefly reviewed below:

Tiwari *et al.* (1998) conducted the research to examine the response of okra on biometric and yield parameters under different irrigation levels by drip and mulching methods. The field experiment was conducted at Kharagpur, West Bengal during summer+spring season for three years on lateritic soil. Researchers determined the actual water requirement by modified Penman Method and results compared with furrow irrigation methods. Black plastic mulch with 100 per cent irrigation level showed significantly higher yield which was 72 per cent more compared with furrow irrigation. It was concluded that enhancement of yield was due to favourable temperature and moisture available under black plastic mulch.

Sunilkumar and Jaikumaran (2002) analyzed the impact of mulch methods and irrigation regimes on yield attributes of bhindi. Ten treatments including the three irrigation systems and three irrigation levels were used to investigate the impact on bhindi and results were statistically compared with furrow irrigation as control methods. Drip irrigation produced 51 to 76 per cent more fruits per plant in three irrigation levels compared to the furrow irrigation method. On an average, mulched and drip irrigated crop produced 22.70 t/ha, whereas mulched and furrow irrigated crop produced fruits 20.95 t/ha, and control crop produced 12.86 t/ha.

Abu-Goukh and Mustafa (2003) carried out the study in Sudan to assess the effect of plastic mulch on growth and yield attributes of okra in the winter season. Three plastic mulch materials viz. black, clear and green plastic mulch were used. Black coloured plastic mulch produced superior yield compared to other mulch as well as compared to control. Plastic mulching increased soil temperature, conserved the soil moisture, increased seed germination but overall black plastic mulches were more effective than other mulches.

Bahadur *et al.* (2009) experimented the influence of irrigation levels and mulch on okra. Authors used 4, 7, 10 and 12 day irrigation intervals as an irrigation level and two mulch (pea straw and no mulch) treatment. The results showed that the pea straw mulch significantly increases the growth and yield parameter due to good moisture conservation as compared to non-mulch methods. Reduction of weed population about 65.34 per cent and water saving about 29.6 per cent was observed under pea straw mulch treatment as compared to non-mulch.

Singh *et al.* (2009) investigated the two year study on impact of drip irrigation and black polyethylene mulch on growth and yield tomato of crops and compared results with surface irrigation method. Water applied to tomato crop through drip irrigation was at different irrigation levels. Black polyethylene mulch with 80 per cent evapotranspiration rate gives significantly superior growth parameters, yield attributes and water use efficiency as compared with surface irrigation.

Gordon *et al.* (2010) conducted the field work on the effect of growth parameters of okra under different colour mulching. Dark colour plastic mulch like blue, red and black colour mulches showed optimum height and yield compared with bare soil. Temperature ranges from 4 to 7 $^{o}$C in all treatments. It was also that increased soil and air temperature didn't always correlate with increase in yield.

Ibarra-Jimenez *et al.* (2011) evaluated different colour mulching effects on soil temperature and potato tuber. Investigators used the black plastic mulch, white colour on black plastic mulch, silver colour appearance on black plastic mulch and aluminium on plastic mulch. It was found that colour plastic mulch gave significantly higher tuber yield than the control method. Leaf canopy and dry weight of shoot increased with the increase in soil temperature due to radiation transmission effect to the soil. Black plastic mulch showed higher soil temperature and significantly showed higher tuber yield.

Chaudhari *et al.* (2012) investigated the impact of drip irrigation and mulching material on okra under two year study at Bikaner. The experiment evaluated the effect on the productivity of okra, nutrient intake and moisture distribution under drip and mulch conditions. The maximum pod yield was recorded at 0.6 pan evaporation fraction with 5.51 and 5.63 q/ha-cm water use efficiency in 2008 and 2009 respectively. Organic mulch gave maximum pod yield (18.19 and 17.91 t/ha) in both years respectively. Overall, the highest pod yield and maximum water-use efficiency were recorded in drip irrigation at 60 % pan evaporation factor along with organic mulch.

Birbal *et al.* (2013) experimented the research trial for two successive years 2009 and 2010 to evaluate the response of okra to irrigation and mulching methods at CAZRI Bikaner. Researchers used two irrigation methods and four mulching methods (plastic, hessian cloth, indigenous material and no mulch ) laid in split plot design with three replication and found that drip irrigation methods gives higher yield compared with furrow irrigation in both the year whereas plastic mulch recorded higher yield compared to all mulching methods.

Dalorima *et al.* (2014) experimented the field trial to assess the performance of okra under various mulching materials. Researchers used inorganic and organic mulch such as sorghum straw, saw dust, and the result of growth parameter compared with control. Due to mulching methods, non-significant effect was recorded on growth parameters of okra but all mulching methods gave superior results over the control. Out of mulching methods, soil moisture retention was observed higher in sorghum straw mulch and plastic mulch.

Mehmood *et al.* (2014) conducted the field trial on different tillage and mulching practices for sorghum crop. Mulching showed the significant effect on pH, electrical conductivity (EC), organic carbon (OC), bulk density (BD). Poultry manure with mulching methods found superior to improve the soil fertility and grain yield but conventional tillage significantly showed higher grain yield (2.75 t/ha) due to moisture conservation and improved soil health.

Mahadeen (2014) conducted the research to investigate mulching effect on biological parameters and yield attributes of okra and summer squash under rainfed condition. He used black polyethylene mulch and found that mulch plots conserved more soil moisture compared with bare soil plots. Author also observed that plots under black polyethylene mulch showed a positive effect on biological parameters and higher yield of both the vegetables.

Ahmad *et al.* (2015) studied the impact of moisture conservation through the mulching methods on cotton in the relation with yield and weed control. Three mulching treatments and three irrigation levels were used and found that minimum weeds and maximum yield was observed under black plastic mulch with five days irrigation interval, followed by straw mulch. Enhancement of yield was due to good moisture conservation near to the root zone under soil cover by straw mulch and black coloured plastic mulch.

Rasal *et al.* (2017) investigated the impact of irrigation level and mulching on growth and yield parameters of Bell pepper (Capsicum annum L.) plants. Authors applied different irrigation levels under drip irrigation and compared the yield with control i.e. flood irrigation. It was observed that the required amount of water applied near to the root zone and reduced the evaporation rate increased the yield and excess water leached the nutrient thus reducing uptake and yield. Significant good growth and higher yield at 100 per cent irrigation under drip plus mulching treatment and less yield at flood irrigation methods was observed.

Jaysawal *et al.* (2018) carried out the research on carrot growth and yield parameters under different mulching treatment. Black, blue and white polyethylene mulch and organic mulch like sugarcane straw, paddy straw, grass mulch and leaves mulch were used. It was observed that black polyethylene mulch recorded taller plant height including all growth parameters as well as maximum yield (54.69 t/ha) followed by blue polyethylene.

Sinha *et al.* (2019) conducted the research on used plastic materials as a mulching for okra crop under drip irrigation at Raipur Chhattisgarh. Investigators used the reddish rice bag, whitish wheat bag and fertilizer bag as conventional mulching materials and compared them with black plastic mulch. The effect on growth and marketable yield parameters of okra along with the moisture conservation and temperature data was measured at different mulching and irrigation techniques. Black plastic maintained the proper temperature and moisture and significantly increased the yield followed by reddish rice bag plastic mulch.

Nagegowda *et al.* (2020) evaluated the performance of mulching and fertigation on nutrient uptake and nutrient use efficiency in okra for Seed Production. Water soluble fertilizers of different NPK doses were applied through fertigation methods in the mulch field of okra. Higher seed yield observed in the interaction treatment of fertilizer and mulching than fertilization through soil application Fertilizer use efficiency and water use efficiency were observed maximum in the treatment with integrated application of fertigation and mulch.

## 2.6 Water use efficiency

Improving water use efficiency (WUE) or agricultural water productivity is a crucial response to increasing water scarcity, which includes the need to leave enough water in rivers and lakes to support ecosystems while also meeting the rising demands of cities and industries. It is important to conserve water and encourage maximum crop growth in order to optimise WUE. Literature reviewed to check the performance of irrigation levels and mulching methods on water use efficiency presented as below.

The seasonal water usage increased as the IW/CPE ratio increased from 0.25 to 0.75 (Patel *et al.* (1993). However, as the IW/CPE ratios increased beyond 0.75, the water usage efficiency exhibited an inverse relationship.

Viswanatha *et al.* (2000) recorded that significant water use efficiency at 0.4 Epan under drip irrigation was 40.04 kg/ ha-mm and it was higher compared to weekly surface irrigation at 0.8 Epan, and saves the water about 187.36 mm.

As per the research conducted by Mahajan and Singh (2006), and observed that the 0.5 Epan and 1.0 Epan was superior over the control practices. Comparing the greenhouse environment (inside and outside), the 0.5 Epan and 1.0 Epan had maximum water use efficiency (0.21 and 0.093 t/ha-mm resp.) than control practices. Drip irrigation level (0.5 Epan) installed in greenhouse saved 48.1 per cent of irrigation water and recorded 51.7 per cent maximum fruit yield. Singh and Kumar (2007) stated that 80% ET with mulch or without mulch had the highest WUE than 100 % ET and 60 % ET at same mulching condition.

Kumar *et al.* (2007) investigated the water use efficiency of onion crops irrigated with a micro sprinkler irrigation system. Four irrigation levels decided on IW/CPE ratio i.e 0.6, 0.8, 1.0 and 1.20. The maximum yield was recorded at 1.0 and 1.20 IW/CPE ratio but the higher water use efficiency was observed in 0.8 IW/CPE ratio. Authors also stated that the water use efficiency decreased with increased IW/CPE ratio.

Singh and Rajput (2007) estimated the water use efficiency of okra irrigated by sub surface drip irrigation in which lateral were laid at different depths. In a two year study, it was observed that the lateral placed at 10 cm depth below the ground surface recorded maximum crop height and crop yield compared to surface drip irrigation. As the discharge increased the yield also increased in all the depths of lateral placement. The water use efficiency was recorded maximum in subsurface drip irrigation when the lateral was placed at 10 cm depth as compared to surface drip irrigation. Thus WUE increased with the increase in lateral discharge for all depths of placement.

Jayapiratha *et al.* (2010) measured biometric observation, yield attributes, and water use efficiency in red yellow soil to assess the yield response of okra irrigated by drip irrigation. Biological parameters and yield attributes were significantly higher in drip systems than in basin irrigation. The significant yield difference recorded in drip system and control plants but non-significant difference in yield recorded in 15 and 30 minute irrigation treatments. The yield for 15 and 30 minutes of irrigation and basin irrigation were 15.16, 15.14, and 10.84 quintal per 1000 $m^2$ area, respectively.

Mukherjee *et al.* 2010 reported that tomato fruit yield and WUE were substantially higher in 25 mm cumulative pan evaporation (CPE) and rainfed conditions than under 50 mm CPE and rainfed conditions. In contrast to the non-mulch situation, mulching increased yield by 23-57 per cent. Black polythene mulch had the highest WUE (25.1 kg $m^3$) among the different mulches, while white polythene mulch, rice straw mulch, and other mulches had the lowest WUE (22, 21 and 39 %).

Kumar and Dey (2011) studied the mulch effect on yield and water-use efficiency (WUE) of strawberry irrigated by drip and surface irrigation methods. Mulching materials showed a positive effect on root growth (63 %), nutrient uptake (179.20 %), WUE (84.40%) and yield (343 %) irrigated by drip irrigation.

Panigrahi *et al.* (2011) conducted a study on partial root zone irrigation for okra crops. Alternate partial root irrigation (APRI) and available soil moisture depletion (ASMD) along with black plastic mulch (BPM) treatments were used and reported that irrigation water use efficiency was the indicator of the pod yield obtained after the application of unit quantity of irrigation water. Maximum output (12.3 $kg/m^3$) was observed under APRI at 50% Available moisture depletion + BPM. The 50 % ASMD+ black plastic mulch yielded more net return with maximum benefit cost ratio.

Yaghi *et al.* (2013) investigated the effects of two forms of plastic mulch i.e black mulch (BM) and transparent mulch (TM) irrigated with drip system on water use, cucumber yield, and maturity period. The study found that the (DI + TM) treatment showed maximum yield and water use efficiency compared to other treatments. However yield and water use efficiency of cucumber decreased in no mulch drip and surface irrigation methods respectively.

Salunkhe *et al.* (2015) reported that higher WUE and FUE drip irrigation systems should be scheduled at alternate day with 0.4 PE depth of irrigation and fertilizer application of 100% RDF. Average water requirement under drip irrigation scheduled at 0.4 PE, 0.6PE and 0.8PE and under surface irrigation was 394.7, 502.1, 609.4 and 660 mm respectively. Water use efficiency and fertilizer use efficiency increased with decrease in the depth of irrigation water applied and fertilizer level respectively. For okra drip irrigation should be scheduled at 0.6 PE with 75% of RDF through water in five equal splits. Drip irrigation increased the okra fruit yield to the tune of 38.33%.

Sedara and Sedara (2020) studied the water use efficiency of okra crops under different irrigation levels irrigated through drip irrigation systems. The irrigation water use efficiency ranges from 24-41kg/ha.mm while the crop water use efficiency ranges from 8.8-13.9 kg/ha.mm. Okra crop irrigated with drip irrigation at 60FIT recorded the highest irrigation and crop water use efficiency with saving 40% water to irrigate additional land.

## 2.7 Economics of drip irrigation and mulching

Drip irrigation is the efficient water saving, labour saving and economic techniques that gives best results if combined with mulching methods. Benefit cost ratio was always more compared with the traditional irrigation methods and non-mulch fields. In spite of higher initial cost and technical aspects, farmers prefer the techniques for increasing their income with higher benefit cost ratio. This statement is supported by various studies as reported below.

Tiwari *et al.* (1998) conducted field experiments for economic evaluation of okra crop irrigation with different irrigation levels and mulching under drip irrigation at Kharagpur. The 100 % irrigation under drip irrigation showed the highest yield which is 72 % higher compared to furrow irrigation. As per the economic feasibility of the research, the net income, BC ratio, yield and water use efficiency was recorded highest in drip irrigation with black plastic mulch.

Singh *et al.* (2009) experimented drip irrigation along with mulching to observe the effect on growth parameter and yield parameter of tomato. Drip irrigation with 80 per cent irrigation and black polyethylene mulch gave higher water use efficiency (1.23 tonnes/ha-cm) and benefit cost ratio (2.03). Drip irrigation saved water about 38 per cent and recorded 55 per cent maximum yield than surface irrigation.

Himanshu *et al.* (2012) evaluated the effect of lateral spacing with irrigation levels on yield and economics of cabbage irrigated by trickle irrigation. In spite of higher initial investment, irrigation at 175% of pan evaporation plus lateral spacing of 1.0 m resulted in maximum B:C ratio (4.48) with gross return and net return per ha of Rs. 271530 and Rs 210972 respectively.

Paul *et al.* (2013) conducted the study to assess the capsicum yield and its economic feasibility under drip irrigation and LLDPE mulching sheets. Higher B:C ratio (2.44) recorded in 100 per cent irrigation volume irrigated through drip irrigation treatment without mulch. The maximum yield (28.7 t/ha) was recorded at 100 per cent irrigation level plus plastic mulching. Drip irrigation without a mulch system could increase the production by 28 per cent than surface irrigation.

Babu *et al.* (2015) performed a research trial to evaluate the response of okra to irrigation levels on yield of okra and water use efficiency at Bapatala, Andhra Pradesh through drip irrigation. The irrigation levels were 1.00 CWR (crop water requirement), 0.80 CWR and 0.60 CWR through the drip irrigation system. The water requirement of vegetable crops was decided through the Cropwat model. Okra crop responded significantly to 0.80 CWR in terms of maximum plant height and root length. The maximum B:C ratio (3.15) was recorded in 0.80 CWR with 21.47 per cent more yield than the conventional method of irrigation and had a water usage efficiency of 0.143 t/ha-cm.

Sharma and Kaushal (2015) studied the economic feasibility of okra irrigated by drip irrigation. Investigators selected nine treatments including the fertigation (60, 80 and 100 per cent) and irrigation levels (60, 80 and 100 per cent). The economic feasibility of drip irrigation level was evaluated by estimating B:C ratio for selected treatment and subsidy of drip irrigation system. The economic evaluation included all the fixed cost and variable cost arose for completion of research. It was concluded that if the government provides a drip irrigation subsidy of more than 30 per cent will be economically feasible to cultivate okra under treatment of 80 per cent nitrogen level and 0.80 IW/CPE ratio irrigation level.

Rao and Lakhawat (2016) conducted a study in the Udaipur district of Rajasthan to assess the economic feasibility of growing okra and tomato crops on silver-colored poly-mulch. The fixed costs for okra and tomato cultivation on silver colored poly-mulch for a six-month span were found to be Rs. 39,835.00/- per hectare. The total variable cost (B) for silver color poly-mulch for okra and tomato cultivation in one hectare area was recorded as Rs. 131,305.00/- and Rs. 140,171.20/- respectively. The cultivation of okra and tomato yielded net returns of Rs. 83,177.50/- and Rs. 419,993.80/- per hectare, respectively. For okra and tomato crops, the input-output ratio (or per-rupee returns) from a 1.0 ha area using silver color poly-mulch was 1.49 and 3.33 respectively.

Sinha *et al.* (2019) evaluated the economics of mulching and irrigation over the okra crop under drip irrigation, maximum B:C ratio (2.09) was observed in black plastic mulch at 120 % irrigation level but compared to initial investment of mulching material and water saving at 80 % ETc, whitish wheat flour plastic mulch was the good alternatives to plastic mulch for economically poor or marginal farmers.

Thokal *et al.* (2020) conducted the field trials to evaluate the growth and yield of okra under the influence of irrigation regimes and fertilization method in Konkan region of Maharashtra. Three irrigation regimes i.e. 100 % ET, 80 % ET and 60% ET were used to assess the biological and yield parameters of okra at fertilizer level. It was observed that the irrigation regime of 80 % with fertigation produced maximum yield and higher water use efficiency was observed at 60 % ET. This treatment resulted in five times more water productivity over the control treatments.

# Chapter III

# MATERIALS AND METHODS

This chapter includes the specific narration of experimental procedure, techniques employed and materials used during research study. The present study was conducted in summer season of year 2019 and 2020. The description of study area, experimental design, techniques involved, observation recorded and methodology adapted during the research study entitled '**Response of okra (*Abelmoschus esculentus L.*) to different irrigation levels and mulching methods under drip irrigation**' are presented as per the headings below.

## 3.1 Description of study area

### 3.1.1 Geographical location of experimental site

The field experiment was conducted at agriculture field of School of Agriculture, Lovely Professional University, Phagwara, Kapurthala district. The Kapurthala district is occupied by Indo-Gangetic alluvium and its major portion lies in river tract falling between the Beas and Black Bein and is called 'BET'. The Kapurthala district is smallest district of Punjab which situated at latitude of 31°16' 40" N and longitude 75° 42' 33" E of having altitude of 218 m above mean seal level. Kapurthala district holding 13$^{th}$ ranks in Punjab having population about 8.17 lakhs which contributes about 3% of the total population of Punjab state. Total geographical area of the Kapurthala district is 1633 sq km which is separated in two units due to Jalandhar district viz. Kapurthala and Phagwara block. The experimental area is situated in Phagwara block at 31$^{o}$ 21' 00" N latitude and 75$^{o}$ 77' 99" E Longitude.

### 3.1.2 Soil type and agro-climatic condition

**3.1.2.1 Soil Type**: The Phagwara region mainly consist of three region namely Sirowal, Dhak and Manjki tracts. The two major soil in Kapurthala districts are arid brown soil and tropical brown soil. Tropical brown soil occurs in Phagwara block and northern part of Kapurthala district. Soil of Kapurthala district is alkaline in nature with the pH value more than 8.5. Most of the soil having electrical conductivity (EC) is less than 1 mmhos/cm. The organic carbon percentage ranged from low to medium may be due to long term cultivation and burning of agriculture residue. Organic carbon percentage is ranged from 0.63 to 0.79 percent in different profile. Most of the soil in Kapurthala is deficit in nitrogen. The available phosphorus is varied from high to very high in all the horizons of profiles. The available potassium content is found to be high and this may be due to release of potassium from intensive weathering, addition of potassium rich fertilizer.

**3.1.2.2 Climatic condition**: The climate of Phagwara block is hot dry sub-humid to semi-arid transition with dry summers and cool winters. There are four seasons in a year namely the cold season (November-March), hot season (April-June), monsoon season (June end-middle September) and post monsoon ( till November). The mean annual temperature ranges from 24 $^{0}$C to 26 $^{0}$C and maximum temperature rises in the month of May and June. The normal annual rainfall of the district is 77.9 cm, which is distributed over 33 days in a year. The peak rainfall received in the month of July and September with less variability.

### 3.1.3 Agrometeorological data during study period

The weather data recorded during the period of investigation is expressed in standard meteorological weeks (Appendix 1 and 2) and presented in Figure 3.1 and Figure 3.2 for the year 2019 and 2020 respectively. The crop sown in the month of April in 2019 and in the month of June in 2020. The crop duration was taken as 110 days in both the year. Maximum weekly temperature of 47 $^{0}$C and 46 $^{0}$C, minimum temperature 23 $^{0}$C and 26 $^{0}$C recorded in the year 2019 and 2020 respectively whereas the relative humidity ranged from 12 to 57 and 17 to 71 per cent respectively. In the year 2019, 22$^{nd}$ meteorological week can be considered as a hottest week with highest temperature 47 $^{0}$C and relative humidity only 30 per cent. In 2020, 24$^{th}$ week can be considered as the hottest week with the highest temperature 47 and lowest relative humidity 15 per cent. Average sunshine hours ranged from 12 to 14 hours. The daily average rainfall recorded for all the crop duration in both the year was 2.8 and 2.5 mm respectively. The maximum rainfall was 56 mm and 27 mm in the year 2019 and 2020 respectively. The average wind speed during experimental duration was 17 km/hr and 16 km/hr per in both year respectively.

### 3.2. Physical and chemical properties of soil

The physical and chemical properties of experimental plot were determined using the standard procedure presented in Table 3.1. The soil texture of the experimental plot was determined by international pipette method (Piper, 1950) and found to be sandy loam soil with 66 percent sand, 23 per cent silt and 11 percent clay. The infiltration rate of the soil was 2.7 cm/h and field capacity found to be 20.05 per cent, permanent wilting point was 9.3 per cent. Bulk density determined by core cutter method was found to be 1.39 $g/cm^3$. The partial density was found to be 2.37 $g/cm^3$. The pH was 7.31 and electrical conductivity was 0.49 mmhos/cm termed as good soil. The soil having deficient in nitrogen (153.62 kg/ha), medium phosphorus (13.62 kg/ha), medium potassium (141.31 kg/ha) and low organic content (0.32 %).

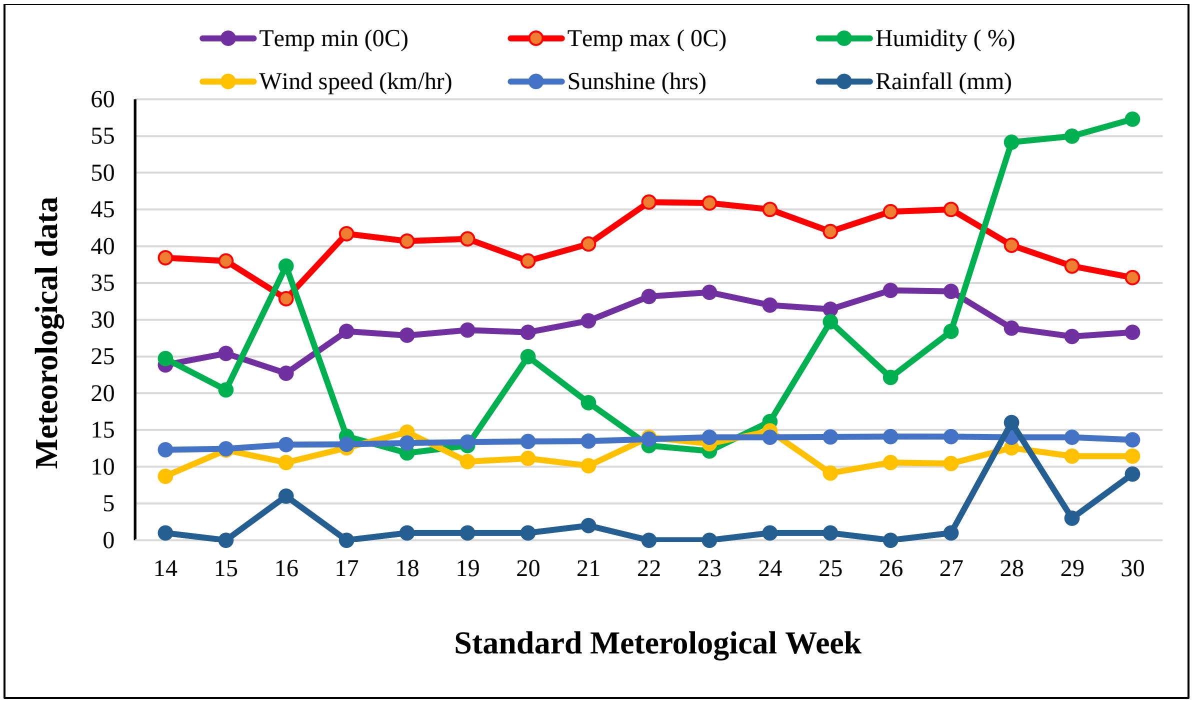


**Fig. 3.1 Meterological data in standard week for the year 2019**

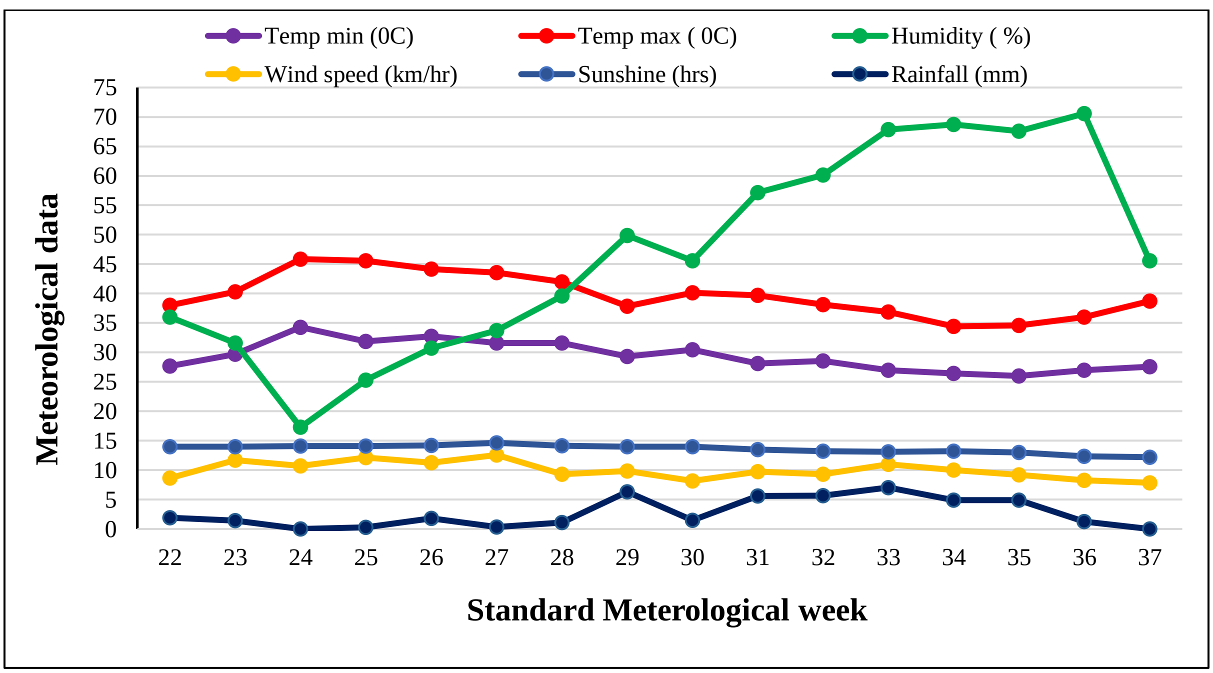


**Fig. 3.2 Meterological data in standard week for the year 2020**

**Plate 1 Estimation of infiltration rate and bulk density**

**Table 3.1 Physical and chemical properties of soil**

| Sr. No | Soil parameter | Method | Value | Reference |
|---|---|---|---|---|
| **Soil physical properties** | | | | |
| **1** | Soil texture | International pipette method | | Piper, 1950 |
| | | Sand (%) | 66 | |
| | | Silt (%) | 23 | |
| | | Clay (%) | 11 | |
| | | Textural class | Sandy loam | |
| **2** | Bulk density ($g/cm^3$) | USDA Core cutter sample method | 1.39 | Blake and Hartge, 1986 |
| **3** | Practical density ($g/cm^3$) | Pycnometer method | 2.37 | |
| **4** | Infiltration rate (cm/hr) | Double ring Infiltrometer | 2.7 | |
| **5** | Field capacity (%) | Field method | 20.05 | |
| **6** | Permanent wilting point (%) | Plant indicator method | 9.3 | Briggs and Shantz, 1912 |
| **Soil chemical properties** | | | | |
| **1** | Soil acidity and basicity (pH) | Electronic glass electrode method | 7.31 | Jackson, 1967 |
| **2** | Electrical conductivity (mmhos/cm) | Electrical conductivity method | 0.14 | Jackson, 1967 |
| **3** | Organic carbon (%) | Wet digestion Method | 0.32 | Walkley and Black, 1934 |
| **4** | Available N ( Kg/ha) | Alkaline Potassium Per manganite method | 153.62 | Subbaiah and Asija, 1956 |
| **5** | Available $P_2O_5$ (Kg/ha) | Olsen's Method | 13.62 | Olsen *et al.* 1954 |
| **6** | Available $K_2O$ (kg/ha) | Flame Photometer method | 141.31 | Merwin and Peech, 1950 |

## 3.3 Treatments details

The experiments were conducted to evaluate the response of okra to different irrigation levels and mulching methods. The irrigation levels were decided based on the crop evapotranspiration rate which was determined by Cropwat model. Organic and inorganic mulching material were selected for mulching method. Soil mulching is one of the treatment considered in this study. Irrigation levels and mulching methods were considered as main plots and sub plots respectively. The experiment laid out by split plot design with three replication.

**Main plot: Irrigation levels**

$I_1$ = 1.00 ETc

$I_2$ = 0.80 ETc

$I_3$ = 0.60 ETc

**Sub plot: Mulching methods**

$M_1$ = Black plastic mulch

$M_2$ = Silver plastic mulch

$M_3$ = Paddy straw mulch

$M_4$ = Soil mulch (20 cm depth)

$M_5$ = No mulch

**Table 3.2 Details of treatments**

| Sr. No | Treatments | Combinations | Treatments details |
|---|---|---|---|
| 1 | $T_1$ | $I_1M_1$ | 1.00ETc + Black plastic mulch |
| 2 | $T_2$ | $I_1M_2$ | 1.00ETc + Silver plastic mulch |
| 3 | $T_3$ | $I_1M_3$ | 1.00ETc + Paddy straw mulch |
| 4 | $T_4$ | $I_1M_4$ | 1.00ETc + Soil mulch (20 cm depth) |
| 5 | $T_5$ | $I_1M_5$ | 1.00ETc + No mulch |
| 6 | $T_6$ | $I_2M_1$ | 0.80ETc + Black plastic mulch |
| 7 | $T_7$ | $I_2M_2$ | 0.80ETc + Silver plastic mulch |
| 8 | $T_8$ | $I_2M_3$ | 0.80ETc + Paddy straw mulch |
| 9 | $T_9$ | $I_2M_4$ | 0.80ETc + Soil mulch (20 cm depth) |
| 10 | $T_{10}$ | $I_2M_5$ | 0.80ETc + No mulch |
| 11 | $T_{11}$ | $I_3M_1$ | 0.60ETc + Black plastic mulch |
| 12 | $T_{12}$ | $I_3M_2$ | 0.60ETc + Silver plastic mulch |
| 13 | $T_{13}$ | $I_3M_3$ | 0.60ETc + Paddy straw mulch |
| 14 | $T_{14}$ | $I_3M_4$ | 0.60ETc + Soil mulch (20 cm depth) |
| 15 | $T_{15}$ | $I_3M_5$ | 0.60ETc + No mulch |

## 3.4. Experimental details

**Table 3.3 Experimental Details**

| | |
|---|---|
| Crop | Okra (*Abelmoschus esculentus L.)* |
| No of treatment | 15 |
| No of replication | 3 |
| Design of experiment | Split plot design |
| Plant to plant spacing | 20 cm |
| Row to row spacing | 30 cm |
| Lateral spacing | 1.0 m |
| Lateral length on each bed | 10 m |
| Plot size of each treatment | (10 x 1) i.e 10 $m^2$ |
| Total bed area | 450 $m^2$ |

## 3.5 Layout of experiment

The experimental design was split plot design. The 25 m x 25 m area was selected for the experimental study. Out of this, actual bed area was 450 $m^2$. The field is divided into three main plots having area of 150 $m^2$ each. Each main plot was again subdivided into three sub plots of 50 $m^2$ area each. In each sub plot, inline drip lateral of length 10 meter was placed on the bed of size 10 $m^2$. The mulching was laid on each bed in randomized way as shown in Figure 3.3.

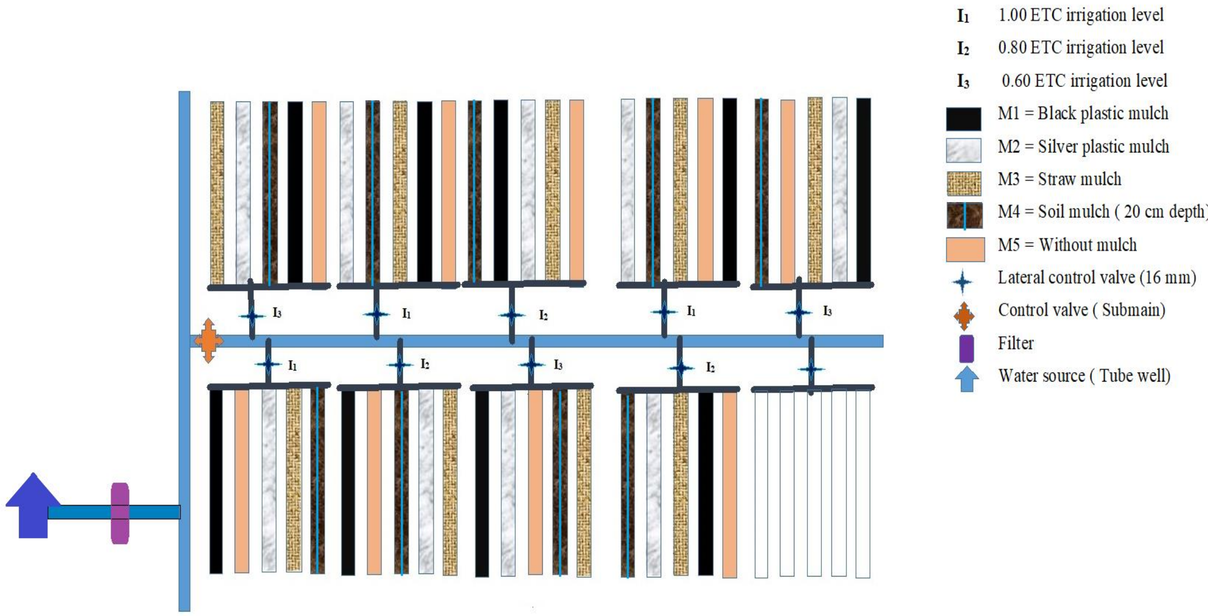


**Fig. 3.3 Layout of experimental field**

### 3.6 Seed bed preparation

Land preparation including deep ploughing which was done by using vertical disc harrow. Clod crushing, land smoothing and pulverizing was done with the help of rotary tiller. All the trash and weeds were collected manually. The seed bed of size 60 cm width, 15 cm height and 10 meter long was prepared manually.

### 3.6.1 Installation of drip irrigation and mulching

Online drip lateral of length 10 m was laid on each bed and flow regulator and end plug was fitted on each lateral. Flow regulator was used to on and off the flow of lateral as per the timing and crop water requirement. The mulching sheet was laid on each bed after the layout of lateral and hole as per the spacing of crop was made by using 63 cm tapered plastic pipe.

**Plate 2 Installation of drip irrigation system in experimental plot**

### 3.6.2 Details of drip irrigation

Drip irrigation system consist of main, submain, control valve, pressure gauge, flush valve, inline dripper lateral and lateral control valve. The diameter of main was 75 mm buried at 45 cm depth to avoid the hindrances for the tillage implements. Submain of 63 mm connected at the middle of main line and divide the submain in two parts. The 16 mm diameter lateral having 4 lph inline emitter attached to submain with the help of grommet take off and control valve also fitted on lateral to control the flow through the lateral. End plug and flush valve was installed at the end of submain to flush out the sediment deposited in submain.

### 3.6.3 Hydraulics of emitters

In a drip irrigation, uniform water application is the major concern to estimate the irrigation efficiency. The important criteria in designing or selection of drip irrigation is to bring the uniform delivery of water through the emitters. The uniformity of emitter and efficient design of micro irrigation system is based on various coefficient namely distribution uniformity (DU), emission uniformity (EU), coefficient of variation (CV) etc.

**Table 3.4 Performance of drip irrigation based on uniformity**

| Performance | Uniformity |
|---|---|
| Excellent | >90 |
| Good | 80-90 |
| Fair | 70-80 |
| Poor | 60-70 |
| Unacceptable | <60 |
| Source : ASAE (1996) | |

**Plate 3 Determination of uniformity distribution of drip irrigation system**

#### 3.6.3.1 Determination of uniformity coefficient (CU)

As suggested by Wu and Gitlin (1974), the uniformity coefficient of drip irrigation system was determined by replacing the water depth in discharge. The emitter discharge measured on volumetric basis at three parts of lateral viz. head, middle and tail end for some known duration and the uniformity coefficient was determined by estimating the average absolute deviation and mean discharge rate.

$$Uniformity\ coefficient\ (\%) = (1 - \frac{s}{q_a})100 \qquad 3.1$$

Where, s = Average absolute deviation from the mean discharge rate.
$q_a$ = mean discharge rate.

#### 3.6.3.2 Determination of distribution uniformity (DU)

The distribution uniformity is the degree at which the water is applied uniformly over the area. It is the ratio of the average discharge at the ¼ the tail end emitters to the average discharge of all emitters and can be determined by using relationship as given below:

$$Distribution\ Uniformity\ (DU) = \frac{Average^{1}/_{4}\ th\ emmiter\ discharge}{Average\ discharge\ of\ emmiter} \qquad 3.2$$

#### 3.6.3.3 Determination of emission uniformity (EU)

The emission uniformity describes the emitter flow variation for a drip irrigation unit. This is the relationship between the pressure head and discharge collected at respective pressure. The emitter discharge uniformity could vary due to pressure variation. The following equation as suggested by Keller and Karmeli (1974) was used:

$$Emission\ Uniformity\ (EU) = \left(\frac{q_n}{q_a}\right)100 \qquad 3.3$$

Where,

$q_n$ = average of the lowest 1/4 of the emission point discharges for field data, lph.

$q_a$ = average emission point discharge of test sample operated at the reference pressure head, lph.

**3.6.4 Laying of mulching:** Mulching of inorganic and organic material was used in this research study. The black plastic mulch (25 micron m), silver plastic mulch (25 micron m), paddy straw mulch and soil mulch (20 cm depth) was considered as a mulching material. The non-mulch treatment is considered as a control. The experimental design was split plot design in which the irrigation treatments laid in main plot and mulching treatments laid in subplot.

**Plate 4 Layout of experimental treatment and laying of mulching on beds**

### 3.6.6 Sowing of okra

Okra seeds were soaked in water for overnight for good germination. Soaked seed was sown at 20 x 30 cm in the holes punched in the laid mulching bed. Sowing was done on 12 April 2019 and 1 June 2020 in two consecutive years respectively. Sowing in year 2020 was delayed due to strict lockdown restriction during first wave of covid-19 pandemic. Paddy straw was laid after seven days to avoid the attack of disease and insect on the seed or grown seed ling.

### 3.6.7 Fertilizer application

Recommended dose of fertilizer was applied manually near to the root zone due to non-availability of required size of fertigation unit in the field. The nitrogen and phosphorus content was low in the experimental plot so 25 % extra dose of nitrogen and phosphorus was added in recommended dose. The recommended dose of chemical fertilizers was applied i.e N: 125 kg/ha, $P_2O_5$: 62 kg/ha and $K_2O$: 50 kg/ha). Out of this recommended dose of fertilizer, the half dose of nitrogen was applied at the time of sowing and half dose after 30 days of sowing. The phosphatic and potassic were applied as a basal dose.

## 3.7 Evapotranspiration determination

### 3.7.1 Reference evapotranspiration by CROPWAT model

Reference crop evapotranspiration ($ET_0$) was calculated by Cropwat 8.0 model. The Cropwat 8.0 model works on Penman-Monteith equation which requires the meteorological data: temperature (maximum and minimum), wind speed, relative humidity, and sunshine duration in hours was collected from meteorological department. Cropwat 8.0 model also required primary data like country name, station name, altitude, latitude and longitude. The meteorological data used for estimation reference crop evapotranspiration was collected from the website *worldweatheronline.com* and authentication checked by the meteorological data obtained from automatic weather station, Agrometeorological Department, School of Agriculture, Lovely Professional University.

### 3.7.2 Crop evapotranspiration (ETc)

Crop evapotranspiration (ETc) is the amount of water lost by the plant through transpiration and evaporation from the soil surface. Actual crop water requirement depends upon the reference evapotranspiration ($ET_0$) and crop coefficient. Crop coefficient varies as per the growth stages of crop. The crop coefficient (Kc) as per the growth stages of okra were selected based on Babu *et al.* (2015) as given below:

**Table 3.5 Crop coefficient values at various crop growth stages**

| **Stage** | **Days** | **Crop coefficient value (Kc)** |
|---|---|---|
| Initial | 28 | 0.7 |
| Development | 30 | 0.83 |
| Mid-season | 31 | 1.01 |
| Late season | 20 | 0.98 |
| Reference : Babu *et al*. (2015) | | |

Crop evapotranspiration ETc was calculated by the equation suggested by Allen, *et al.*, *(*1998)

$$ETc = ETo \ x \ Kc \qquad 3.4$$

### 3.7.3 Irrigation water and irrigation scheduling

The net depth of water requirement varies as per the crop evapotranspiration (ETc), effective rainfall and ground water contribution in experimental field. The effective rainfall ($P_e$) was calculated by using Cropwat model and ground water contribution ($G_w$) during the study was considered as nil. The net depth of water requirement (IR) mm per day per plant was calculated by the equation given below.

$$IR = ETc - Pe \quad 3.5$$

The net depth of water requirement and time required to operate the system to meet the water requirement of the crop was presented in Appendix 7 and Appendix 8.

### 3.8 Soil moisture distribution.

Soil moisture distribution was estimated at various depth and horizontal distances. The soil sample was taken at 5, 10, 15 and 20 cm depth near the emitter and 5, 10, 15 and 20 cm horizontal distance from the emitter by using soil sampler and soil moisture content was determined by gravimetric method.

**Plate 5 Soil sampling for soil moisture determination**

**3.9 Growth parameters**: In order to study the various biometric parameter of crops, data for plant height, no of branches, days of first flower emergence and number of pods per plant were recorded.

**3.9.1 Plant population:** Plant population was measured after 7 days of plant emergence. To maintain the 100 per cent plant population, one time gap filling was done after 10 days. After gap filling, again plant population was measured after 15 days. Five plants from each treatment were selected randomly and tagged for the further study.

**Plate 6 Recording of biometric observation (Plant height)**

**3.9.2 Plant height:** In order to study the effect of different irrigation level and mulching method on growth of plant, plant height of tagged plant, data were recorded at 30, 60 and 90 days interval. The mean height (in cm) of these five plant was determined and noted for further analysis.

**3.9.3 Number of branches:** Branch formation from the main stem of the crop indicate the good vegetative growth of the plant. In this study, number of branches of selected plant were recorded at 30, 60 and 90 days interval.

**3.9.4 First flower emergence:** First flower emergence indicates the response of crop over the treatment. The first flower emergence was recorded after 35 days of sowing.

**3.10 Yield parameters of okra:** Yield attributes i.e no of pods per plant, pod yield per plant and yield per ha was recorded at regular interval.

**3.10.1 Number of pods per plant:** Total no of pods per plant was determined by harvesting the mature pod from the tagged plants at every picking.


**Plate 7 Observation of first flower emergence of tagged plant**

**Plate 8 Flowering and harvesting stage of okra crop**

**3.10.2 Yield per plant:** Weight of pod harvested at every picking was recorded and yield of pods was calculated by summing all the weight observed after all picking.

**3.10.3 Total yield**: Fruit yield observed per treatment was recorded and expressed in t/ha

**3.11 Water use efficiency:** Water use efficiency is the ratio of total yield of crop to amount of water used consumptively. It is denoted by kg/ha-cm. The water use efficiency was recorded after getting total yield of the crop at last harvesting stage.

$$Water\ use\ efficiency = \frac{Yt}{ETc} \qquad 3.6$$

Where Yt = total crop yield (kg/ha)

ETc = crop evapotranspiration (cm)

### 3.12 Economic evaluation

The economic evaluation of drip irrigation along with mulching worked out for okra crop by estimating fixed cost, variable cost i.e. cost of cultivation and total marketable yield of okra. The net income was considered as the income generated from the produce. The B: C ratio was determine treatment wise. The economic evaluation was expressed for one hectare area under test crop

#### 3.12.1 Total cost of okra production

Total cost includes the cost of drip irrigation system and cost of cultivation

##### 3.12.1.1 Cost of drip irrigation system

The cost of drip system may be termed as the fixed cost. It is estimated as per the layout of the experimental plot. The cost of drip system includes the cost of material for one hectare area, depreciation cost, interest and repair and maintenance cost. Depreciation cost calculated by considering the salvage value @ 10 per cent of initial cost and life of system was considered as 10 years. The interest on the initial cost was considered @ 12 per cent. The repair and maintenance cost of the system was also considered @ 1 per cent. The details of the cost distribution is presented in Table 3.6.

**Table 3.6 Cost of drip irrigation as per the layout of experimental plot (Rs/ha)**

| Component | Specification | Requirement | Cost/item (Rs) | Total cost ( Rs/ha) |
|---|---|---|---|---|
| Pump with electric motor | 3 hp | 1 | 23500 | 23500 |
| Main pipe (4 kg/cm$^2$) | 75 mm | 20 | 415 | 8300 |
| Sub main (4 kg/cm$^2$) | 63 mm, | 40 | 320 | 12800 |
| Hydro cyclone filter | 75 mm | 1 | 6250 | 6250 |
| Inline Lateral ( one unit @ 300 m long) | 16 mm | 34 | 1350 | 45900 |
| Grommet take off | 16 mm | 600 | 1.5 | 900 |
| End cap | 16 mm | 600 | 0.75 | 450 |
| PVC Ball valve | 75 mm | 3 | 750 | 2250 |
| PVC Ball valve | 63 mm | 6 | 490 | 2940 |
| Control valve | 16 mm | 120 | 3 | 360 |
| T cum reducer | 63 mm | 3 | 80 | 240 |
| Pressure gauge | 63 mm | 3 | 350 | 1050 |
| Accessories (T joint, L joint, flush valve, end cap etc.) | | | | 1000 |
| **Total cost of drip irrigation material** | | | | **105940** |
| Installation cost @5 % of total cost | | | | 5297 |
| **Total cost of drip irrigation per ha** | | | | **111237** |
| Depreciation cost ( Rs/ha) | | | | 10011 |
| Interest on capital @ 12 % | | | | 13348 |
| Repair and Maintenance @ 1 % | | | | 1112 |
| **Total Fixed cost ( Rs/ha)** | | | | **24472** |

### 3.12.1.2 Cost of cultivation

The cost of cultivation is also termed as variable cost was estimated by considering the variable resources required for the experimental area. The cost of cultivation was estimated for one ha area. The cost of cultivation includes cost of land preparation, intercultural operation, mulching cost, cost of fertilizer and crop protection, labour cost and presented in Table 3.7

**Table 3.7 Cost of cultivation as per the layout of experiments plot (Rs/ha)**

| **Particular** | **Requirement per ha** | **Cost per item** | **Total cost (Rs/ha)** |
|---|---|---|---|
| **(A)Inputs** | | | |
| Seed (kg/ha) | 8 | 1200 | 9600 |
| Fertilizer ( kg/ha) | N=125, P= 62 and K= 50 | | 5530 |
| Plant protection | 2 spraying | 875 | 1750 |
| Plastic mulch | 25 | 1800 | 45000 |
| **(B)Land preparations** | | | |
| Ploughing | 3 hrs | 850 | 2550 |
| Harrowing | 3 hrs | 850 | 2550 |
| Bed preparation | 10 labour per day | 480 | 4800 |
| Trench preparation | 10 labors per day | 480 | 4800 |
| **(C) Labour requirement** | | | |
| Mulch Spreading | 10 labour per day | 480 | 4800 |
| Sowing | 8 labour per day | 480 | 3840 |
| Weeding (Non-Mulch) | 20 labour per day | 480 | 9600 |
| Plant protection | 2 labour per day | 480 | 960 |
| Harvesting | 5 labour per day | 10 times @480 | 24000 |
| **Total (A+B+C)** | | | **119780** |

### 3.12.2 Income from produce

The income obtained for the okra produce per hectare was calculated on the basis of market price and considered as Rs 2500 per quintal.

### 3.12.3 Benefit cost (B:C) ratio

The benefit cost ratio is the index that shows the profitability of the technology. The net income was determined by subtracting the total cost of cultivation from the gross return of produce. The benefit cost ratio was estimated by dividing the gross return obtained from the produce to total cost raised for each treatment.

$$Benefit\ cost\ ratio\ = \frac{Gross\ return\ (Rs/ha)}{Cost\ of\ cultivation\ (Rs/ha)} \qquad 3.7$$

### 3.13 Statistical analysis

The present research was laid out in split plot design. The observation recorded for the various parameter based on irrigation levels and mulching methods were statistically analyzed by the method of ANOVA as described by Gomez and Gomez (1984). The data were tested by F ratio to find out the significant difference between the treatments and least significant difference (LSD) determined for recorded observation of each character.

# Chapter IV

# RESULTS AND DISCUSSION

The results obtain during the experimental study on "Response of okra (*Abelmoschus esculentus* L.) to different irrigation levels and mulching methods under drip irrigation" were tabulated and discussed. The results obtained on study of moisture distribution, hydraulics of drip irrigation, crop water requirement, plant growth attributes, yield attributes and economics of drip irrigation have been statistically analyzed and presented under following headings as given below.

4.1 Hydraulic performance of emitters

4.2 Soil moisture distribution pattern

4.3 Crop evapotranspiration by Cropwat model

4.4 Effect on plant growth parameters

4.5 Effect on plant yield parameters

4.6 Effect on water use efficiency

4.7 Economics of drip irrigation

## 4.1 Hydraulic performance of emitters

Performance of drip irrigation was evaluated based on the uniformity coefficient, distribution uniformity and emission uniformity by measuring the discharge from first, middle and end laterals for 5 minutes and then converted into the lph. The hydraulic performance of drip system is summarized in Table 4.1. The system was made to run at fixed pressure (1 $kg/cm^2$) throughout the period of experiment. The maximum discharge observed as 3.52, 3.48 and 3.46 lph at starting point of the lateral in middle, first and last lateral respectively. Minimum discharge was occurred at first lateral then followed by last and middle lateral respectively. The average discharge of first, middle and last lateral was 3.33, 3.35 and 3.31 respectively, with overall average discharge of system was 3.33 lph which was 83.33 % of manufacturer discharge (4 lph). As such this is considered as a good discharge.

**Table 4.1 Evaluation of hydraulic performance of drip irrigation system**

| Variation | First lateral | Middle lateral | Last lateral | Average |
|---|---|---|---|---|
| Maximum Discharge (lph) | 3.48 | 3.52 | 3.46 | 3.49 |
| Minimum Discharge (lph) | 2.98 | 3.17 | 3.00 | 3.05 |
| Average Discharge (lph) | 3.33 | 3.35 | 3.31 | 3.33 |
| Average of 1/4 the lowest emitter discharge (lph) | 3.14 | 3.22 | 3.14 | 3.17 |
| Standard deviation (SD) | 0.14 | 0.10 | 0.13 | 0.12 |
| Coefficient of variation ($Q_{var}$) | 0.04 | 0.03 | 0.04 | 0.04 |
| Uniformity coefficient (%) | 95.78 | 97.05 | 96.18 | 96.34 |
| Distribution Uniformity (%) | 94.29 | 96.12 | 94.86 | 95.09 |
| Emission Uniformity (%) | 94.29 | 96.70 | 94.29 | 95.10 |

### 4.1.1 Uniformity coefficient

In the present study, the uniformity coefficient at the first, middle and last lateral was estimated as 95.78, 97.05 and 96.18 per cent, in which middle lateral recorded maximum value of uniformity coefficient and overall average uniformity coefficient was 96.34 %. The uniformity coefficient (%) of more than 90 per cent is considered as excellent design of drip system. The same finding was recorded by Sudarshan (2014) and Priya (2018).

### 4.1.2 Distribution Uniformity

The distribution uniformity (%) at first, middle and last lateral was recorded as 94.29, 96.12 and 94.86 per cent, with the overall average distribution uniformity was 95.09 % which is considered as excellent design of drip system. The maximum distribution was recorded in middle of the lateral (96.12 %) and it was also observed that the distribution uniformity values are lower than the uniformity coefficient value. The water could not reach with proper pressure at the tail end of lateral so it can be concluded that, as length of lateral increases, distribution uniformity decreases. The obtained results corroborate well with the observation of Sudarshan (2014).

### 4.1.3 Emission Uniformity

To assess the performance of drip system, emission uniformity is of major concern, which indicates the uniformity of water emittance. The emission uniformity of the present system was observed as 94.29, 96.70 and 94.29 % at first lateral, middle lateral and last lateral respectively. The average emission uniformity was recorded as 95.10 % which was excellent as per the recommendation. The increase in emission uniformity was due to increase in pressure. Water emission rate more than 90 per cent compared to the actual manufactured discharge is considered as excellent. Shashikant (2016) experienced that the emission uniformity increases as the pressure increases and recorded maximum emission uniformity (95.75 %) at pressure 1.5 kg/cm$^2$. The similar results have been reported by Deshmukh (2014) and Changade *et al.* (2009).

## 4.2 Soil moisture distribution pattern

Soil moisture content under mulching treatment were collected at 5, 10, 15 and 20 cm in vertical as well as horizontal distance away from the emitter by using soil sampler and moisture content was estimated by gravimetric method. Drip irrigation system was made to run for one hour and moisture content recorded at 24 hours after irrigation.

### 4.2.1 Soil moisture distribution under black plastic mulch

The moisture content at the vertical and horizontal axis from the drip emitters under black plastic mulch was obtained as per the Table 4.2.

**Table 4.2 Soil moisture content (%) at vertical and horizontal distance under black plastic mulch.**

| Vertical distance (cm) | Horizontal distance (cm) | | | | |
|---|---|---|---|---|---|
| | **5** | **10** | **15** | **20** | **Average** |
| **5** | 21.23 | 20.05 | 19.74 | 18.11 | 19.78 |
| **10** | 22.14 | 20.90 | 20.00 | 19.13 | 20.54 |
| **15** | 22.95 | 21.43 | 20.30 | 19.00 | 20.92 |
| **20** | 23.00 | 22.84 | 20.41 | 18.73 | 21.25 |
| **Average** | 22.33 | 21.31 | 20.11 | 18.74 | |

Data from the Table 4.2 indicated that, moisture content vertically ranges from 18.11 to 23.00 per cent and the average maximum moisture content was 22.33 per cent at the depth 0-20 cm just below the emitter. Minimum moisture content (18.11 %) was observed at distance 20 cm horizontally at 5 cm depth and the average minimum moisture was 19.78 per cent at same depth (5 cm) whereas maximum average soil moisture was obtained as 21.25 per cent at 20 cm depth horizontally. Maximum and minimum average soil moisture was obtain as 22.33 and 18.74 per cent at depth 20 cm. Minimum average moisture content (18.73 %) at 20 cm vertically and horizontally indicates the less moisture content availability at 20 cm away from the point source. Average maximum moisture content (22.33%) was observed just below the emitter in 0-20 cm depth and its value was decreased while going away from the dripper (21.31, 20.11 and 18.74% at 10, 15 and 20 cm, respectively).

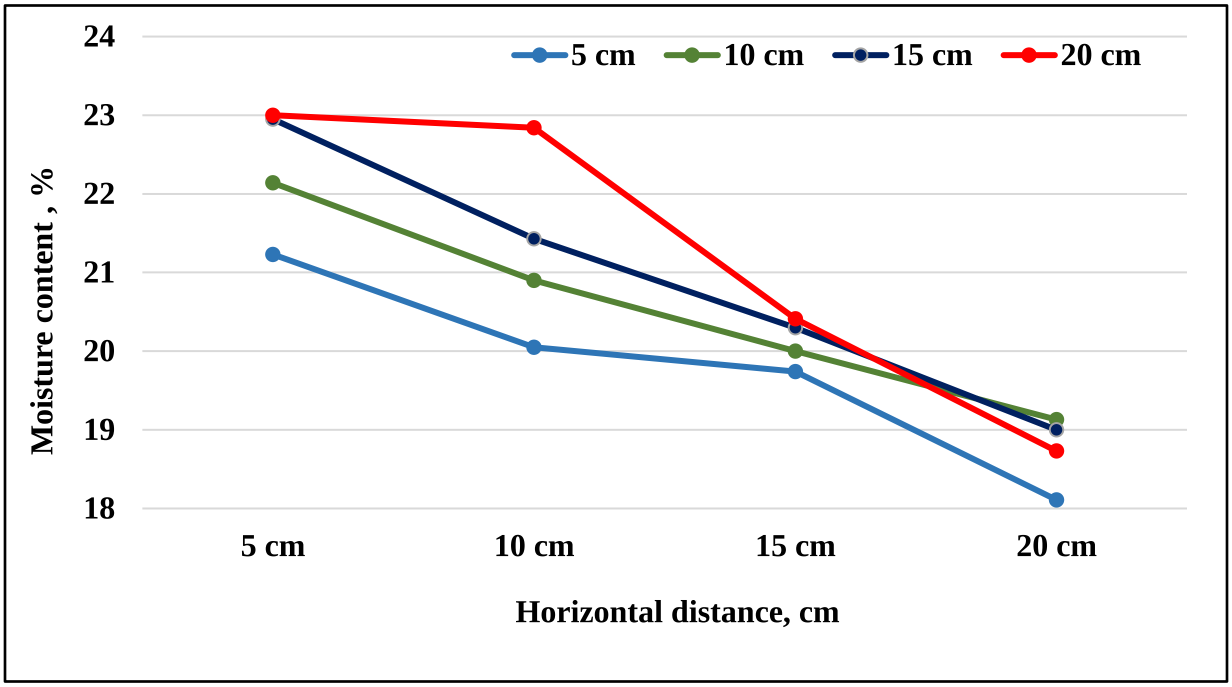


**Fig. 4.1 Soil moisture distribution under black plastic mulch**

As shown in Figure 4.1, the maximum soil moisture content at 20 cm depth near to the point source was 23.0 % showed good vertical movement of water but at the same time less moisture content obtained near to the point source at 5 cm depth. This may be due to the reason that the black sheet absorbed more solar radiation that may have resulted in increase in the soil temperature and increase in evaporation. The soil moisture content decreased horizontally away from the point source indicating that there was slow water movement laterally. It was clear that the moisture content up to field capacity was available up to 15 cm horizontal distance and 20 cm vertically from the point source. Similar results reported by Sharma and Meshram (2015) during the study of soil moisture content under black plastic mulch and paddy straw mulch irrigated by drip irrigation for capsicum.

### 4.2.2 Soil moisture distribution under silver plastic mulch

The moisture content at the vertical and horizontal axis from the drip emitters under silver plastic mulch was recorded and indicated in the Table 4.3.

**Table 4.3 Soil moisture content (%) at vertical and horizontal distance under silver plastic mulch.**

| Vertical distance (cm) | Horizontal distance (cm) | | | | |
|---|---|---|---|---|---|
| | **5** | **10** | **15** | **20** | **Average** |
| **5** | 22.00 | 20.97 | 19.81 | 18.19 | 20.24 |
| **10** | 22.23 | 21.05 | 20.10 | 19.23 | 20.65 |
| **15** | 23.10 | 21.51 | 20.35 | 18.96 | 20.98 |
| **20** | 23.36 | 23.12 | 20.43 | 18.62 | 21.38 |
| **Average** | 22.67 | 21.66 | 20.17 | 18.75 | |

From the Table 4.3, data indicated that, moisture content vertically ranged from 18.19 to 23.36 per cent with the average maximum moisture content was 22.67 per cent in the depth 0-20 cm just below the emitter. Minimum moisture content (18.19 %) was observed at distance 0-20 cm horizontally at 5 cm depth and the average minimum moisture was 20.24 at same depth (5 cm) whereas, maximum average soil moisture was obtained as 21.38 % at 20 cm depth horizontally. Minimum average moisture content (18.62 %) at 20 cm vertically and horizontally indicates the less moisture content availability at 20 cm away from the point source. Average maximum moisture content (22.67%) was observed just below the emitter in 0-20 cm depth and its value was decreased while going away from the dripper (21.66, 20.17 and 18.77% at 10, 15 and 20 cm, respectively).

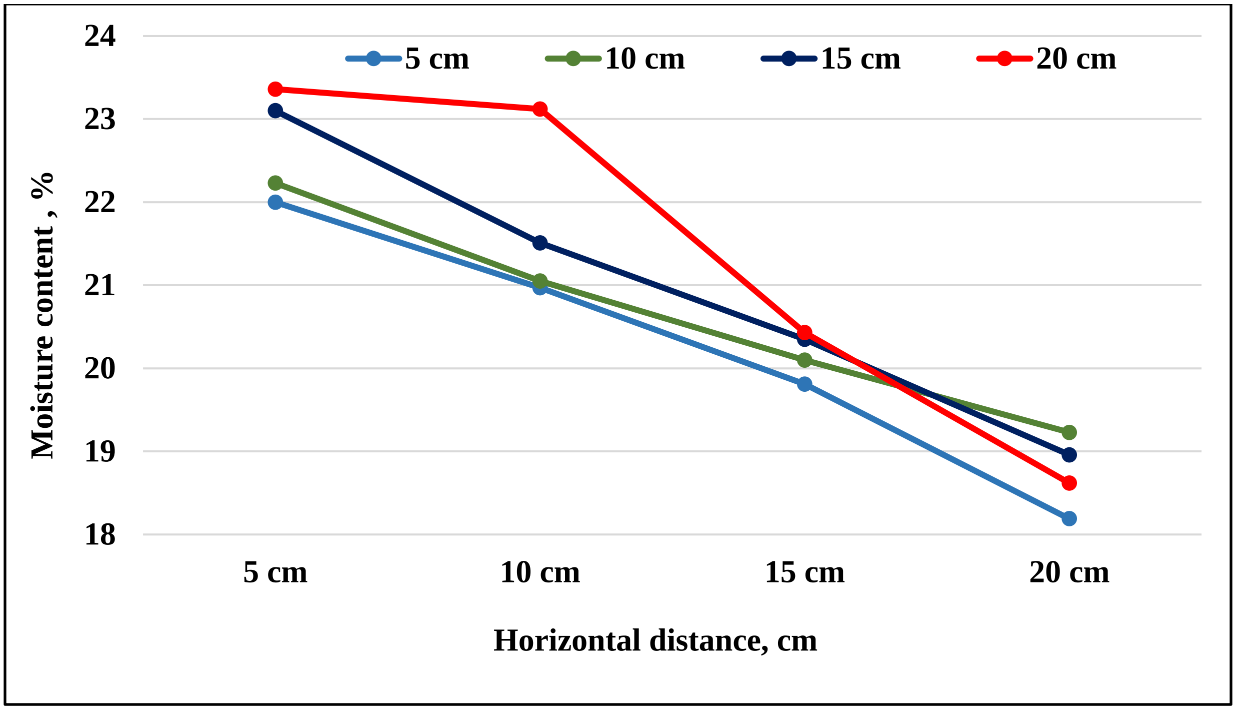


**Fig. 4.2 Soil moisture distribution under silver plastic mulch**

As shown in Figure 4.2, the maximum soil moisture content (23.36 %) at 20 cm depth near to the point source showed the good vertical movement water. Good moisture content available near to the crop root zone i.e. up to 20 cm below the emitter and 15 cm away from the emitters. There was not much variation in 0 to 10 cm depth and 10 to 20 cm depth vertically but about 4 % moisture content difference between point source to 20 cm distance horizontally. It was observed that, the soil moisture content in silver plastic mulch is more than the black plastic mulch sheet and this may be due to less evaporation due to soil temperature under silver plastic mulch. The Soil moisture content decreased horizontally away from the point source indicating slow water movement laterally. Same as per the black plastic mulch, it was clear that the moisture content up to field capacity was available up to 15 cm horizontal distance and 20 cm vertically from the point source. Sharma and Meshram (2015) recoded the maximum moisture content at 15 cm depth which corroborated the results obtain in present study.

### 4.2.3 Soil moisture distribution under paddy straw mulch

The moisture content at the vertical and horizontal axis recorded from the drip emitters under paddy straw mulch are presented in the Table 4.4.

**Table 4.4 Soil moisture content (%) at vertical and horizontal distance under paddy straw mulch.**

| Vertical distance (cm) | Horizontal distance (cm) | | | | |
|---|---|---|---|---|---|
| | **5** | **10** | **15** | **20** | **Average** |
| **5** | 20.98 | 20.05 | 19.82 | 18.00 | 19.71 |
| **10** | 21.68 | 20.76 | 20.00 | 18.95 | 20.35 |
| **15** | 22.30 | 21.50 | 20.12 | 19.00 | 20.73 |
| **20** | 22.60 | 22.09 | 20.00 | 19.00 | 20.92 |
| **Average** | 21.89 | 21.10 | 19.99 | 18.74 | |

Recorded data indicated that, moisture content vertically ranged from 18.00 to 22.60 per cent with the average maximum moisture content of 21.89 per cent in the depth 0-20 cm just below the emitter. Minimum moisture content (18.00 %) was observed at distance 20 cm horizontally at 5 cm depth. Maximum average soil moisture was obtained as 20.92 percent at 20 cm depth horizontally. Average maximum moisture content (21.89%) was observed just below the emitter in 0-20 cm depth and its value was decreased while going away from the dripper (21.10, 19.99 and 18.74 % at 10, 15 and 20 cm, respectively). Minimum average moisture content (19.00 %) at 20 cm vertically and horizontally indicates the moisture content availability was below than field capacity at 20 cm away from the point source. Moisture content up to field capacity was available near to the crop root zone i.e. up to 20 cm below the emitter and 15 cm away from the emitters.

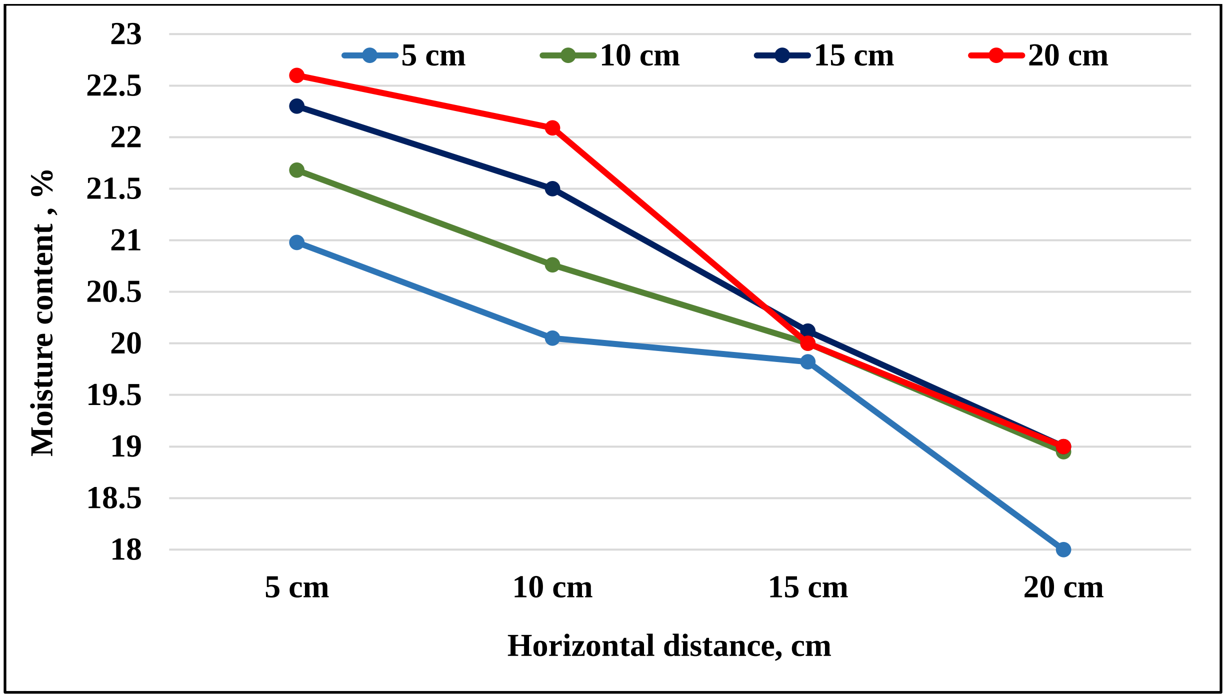


**Fig. 4.3 Soil moisture distribution under paddy straw mulch**

From the Figure 4.3, it was observed that the maximum soil moisture content at 20 cm depth near to the point source was 22.60 per cent showing the good vertical movement of water. There was not much variation in 0 to 10 cm depth and 10 to 20 cm depth vertically below the point source but moisture content less than field capacity was observed at 10 to 20 cm horizontal distance from point source. The less moisture content was observed near to surface may be due to moisture absorbed by paddy straw or more evaporation rate. The soil moisture content decreased horizontally away from the point source indicating slow water movement laterally. The above result findings supports from Shirahatti *et al.* (2007), who recorded the moisture content increased vertically (0-10) cm just below the emitter source and decreased as the distance from the trickle sources increases horizontally.

### 4.2.4 Soil moisture distribution under soil mulch

The moisture content at the vertical and horizontal axis from the drip emitters under soil mulch are reported in Table 4.5.

**Table 4.5 Soil moisture content (%) at vertical and horizontal distance under soil mulch (20 cm depth)**

| Vertical distance (cm) | Horizontal distance (cm) | | | | |
|---|---|---|---|---|---|
| | 5 | 10 | 15 | 20 | Average |
| **5** | 15.26 | 14.92 | 14.72 | 14.65 | 14.89 |
| **10** | 21.08 | 20.90 | 20.10 | 17.80 | 19.97 |
| **15** | 23.56 | 23.50 | 22.60 | 19.83 | 22.37 |
| **20** | 24.80 | 24.60 | 23.00 | 20.50 | 23.23 |
| **Average** | 21.18 | 20.98 | 20.10 | 18.19 | |

The moisture content vertically ranges from 14.65 to 24.80 per cent with the average maximum moisture content of 21.18 per cent at 20 cm depth just below the emitters. Data indicated that very less moisture content was observed at upper surface i.e. at 5 cm depth horizontally but higher at depth 20 cm. Minimum moisture content (14.65 %) recorded at distance 20 cm horizontally at 5 cm depth which is less than field capacity. Average maximum moisture content (21.18 %) was observed just below the emitter in 0-20 cm depth and its value was decreased while going away from the dripper (20.98, 20.10 and 18.19 % at 10, 15 and 20 cm, respectively). Moisture content (20.50 %) at 20 cm vertically and horizontally indicates that the moisture content availability was near to field capacity. Moisture content more than field capacity was available near to the crop root zone i.e. up to 0- 20 cm just below the emitter and 0-15 cm away from the emitters.

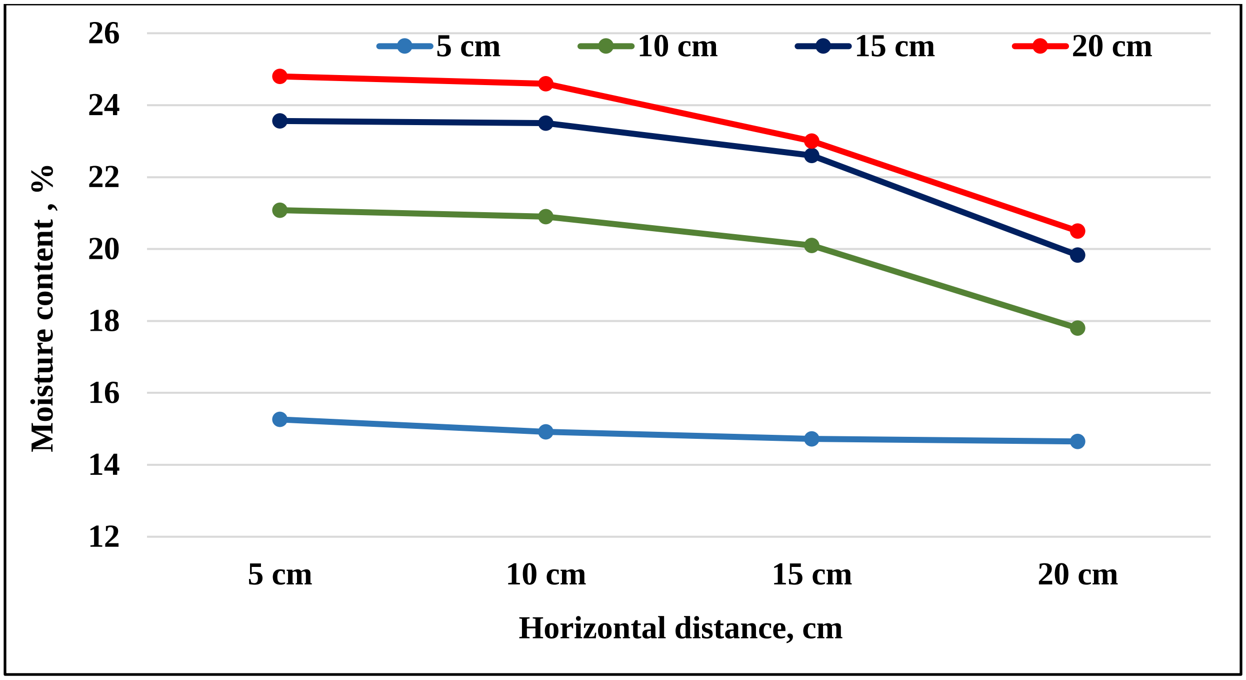


**Fig 4.4 Soil moisture distribution under soil mulch (Lateral placed at 20 cm depth)**

As shown in Figure 4.4, maximum soil moisture content observed at 15 - 20 cm depth near to the point source and ranged from 24.80 to 20.50 per cent shows the good availability of moisture. Less moisture content (14.89 %) was available near to the ground surface at 5 cm depth indicated that slow movement of water towards upward side from the point source. Moreover the water reaches to the surface of soil by upward movement may be loss due to evaporation. Enough moisture content at depth 20 cm below the surface of soil and near to the point source indicated the good root zone for the crop. The soil moisture content decreased horizontally and vertically upward away from the point source indicate that there was slow water movement in both directions. Vadar *et al.* (2019) recorded that the lateral placed between 15 to 20 cm shows good distribution of soil moisture. Douh et al (2013) reported that, the lateral placed at 20 cm depth shows the circular shape curve of moisture content around the dripper with initial moisture content (29 %) near to the emitter which reduces up to 24.5 per cent after 4 hours and 18 per cent moisture content at 30 cm radial distance.

### 4.2.5 Soil moisture distribution under no mulch plot

The moisture content at the vertical and horizontal distance from the drip emitters under no mulch condition was recorded and indicated in Table 4.6.

**Table 4.6 Soil moisture content (%) at vertical and horizontal distance under no mulch**

| Vertical distance (cm) | Horizontal distance (cm) | | | | |
|---|---|---|---|---|---|
| | **5** | **10** | **15** | **20** | **Average** |
| **5** | 18.70 | 18.52 | 17.60 | 15.35 | 17.54 |
| **10** | 20.60 | 19.56 | 18.80 | 16.80 | 18.94 |
| **15** | 21.75 | 20.90 | 19.00 | 17.60 | 19.81 |
| **20** | 22.10 | 21.92 | 19.30 | 17.12 | 19.86 |
| **Average** | 20.79 | 19.98 | 18.66 | 16.72 | |

Recorded data indicate that moisture content vertically ranged from 22.10 to 15.35 per cent with the average maximum moisture content was 20.79 per cent at 20 cm depth just below the emitters. Minimum moisture content (15.35 %) was observed at distance 20 cm horizontally at 5 cm depth and the average minimum moisture was 17.54 at same (5 cm) depth which was less than the field capacity. Maximum average soil moisture was obtained as 19.86 per cent at 20 cm depth horizontally. Average maximum moisture content (20.79 %) was observed just below the emitter in 0-20 cm depth and its value was decreased while going away from the dripper (19.98, 18.66 and 16.72 % at 10, 15 and 20 cm, respectively). Away from the point source at 20 cm horizontal distance, average moisture content (16.72 %) indicates the moisture content availability was below than field capacity at 20 cm depth from the point source.

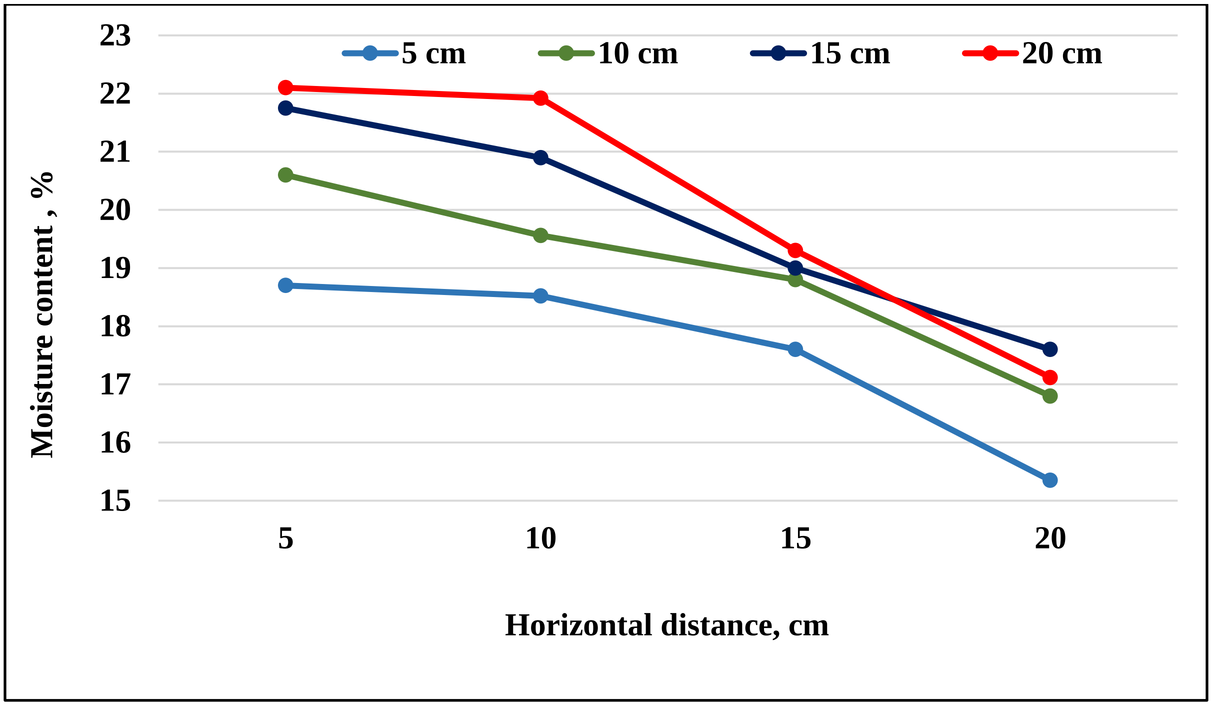


**Fig 4.5 Soil moisture distribution under no mulch**

As shown in Figure 4.5, Moisture content up to field capacity was available near to the crop root zone i.e up to 20 cm below the emitter and 10 cm horizontally from the emitters. Minimum moisture content was recorded at 5 cm depth as well as away from the emitter. Moisture content less than field capacity was observed near to surface may be due to more evaporation from surface soil. The Soil moisture content was decreased horizontally away from the point source indicating that there was very slow water movement laterally due to more evaporation rate. Kaute and Gaikwad (2011) also found similar results and observed that at the emitter discharge 2 lph, the horizontal water movement was more than vertical at initial level but vertical movement of water increased and horizontal water movement decreased with the increment of time.

### 4.3 Crop evapotranspiration by Cropwat model

Water requirement of crop was determined by Cropwat model by entering the needed meteorological data. Crop Evapotranspiration (ETc) was determined by multiplying the reference evapotranspiration ($ET_0$) and crop coefficient (Kc). The estimated data is presented as daily, monthly and decade wise in tables as below.

#### 4.3.1 Monthly evapotranspiration ($ET_0$)

Monthly evapotranspiration ($ET_0$) of both years as determined by Cropwat model is presented in Table 4.7.

**Table 4.7 Monthly evapotranspiration ($ET_0$) for the year 2019 and 2020**

| **( A) Year 2019** | | | | | |
|---|---|---|---|---|---|
| **Month** | **Days** | **Average $ET_0$ (mm/day)** | **Maximum $ET_0$ (mm/day)** | **Minimum $ET_0$ (mm/day)** | **Total $ET_0$ ( mm/month)** |
| April | 18 | 4.57 | 5.03 | 4.22 | 86.91 |
| May | 31 | 4.95 | 5.27 | 4.27 | 153.41 |
| June | 30 | 5.68 | 6.36 | 5.01 | 170.3 |
| July | 30 | 6.35 | 7.28 | 5.59 | 190.49 |
| **Total** | **109** | **5.38** | **5.98** | **4.7** | **601.11** |
| **(B) Year 2020** | | | | | |
| **Month** | **Days** | **Average $ET_0$ (mm/day)** | **Maximum $ET_0$ (mm/day)** | **Minimum $ET_0$ (mm/day)** | **Total $ET_0$ ( mm/month)** |
| June | 30 | 5.98 | 6.44 | 5.55 | 179.42 |
| July | 31 | 6.37 | 6.73 | 5.97 | 197.67 |
| August | 31 | 5.92 | 6.32 | 5.44 | 183.73 |
| September | 17 | 5.02 | 5.86 | 4.23 | 85.76 |
| **Total** | **109** | **5.82** | **6.34** | **5.29** | **646.58** |

Data in Table 4.7 indicated that the maximum total monthly evapotranspiration was 190.49 mm and 197.67 mm in the month of July in year 2019 and 2020, respectively during the cropping season. Average $ET_0$ was recorded as 5.38 mm/day and 5.82 mm per day in both year respectively. The maximum $ET_0$ was recorded as 7.28 and 6.73 mm in the month of July in year 2019 and 2020 respectively. This may be due to prevailing wind and higher temperature in the month of July.

**Table 4.8 Monthly crop evapotranspiration (ETc) for the year 2019 and 2020**

| **(A) Year 2019** | | | | | |
|---|---|---|---|---|---|
| **Month** | **Day** | **Average ETc (mm/day)** | **Maximum ETc (mm/day)** | **Minimum ETc (mm/day)** | **Total ETc (mm/month)** |
| April | 18 | 3.2 | 3.37 | 2.95 | 60.83 |
| May | 31 | 3.93 | 4.57 | 3.07 | 122.02 |
| June | 30 | 5.47 | 6.42 | 4.15 | 164.09 |
| July | 30 | 6.27 | 6.74 | 5.48 | 188.38 |
| **Total** | **109** | **4.70** | **5.27** | **3.91** | **535.32** |
| **(B) Year 2020** | | | | | |
| **Month** | **Day** | **Average ETc (mm/day)** | **Maximum ETc (mm/day)** | **Minimum ETc (mm/day** | **Total ETc (mm/month)** |
| June | 30 | 4.24 | 5.34 | 3.88 | 127.25 |
| July | 31 | 5.41 | 6.7 | 4.95 | 161.61 |
| August | 31 | 5.97 | 6.38 | 5.33 | 185.07 |
| September | 17 | 4.94 | 5.74 | 4.14 | 84.04 |
| **Total** | **109** | **5.14** | **6.04** | **4.56** | **557.97** |

Data in Table 4.8, indicated that the maximum total monthly crop evapotranspiration was 188.38 mm and 185.07 mm in the month of July and August in year 2019 and 2020, respectively during the cropping season. Average ETc was recorded as 4.70 mm/day and

5.14 mm per day in both year respectively. The maximum $ET_c$ was recorded as 6.74 and 6.70 mm in the month of July in year 2019 and 2020 respectively. This may be due to maximum temperature and variation in crop coefficient value in the year 2019 and 2020 respectively.

### 4.3.2 Decade wise evapotranspiration ($ET_0$)

Ten days cumulative evapotranspiration data was estimated and it termed as decade wise evapotranspiration data. Decade wise evapotranspiration data may help for irrigation scheduling. Decade wise evapotranspiration and crop evapotranspiration was determined by the Cropwat model and presented in Tables 4.9 and 4.10 for the year 2019 and 2020 respectively.

**Table 4.9 Decade wise evapotranspiration ($ET_0$) and crop evapotranspiration (ETc) for the year 2019**

| Month | Decade | $ET_0$ (mm) | Average Kc | ETc (mm) | $I_1$ (1.0ETc) | $I_2$ (0.8ETc) | $I_3$ (0.6ETc) |
|---|---|---|---|---|---|---|---|
| **April** | 2nd | 40.79 | 0.70 | 28.55 | 171.32 | 137.05 | 102.79 |
| | 3rd | 46.12 | 0.70 | 32.28 | 193.70 | 154.96 | 116.22 |
| **May** | 1st | 45.19 | 0.73 | 32.19 | 193.19 | 154.55 | 115.91 |
| | 2nd | 52.26 | 0.83 | 43.37 | 260.25 | 208.20 | 156.15 |
| | 3rd | 55.96 | 0.83 | 46.45 | 278.68 | 222.94 | 167.21 |
| **June** | 1st | 54.33 | 0.88 | 46.97 | 281.82 | 225.45 | 169.09 |
| | 2nd | 56.57 | 1.01 | 57.14 | 342.81 | 274.25 | 205.68 |
| | 3rd | 59.4 | 1.01 | 59.99 | 359.96 | 287.97 | 215.98 |
| **July** | 1st | 63.02 | 1.00 | 63.45 | 380.68 | 304.54 | 228.41 |
| | 2nd | 64.51 | 0.98 | 63.21 | 379.32 | 303.46 | 227.59 |
| | 3rd | 62.96 | 0.98 | 61.71 | 370.20 | 296.16 | 222.12 |
| **Total** | 110 | 601.11 | | 535.32 | 3211.923 | 2569.54 | 1927.15 |

Highest $ET_0$ (64.51 mm) was recorded in third decade of July with the total $ET_0$ of 601.11 mm. The highest ETc (63.21 mm) was recorded in the second decade of July month. It was observed that, out of total $ET_0$, 31.68 per cent $ET_0$ and out of total ETc, 35.18 per cent ETc was recorded in the month of July. This was late season stage and as well as higher temperature was noted in this month. Minimum $ET_0$ and ETc value was recorded in the month of April at initial stage i.e 40.79 mm and 28.55 mm respectively. Total ETc recorded in irrigation level $I_1$, $I_2$ and $I_3$ was 3211.92 mm, 2569.54 mm and 1927.15 mm respectively.

**Table 4.10 Decade wise evapotranspiration ($ET_0$) and crop evapotranspiration (ETc) for the year 2020**

| Month | Decade | $ET_0$ (mm) | Average Kc | ETc (mm) | $I_1$ (1.0ETc) | $I_2$ (0.8ETc) | $I_3$ (0.6ETc) |
|---|---|---|---|---|---|---|---|
| **June** | 1st | 59.14 | 0.70 | 41.40 | 248.39 | 198.71 | 149.03 |
| | 2nd | 57.26 | 0.70 | 40.08 | 240.49 | 192.39 | 144.30 |
| | 3rd | 63.02 | 0.73 | 45.77 | 274.62 | 219.70 | 164.77 |
| **July** | 1st | 64.54 | 0.83 | 53.57 | 321.41 | 257.13 | 192.85 |
| | 2nd | 63.69 | 0.83 | 52.86 | 317.18 | 253.74 | 190.31 |
| | 3rd | 69.44 | 0.88 | 61.18 | 367.10 | 293.68 | 220.26 |
| **August** | 1st | 61.69 | 1.01 | 62.31 | 373.84 | 299.07 | 224.30 |
| | 2nd | 60.24 | 1.01 | 60.84 | 365.05 | 292.04 | 219.03 |
| | 3rd | 61.8 | 1.00 | 61.93 | 371.56 | 297.24 | 222.93 |
| **September** | 1st | 53.2 | 0.98 | 52.14 | 312.82 | 250.25 | 187.69 |
| | 2nd | 32.56 | 0.98 | 31.91 | 191.45 | 153.16 | 114.87 |
| **Total** | 110 | **646.58** | | **563.98** | **3383.91** | **2707.12** | **2030.34** |

Highest $ET_0$ (69.44 mm) was recorded in third decade of July month with the total $ET_0$ was 646.58 mm and highest ETc (62.31 mm) was recorded in the first decade of August month. It was observed that, out of total $ET_0$, 30.35 per cent $ET_0$ and out of total ETc, 32.81 per cent ETc was recorded in the month of July and august respectively. This was the development stage as well as higher temperature was noted in these month. Minimum $ET_0$ and ETc value was recorded in the month of September at late season stage i.e. 37.22 mm and 31.91 mm respectively. Total ETc recorded in irrigation level $I_1$, $I_2$ and $I_3$ was 3383.91 mm, 2707.12 mm and 2030.345 mm respectively.

#### 4.3.3 Growth stage wise evapotranspiration ($ET_0$)

Crop growth stage wise evapotranspiration and crop evapotranspiration was analyzed from the data obtained by the Cropwat model are presented in Table 4.11 for the year 2019 and 2020 and discussed below.

**Table 4.11 Stage wise evapotranspiration ($ET_0$) and crop evapotranspiration (ETc) for the year 2019 and 2020.**

| Crop stages | | | Year | | | |
|---|---|---|---|---|---|---|
| | | | 2019 | | 2020 | |
| **Stages** | **Days** | **Kc** | **$ET_0$** | **ETc** | **$ET_0$** | **ETc** |
| **Initial stage** | 28 | 0.70 | 127.74 | 89.42 | 166.68 | 116.67 |
| **Development stage** | 30 | 0.83 | 156.49 | 129.89 | 190.70 | 158.28 |
| **Mid-season stage** | 31 | 1.01 | 182.65 | 184.48 | 187.04 | 188.91 |
| **Late season** | 20 | 0.98 | 126.95 | 124.41 | 102.16 | 100.12 |

In year 2019, highest $ET_0$ was recorded as 182.65 mm at mid-season stage and lowest $ET_0$ was recorded at initial stages i.e 127.74 mm whereas higher and lower crop evapotranspiration rate was recorded as 184.48 mm and 89.42 mm at mid-season and initial stage respectively. In year 2020, highest $ET_0$ was recorded as 190.70 mm at development stage and lowest $ET_0$ was recorded at late season stages i.e 102.16 mm whereas highest and lowest crop evapotranspiration rate was recorded as 188.91 mm and 100.12 mm at mid-season and late season stage respectively. The variation in $ET_0$ and ETc values in the year 2019 and 2020 at different stages are due to different temperature, wind velocity, relative humidity and sunshine hour as indicated in Figure 3.1 and 3.2.

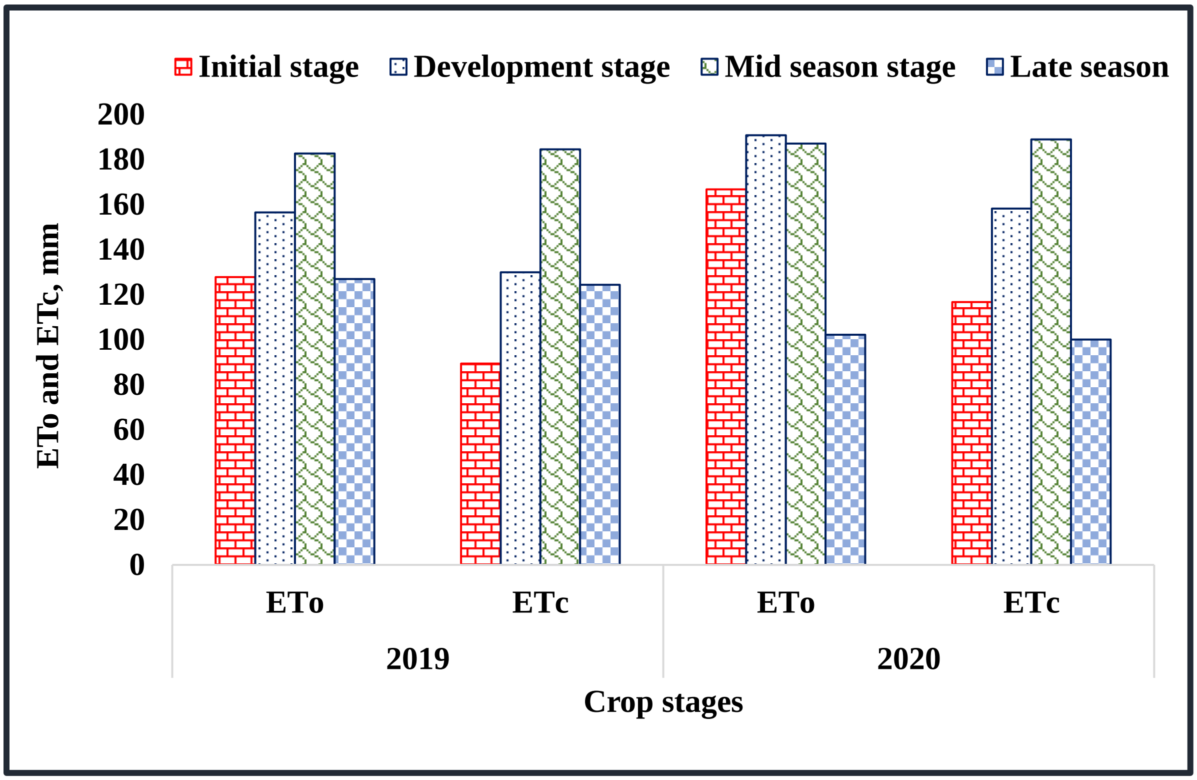


**Fig. 4.6 $ET_0$ and ETc value of okra at different growth stages in year 2019 and 2020**

### 4.4 Effect on plant growth parameters

To investigate the response of drip irrigation levels and mulching on okra crop, data on various growth parameters were recorded and interpreted statistically. The data on plant population, plant height, no of branches, days of first flowering are presented as below.

#### 4.4.1 Plant population

Plant population is the primary growth parameter which was investigated for germination status under different irrigation levels and mulching methods. Irrigation levels were not applicable during initial seven days for better germination but mulching method did affect the germination. The gap filling was done after seven days to bring the 100 per cent plant population. The plant population measured after 15 days were recorded and tabulated in Table 4.12a and 4.12b.

**Table 4.12a Effect of irrigation levels and mulching methods on plant population (%) of okra**

| Irrigation levels | 2019 | 2020 |
|---|---|---|
| $I_1$ | 83.20[a] | 83.13[a] |
| $I_2$ | 80.60[a] | 79.47[b] |
| $I_3$ | 78.47[b] | 77.00[c] |
| SEm± | 0.83 | 0.54 |
| LSD (0.05) | 3.26 | 2.11 |
| | | |
| **Mulching methods** | **2019** | **2020** |
| $M_1$ | 84.78[a] | 84.22[a] |
| $M_2$ | 83.22[a] | 81.89[ab] |
| $M_3$ | 80.22[b] | 77.33[bc] |
| $M_4$ | 79.22[b] | 78.67[c] |
| $M_5$ | 76.33[c] | 77.22[c] |
| SEm± | 0.88 | 1.39 |
| LSD (0.05) | 2.57 | 4.06 |

The plant population was recorded as 83.20, 80.60, 78.47 per cent in year 2019 and 83.13, 79.47, 77.00 per cent in year 2020 under irrigation level $I_1$, $I_2$ and $I_3$ respectively. In year 2019, irrigation levels significantly influenced plant population (F calculated > F tabulated, Appendix 3). Irrigation level ($I_1$) showed maximum plant population (83.20) which was at par with irrigation level $I_2$ (83.20) whereas, irrigation level $I_3$ showed significantly lower plant population (78.47). In year 2020, Plant population were significantly affected by irrigation levels (F calculated > F tabulated, Appendix 4). Maximum plant population was observed in irrigation level $I_1$ (83.13) followed by $I_2$ (79.47) and $I_3$ (77.00). Maximum plant population was observed in irrigation level $I_{1,}$ this may be due to proper moisture available at germination stage. Sharma and Kaushal (2015) reported that the Irrigation level $I_2$ (0.8 ETc) showed best results on plant population compared to $I_1$ and $I_{3.}$

Looking to the mulching treatments, The mulching treatments $M_1$, $M_2$, $M_{3,}$ $M_4$ and $M_5$ recorded the plant population as 84.78, 83.22, 80.22, 79.22 and 76.33 per cent respectively in year 2019 and 84.22, 81.89, 77.33, 78.67 and 77.22 per cent respectively in year 2020. In both the years, black plastic mulch recorded higher plant population and no mulch treatments recorded lowest plant population compared to other mulching treatments. As per the anova results, F calculated is greater than F tabulated, so statically it can be concluded that the mulching treatments significantly influenced the plant populations in both the years (Appendix 3 and 4). In both the years, black plastic mulch ($M_1$) recorded significantly higher plant populations than straw mulch ($M_3$), soil mulch ($M_4$) and no mulch ($M_5$) treatment where as it is at par with silver plastic mulch ($M_2$). Soil mulch had higher plant population than no mulch in both the year.

**Table 4.12b Interaction effect of irrigation and mulching methods on plant population (%) of okra in year 2019 and 2020**

| Treatments | Treatments details | 2019 | 2020 |
|---|---|---|---|
| $I_1M_1$ | 1.00ETc + Black plastic mulch | 85.67 | 88.00 |
| $I_1M_2$ | 1.00ETc + Silver plastic mulch | 86.33 | 83.67 |
| $I_1M_3$ | 1.00ETc + Paddy straw mulch | 82.67 | 81.67 |
| $I_1M_4$ | 1.00ETc + Soil mulch (20 cm depth) | 83.00 | 80.67 |
| $I_1M_5$ | 1.00ETc + No mulch | 78.33 | 81.67 |
| $I_2M_1$ | 0.80ETc + Black plastic mulch | 86.67 | 84.67 |
| $I_2M_2$ | 0.80ETc + Silver plastic mulch | 83.33 | 83.67 |
| $I_2M_3$ | 0.80ETc + Paddy straw mulch | 80.00 | 75.67 |
| $I_2M_4$ | 0.80ETc + Soil mulch (20 cm depth) | 78.00 | 77.67 |
| $I_2M_5$ | 0.80ETc + No mulch | 75.00 | 75.67 |
| $I_3M_1$ | 0.60ETc + Black plastic mulch | 82.00 | 80.00 |
| $I_3M_2$ | 0.60ETc + Silver plastic mulch | 80.00 | 78.33 |
| $I_3M_3$ | 0.60ETc + Paddy straw mulch | 78.00 | 74.67 |
| $I_3M_4$ | 0.60ETc + Soil mulch (20 cm depth) | 76.67 | 77.67 |
| $I_3M_5$ | 0.60ETc + No mulch | 75.67 | 74.33 |
| | **SEm±** | 1.53 | 2.41 |
| | **LSD (0.05)** | NS | NS |

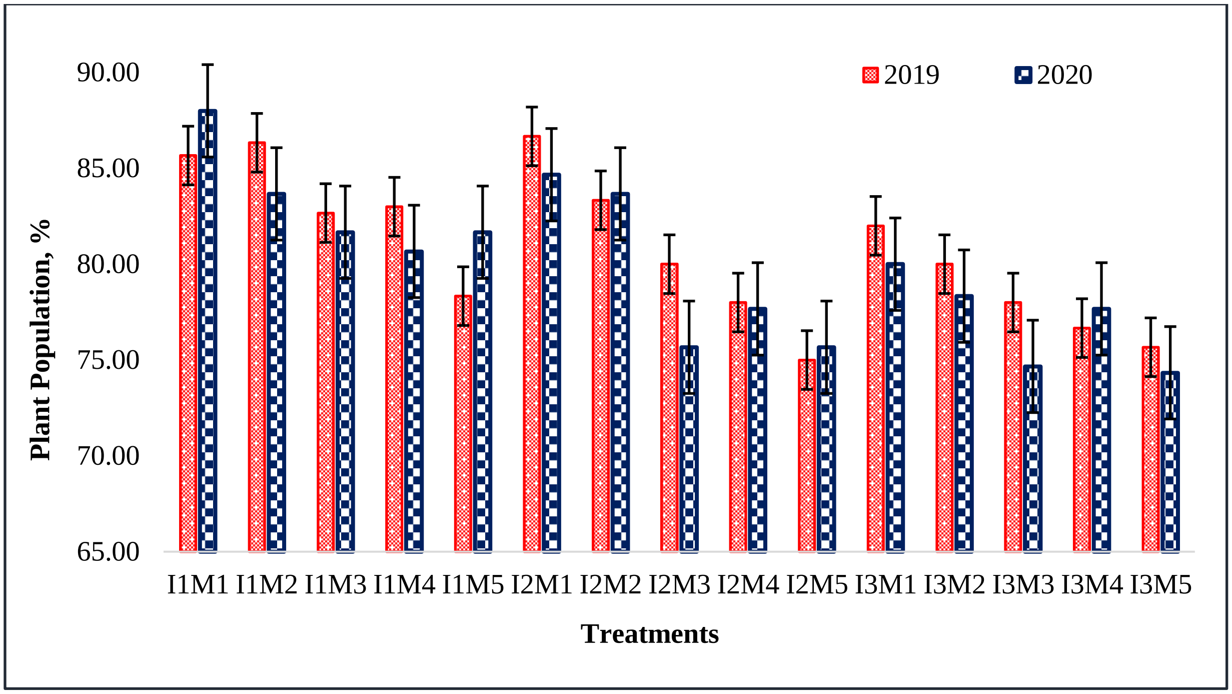


**Fig. 4.7 Effect of irrigation levels and mulching methods on plant population (%) of okra in year 2019 and 2020.**

The result of analysis variance showed that plant populations were not significantly affected by the interaction of irrigations and mulching treatments in both the years ( Table 4.12b and Appendix 3 and 4). In year 2019, maximum plant population (86.67 %) recorded in treatment $I_2M_1$ and lowest plant population recorded in treatment $I_2M_5$ (75 %). In year 2020, maximum plant population (88.00 %) recorded in treatment $I_1M_1$ and lowest plant population recorded in treatment $I_3M_5$ (74.33 %). Highest plant population was observed may be due to good moisture under mulching treatment whereas lowest plant population was due to the more evaporation on the surface and less moisture availability. The similar results were reported by Kumar *et al.* (2018). Investigators reported that irrigation levels and mulching did not showed any significant effect on plant populations of barley crop but they also concluded that one irrigation and mulching reported maximum plant populations.

### 4.4.2 Plant height

#### 4.4.2.1 Plant height in the year 2019

The plant height of okra at 30, 60 and 90 days after sowing as recorded from five tagged plants are tabulated in Table 4.13a and 4.13b.

**Table 4.13a Effect of irrigation levels and mulching methods on plant height (cm) of okra in year 2019**

| Treatments | 30 DAS | 60 DAS | 90 DAS |
|---|---|---|---|
| **Irrigation levels ( I )** | | | |
| **$I_1$** | $18.23^{ab}$ | $70.69^{ab}$ | $95.57^{ab}$ |
| **$I_2$** | $19.52^{a}$ | $75.60^{a}$ | $100.45^{a}$ |
| **$I_3$** | $17.00^{b}$ | $66.29^{b}$ | $88.64^{b}$ |
| **SEm±** | 0.35 | 1.37 | 2.21 |
| **LSD 0.05** | 1.36 | 5.36 | 8.68 |
| | | | |
| **Mulching methods (M)** | | | |
| **$M_1$** | $24.09^{a}$ | $84.13^{a}$ | $110.42^{a}$ |
| **$M_2$** | $23.82^{a}$ | $80.96^{a}$ | $103.02^{b}$ |
| **$M_3$** | $15.33^{b}$ | $66.69^{b}$ | $92.13^{c}$ |
| **$M_4$** | 14.56bc | $64.64^{b}$ | $89.53^{c}$ |
| **$M_5$** | 13.44c | $57.89^{c}$ | $79.33^{d}$ |
| **SEm±** | 0.47 | 1.59 | 1.85 |
| **LSD 0.05** | 1.38 | 4.63 | 5.40 |
| Means followed by different alphabet(s) indicate significant difference at the 5% probability level | | | |

The anova result showed that (Appendix 3) the irrigation levels significantly influenced plant height. At 30 days, the plant height recorded as 18.23, 19.52 and 17.00 cm in irrigation levels $I_1$, $I_2$ and $I_3$ respectively, in which irrigation level $I_2$ recorded maximum height and lowest plant height recorded in irrigation level $I_3$. At 60 days, the maximum plant height recorded in $I_2$ (75.60 cm) and lowest plant height recorded in $I_3$ (66.29 cm).

Similar trend was observed in 90 days. At 90 days, maximum plant height (100.45 cm) was recorded in $I_2$ irrigation level which is significantly superior to $I_3$ (88.64 cm) and at par to $I_1$ (95.57 cm). Lowest height was observed in $I_3$ irrigation level, which is 11.75 per cent less than $I_2$. The maximum plant height recorded in irrigation level $I_2$, this may be due to the availability of proper air and water proportion.

Looking to the mulching effect, plant height was observed at 30, 60 and 90 days and presented in the Table 4.13a. At 30 days, plant height recorded at mulching treatment $M_1$, $M_2$, $M_3$, $M_4$ and $M_5$ were 24.09, 23.82, 15.33, 14.56 and 13.44 cm respectively. At 60 days, plant height recorded at mulching treatment $M_1$, $M_2$, $M_3$, $M_4$ and $M_5$ were 84.13, 80.96, 66.69, 64.64 and 57.89 cm respectively. At 90 days, plant height recorded at mulching treatment $M_1$, $M_2$, $M_3$, $M_4$ and $M_5$ were 110.42, 103.02, 92.13, 89.53 and 79.33 cm respectively. It had been reported that from the Table 14.3a, black mulching methods recorded significantly maximum height than straw mulch, soil mulch, no mulch at 30, 60 and 90 days and at par with silver plastic mulching methods at 30, 60 days. As per the results of anova table Appendix 3, the Fcal (42.699) is greater than F tab (2.766), it concluded that the mulching methods significantly influenced plant height at 90 days. At 90 days, black plastic mulching and silver plastic mulch showed significant effect on plant height and found to be superior to other mulching methods. Lowest plant height recorded in no mulching ($M_5$) treatment compared to other mulching treatment. Among the mulching methods, the paddy straw and soil mulch treatment did not significantly influenced plant height. The highest plant height was recorded in both plastic mulching treatment. This may be due to the fact that mulch conserve the moisture and absorbs the large amounts of solar radiation and maintain the desirable soil temperature for plant growth. The similar observation have been reported by Birbal *et al.* (2013) Tarara (2000) and Parate *et al.* (2020).

**Table 4.13b Interaction effect of irrigation and mulching methods on plant height (cm) of okra in year 2019**

| Treatments | Treatments details | 30 DAS | 60 DAS | 90 DAS |
|---|---|---|---|---|
| **$I_1M_1$** | 1.00ETc + Black plastic mulch | 24.27 | 83.13 | 110.40 |
| **$I_1M_2$** | 1.00ETc + Silver plastic mulch | 22.60 | 80.87 | 102.87 |
| **$I_1M_3$** | 1.00ETc + Paddy straw mulch | 15.20 | 67.60 | 92.80 |
| **$I_1M_4$** | 1.00ETc + Soil mulch (20 cm depth) | 15.00 | 62.53 | 88.00 |
| **$I_1M_5$** | 1.00ETc + No mulch | 14.07 | 59.33 | 83.80 |
| **$I_2M_1$** | 0.80ETc + Black plastic mulch | 25.87 | 89.73 | 115.13 |
| **$I_2M_2$** | 0.80ETc + Silver plastic mulch | 26.47 | 87.20 | 113.40 |
| **$I_2M_3$** | 0.80ETc + Paddy straw mulch | 17.13 | 73.53 | 94.20 |
| **$I_2M_4$** | 0.80ETc + Soil mulch (20 cm depth) | 14.87 | 69.87 | 99.00 |
| **$I_2M_5$** | 0.80ETc + No mulch | 13.27 | 57.67 | 80.53 |
| **$I_3M_1$** | 0.60ETc + Black plastic mulch | 22.13 | 79.53 | 105.73 |
| **$I_3M_2$** | 0.60ETc + Silver plastic mulch | 22.40 | 74.80 | 92.80 |
| **$I_3M_3$** | 0.60ETc + Paddy straw mulch | 13.67 | 58.93 | 89.40 |
| **$I_3M_4$** | 0.60ETc + Soil mulch (20 cm depth) | 13.80 | 61.53 | 81.60 |
| **$I_3M_5$** | 0.60ETc + No mulch | 13.00 | 56.67 | 73.67 |
| | **SEm±** | 0.82 | 2.75 | 3.21 |
| | **LSD (0.05)** | NS | NS | NS |

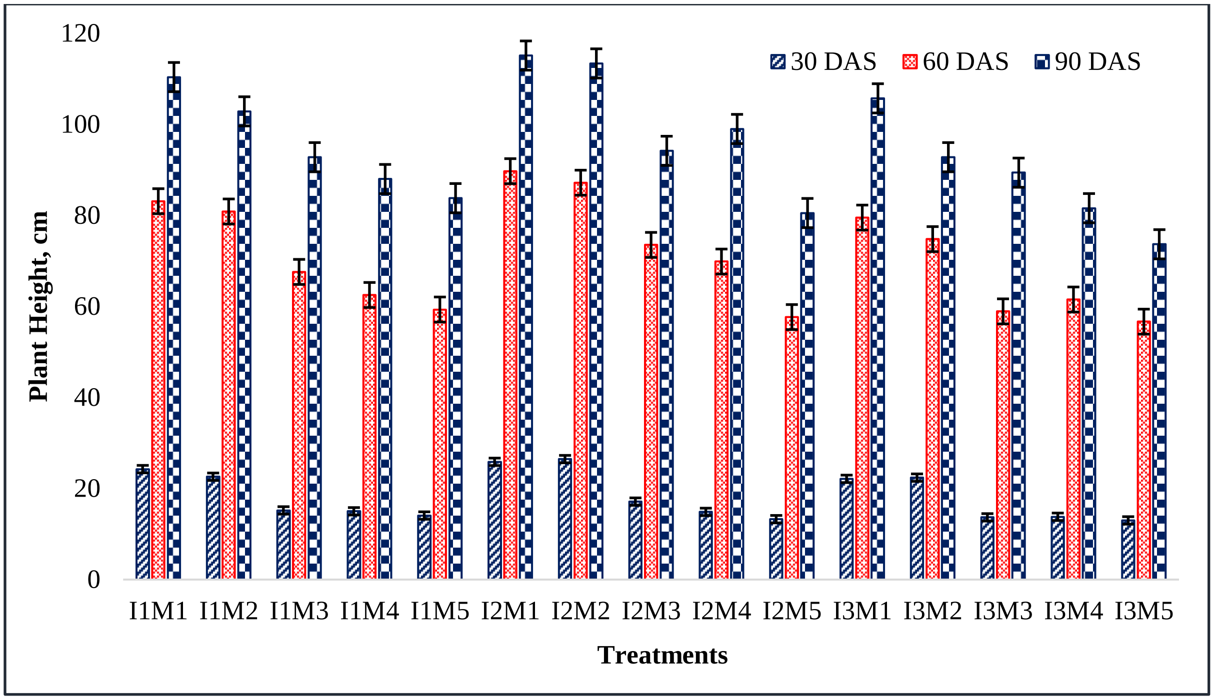


**Fig. 4.8 Effect of irrigation levels and mulching methods on plant height of okra in year 2019.**

In interaction of irrigation levels and mulching, the plant height recorded at 30, 60 and 90 days are presented in Table 4.13b and graphically in Figure 4.8. The result of analysis variance showed that plant height were not significantly affected by the interaction of irrigation and mulching treatment (Table 4.13b and Appendix 3). Maximum plant height recorded at 30 days in treatment $I_2M_2$ was 26.47 cm, at 60 and 90 days in treatment $I_2M_1$ was 89.73 and 115.13 cm respectively. The lowest plant height recorded at 30, 60 and 90 days in treatment $I_3M_5$ was 13.00, 56.67 and 73.67 cm respectively. No mulch treatment combined with all three irrigation levels shows the lowest plant height. This may be due to, mulching with plastic film conserved the more soil moisture compared with the no mulch and straw mulch. The same results was found by Parate *et al.* (2020) and reported that taller plant height was recorded in plastic mulch than other mulch.

#### 4.4.2.2 Plant Height in the year 2020

The plant height of okra at 30, 60 and 90 days after sowing was recorded from five tagged plant and tabulated in table 4.14a and 4.14b.

**Table 4.14a Effect of irrigation levels and mulching methods on plant height (cm) of okra in year 2020**

| Treatments | 30 DAS | 60 DAS | 90 DAS |
|---|---|---|---|
| **Irrigation levels ( I )** | | | |
| **$I_1$** | $18.85^{ab}$ | $71.12^{ab}$ | $96.80^{bc}$ |
| **$I_2$** | $20.87^{a}$ | $77.51^{a}$ | $105.04^{a}$ |
| **$I_3$** | $17.91^{b}$ | $68.09^{b}$ | $92.92^{c}$ |
| **SEm±** | 0.53 | 1.67 | 1.64 |
| **LSD 0.05** | 2.07 | 6.54 | 6.43 |
| | | | |
| **Mulching methods (M)** | | | |
| **$M_1$** | $25.31^{a}$ | $85.40^{a}$ | $110.98^{a}$ |
| **$M_2$** | $24.96^{a}$ | $84.20^{a}$ | $107.09^{a}$ |
| **$M_3$** | $16.44^{b}$ | $65.89^{b}$ | $98.33^{b}$ |
| **$M_4$** | $15.09^{c}$ | $65.36^{b}$ | $90.47^{c}$ |
| **$M_5$** | $14.24^{c}$ | $60.33^{c}$ | $84.40^{d}$ |
| **SEm±** | 0.45 | 0.45 | 1.43 |
| **LSD 0.05** | 1.31 | 1.31 | 4.18 |
| Means followed by different alphabet(s) indicate significant difference at the 5% probability level | | | |

At 30 days, the plant height was observed as 18.85, 20.87 and 17.91 cm in irrigation level $I_1$, $I_2$ and $I_3$ respectively, in which irrigation level $I_2$ recorded maximum plant height and significantly different than irrigation level $I_3$ and at par to $I_1$. The similar trend was obtained at 60 days too. At 90 days, the maximum plant height (105.04 cm) was recorded in irrigation level $I_2$ which is significantly superior to irrigation level $I_1$ (96.80 cm) and $I_3$ (92.92 cm). Lowest plant height (92.92 cm) was measure in $I_3$ irrigation level, which is

11.53 per cent less than $I_2$. The anova results showed that irrigation levels significantly influenced plant height (Appendix 4). At 30, 60 and 90 days, the maximum plant height recorded at irrigation level $I_2$ followed by $I_3$. Tiwari *et al.* (1998) also reported same results and stated that the plant height significantly influenced by the irrigation level.

In mulching treatments, plant height recorded at 30, 60 and 90 days and presented in Table 4.14a. At 30 days, plant height recorded at mulching treatment $M_1$, $M_2$, $M_3$, $M_4$ and $M_5$ were 25.13, 24.96, 16.44, 15.09 and 14.24 cm respectively. At 60 days, plant height recorded at mulching treatment $M_1$, $M_2$, $M_3$, $M_4$ and $M_5$ were 85.40, 84.20, 65.89, 65.36 and 60.33 cm respectively. At 90 days, plant height recorded at mulching treatment $M_1$, $M_2$, $M_3$, $M_4$ and $M_5$ were 110.98, 107.09, 98.33, 90.47 and 84.40 cm respectively. As per the result of anova, the F calculated ratio is more than F tabulated, it can be concluded that mulching methods significantly influenced plant height. At 90 days, maximum crop height (110.98 cm) recorded in black plastic mulch was significantly superior than other mulching methods and at par with silver plastic mulch. No mulching ($M_5$) treatment showed the lowest plant height (84.40 cm) compared to other mulching treatment. At 90 days paddy straw and soil mulch was significantly affected on plant height. Maximum plant height in plastic mulch was may be due to the fact that plastic mulch conserve the moisture and absorbs the large amounts of solar radiation and maintain the desirable soil temperature for plant growth. These results were supported by Dalorima *et al.* (2014) who also recorded the higher plant height under plastic mulch and straw mulch.

**Table 4.14b Interaction effect of irrigation and mulching methods on plant height (cm) of okra in year 2020**

| Treatments | Treatments details | 30 DAS | 60 DAS | 90 DAS |
|---|---|---|---|---|
| $I_1M_1$ | 1.00ETc + Black plastic mulch | 24.93 | 84.13 | 110.67 |
| $I_1M_2$ | 1.00ETc + Silver plastic mulch | 23.40 | 81.27 | 106.40 |
| $I_1M_3$ | 1.00ETc + Paddy straw mulch | 16.07 | 64.80 | 94.53 |
| $I_1M_4$ | 1.00ETc + Soil mulch (20 cm depth) | 15.40 | 63.40 | 88.00 |
| $I_1M_5$ | 1.00ETc + No mulch | 14.47 | 61.93 | 84.40 |
| $I_2M_1$ | 0.80ETc + Black plastic mulch | 27.07 | 90.53 | 115.53 |
| $I_2M_2$ | 0.80ETc + Silver plastic mulch | 28.47 | 92.20 | 115.33 |
| $I_2M_3$ | 0.80ETc + Paddy straw mulch | 18.53 | 74.00 | 106.67 |
| $I_2M_4$ | 0.80ETc + Soil mulch (20 cm depth) | 15.73 | 70.60 | 100.53 |
| $I_2M_5$ | 0.80ETc + No mulch | 14.53 | 60.20 | 87.13 |
| $I_3M_1$ | 0.60ETc + Black plastic mulch | 23.93 | 81.53 | 106.73 |
| $I_3M_2$ | 0.60ETc + Silver plastic mulch | 23.00 | 79.13 | 99.53 |
| $I_3M_3$ | 0.60ETc + Paddy straw mulch | 14.73 | 58.87 | 93.80 |
| $I_3M_4$ | 0.60ETc + Soil mulch (20 cm depth) | 14.13 | 62.07 | 82.87 |
| $I_3M_5$ | 0.60ETc + No mulch | 13.73 | 58.87 | 81.67 |
| | **SEm±** | 0.78 | 2.53 | 2.48 |
| | **LSD (0.05)** | NS | NS | NS |

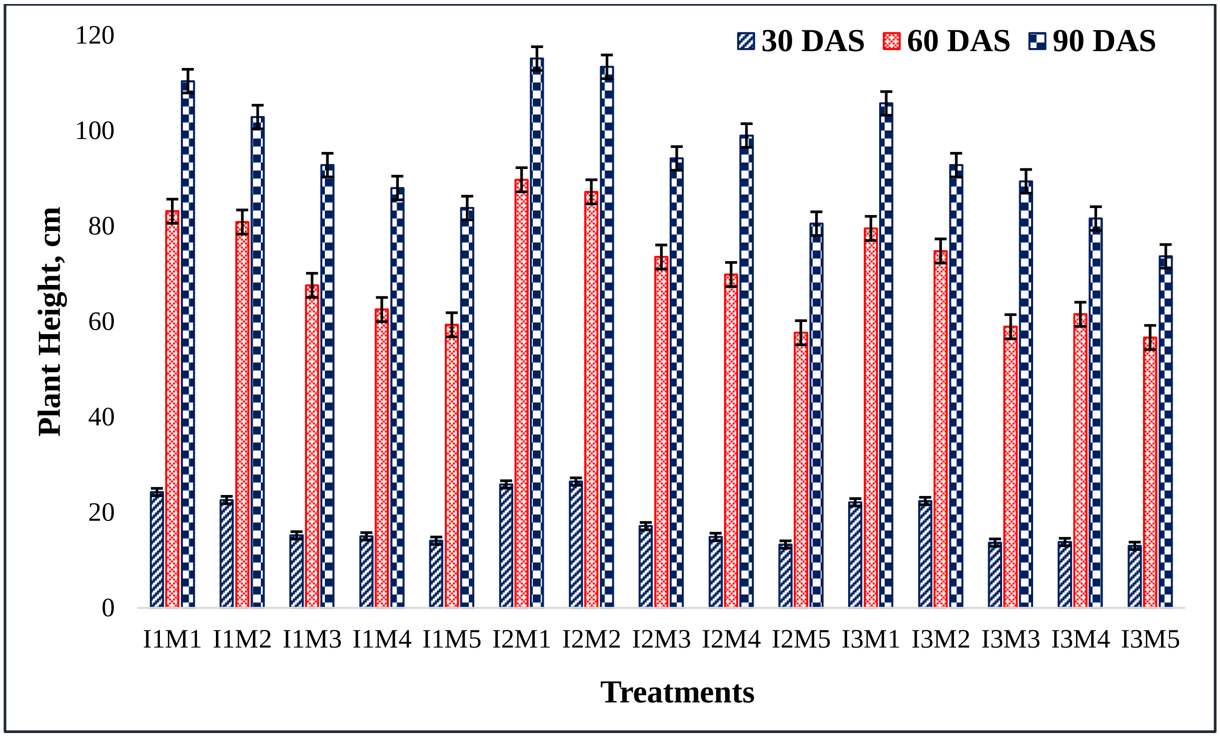


**Fig. 4.9 Effect of irrigation levels and mulching methods on plant height of okra in year 2020.**

Interaction of irrigation levels and mulching methods on plant height was recorded and presented in Table 4.14b and Figure 4.9. The result of analysis variance showed that plant height were not significantly affected by the interaction of irrigation and mulching treatment (Table 4.14b and Appendix 4). The treatment $I_2M_2$ recorded maximum plant height as 28.47 and 92.20 cm at 30 and 60 days whereas the treatment $I_2M_1$ recorded maximum plant height (115.53 cm) at 90 days. Lowest plant height was recorded as 13.73, 58.87 and 81.67 cm at 30, 60 and 90 days in treatment $I_3M_5$. The reduction in plant height in no mulch treatment was may be due to less moisture conservation, more evaporation rate and less irrigation application i.e 0.8 and 0.6 ETc. Both the plastic mulch showed superior plant height, this may be due to conservation of moisture and less evaporation. The above results supported by Chandra and Singh (2019) and recorded that maximum plant height in interactive treatment of drip irrigation and plastic mulching. Birbal *et al*. (2013) also reported that plant height showed significance response to the interaction of irrigation and plastic mulch at 30, 60 and 90 days of sowing.

### 4.4.3 Number of branches per plant

**Table 4.15a Effect of irrigation levels and mulching methods on number of branches per plant of okra in year 2019 and 2020**

| **Irrigation levels** | **2019** | **2020** |
|---|---|---|
| **I1** | 1.49[b] | 1.36[b] |
| **I2** | 1.77[a] | 1.84[a] |
| **I3** | 1.29[b] | 1.39[b] |
| **SEm±** | 0.05 | 0.09 |
| **LSD (0.05)** | 0.21 | 0.35 |
| | | |
| **Mulching methods** | **2019** | **2020** |
| **M1** | 2.00[a] | 2.02[a] |
| **M2** | 1.62[b] | 2.09[a] |
| **M3** | 1.49[b] | 1.56[b] |
| **M4** | 1.56[b] | 1.00[c] |
| **M5** | 0.93[c] | 0.98[c] |
| **SEm±** | 0.09 | 0.09 |
| **LSD (0.05)** | 0.26 | 0.27 |
| Means followed by different alphabet(s) indicate significant difference at the 5% probability level | | |

The number of branches in the okra crop were counted on 30, 60 and 90 days. To avoid the confusion of counting the same number branches multiple times, the final 90 days branches were considered and are presented in Table 4.15a. In year 2019, the average number of branches were recorded as 1.49, 1.77 and 1.29 in irrigation treatment $I_1$, $I_2$ and $I_3$

respectively. In year 2020, the average number of branches were recorded in irrigation level $I_1$, $I_2$ and $I_3$ as 1.36, 1.84 and 1.39 respectively. The table of analysis of variance (Appendix 3 and 4) showed that the F calculated value is more than F tabulated value, it implied that irrigation levels significantly influenced number of branches per plant. It has been observed that in both the year, the irrigation level $I_2$ significantly influenced the number of branches per plant and showed maximum number of branches per plant compared to $I_1$ and $I_3$ whereas irrigation level $I_1$ and $I_3$ are at par to each other. This may be due to proper amount of moisture maintain favorable environment which promote the good vegetative growth of the plant. Similar results reported by Kamble *et al.* (2020) and reported that the irrigation levels $I_1$ (1.0 ETc) and $I_2$ (0.8 ETc) showed significant higher yield than irrigation level $I_3$ (0.6 ETc).

Looking the mulching effects, in year 2019 and 2020, the table of analysis of variance (Appendix 3 and 4) showed that the F calculated value is more than F tabulated value, it implied that mulching methods significantly influenced number of branches per plant. In year 2019, the number of branches per plant were recorded as 2.00, 1.62, 1.49, 1.56 and 0.93 in black plastic mulch ($M_1$), silver mulch ($M_2$), straw mulch ($M_3$), soil mulch ($M_4$) and no mulch ($M_5$) respectively. Black plastic mulch ($M_1$) recorded higher mean number of branches and significantly superior than silver mulch ($M_2$), straw mulch ($M_3$), soil mulch ($M_4$) and no mulch ($M_5$). Among the Silver mulch, straw mulch and soil mulch, these methods did not significantly influenced the number of branches whereas no mulch showed significantly lower number of branches (0.93). In year 2020, the number of branches per plant were recorded as 2.02, 2.09, 1.56, 1.00 and 0.98 in black plastic mulch ($M_1$), silver mulch ($M_2$), straw mulch ($M_3$), soil mulch ($M_4$) and no mulch ($M_5$) respectively. In this year, higher number of branches recorded in silver plastic mulch which was at par with black plastic mulch and significantly superior to straw mulch, soil mulch and no mulch. In both the year, plastic mulch shows the maximum number of branches per plant and no mulch shows minimum number of branches per plant. This may be due the fact that plastic mulch absorbs large amounts of solar radiation and maintain the favorable moisture compared to other organic mulch and no mulch. Similar results reported by Parate (2020) and recorded that plastic mulch showed maximum number of branches compared to grass and wheat straw mulching. Tarara (2000) reported that the plastic mulching maintain the favorable environment to crop growth.

**Table 4.15b Interaction effect of irrigation and mulching methods on number of branches per plant in year 2019 and 2020**

| Treatments | Treatments details | 2019 | 2020 |
|---|---|---|---|
| $I_1M_1$ | 1.00ETc + Black plastic mulch | 1.93 | 2.00 |
| $I_1M_2$ | 1.00ETc + Silver plastic mulch | 1.53 | 1.87 |
| $I_1M_3$ | 1.00ETc + Paddy straw mulch | 1.40 | 1.27 |
| $I_1M_4$ | 1.00ETc + Soil mulch (20 cm depth) | 1.60 | 0.73 |
| $I_1M_5$ | 1.00ETc + No mulch | 1.00 | 0.93 |
| $I_2M_1$ | 0.80ETc + Black plastic mulch | 2.27 | 2.13 |
| $I_2M_2$ | 0.80ETc + Silver plastic mulch | 1.80 | 2.53 |
| $I_2M_3$ | 0.80ETc + Paddy straw mulch | 1.87 | 2.07 |
| $I_2M_4$ | 0.80ETc + Soil mulch (20 cm depth) | 1.73 | 1.27 |
| $I_2M_5$ | 0.80ETc + No mulch | 1.20 | 1.20 |
| $I_3M_1$ | 0.60ETc + Black plastic mulch | 1.80 | 1.93 |
| $I_3M_2$ | 0.60ETc + Silver plastic mulch | 1.53 | 1.87 |
| $I_3M_3$ | 0.60ETc + Paddy straw mulch | 1.20 | 1.33 |
| $I_3M_4$ | 0.60ETc + Soil mulch (20 cm depth) | 1.33 | 1.00 |
| $I_3M_5$ | 0.60ETc + No mulch | 0.60 | 0.80 |
| | **SEm±** | 0.16 | 0.16 |
| | **LSD (0.05)** | NS | NS |

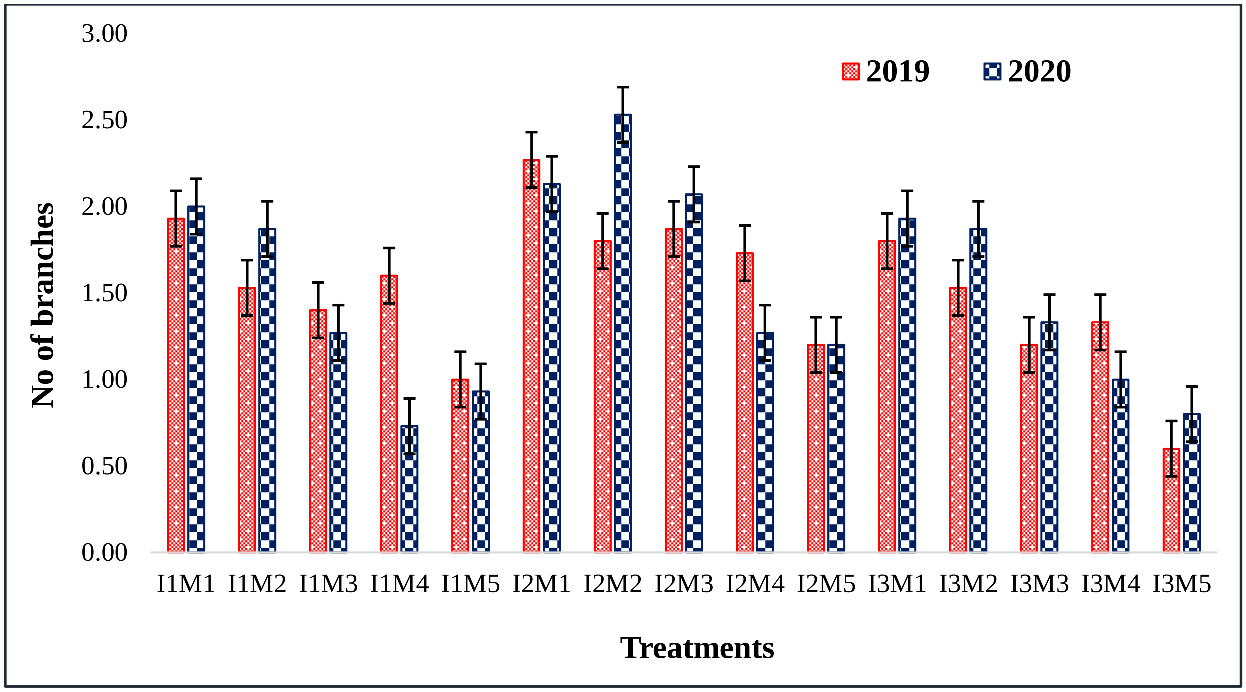


**Fig. 4.10 Effect of irrigation levels and mulching methods on number of branches per plant of in year 2019 and 2020**

Data of number of branches per plant under interaction of irrigation and mulching recorded and presented in Table 4.15b and Figure. 4.10. The table of analysis of variance (Appendix 3 and 4) showed that the F calculated is less than F tabulated, it implied that interaction of irrigation and mulching did not significantly influenced number of branches per plant in both the year. In year 2019, maximum number of branches per plant was recorded in treatment $I_2M_1$ (2.27) followed by treatment $I_1M_1$ (1.93). Lowest number of branches (0.60) per plant was recorded in no mulch treatment interacted with 0.6 ETc i.e $I_3M_{5.}$ In year 2020, the maximum number of branches per plant was recorded in treatment $I_2M_2$ (2.53) followed by treatment $I_2M_1$ (2.13). The minimum number of branches (0.80) per plant was observed in treatment $I_3M_{5.}$ The interaction of mulching and irrigation did not showed significant effect on number of branches, but the plastic mulch with the 0.8ETc treatment were superior compared to other treatment and no mulch treatment. Kamble *et al.* (2020) reported that the interaction effect of irrigation level and mulching showed significant effect on number of branches per plant. Among the mulching, silver-black plastic interacted with irrigation level recorded the maximum number of branches per plant.

#### 4.4.4. Number days for first flowering

The flower emergence is the process of initiation of pod formation which depend on the physiological growth of the crop. The number of days of first flowering were monitored from fourth week after sowing. The replication wise data recorded and statistically analyzed at significant level $P<0.05$ and presented in the Table 4.16a and 4.16b.

**Table 4.16a Effect of irrigation levels and mulching methods on number of days for first flowering of okra in year 2019 and 2020**

| Irrigation levels | 2019 | 2020 |
|---|---|---|
| $I_1$ | $36.67^b$ | $35.87^b$ |
| $I_2$ | $36.00^b$ | $35.80^b$ |
| $I_3$ | $39.73^a$ | $37.93^a$ |
| SEm± | 0.67 | 0.41 |
| LSD (0.05) | 2.62 | 1.59 |
| | | |
| **Mulching methods** | **2019** | **2020** |
| $M_1$ | $33.78^c$ | $33.78^c$ |
| $M_2$ | $34.22^c$ | $34.44^c$ |
| $M_3$ | $38.67^b$ | $37.78^b$ |
| $M_4$ | $37.78^b$ | $36.33^b$ |
| $M_5$ | $43.00^a$ | $40.33^a$ |
| SEm± | 0.61 | 0.42 |
| LSD (0.05) | 1.77 | 1.23 |
| Means followed by different alphabet(s) indicate significant difference at the 5% probability level | | |

Effect of irrigation levels and mulching methods on the first flower emergence is presented in Table 4.16a. Day of first flower was counted from the date of sowing. The table of analysis of variance (Appendix 3 and 4) showed that the F calculated is more than F tabulated, it implied that irrigation methods significantly influenced days of first flower emergence in both the year. In year 2019, days required for flowering were 36.67, 36.00 and 39.73 days in irrigation level $I_1$, $I_2$ and $I_3$ respectively whereas in year 2020, days were 35.87, 35.80 and 37.93 in same treatment respectively. The lowest number of days required for first flower emergence was recorded in treatment $I_2$ i.e. 0.8ETc in both the year 2019 and 2020 and at par with irrigation level $I_1$ followed by irrigation level $I_3$. The Irrigation level $I_3$ took maximum days for first flowering in both the year. Thokal *et al.* (2020) found the similar results and reported that the 80% ETc took less days for flowering and maturity of fruits compared to 1.00 ETc but investigators also added that 60% ETc took lowest days for 50 % flowering stage and concluded that moisture stress matured the fruits early.

Looking towards the mulch treatments, in year 2019, the first day of flowering recorded as 33.78, 34.22, 38.67, 37.78 and 43.00 days in black plastic mulch ($M_1$), silver mulch ($M_2$), straw mulch ($M_3$), soil mulch ($M_4$) and no mulch ($M_5$) respectively. In year 2020, the first day of flowering recorded as 33.78, 34.44, 37.78, 36.33 and 40.33 days in mulch treatment $M_1$, $M_2$, $M_3$, $M_4$ and $M_5$ respectively. From the results of analysis of variance ($F_{cal} > F_{tab}$) depicted in Appendix 3, Appendix 4 and Table 4.16a, the first day of flowering was significantly affected by mulch treatments. Black plastic mulch treatment took lowest days (33.78) in both year which was at par to silver plastic mulch (34.22 and 34.44) in both the year 2019 and 2020. No mulch treatment took maximum number of days i.e 43.00 and 40.33 days for first flowering in both the year 2019 and 2020 which was about seven days late than plastic mulch treatments. Paddy straw and soil mulch did not significantly influenced the number of days of flowering in year 2019 but influenced in year 2020. The plastic mulching conserved more moisture compared to straw mulch and significantly impacted the vegetative growth including flowering stages. Goukh and Mustafa (2003) also reported similar finding.

**Table 4.16b Interaction effect of irrigation and mulching methods on number of days for first flowering of okra in year 2019 and 2020**

| Treatments | Treatments details | 2019 | 2020 |
|---|---|---|---|
| $I_1M_1$ | 1.00ETc + Black plastic mulch | 33.33 | 32.33 |
| $I_1M_2$ | 1.00ETc + Silver plastic mulch | 32.67 | 34.67 |
| $I_1M_3$ | 1.00ETc + Paddy straw mulch | 39.00 | 37.67 |
| $I_1M_4$ | 1.00ETc + Soil mulch (20 cm depth) | 36.00 | 34.67 |
| $I_1M_5$ | 1.00ETc + No mulch | 42.33 | 40.00 |
| $I_2M_1$ | 0.80ETc + Black plastic mulch | 31.33 | 33.67 |
| $I_2M_2$ | 0.80ETc + Silver plastic mulch | 31.67 | 33.67 |
| $I_2M_3$ | 0.80ETc + Paddy straw mulch | 37.67 | 36.67 |
| $I_2M_4$ | 0.80ETc + Soil mulch (20 cm depth) | 37.00 | 35.33 |
| $I_2M_5$ | 0.80ETc + No mulch | 42.67 | 39.67 |
| $I_3M_1$ | 0.60ETc + Black plastic mulch | 36.67 | 35.33 |
| $I_3M_2$ | 0.60ETc + Silver plastic mulch | 38.33 | 35.00 |
| $I_3M_3$ | 0.60ETc + Paddy straw mulch | 39.33 | 39.00 |
| $I_3M_4$ | 0.60ETc + Soil mulch (20 cm depth) | 40.33 | 39.00 |
| $I_3M_5$ | 0.60ETc + No mulch | 44.00 | 41.33 |
| | **SEm±** | 1.05 | 0.73 |
| | **LSD (0.05)** | NS | NS |

The table of analysis of variance (Appendix 3 and 4) showed that the F calculated is less than F tabulated, it implied that interaction of irrigation levels and mulching methods did not significantly influenced days of first flowering per plant in both the year.

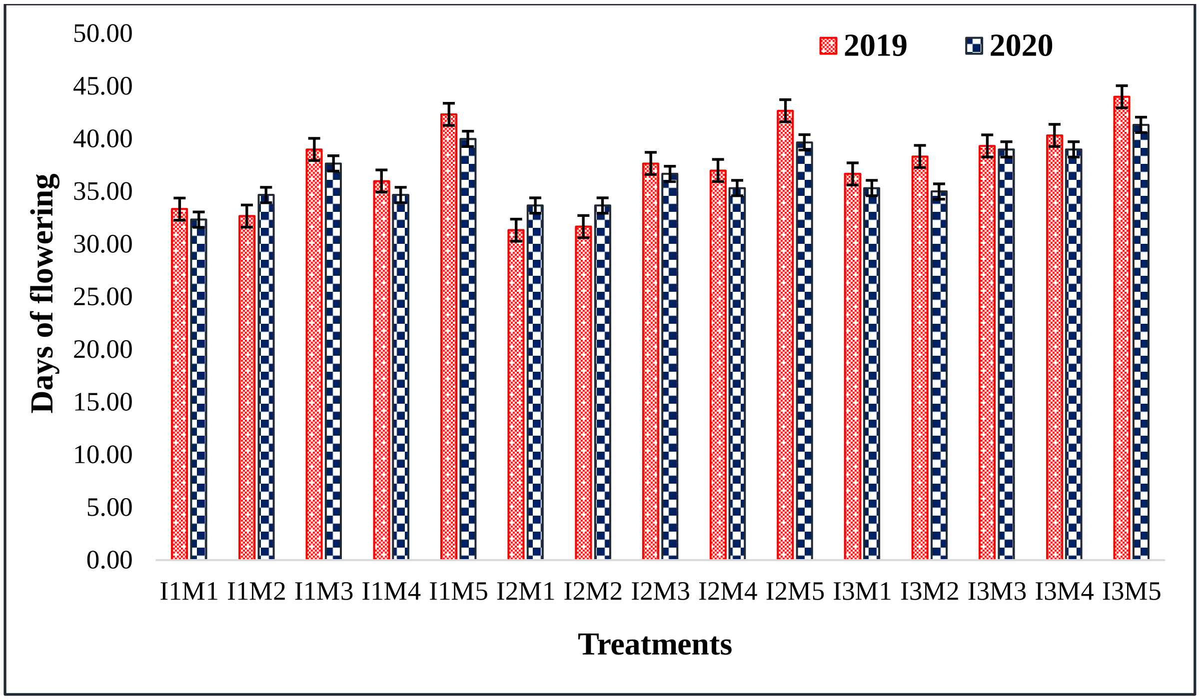


**Fig. 4.11 Effect of irrigation levels and mulching methods on days of first flowering of okra crop in year 2019 and 2020.**

Data from Table 4.16b and Figure 4.11 indicates that, in interaction effect, treatment $I_2M_1$ and $I_2M_2$ took lowest days (31.33 and 31.67) for first flowering in year 2019. Maximum days (44.00) recorded in treatment $I_3M_5$ (0.6 ETc + no mulch). In year 2020, lowest days (32.33) were recorded in treatment $I_1M_1$ (1.00 ETc + black plastic mulch) and maximum days (41.33) recorded in treatment $I_3M_5$. Black plastic mulch interacted with irrigation level (1.0 ETc and 0.8 ETc) showed lowest days for first flowering and this may be due to the proper conservation of moisture and favorable environmental for crop growth. In interaction effect, there were no specific trend observed for the early days of flowering but the non-mulch techniques took maximum days when interacted with all three irrigation levels. Jayapiratha (2010) suggested that flowering percentage can be promoted by avoiding the water stress condition.

### 4.5 Effect on plant yield parameters

### 4.5.1. Number of pods per plant

The Pod formation started after seven to eight days from the start of flowering. The pods of tagged plants were harvested and counted as number per plants. The recorded data had been statistically analyzed at probability level $p<0.05$ and presented in Table 4.17a and 4.17b.

**Table 4.17a Effect of irrigation levels and mulching methods on number of pods per plant of okra in year 2019 and 2020**

| **Irrigation levels** | **2019** | **2020** |
|---|---|---|
| **$I_1$** | 17.11[a] | 18.35[a] |
| **$I_2$** | 16.25[ab] | 17.29[a] |
| **$I_3$** | 14.84[b] | 15.02[b] |
| **SEm±** | 0.37 | 0.27 |
| **LSD (0.05)** | 1.45 | 1.06 |
| | | |
| **Mulching methods** | **2019** | **2020** |
| **$M_1$** | 18.23[a] | 18.70[a] |
| **$M_2$** | 18.03[a] | 18.59[a] |
| **$M_3$** | 15.39[b] | 16.02[b] |
| **$M_4$** | 14.53[b] | 16.64[b] |
| **$M_5$** | 14.16[b] | 14.48[c] |
| **SEm±** | 0.58 | 0.52 |
| **LSD (0.05)** | 1.69 | 1.52 |
| Means followed by different alphabet(s) indicate significant difference at the 5% probability level | | |

In year 2019, the number of pods per plants were recorded as 17.11, 16.25, and 14.84 in irrigation level $I_1$, $I_2$ and $I_3$ respectively as shown in Table 4.17a. In year 2020, the irrigation level $I_1$, $I_2$ and $I_3$ recorded 18.35, 17.29 and 15.20 pods per plants respectively. As per the results of analysis of variance ( Appendix 5 and 6), F calculated is greater than F tabulated, so statically it can be concluded that the irrigation levels significantly influenced the number of pods per plants in both the years.

Among the irrigation level $I_1$ and $I_{2,}$ number of pods per plants were not affected by irrigation levels $I_1$ and $I_{2.}$ Irrigation levels $I_1$ recorded higher number of pods per plant (17.11 and 18.35) in both the year 2019 and 2020 which was at par with irrigation level $I_2$ (16.25 and 17.29 respectively) whereas the irrigation level $I_3$ recorded significantly lowest number of pods per plant (14.84 and 15.02) in both the years. Maximum number of pods in irrigation $I_1$ and $I_2$ is due to the adequate amount of water near to the root zone. Similar finding resulted by Thokal *et al.* (2020) and reported that the maximum number of pods per plant observed in 0.8 ETc irrigation level followed by 1.0ETc.

The pods per plants under different mulching methods were presented in Table 4.17a. The results of analysis of variance reveled that the mulching treatments significantly influenced number of pods per plants in both year ( Appendix 5 and 6). Data in year 2019 shows that the number of pods per plant were recorded as 18.13, 18.03, 15.39, 14.53 and 14.16 in black mulch ( $M_1$), silver mulch ($M_2$), straw mulch ($M_3$), soil mulch ($M_4$) and no mulch ($M_5$) respectively. The number of pods per plant responded significantly to the mulch treatment. The highest number of pods per plant was recorded in black plastic mulch (18.23) which is at par with silver plastic mulch(18.03) and significantly 28 per cent more than the non mulch (14.16).

In the year 2020, the number of pods per plant recorded in treatment $M_1$, $M_2$, $M_3$,$M_4$ and $M_5$ was 18.70, 18.59, 16.02, 16.64 and 14.48 respectively. Black plastic mulch recorded maximum number of pods per plant (18.70) which was at par with silver plastic mulch (18.59) and showed significantly 29 per cent more number of pods than non mulch treatments (14.48). Among the straw mulch (16.02) and soil mulch (16.64), these methods were not significantly influenced on number of pods per plant but these mulching methods recorded more number of pods compared with non mulch condition.

From the research trial of two year study, it was observed that, plastic mulch showed more number of pods per plant compared with non mulch where as straw mulch and soil mulch were not significantly different from each other. The higher number of pods may be due to optimum moisture and favourable enviroment under plastic much which enhance the plant rowth. Same finding were recorded by Olabode *et al.* (2007) who recorded the higher number of pods per plants under plastic mulch. Sunilkumar and Jaikumaran (2002) also recorded the similar results. Birbal *et al.* (2013) reported that, plastic mulch showed highest number of fruits per plant compared to hessian cloth and indigenous material mulch.

**Table 4.17b Interaction effect of irrigation and mulching methods on number of pods per plant of okra in year 2019 and 2020**

| Treatments | Treatments details | 2019 | 2020 |
|---|---|---|---|
| **$I_1M_1$** | 1.00ETc + Black plastic mulch | 18.67 | 19.77 |
| **$I_1M_2$** | 1.00ETc + Silver plastic mulch | 19.03 | 19.53 |
| **$I_1M_3$** | 1.00ETc + Paddy straw mulch | 16.57 | 17.40 |
| **$I_1M_4$** | 1.00ETc + Soil mulch (20 cm depth) | 15.43 | 18.49 |
| **$I_1M_5$** | 1.00ETc + No mulch | 15.87 | 16.53 |
| **$I_2M_1$** | 0.80ETc + Black plastic mulch | 18.83 | 19.50 |
| **$I_2M_2$** | 0.80ETc + Silver plastic mulch | 18.00 | 19.10 |
| **$I_2M_3$** | 0.80ETc + Paddy straw mulch | 15.87 | 16.40 |
| **$I_2M_4$** | 0.80ETc + Soil mulch (20 cm depth) | 14.73 | 16.70 |
| **$I_2M_5$** | 0.80ETc + No mulch | 13.83 | 14.77 |
| **$I_3M_1$** | 0.60ETc + Black plastic mulch | 17.20 | 16.83 |
| **$I_3M_2$** | 0.60ETc + Silver plastic mulch | 17.07 | 17.13 |
| **$I_3M_3$** | 0.60ETc + Paddy straw mulch | 13.73 | 14.27 |
| **$I_3M_4$** | 0.60ETc + Soil mulch (20 cm depth) | 13.43 | 14.73 |
| **$I_3M_5$** | 0.60ETc + No mulch | 12.77 | 12.13 |
| | **SEm±** | 1.01 | 0.90 |
| | **LSD (0.05)** | NS | NS |

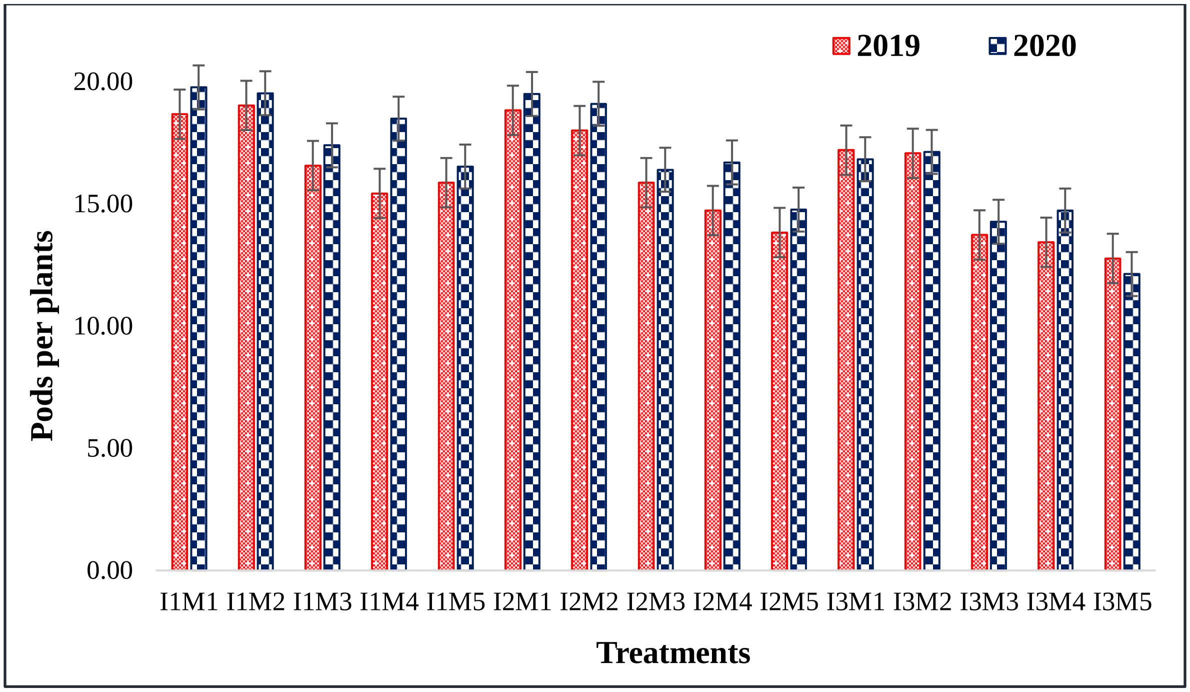


**Fig. 4.12. Effect of irrigation levels and mulching methods on number of pods per plant of okra crop in the year 2019 and 2020**

The data of number of pods per plants affected by interaction of irrigation levels and mulching is recorded in Table 4.17b and Figure 4.12. The table of analysis of variance (Appendix 5 and 6) showed that the F calculated is less than F tabulated, it implied that interaction of irrigation and mulching did not significantly influenced the number of pods per plant in both the year. In year 2019, silver plastic mulch interacted with 1.0 ETc i.e treatment $I_1M_2$ shows higher number of pods (19.03) followed by treatment $I_2M_1$ whereas treatment $I_3M_5$ (non-mulch + 0.6 ETc) recorded the lowest pods per plant (12.77). In year 2020, treatment $I_1M_1$ recorded 19.77 pods per plant followed by treatment $I_1M_2$ (19.53) whereas treatment $I_3M_5$ recorded lowest number of pods (12.13) per plant. Interaction effect did not significantly influenced the pods per plants but both the plastic mulch interacted with irrigation levels reported maximum number of pods per plant compared to other interaction level. The opposite results were obtained by Birbal *et al.* (2013) who reported that number of pod of pea per plant significantly responded to the interaction effect of drip irrigation and plastic mulch followed by hessian cloth mulch.

### 4.5.2. Crop yield (g/plant)

The average yield of tagged plants was recorded as grams and tabulated in Table 4.18a and 4.18b. The irrigation levels and mulching treatments shows the significant on yield per plant.

**Table 4.18a Effect of irrigation levels and mulching methods on crop yield (g) per plant of okra in year 2019 and 2020**

| **Irrigation levels** | **2019** | **2020** |
|---|---|---|
| **$I_1$** | 206.89$^{a}$ | 210.23$^{b}$ |
| **$I_2$** | 216.59$^{a}$ | 228.59$^{a}$ |
| **$I_3$** | 158.69$^{b}$ | 160.36$^{c}$ |
| **SEm±** | 4.04 | 2.37 |
| **LSD (0.05)** | 15.88 | 9.31 |
| | | |
| **Mulching methods** | **2019** | **2020** |
| **$M_1$** | 243.86$^{a}$ | 250.49$^{a}$ |
| **$M_2$** | 234.42$^{a}$ | 242.32$^{a}$ |
| **$M_3$** | 180.45$^{b}$ | 187.72$^{b}$ |
| **$M_4$** | 170.01$^{b}$ | 173.33$^{b}$ |
| **$M_5$** | 141.56$^{c}$ | 144.78$^{c}$ |
| **SEm±** | 7.07 | 6.81 |
| **LSD (0.05)** | 20.64 | 19.86 |
| Means followed by different alphabet(s) indicate significant difference at the 5% probability level | | |

In year 2019, the crop yield per plant of okra recorded as 206.89, 216.59, and 158.69 g/plant in irrigation level $I_1$, $I_2$ and $I_3$ respectively. The results from table of analysis of variance (appendix 5 and 6) revealed that the irrigation levels significantly influenced the yield per plant (F cal > F tab). The irrigation level $I_2$ recorded significantly higher yield (216.59 g/plant) than $I_3$ (158.69 g/plant) and was at par with $I_1$ (206.89 g/plant) in year 2019. In the year 2020, irrigation levels $I_1$, $I_2$ and $I_3$ recorded yield per plant as 210.23, 228.59 and 160.36 g/plant. The trend was similar in 2020 too i.e the yield of plant was $I_2 > I_1 > I_3$ and showed significantly affected by irrigation levels. The irrigation level $I_2$ showed the maximum yield per plant in both the year and this might be due to the proper air water ratio near to the root zone which help the crop for better environment.

With respect to mulching effect, the plant yield (g/plant) recorded as 243.86, 234.42, 180.45, 170.01, 141.56 in year 2019 and 250.49, 242.32, 187.72, 173.33, 144.78 in year 2020 in black plastic mulch ($M_1$), silver plastic mulch ($M_2$), paddy straw mulch ($M_3$), soil mulch ($M_4$), no mulch ($M_5$) respectively. Highest plant yield was recorded in black plastic mulch followed by silver mulch and lowest yield was observed in non-mulch treatment in both year. Black plastic mulch showed significantly higher plant yield (243.86 and 250.49) than straw mulch, soil mulch and non-mulch field and was at par with silver plastic mulch in both year. Straw mulch ($M_3$) and soil mulch ($M_4$) did not showed any significant different to each other in both year. Maximum plant yield in plastic mulch may be due to proper moisture and favorable environment in the rooting zone which gives good quality of pod yield. The similar results observed by Mahadeen (2014) and reported that black plastic mulch showed maximum pod yield per plant (255.6 g/plant) than no mulch treatments (152.1 g/plant). Investigator added that the black plastic mulch prevent the soil water evaporation rate and maintain the adequate environment near the root zone.

**Table 4.18b Interaction effects of irrigation and mulching methods on crop yield (g) per plant of okra in year 2019 and 2020**

| Treatments | Treatments details | 2019 | 2020 |
|---|---|---|---|
| **$I_1M_1$** | 1.00ETc + Black plastic mulch | 242.67 | 256.97 |
| **$I_1M_2$** | 1.00ETc + Silver plastic mulch | 245.53 | 251.98 |
| **$I_1M_3$** | 1.00ETc + Paddy straw mulch | 173.95 | 182.70 |
| **$I_1M_4$** | 1.00ETc + Soil mulch (20 cm depth) | 213.63 | 194.18 |
| **$I_1M_5$** | 1.00ETc + No mulch | 158.67 | 165.33 |
| **$I_2M_1$** | 0.80ETc + Black plastic mulch | 282.50 | 292.50 |
| **$I_2M_2$** | 0.80ETc + Silver plastic mulch | 270.00 | 286.50 |
| **$I_2M_3$** | 0.80ETc + Paddy straw mulch | 230.07 | 237.80 |
| **$I_2M_4$** | 0.80ETc + Soil mulch (20 cm depth) | 162.05 | 178.48 |
| **$I_2M_5$** | 0.80ETc + No mulch | 138.33 | 147.67 |
| **$I_3M_1$** | 0.60ETc + Black plastic mulch | 206.40 | 202.00 |
| **$I_3M_2$** | 0.60ETc + Silver plastic mulch | 187.73 | 188.47 |
| **$I_3M_3$** | 0.60ETc + Paddy straw mulch | 137.33 | 142.67 |
| **$I_3M_4$** | 0.60ETc + Soil mulch (20 cm depth) | 134.33 | 147.33 |
| **$I_3M_5$** | 0.60ETc + No mulch | 127.67 | 121.33 |
| | **SEm±** | 12.25 | 11.79 |
| | **LSD (0.05)** | 35.74 | 34.40 |

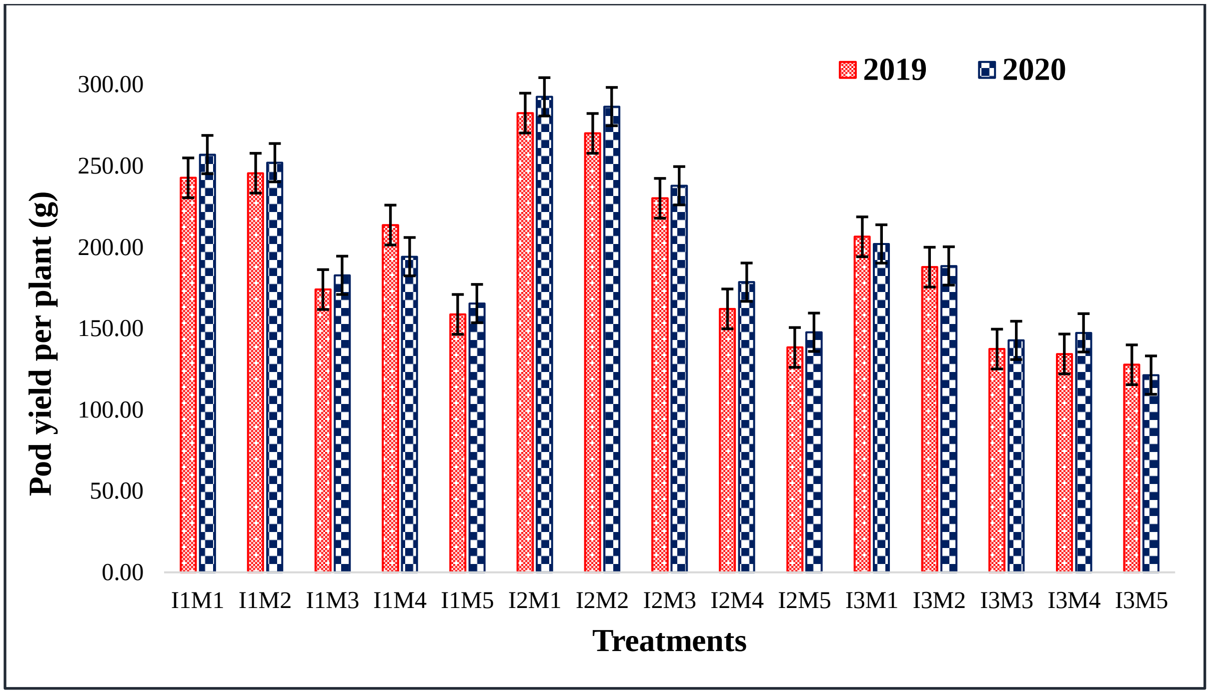


**Fig. 4.13 Effect of irrigation levels and mulching methods on pod yield per plant of okra crop in year 2019 and 2020**

Interaction of irrigation and mulching on plant yield recorded in both year and shown in Table 4.18b and Figure 4.13. The interaction effect of irrigation and mulching shows the significant effect on yield per plant in both the year (Fcal>Ftab) In year 2019, maximum yield per plant (282.50 g) was recorded in treatment $I_2M_1$ and at par to $I_2M_2$ (270.50 g) followed by other interaction treatment and lowest yield per plant was recorded in $I_3M_3$ (127.67 g). The trend was similar in the year 2020 also, the maximum yield was recorded in the treatment $I_2M_1$ (292.50) and at par to $I_2M_2$ (286.50) which were mulched with plastic sheet and the lowest yield was observed in $I_3M_3$ (121.33 gm). The yield per plant was decreased due to the non-mulch condition as well as less water application (0.6 ETc). The similar results was observed by Mahadeen (2014) reported the maximum plant yield recorded in black plastic mulch than no mulch treatment.

### 4.5.3 Crop yield in t/ha

The total crop yield of okra was noted and presented in the Table 4.19a and 4.19b. The recorded data was analysed statistically at $P<0.05$ level of significance for estimation of significant effect of irrigation levels and mulching treatments on the crop yield.

**Table 4.19a Effect of irrigation levels and mulching methods on crop yield (t/ha) of okra in year 2019 and 2020**

| **Irrigation levels** | **2019** | **2020** |
|---|---|---|
| **$I_1$** | $15.59^a$ | $16.10^a$ |
| **$I_2$** | $15.36^a$ | $15.69^a$ |
| **$I_3$** | $13.25^b$ | $13.95^b$ |
| **SEm±** | 0.35 | 0.32 |
| **LSD (0.05)** | 1.39 | 1.26 |
| | | |
| **Mulching methods** | **2019** | **2020** |
| **$M_1$** | $19.09^a$ | $18.83^a$ |
| **$M_2$** | $19.01^a$ | $18.09^a$ |
| **$M_3$** | $13.05^b$ | $14.32^b$ |
| **$M_4$** | $11.31^c$ | $13.47^c$ |
| **$M_5$** | $11.21^c$ | $11.54^d$ |
| **SEm±** | 0.56 | 0.28 |
| **LSD (0.05)** | 1.63 | 0.83 |
| Means followed by different alphabet(s) indicate significant difference at the 5% probability level | | |

The crop yield recorded in irrigation levels $I_1$ (1.0 ETc), $I_2$ (0.8 ETc), $I_3$ (0.6 ETc) was 15.59, 15.36, 13.25 and 16.10, 15.69, 13.95 in year 2019 and 2020 respectively. The results from table of analysis of variance (Appendix 5 and 6) revealed that the irrigation levels significantly influenced the crop yield per hector (F cal > F tab) in both the year. The maximum crop yield was recoreded in irrigation level $I_1$ ( 15.59 and 16.10) which was at par to irrigation level $I_2$ (15.36 and 15.69) and significantly more than $I_3$ (13.25 and 13.95) in both the years. Irrigation level $I_1$ (17.66 and 15.41 %) and irrigation level $I_2$ (15.92 and 12.47 %) recorded significantly higher yield compared to irrgation level $I_3$ in both the years. This implies that increase in moisture resulted in increased yield. The similar results were observed by Thokal *et al.* (2020) during the study influence of irrigation regime on okra crop in konkan reagion, who reported that maximum okra yield was recorded at irrigation level at 0.80 ETc and 1.00 ETc. The above results was also supported by Chandra and Singh (2019).

In year 2019, the okra yield recorded as 19.09, 19.01, 13.05, 11.31 and 11.21 t/ha in mulch treatments $M_1$ (black plastic mulch), $M_2$ (silver plastic mulch), $M_3$ (paddy straw mulch), $M_4$ (soil mulch) and $M_5$ (no mulch) respectively. The mulching treatments showed significant effect on crop yield. The black plastic mulches recorded significantly higher yield than straw mulch, soil mulch, no mulch and at par with silver plastic mulch. No mulch treatment recorded lowest yield which was 41.27 per cent less than black plastic mulch. In year 2020, the crop yield recorded as 18.83, 18.09, 14.32, 13.47 and 11.54 t/ha in mulching treatment $M_1$, $M_2$, $M_3$, $M_4$ and $M_5$ respectively. The mulching treatment significantly incluenced the crop yield. In this year too, the black plastic mulches recorded significantly higher yield than straw mulch, soil mulch, no mulch and at par with silver plastic mulch. No mulch ($M_5$) treatment recorded lowest yield which was 38.71 per cent less than black plastic mulch. Among the plastic mulch, it did not showed the significant effect on crop yield over each other but recorded significantly superior yield than other mulching treatment in both the year. The maximum yield in plastic mulch may be due the the better moisture conservation and favourable enviroment obtained near to the root zone. The similar results have been reported by Sunilkumar and Jaikumaran (2002), Tarara (2000) and Tiwari *et al.* (1998).

**Table 4.19b Interaction effect of irrigation and mulching methods on crop yield (t/ha) of okra in year 2019 and 2020**

| Treatments | Treatments details | 2019 | 2020 |
|---|---|---|---|
| $I_1M_1$ | 1.00ETc + Black plastic mulch | 19.18 | 18.86 |
| $I_1M_2$ | 1.00ETc + Silver plastic mulch | 19.01 | 18.30 |
| $I_1M_3$ | 1.00ETc + Paddy straw mulch | 14.22 | 15.18 |
| $I_1M_4$ | 1.00ETc + Soil mulch (20 cm depth) | 12.35 | 14.63 |
| $I_1M_5$ | 1.00ETc + No mulch | 13.22 | 13.55 |
| $I_2M_1$ | 0.80ETc + Black plastic mulch | 19.82 | 20.01 |
| $I_2M_2$ | 0.80ETc + Silver plastic mulch | 20.18 | 19.08 |
| $I_2M_3$ | 0.80ETc + Paddy straw mulch | 13.49 | 14.99 |
| $I_2M_4$ | 0.80ETc + Soil mulch (20 cm depth) | 11.79 | 13.47 |
| $I_2M_5$ | 0.80ETc + No mulch | 11.53 | 10.92 |
| $I_3M_1$ | 0.60ETc + Black plastic mulch | 18.29 | 17.62 |
| $I_3M_2$ | 0.60ETc + Silver plastic mulch | 17.83 | 16.88 |
| $I_3M_3$ | 0.60ETc + Paddy straw mulch | 11.44 | 12.79 |
| $I_3M_4$ | 0.60ETc + Soil mulch (20 cm depth) | 9.80 | 12.32 |
| $I_3M_5$ | 0.60ETc + No mulch | 8.89 | 10.15 |
| | **SEm±** | 0.97 | 0.49 |
| | **LSD (0.05)** | NS | 1.44 |

The interaction of irrigation levels and mulching methods on crop yield is presented in Table 4.19b and Figure 4.14. The interaction effect of irrigation and mulching did not showed significant effect on crop yield in 2019 (Fcal < Ftab, Appendix 5 and 6). Maximum crop yield (20.18 t/ha) was recorded in treatment $I_2M_2$ followed by $I_2M_1$ (19.82 t/ha) in year 2019. The lowest yield was recorded in $I_3M_5$ treatment (8.89) which was 126 per cent less than the black plastic mulch. Among the paddy straw and soil mulch interacted with irrigation, treatment $I_3M_3$ (11.44 t/ha) and $I_3M_4$ (9.80 t/ha) recorded lowest crop yield.

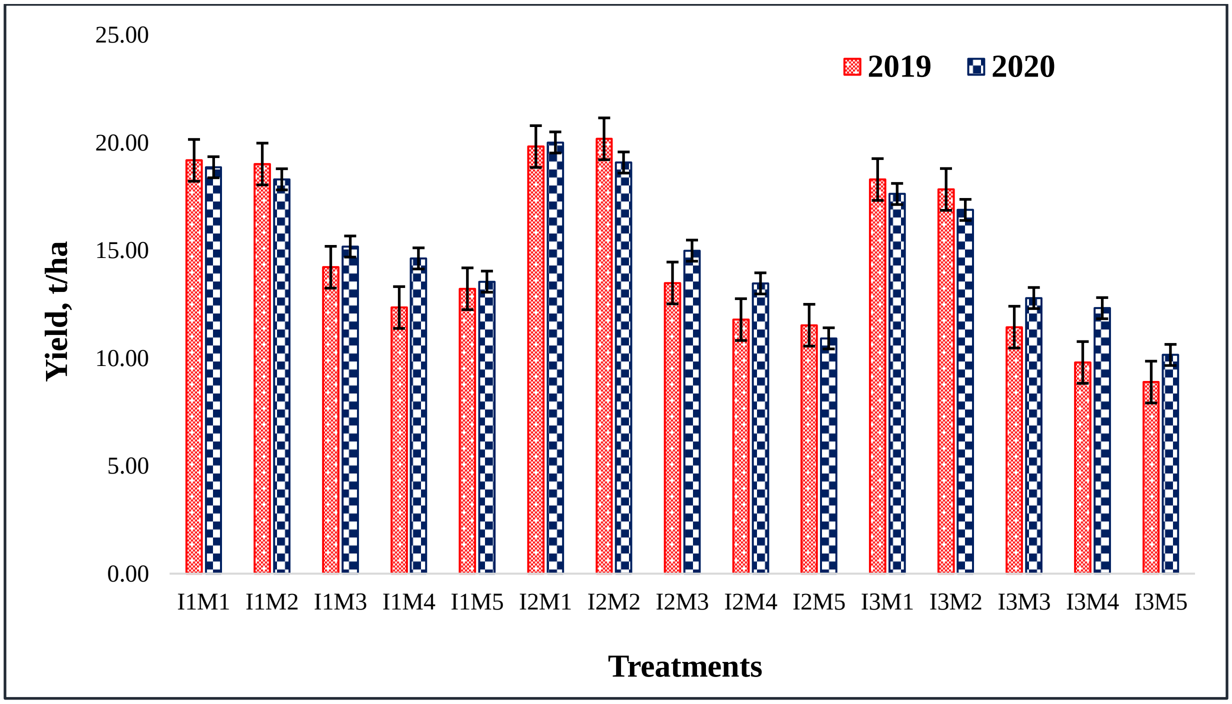


**Fig. 4.14 Effect of irrigation levels and mulching methods on yield of okra crop in year 2019 and 2020.**

The interaction effect of irrigation and mulching showed significant effect on crop yield in 2020 (Fcal > Ftab, Appendix 5 and 6). In year 2020, the $I_2M_1$ (20.01 t/ha) showed maximum yield which was at par to treatment $I_2M_2$ (19.08 t/ha). The no mulch interacted with $I_3$ showed the lowest yield 10.15 t/ha which is 97 per cent lower than treatment $I_2M_1$. Among the paddy straw and soil mulch interacted with irrigation, treatment $I_3M_3$ (12.79 t/ha) and $I_3M_4$ (12.32 t/ha) recorded lowest crop yield. From the above analysis and Figure 4.10, it has been concluded that the black plastic mulch and silver plastic mulch interacted with irrigation level $I_2$ recorded the significant higher yield compared with all the treatment. The similar results was observed by Bahadur *et al.* (2009), Singh *et al.* (2009)

and *Tiwari et al.* (1998). The scientist supported that the plastic mulch maintain the favorable environment to the crop by absorbing the solar radiation.

### 4.6 Effect on water use efficiency

The water use efficiency of okra in both the year was calculated and presented in Table 4.20a and 4.20b and graphically in Figure 4.15.

**Table 4.20a Effect of irrigation levels and mulching methods on water use efficiency (kg/ha-cm) of okra in year 2019 and 2020**

| Irrigation levels | 2019 | 2020 |
|---|---|---|
| $I_1$ | 291.35$^{c}$ | 288.59$^{c}$ |
| $I_2$ | 358.66$^{b}$ | 351.58$^{b}$ |
| $I_3$ | 412.56$^{a}$ | 416.79$^{a}$ |
| SEm± | 8.74 | 6.38 |
| LSD (0.05) | 34.32 | 25.05 |
| | | |
| **Mulching methods** | **2019** | **2020** |
| $M_1$ | 463.53$^{a}$ | 437.53$^{a}$ |
| $M_2$ | 460.53$^{a}$ | 419.87$^{a}$ |
| $M_3$ | 312.29$^{b}$ | 329.9$^{b}$ |
| $M_4$ | 270.34$^{bc}$ | 310.7$^{b}$ |
| $M_5$ | 264.27$^{c}$ | 263.61$^{c}$ |
| SEm± | 15.11 | 6.70 |
| LSD (0.05) | 44.11 | 19.57 |
| Means followed by different alphabet(s) indicate significant difference at the 5% probability level | | |

Irrigation level $I_1$, $I_2$, $I_3$ recorded the water use efficiency as 291.35, 358.66, 412.56 kg/ha-cm and 288.59, 351.58, 416.79 kg/ha-cm in year 2019 and 2020. The results from table of analysis of variance (Appendix 5 and 6) revealed that the irrigation levels significantly influenced the water use efficiency (F cal > F tab) in both the year. In both the years, $I_3$ recorded higher WUE Followed by irrigation level $I_2$ and $I_1$ . Irrigation level $I_1$ and $I_2$ recorded 29.37 and 13.06 per cent lower WUE than $I_3$ in year 2019 whereas it showed 30.75 and 15.64 per cent lower WUE in year 2020. Maximum water use efficiency is due to good yield with less amount water applied. Kumar (2009) reported the higher water use efficiency in 0.8 IW/CPE ratio compared to 1.00 and 1.20 IW/CPE ratio.

Looking the mulching effect, the black plastic mulch ($M_1$) recorded higher WUE (463.53 and 437.53 kg/ha-cm) which is at par with $M_2$ (460.53 and 419.87 kg/ha-cm) in year 2019 and 2020 respectively and significantly superior over non mulch treatment (264.27 and 263.61 Kg/ha-cm) respectively. Water use efficiency significantly responded to the mulching treatments. In both the year paddy straw mulch and soil mulch did not significantly differ to each other. Black plastic mulch showed higher water use efficiency due to its moisture conservation property, favourable enviroment and less eveporation rate. The similar results have been reported by Chaudhari *et al.* (2012) and Salunkhe *et al.* (2015).

**Table 4.20b Interaction effect of irrigation and mulching methods on water use efficiency (kg/ha-cm) in year 2019 and 2020**

| Treatments | Treatments details | 2019 | 2020 |
|---|---|---|---|
| **$I_1M_1$** | 1.00ETc + Black plastic mulch | 358.34 | 338.07 |
| **$I_1M_2$** | 1.00ETc + Silver plastic mulch | 355.15 | 327.91 |
| **$I_1M_3$** | 1.00ETc + Paddy straw mulch | 265.63 | 272.00 |
| **$I_1M_4$** | 1.00ETc + Soil mulch (20 cm depth) | 230.64 | 262.14 |
| **$I_1M_5$** | 1.00ETc + No mulch | 247.00 | 242.84 |
| **$I_2M_1$** | 0.80ETc + Black plastic mulch | 462.84 | 448.21 |
| **$I_2M_2$** | 0.80ETc + Silver plastic mulch | 471.16 | 427.37 |
| **$I_2M_3$** | 0.80ETc + Paddy straw mulch | 314.92 | 335.75 |
| **$I_2M_4$** | 0.80ETc + Soil mulch (20 cm depth) | 275.22 | 301.84 |
| **$I_2M_5$** | 0.80ETc + No mulch | 269.18 | 244.71 |
| **$I_3M_1$** | 0.60ETc + Black plastic mulch | 569.42 | 526.32 |
| **$I_3M_2$** | 0.60ETc + Silver plastic mulch | 555.27 | 504.31 |
| **$I_3M_3$** | 0.60ETc + Paddy straw mulch | 356.31 | 381.94 |
| **$I_3M_4$** | 0.60ETc + Soil mulch (20 cm depth) | 305.15 | 368.10 |
| **$I_3M_5$** | 0.60ETc + No mulch | 276.65 | 303.28 |
| | **SEm±** | 26.18 | 11.61 |
| | **LSD (0.05)** | 76.40 | 33.89 |

The influence of irrigation and mulching treatments on the WUE of okra are presented in Table 4.20b and in Figure 4.15. The interaction effect of irrigation levels and mulching showed significant effect on water use efficiency in both year (Fcal > Ftab, Appendix 5 and 6).

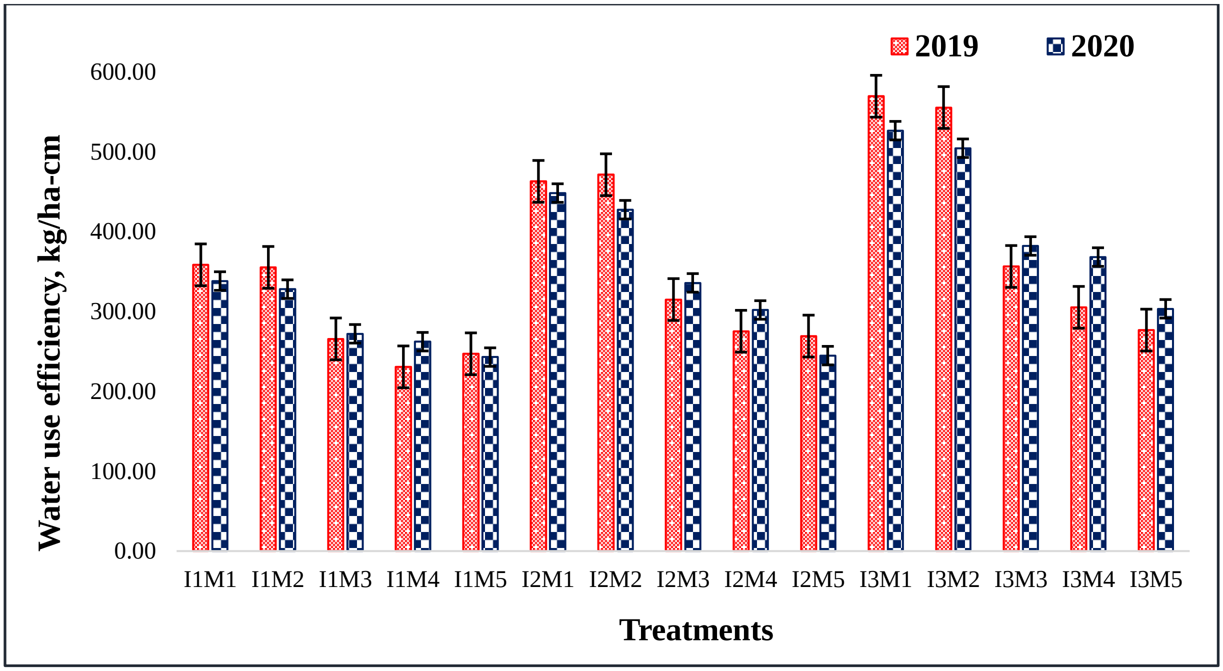


**Fig. 4.15 Effect of irrigation levels and mulching methods on water use efficiency of okra crop in year 2019 and 2020.**

Data showed that, the black plastic mulch ($M_1$) interacted with irrigation level $I_3$ resulted higher WUE followed by silver plastic mulch. The treatment $I_3M_1$ (569.42 and 526.32) and $I_3M_2$ (555.27 and 504.31) showed the higher WUE compared to other treatment in both the year respectively. In year 2019, treatment $I_1M_4$ (230.64 kg/ha-cm) recorded the lowest WUE which was 59 per cent less than treatment $I_3M_1$. In year 2020, treatment $I_1M_5$ (242.84 kg/ha-cm), recorded the lowest WUE which was 53 per cent less than treatment $I_3M_2$. Though the interaction showed the significant effect on WUE but the paddy straw mulch and soil mulch interacted with irrigation and mulching did not significantly different over each other. Tarara (2000) reported that the black plastic mulch maintain the favorable environment, soil water ratio and retard evaporation which enhance the crop yield. This statement support to the reported result that the higher water use efficiency in black plastic mulch and 0.8 ETc irrigation level was may be due to favorable environment in root zone.

The similar results were recorded by Chandra and Singh (2019) and Kumar (2009). Kumar reported that water use efficiency increased with decreased in amount of irrigation.

### 4.7. Economics of drip irrigation

The economic evaluation of drip irrigation and mulching method is presented in the Appendix 9. The cost of drip irrigation and cost cultivation were determined based on the present market rate and presented in Table 3.6 and 3.7 respectively.

#### 4.7.1 Benefit cost ratio

The benefit cost ratio (B:C) of the two year study was estimated based on gross returns from the crop yield and the total cost of cultivation and are presented in Table 4.21a and 4.21b.

**Table 4.21a Effect on irrigation levels and mulching methods on benefit-cost ratio of okra in year 2019 and 2020**

| **Irrigation levels** | **2019** | **2020** |
|---|---|---|
| **$I_1$** | $3.62^{a}$ | $3.77^{a}$ |
| **$I_2$** | $3.53^{a}$ | $3.63^{a}$ |
| **$I_3$** | $3.02^{b}$ | $3.23^{b}$ |
| **SEm±** | 0.08 | 0.08 |
| **LSD (0.05)** | 0.32 | 0.33 |
| | | |
| **Mulching methods** | **2019** | **2020** |
| **$M_1$** | $3.68^{a}$ | $3.63^{b}$ |
| **$M_2$** | $3.66^{a}$ | $3.48^{b}$ |
| **$M_3$** | $3.48^{a}$ | $3.82^{a}$ |
| **$M_4$** | $2.99^{bc}$ | $3.57^{b}$ |
| **$M_5$** | $3.13^{c}$ | $3.22^{c}$ |
| **SEm±** | 0.12 | 0.07 |
| **LSD (0.05)** | 0.36 | 0.19 |
| Means followed by different alphabet(s) indicate significant difference at the 5% probability level | | |

The B:C ratio at irrigation levels $I_1$, $I_2$ and $I_3$ was recorded as 3.62, 3.53 and 3.02 respectively in year 2019 and 3.77, 3.63 and 3.23 respectively in year 2020. The results from table of analysis of variance (Appendix 10) revealed that the irrigation levels significantly influenced the benefit cost ratio (F cal > F tab) in both the year. The irrigation treatment $I_1$ resulted significantly maximum B:C ratio 3.62 which was at par with $I_2$ (3.53) in year 2019 whereas in year 2020, $I_1$ resulted maximum B:C ratio 3.77 which was at par with $I_2$ (3.63). Lowest B:C were observed in $I_3$ (3.02 and 3.23) in both the year. The similar results was reported by Thokal (2020), who found the highest B:C ratio in 0.8ETc followed by 1.0ETc and lowest B:C ratio was obtained in 0.6ETc.

In year 2019, the B:C ratio recorded in mulch treatment black plastic mulch ($M_1$), silver plastic mulch ($M_2$), straw mulch ($M_3$), soil mulch ($M_4$) and no mulch ($M_5$) was 3.68, 3.66, 3.48, 2.99 and 3.13 respectively. In year 2020, the B:C ratio recorded in mulch treatment black plastic mulch ($M_1$), silver plastic mulch ($M_2$), straw mulch ($M_3$), soil mulch ($M_4$) and no mulch ($M_5$) was 3.63, 3.48, 3.82, 3.57 and 3.22 respectively. The results from table of analysis of variance (Appendix 10) revealed that the mulching methods significantly influenced the benefit cost ratio (F cal > F tab) in both the year. The mulching treatments also showed the significant effect on B:C ratio in both the year. In year 2019, the highest B:C ratio was recorded in $M_1$ (3.68) and at par with $M_2$ (3.66), $M_3$ (3.48) and lowest B:C ratio was recorded in $M_4$ (2.99). In year 2020, maximum B:C ratio recorded in $M_3$ (3.82) followed by $M_1$ (3.63) and significant lowest B:C ratio (3.22) recorded in no mulch ($M_5$). Comparing between the paddy straw mulch ($M_3$) and soil mulch ($M_4$); paddy straw mulch had the maximum B:C ratio (3.48 and 3.82) in years 2019 and 2020. The higher the B:C ratio in plastic mulch and straw mulching treatment was due to higher yield in plastic mulch lower total cost of cultivation in paddy straw mulch. The similar results were obtained by Sinha *et al.* (2019) who reported that the highest B:C ratio was in black plastic mulch.

**Table 4.21b Interaction effect of irrigation and mulching methods on benefit-cost ratio of okra in year 2019 and 2020**

| Treatments | Treatments details | 2019 | 2020 |
|---|---|---|---|
| **$I_1M_1$** | 1.00ETc + Black plastic mulch | 3.69 | 3.63 |
| **$I_1M_2$** | 1.00ETc + Silver plastic mulch | 3.66 | 3.52 |
| **$I_1M_3$** | 1.00ETc + Paddy straw mulch | 3.80 | 4.05 |
| **$I_1M_4$** | 1.00ETc + Soil mulch (20 cm depth) | 3.27 | 3.87 |
| **$I_1M_5$** | 1.00ETc + No mulch | 3.69 | 3.78 |
| **$I_2M_1$** | 0.80ETc + Black plastic mulch | 3.82 | 3.85 |
| **$I_2M_2$** | 0.80ETc + Silver plastic mulch | 3.88 | 3.67 |
| **$I_2M_3$** | 0.80ETc + Paddy straw mulch | 3.60 | 4.00 |
| **$I_2M_4$** | 0.80ETc + Soil mulch (20 cm depth) | 3.12 | 3.57 |
| **$I_2M_5$** | 0.80ETc + No mulch | 3.21 | 3.05 |
| **$I_3M_1$** | 0.60ETc + Black plastic mulch | 3.52 | 3.39 |
| **$I_3M_2$** | 0.60ETc + Silver plastic mulch | 3.43 | 3.25 |
| **$I_3M_3$** | 0.60ETc + Paddy straw mulch | 3.06 | 3.41 |
| **$I_3M_4$** | 0.60ETc + Soil mulch (20 cm depth) | 2.59 | 3.26 |
| **$I_3M_5$** | 0.60ETc + No mulch | 2.48 | 2.83 |
| | **SEm±** | 0.21 | 0.11 |
| | **LSD (0.05)** | NS | 0.33 |

The interaction of irrigation levels and mulching methods did not showed significant effect on benefit cost ratio in 2019 (Fcal<Ftab). Maximum B:C ratio (3.88) was recorded in treatment $I_1M_2$ followed by $I_2M_1$ (3.82) in year 2019. Among the paddy straw mulch and soil mulch interacted with irrigation, treatment $I_1M_3$ (3.80) and $I_1M_4$ (3.27) recorded maximum B:C ratio. The lowest B:C ratio was recorded in $I_3M_5$ treatment (2.48).

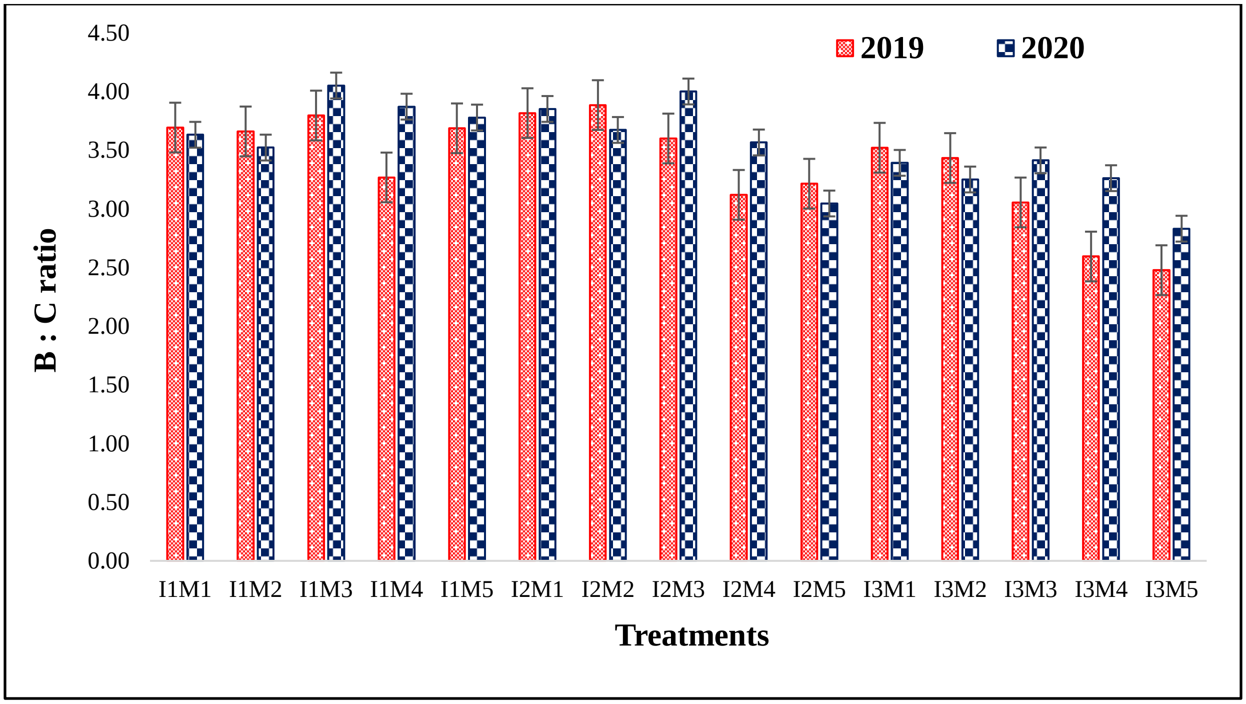


**Fig. 4.16 Effect of irrigation levels and mulching methods on benefit-cost ratio of okra crop in year 2019 and 2020.**

The interaction effect of irrigation and mulching significantly influenced on benefit cost ratio in 2020 (Fcal>Ftab). In year 2020, the $I_1M_3$ (4.05) showed maximum B:C ratio followed by treatment $I_2M_3$ (4.00). No mulch treatment interacted with 0.6ETc showed the lowest B:C ratio 2.83. Among the paddy straw and soil mulch interacted with irrigation, treatment $I_1M_3$ (4.05) and $I_1M_4$ (3.87) recorded maximum B:C ratio. The Interaction effect of irrigation level and mulching did not showed significant effect on B:C ratio in year 2019 but showed significant effect in year 2020.

From the above analysis and Figure 4.16, it had been concluded that the paddy straw mulch interacted with irrigation level recorded the significant higher B:C ratio compared with all the treatment. This is due to lower total cost of cultivation compared with the plastic mulch treatment. Plastic mulch recorded higher yield compared to other mulch and no mulch treatment but showed lower B: C ratio due to its higher initial cost. The opposite results obtained by Singh *et al.* (2009) recorded the highest B:C ratio in black plastic mulch with 0.8ETc irrigation level. He added that the irrigation at 80 % together with plastic mulch resulted to maintain the optimum moisture for plant growth and development. Babu *et al.* (2015) also supported the above results.

## Chapter V

## SUMMARY AND CONCLUSIONS

The research experiment pertaining to response of okra (*Abelmoschus esculentus* ***L.)*** to different irrigation levels and mulching methods under drip irrigation was conducted on the experimental Farm of School of Agriculture, Lovely Professional University, Phagwara, in the year 2019 and 2020. The aim of the study was to investigate the response of okra to the minimum water application rate and water conservation techniques. Minimum water application rate was decided based on the actual water needed (ETc) to the crop and then reducing its proportion at 80 and 60 per cent treated as irrigation level and applied to the crop along with moisture conservation techniques such as plastic mulch, straw mulch and soil mulch. The irrigation levels were $I_1$ = 1.0ETc, $I_2$ = 0.8 ETc and $I_3$ = 0.6 ETc and mulching methods as $M_1$ = black plastic mulch, $M_2$ = silver plastic mulch. $M_3$ = paddy straw mulch, $M_4$ = sub surface at 20 cm depth treated as Soil mulch and $M_5$ = no mulch. Experiment consists of 15 treatments replicated thrice laid in randomized split plot design. The sowing date of the first trial was 12 April 2019 and second trial was on 1 June 2020. Sowing in year 2020 was delayed due to strict lockdown restriction during the first wave of covid-19 pandemic.

**Salient finding of results, of this study as presented in chapter IV are summarized below:**

1. **Hydraulic performance of drip irrigation system**: Hydraulic performance of drip irrigation system was evaluated by estimating uniformity coefficient, the distribution uniformity and emission uniformity.

   The uniformity coefficient at the first, middle and last lateral was estimated as 95.78, 97.05 and 96.18 per cent, in which middle lateral recorded maximum value of uniformity coefficient and overall average uniformity coefficient was 96.34 %.

The observed uniformity coefficient indicated an excellent design of drip system in the conducted field experiment.

The distribution uniformity at first, middle and last lateral was recorded as 94.29, 96.12 and 94.86 per cent, with the overall average distribution uniformity was 95.09 per cent which is considered as an excellent design of drip system.

The emission uniformity of the present system was observed as 94.29, 96.70 and 94.29 per cent at first lateral, middle lateral and last lateral respectively. The average emission uniformity was recorded as 95.10 per cent which was excellent as per the recommendation (ASAE 1996).

2. **Soil moisture distribution pattern**: The soil moisture contents were measured at 5, 10, 15, 20 cm distance from the lateral horizontally and vertically. The moisture content for all five treatments are summarized as per below:

   In a black plastic mulch treatment, the minimum average moisture content (18.74 %) away from emitters at 20 cm vertically and horizontally indicated the less moisture availability at 20 cm away from the point source. Good moisture content available near to the crop root zone i.e up to 20 cm below the emitter and 15 cm away from the emitters. The soil moisture content decreased horizontally away from the point source indicating that there was slow water movement laterally. It was clear that the moisture content up to field capacity was available up to 15 cm horizontal distance and 20 cm depth from the point source.

   In silver plastic mulch treatment, it was observed that the soil moisture content is more than the black plastic mulch sheet and this may be due to less evaporation under silver plastic mulch. The soil moisture content decreased horizontally away from the point source indicating slow water movement in lateral direction.

   In paddy straw mulch, there is not much variation in 0 to 10 cm and 10 to 20 cm depth vertically below the point source but moisture content less than field capacity was observed at 10 to 20 cm horizontal distance from the point source. The less moisture content observed near to the surface may be due to moisture absorbed by paddy straw or evaporation rate. The soil moisture content decreased horizontally away from the point source indicating slow lateral movement of water.

The lateral placed at depth 20 cm considered as soil mulch treatment and it was observed that less moisture content was available at the 5 cm depth. It showed that upward movement from the point source was slow resulting in low moisture content (14.88 %). Moreover the water moving to the surface of soil by upward movement may be lost due to evaporation. Enough moisture content at depth 20 cm below the surface of soil and near to the point source indicated a good root zone for the crop.

In no mulch treatment, there is not much variation in 0 to 10 cm and 10 to 20 cm depth vertically below the point source but moisture content less than field capacity was observed at 10 to 20 cm horizontal distance from point source. The less moisture content observed near to the surface may be due to more evaporation on the surface. The soil moisture content decreased horizontally away from the point source indicating very slow water movement laterally.

3. **Crop evapotranspiration**: The crop evapotranspiration determined by feeding the meteorological and required soil data in Cropwat model and reference evapotranspiration ($ET_0$) was determined.

   The maximum total monthly crop evapotranspiration recorded as 188.38 mm and 185.07 mm in the months of July and August in the year 2019 and 2020 respectively. Average ETc was recorded as 4.70 mm/day and 5.14 mm per day in both years respectively. The maximum $ET_0$ was recorded as 6.27 and 5.97 mm in the month of July and August in year 2019 and 2020 respectively.

   The decade-wise highest $ET_0$ (69.44 mm) was recorded in the third decade of July month with the total $ET_0$ was 651.24 mm. The highest ETc i.e 62.31 mm was recorded in the first decade of August month. The Minimum $ET_0$ and ETc value was recorded in the month of September at late season stage i.e 37.22 mm and 31.91 mm respectively. Total ETc recorded in irrigation level $I_1$, $I_2$ and $I_3$ was 3383.91 mm, 2707.12 mm and 2030.345 mm respectively.

In year 2019, highest $ET_0$ was recorded as 182.65 mm at mid-season stage and lowest $ET_0$ was recorded at initial stages i.e 127.74 mm whereas higher and lower crop evapotranspiration rate was recorded as 184.48 mm and 89.42 mm at mid-season and initial stage respectively. In year 2020, highest $ET_0$ was recorded as 190.70 mm at development stage and lowest $ET_0$ was recorded at late season stages i.e 102.16 mm whereas higher and lower crop evapotranspiration rate was recorded as 188.91 mm and 100.12 mm at mid-season and late season stage respectively.

4. **Plant Population:** There was not much difference in plant population in both the years but irrigation treatment and mulching methods significantly influenced the plant population. The plant population was recorded as 83.20, 80.60, 78.47 in year 2019 and 83.13, 79.47, 77.00 in year 2020 under irrigation level $I_1$ (1.0 ETc), $I_2$ (0.80 ETc) and $I_3$ (0.60 ETc) respectively. The black plastic mulch showed higher plant population (84.78) than straw mulch (80.22), soil mulch (79.22) and no mulch (76.33) whereas it was at par with silver plastic mulch (83.22) in the year 2019. In year 2020 also, black plastic mulch recorded a higher plant population (84.22) than straw mulch (77.33), soil mulch (78.67) and no mulch (77.22) whereas it was at par with silver plastic mulch.

   Interaction of irrigation and mulching did not showed significant effect on plant population in both the years but highest plant population was recorded in year 2020 in treatment $I_1M_1$ (1.0 ETc+ black plastic mulch) followed by treatment $I_2M_1$ (0.8 ETc + black plastic mulch) in year 2019. The no mulch treatment with 0.6 ETc irrigation shows lowest plant population in both the years. Highest plant population was observed due the good moisture under mulching treatment whereas lowest plant population was due to the more evaporation on the surface and less moisture availability.

5. **Plant height:** In the year 2019, maximum plant height (100.45 cm) was recorded in $I_2$ (0.8ETc) irrigation level which is significantly superior to irrigation level $I_1$

(95.57 cm) and $I_3$ (88.64 cm). Lowest height was measured in 0.6 ETc irrigation level, which is 11.75 per cent less than 0.8 ETc. In 2020, maximum plant height (105.04 cm) was recorded in $I_2$ (0.8ETc) irrigation level which is significantly superior to irrigation level $I_1$ (96.80 cm) and $I_3$ (92.92 cm). Lowest plant height (92.92 cm) was measured in $I_3$ (0.6 ETc) irrigation level, which is 11.53 per cent less than 0.8 ETc.

In year 2019, among the mulching treatment black plastic mulch ($M_1$) shows highest plant height (110.42 cm) and significantly different than silver plastic mulch ($M_2$), paddy straw mulch ($M_3$), soil mulch ($M_4$) and no mulch ($M_5$). In year 2020, black plastic mulch recorded maximum plant height (110.98 cm) which is 31 per cent more height compared to no mulch treatment (84.40 cm) and significantly different to each other. Straw mulch ($M_3$) recorded 98.33 cm plant height which was statistically significantly superior to soil mulch ($M_4$) and no mulch ($M_5$).

In year 2019, maximum plant height was recorded at 90 days in treatment $I_2M_1$ (115.13 cm) and lowest plant height recorded at 90 days in treatment $I_3M_5$ (73.67 cm). In year 2020 treatment $I_2M_1$ recorded maximum plant height (115.53 cm) and lowest plant height was recorded in treatment $I_3M_5$ (81.67 cm) at 90 days. Interaction effect of mulching and irrigation treatment did not showed any significant result on plant height but plastic mulch interacted with all irrigation levels showed good plant height. Significant reduction in plant height was recorded in no mulch interacted with all irrigation levels.

6. **Number of branches per plant:** In year 2019, the average number of branches were 1.77, 1.49, and 1.29 in irrigation treatment $I_2$ (0.8 ETc), $I_1$ (1.0 ETc) and $I_3$ (0.60 ETc) respectively and showed significantly different to each other. In 2020, irrigation level $I_2$, $I_3$ and $I_1$ showed the significantly influenced number of branches were 1.84, 1.39 and 1.36 respectively**.** In both the year, the irrigation level $I_2$ showed a significantly higher number of branches per plant compared to $I_1$ (1.0 ETc) and $I_3$ (0.6 ETc).

The mulching material also significantly influenced the number of branches. In 2019, black plastic mulch ($M_1$) recorded a higher mean number of branches (2.00) and significantly superior than silver mulch ($M_2$), straw mulch ($M_3$), soil mulch ($M_4$) and no mulch ($M_5$). Silver mulch, straw mulch and soil mulch had no significant effect on number of branches whereas no mulch showed significantly lower number of branches (0.93). In year 2020, silver plastic mulch recorded a higher number of branches (2.09) followed by black plastic mulch (2.02), but both the treatment were not statically significantly different to each other.

As per interaction effect in year 2019, the maximum number of branches per plant was recorded in treatment $I_2M_1$ (2.27) followed by treatment $I_1M_1$ (1.93). Lowest number of branches (0.60) per plant was recorded in no mulch treatment interacted with 0.6 ETc i.e $I_3M_5$. In year 2020, the maximum number of branches per plant was recorded in treatment $I_2M_2$ (2.53) followed by treatment $I_2M_1$ (2.13). The minimum number of branches per plant was observed in treatment $I_3M_5$. (0.8 number of branches per plant). The interaction effect of mulching and irrigation did not significantly influenced the number of branches, but the plastic mulch with the 0.8ETc treatment was superior compared to other treatment and no mulch treatment.

7. **Number of first flower emergence:** The irrigation effect showed the significant effect on first flower emergency for both the years. In year 2019, days required for flowering were 36.67, 36.00 and 39.73 days in irrigation level $I_1$ (1.0 ETc), $I_2$ (0.8 ETc) and $I_3$ (0.6 ETc) respectively whereas in year 2020, lowest days were 35.87, 35.88 and 37.93 in same treatment respectively. The lowest number of days required for first flower emergence was recorded in treatment $I_2$ i.e. 0.8ETc in both the year.

   In mulching treatments, black plastic mulch ($M_1$) treatment took lowest days (33.78 and 33.78) for first flower emergence in both years which was at par to silver plastic mulch (34.22 and 34.44) in both year. The plastic mulching showed a significant different with no mulch treatment for the first flower emergence.

The interaction of irrigation and mulching did not significantly influenced flowering stage of okra in both the years. Treatment $I_2M_1$ and $I_2M_2$ took lowest days (31.33 and 31.67) for first flowering in year 2019 and $I_1M_1$, $I_2M_1$ took 31.32 and 33.67 days in 2020 respectively and this was due to the proper conservation of moisture and favourable environmental for crop growth.

8. **Number of pods per plants:** In year 2019, the number of pods per plants were recorded as 17.11, 16.25, 14.84 in irrigation level $I_1$ (1.0 ETc), $I_2$ (0.80 ETc) and $I_3$ (0.60 ETc) and in 2020, the irrigation level $I_1$, $I_2$ and $I_3$ recorded 18.35, 17.29 and 15.20 pods per plants respectively. Irrigation levels $I_1$ recorded higher number of pods per plant (17.11 and 18.35) in both the years which was at par with irrigation level $I_2$ (16.25 and 17.29 respectively) whereas the irrigation level $I_3$ recorded significantly lowest number of pods per plant (14.84 and 15.02) in both the years.

In mulch treatment, data in year 2019 showed that the number of pods per plant were recorded as 18.13, 18.03, 15.39, 14.53 and 14.16 in black mulch ( $M_1$), silver mulch ($M_2$), straw mulch ($M_3$), soil mulch ($M_4$) and no mulch ($M_5$) respectively and in year 2020, the number of pods per plant recorded in treatment $M_1$, $M_2$, $M_3$,$M_4$ and $M_5$ was 18.70, 18.59, 16.02, 16.64 and 14.48 respectively. The number of pods per plant significantly responded to the mulch treatment. The highest number of pods per plant was recorded in black plastic mulch which was 28 and 29 per cent more than the no mulch treatment in year 2019 and 2020 respectively.

In year 2019, silver plastic mulch interacted with 1.0 ETc i.e treatment $I_1M_2$ shows higher number of pods (19.03) followed by treatment $I_2M_1$ whereas treatment $I_3M_5$ (non-mulch + 0.6 ETc) recorded the lowest pods per plant (12.77). In year 2020, treatment $I_1M_1$ recorded 19.77 pods per plant followed by treatment $I_1M_2$ (19.53) whereas treatment $I_3M_5$ recorded the lowest number of pods (12.13) per plant.

9. **Crop Yield (g/plant):** The irrigation $I_2$ recorded higher yield (216.59 g) per plant which is at par with $I_1$ (206.89 g) and statistically significant with $I_3$ (158.69) in year 2019. In the year 2020, the trend was similar i.e the yield of plants was $I_2$ (228.59 g) > $I_1$ (210.23 g) > $I_3$ (160.36 g) and shows significantly differ to each other.

   With respect to mulching effect, the plant yield (g/plant) recorded as 243.86, 234.42, 180.45, 170.01, 141.56 in year 2019 and 250.49, 242.32, 187.72, 173.33, 144.78 in year 2020 in $M_1$, $M_2$, $M_3$, $M_4$, $M_5$ respectively. Highest plant yield was recorded in black plastic mulch which was at par to silver mulch and lowest yield was observed in non-mulch treatment in both year. Straw mulch ($M_3$) and soil mulch ($M_4$) did not showed any significant difference to each other in both year.

   Interaction effect of irrigation and mulching significantly influenced plant yield in both year. In year 2019, maximum yield per plant (282.50 g) was recorded in treatment $I_2M_1$ which was at par to $I_2M_2$ (270.50 g) and lowest yield per plant was recorded in $I_3M_3$ (127.67 g). The trend was similar in the year 2020 also, the maximum yield was recorded in the treatment $I_2M_1$ > $I_2M_2$ (i.e 292.50 and 286.50) which were mulched with plastic sheet and the lowest yield was observed in $I_3M_3$ (121.33 gm).

10. **Crop yield t/ha**: The crop yield recorded in irrigation levels $I_1$ (1.0 ETc), $I_2$ (0.8 ETc), $I_3$ (0.6 ETc) was 15.59, 15.36, 13.25 and 16.10, 15.69, 13.95 in year 2019 and 2020 respectively. The irrigation levels significantly influenced the crop yield per hectare in both the year. The maximum crop yield was recoreded in irrigation level $I_1$ ( 15.59 and 16.10) which was at par to irrigation level $I_2$ (15.36 and 15.69) and significantly more than $I_3$ (13.25 and 13.95) in both the years. In year 2019, the okra yield recorded as 19.09, 19.01, 13.05, 11.31 and 11.21 t/ha in mulch treatments $M_1$ $M_2$, $M_3$, $M_4$ and $M_5$ respectively. The mulching treatment showed a significant effect on crop yield. The black plastic mulches recorded significantly higher yield than straw mulch, soil mulch, no mulch and at par with silver plastic

mulch. No mulch treatment recorded lowest yield which was 41.27 per cent less than black plastic mulch. In year 2020, the crop yield recorded as 18.83, 18.09, 14.32, 13.47 and 11.54 t/ha in mulching treatment $M_1$, $M_2$, $M_3$, $M_4$ and $M_5$ respectively. The mulching treatment significantly influenced the crop yield. In this year too, the black plastic mulches recorded a significantly higher yield than straw mulch, soil mulch, no mulch and at par with silver plastic mulch. No mulch ($M_5$) treatment recorded lowest yield which was 38.71 per cent less than black plastic mulch.

The interaction effect of irrigation and mulching did not showed significant effect on crop yield in 2019 but showed significant effect on crop yield in year 2020. Maximum crop yield (20.18 t/ha) was recorded in treatment $I_2M_2$ followed by $I_2M_1$ (19.82 t/ha) in year 2019. The lowest yield was recorded in $I_3M_5$ treatment (8.89) which was 126 per cent less than the black plastic mulch. Among the paddy straw and soil mulch interacted with irrigation, treatment $I_3M_3$ (11.44 t/ha) and $I_3M_4$ (9.80 t/ha) recorded lowest crop yield. In year 2020, the $I_2M_1$ (20.01 t/ha) showed maximum yield which was at par to treatment $I_2M_2$ (19.08 t/ha). The no mulch interacted with $I_3$ showed the lowest yield 10.15 t/ha which is 97 per cent lower than treatment $I_2M_1$. Among the paddy straw and soil mulch interacted with irrigation, treatment $I_3M_3$ (12.79 t/ha) and $I_3M_4$ (12.32 t/ha) recorded lowest crop yield.

11. **Water use efficiency (kg/ha-cm):** The water use efficiency (kg/ha-cm) in irrigation level $I_1$ (1.0 ETc), $I_2$ (0.8 ETc), $I_3$ (0.6 ETc) was recorded as 291.35, 358.66, 412.56 kg/ha-cm and 288.59, 351.58, 416.79 kg/ha-cm in year 2019 and 2020 respectively. In both the year, $I_3$ recorded higher WUE and significantly superior than $I_2$ and $I_1$ .The irrigation level significantly influenced WUE. Irrigation level $I_1$ and $I_2$ recorded 29.37 and 13.06 per cent lower WUE than irrigation level $I_3$ in year 2019 whereas it showed 30.75 and 15.64 per cent lower WUE than irrigation level $I_3$ in year 2020.

In the mulch effect, the black plastic mulch ($M_1$) recorded higher WUE (463.53 and 437.53 kg/ha-cm) which is at par with silver plastic mulch $M_2$ (460.53 and 419.87 kg/ha-cm) in year 2019 and 2020 respectively and significantly superior over non mulch treatment (264.27 and 263.61 Kg/ha-cm) respectively. Water use efficiency significantly responded to the mulching treatments. In both the year paddy straw mulch and soil mulch did not significantly different to each other.

The black plastic mulch ($M_1$) interacted with irrigation level $I_3$ resulted a higher WUE followed by silver plastic mulch. The treatments $I_3M_1$ (569.42 and 526.32) and $I_3M_2$ (555.27 and 504.31) showed a higher WUE compared to other treatment in both the years respectively. In year 2019, treatment $I_1M_4$ (230.64 kg/ha-cm) recorded the lowest WUE which was 59 per cent less than treatment $I_3M_1$. In year 2020, treatment $I_1M_5$ (242.84 kg/ha-cm), recorded the lowest WUE which was 53 per cent less than treatment $I_3M_2$. Interaction of irrigation and mulching methods showed significant effect on WUE. Though the interaction showed the significant effect on WUE but the paddy straw mulch and soil mulch interacted with irrigation and mulching did not significantly different over each other.

12. **Economics of drip irrigation:** Economic evaluation of drip irrigation along with mulching worked out for okra crop by considering the fixed cost, variable cost i.e. cost of cultivation and total marketable yield of okra. The cost of the drip system is considered as the fixed cost. The total cost (fixed cost +variable cost) determined for plastic mulch treatment was Rs. 129852, straw mulch treatment Rs. 93652, soil mulch Rs 94452, and no mulch Rs 89652 as shown in Appendix 9. Marketable rate was taken as Rs 25000 per ton. The gross return was estimated by product of crop yield and marketable rate of okra. Benefit cost ratio was estimated and summarized as below.

The B:C ratio at irrigation level $I_1$, $I_2$ and $I_3$ was recorded as 3.62, 3.53 and 3.02 respectively in year 2019 and 3.77, 3.63 and 3.23 respectively in year 2020. The irrigation treatment $I_1$ resulted in a maximum B:C ratio 3.62 which was at par with

$I_2$ (3.53) in year 2019 whereas in year 2020, $I_1$ resulted in maximum B:C ratio 3.77 and followed by irrigation level $I_2$ (3.63). Lowest B:C were observed in $I_3$ (3.02 and 3.23) in both the year. The irrigation levels significantly influenced the B:C ratio in both the years but irrigation levels $I_1$ (1.0ETc) and $I_2$ (0.8ETc) were not significantly different from each other in year 2019 but had the significant higher B:C ratio comparing to $I_3$ (0.6ETc) in both the year.

In year 2019, the B:C ratio recorded in mulch treatment black plastic mulch ($M_1$), silver plastic mulch ($M_2$), straw mulch ($M_3$), soil mulch ($M_4$) and no mulch ($M_5$) was 3.68, 3.66, 3.48, 2.99 and 3.13 respectively. In year 2020, the B:C ratio recorded in $M_1$, $M_2$, $M_3$, $M_4$ and $M_5$ was 3.63, 3.48, 3.82, 3.57 and 3.22 respectively. The mulching treatments showed the significant effect on B:C ratio in both the year. In year 2019, the highest B:C ratio was recorded in $M_1$ (3.68) and at par with $M_2$ (3.66), $M_3$ (3.48) and lowest B:C ratio was recorded in $M_4$ (2.99). In year 2020, maximum B:C ratio recorded in $M_3$ (3.82) followed by $M_1$ (3.63) and significant lowest B:C ratio (3.22) recorded in no mulch ($M_5$). Comparing between the paddy straw mulch ($M_3$) and soil mulch ($M_4$); paddy straw mulch had the maximum B:C ratio (3.48 and 3.82) in years 2019 and 2020.

The Interaction effect of irrigation level and mulching did not showed significant effect on B:C ratio in year 2019 but showed significant effect in year 2020. Paddy straw mulch interacted with irrigation level recorded the significant higher B:C ratio compared with all the treatment.

**Conclusion:** Based on the results obtained during the two year study on response of okra crop to irrigation level and mulching methods, following points can be concluded.

1. Soil moisture distribution pattern is good near the dripper and vertical downward movement is more compared to the horizontal movement of water. The lateral placed at 20 cm depth, does not provide the sufficient moisture near to the 5-10 cm below from the ground surface.
2. Maximum crop evapotranspiration (ETc) was found in the month of July and August during the study year respectively and this may be due to higher temperature and crop coefficient.
3. Black plastic mulch gives superior results compared to other mulching treatments with respect to growth and yield parameters of okra and this due to moisture conservation characteristic of plastic mulch.
4. Soil mulch (20 cm depth lateral) does not show any significant effect on response of okra to irrigation because there was less upward vertical movement of water and greater evaporation rate on ground surface.
5. Higher yield and average B:C ratio was observed in plastic mulch with 0.8 crop evapotranspiration irrigation level.
6. Black plastic mulch and silver plastic mulch showed higher water use efficiency interacted with 0.8ETc irrigation level.

From the above, it was concluded that the okra crop responded better to black plastic mulch interacted with 0.8 crop evapotranspiration in terms of growth and yield.

**Recommendations:** From the above results, following recommendations are suggested.

1. Farmers should try black plastic mulch with 0.8 ETc irrigation for better yield of okra or other vegetable.
2. In case of subsurface drip irrigation for vegetable crop, depth of placement of lateral is suggested at 15 cm instead of 20 cm for better moisture conservation near to the root zone.
3. Where plastic mulch is not possible from economic point of view, straw mulch is good option in place of non-mulch planting method.
4. Further studies needed on the soil temperature, microbial activity and irrigation levels at different mulching methods.

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*Originally not seen

## APPENDICES

### Appendix 1 Standard meteorological week data in year 2019

| SMW | Temp max ( $^0$C) | Temp min ($^0$C) | Humidity (%) | Wind speed (km/hr) | Sunshine (hrs) | Radiation | Rainfall (mm) | $ET_0$ | Total $ET_0$ |
|---|---|---|---|---|---|---|---|---|---|
| 14 | 38 | 24 | 25 | 9 | 12 | 26 | 1.0 | 4.16 | 29.14 |
| 15 | 38 | 25 | 20 | 12 | 12 | 27 | 0.0 | 4.31 | 30.14 |
| 16 | 33 | 23 | 37 | 11 | 13 | 28 | 6.0 | 4.67 | 32.70 |
| 17 | 42 | 28 | 14 | 13 | 13 | 29 | 0.0 | 4.57 | 32.00 |
| 18 | 41 | 28 | 12 | 15 | 13 | 29 | 1.0 | 4.61 | 32.26 |
| 19 | 41 | 29 | 13 | 11 | 13 | 30 | 1.0 | 4.67 | 32.69 |
| 20 | 38 | 28 | 25 | 11 | 13 | 30 | 1.0 | 5.30 | 37.09 |
| 21 | 40 | 30 | 19 | 10 | 13 | 30 | 2.0 | 5.16 | 36.11 |
| 22 | 46 | 33 | 13 | 14 | 14 | 31 | 0.0 | 5.31 | 37.20 |
| 23 | 46 | 34 | 12 | 13 | 14 | 31 | 0.0 | 5.28 | 36.98 |
| 24 | 45 | 32 | 16 | 15 | 14 | 31 | 1.0 | 5.49 | 38.46 |
| 25 | 42 | 31 | 30 | 9 | 14 | 31 | 1.0 | 6.02 | 42.17 |
| 26 | 45 | 34 | 22 | 11 | 14 | 31 | 0.0 | 5.90 | 41.27 |
| 27 | 45 | 34 | 28 | 10 | 14 | 31 | 1.0 | 6.24 | 43.66 |
| 28 | 40 | 29 | 54 | 13 | 14 | 31 | 16.0 | 6.65 | 46.55 |
| 29 | 37 | 28 | 55 | 11 | 14 | 31 | 3.0 | 6.32 | 44.26 |
| 30 | 36 | 28 | 57 | 11 | 14 | 30 | 9.0 | 6.12 | 42.81 |

**Appendix 2 Standard meteorological week data in year 2020**

| SMW | Temp max ( $^0$C) | Temp min ($^0$C) | Humidity (%) | Wind speed (km/hr) | Sunshine (hrs) | Radiation | Rainfall (mm) | $ET_0$ | Total $ET_0$ |
|---|---|---|---|---|---|---|---|---|---|
| 22 | 28 | 38 | 36 | 9 | 14 | 31 | 1.9 | 5.87 | 17.61 |
| 23 | 30 | 40 | 32 | 12 | 14 | 31 | 1.4 | 5.93 | 41.53 |
| 24 | 34 | 46 | 17 | 11 | 14 | 31 | 0.0 | 5.67 | 39.71 |
| 25 | 32 | 46 | 25 | 12 | 14 | 31 | 0.3 | 6.10 | 42.71 |
| 26 | 33 | 44 | 31 | 11 | 14 | 31 | 1.8 | 6.33 | 44.33 |
| 27 | 32 | 44 | 34 | 13 | 15 | 32 | 0.3 | 6.42 | 44.94 |
| 28 | 32 | 42 | 40 | 9 | 14 | 31 | 1.1 | 6.45 | 45.12 |
| 29 | 29 | 38 | 50 | 10 | 14 | 31 | 6.3 | 6.26 | 43.85 |
| 30 | 30 | 40 | 46 | 8 | 14 | 30 | 1.5 | 6.33 | 44.31 |
| 31 | 28 | 40 | 57 | 10 | 14 | 30 | 5.6 | 6.31 | 44.14 |
| 32 | 29 | 38 | 60 | 9 | 13 | 29 | 5.6 | 6.14 | 42.95 |
| 33 | 27 | 37 | 68 | 11 | 13 | 28 | 7.0 | 6.02 | 42.12 |
| 34 | 26 | 34 | 69 | 10 | 13 | 28 | 4.9 | 5.72 | 40.01 |
| 35 | 26 | 35 | 68 | 9 | 13 | 27 | 4.9 | 5.50 | 27.49 |
| 36 | 27 | 36 | 71 | 8 | 12 | 26 | 1.3 | 5.30 | 37.08 |
| 37 | 28 | 39 | 46 | 8 | 12 | 25 | 0.0 | 4.71 | 32.97 |

**Appendix 3 Anova table of growth parameter 2019**

| Source of Variation | DF | SS | MSS | $F_{Cal}$ | $F_{Tab}$ (5%) | Sig |
|---|---|---|---|---|---|---|
| **1. Plant population** | | | | | | |
| Replication | 2 | 0.311 | 0.156 | 0.022 | 6.944 | 0.978 |
| Irrigation levels (I) | 2 | 168.578 | 84.289 | 8.139 | 6.944 | 0.000 |
| Error (a) | 4 | 41.422 | 10.356 | | | 0.239 |
| Mulching methods (M) | 4 | 400.089 | 100.022 | 14.323 | 2.776 | 0.000 |
| I x M | 8 | 46.311 | 5.789 | 0.829 | 2.355 | 0.586 |
| Error (b) | 24 | 167.600 | 6.983 | | | |
| Total | 44 | 824.311 | | | | |
| **2. Plant height 90 days** | | | | | | |
| Replication | 2 | 104.455 | 52.228 | 1.692 | 6.944 | 0.205 |
| Irrigation levels (I) | 2 | 1057.202 | 528.601 | 7.205 | 6.944 | 0.000 |
| Error (a) | 4 | 293.476 | 73.369 | | | 0.080 |
| Mulching methods (M) | 4 | 5271.173 | 1317.793 | 42.699 | 2.776 | 0.000 |
| I x M | 8 | 373.776 | 46.722 | 1.514 | 2.355 | 0.204 |
| Error (b) | 24 | 740.683 | 30.862 | | | |
| Total | 44 | 7840.764 | | | | |
| **3. Number of branches per plant** | | | | | | |
| Replication | 2 | 0.325 | 0.163 | 2.205 | 6.944 | 0.205 |
| Irrigation levels (I) | 2 | 1.744 | 0.872 | 20.438 | 6.944 | 0.000 |
| Error (a) | 4 | 0.171 | 0.043 | | | 0.080 |
| Mulching methods (M) | 4 | 5.285 | 1.321 | 17.909 | 2.776 | 0.000 |
| I x M | 8 | 0.256 | 0.032 | 0.434 | 2.355 | 0.204 |
| Error (b) | 24 | 1.771 | 0.074 | | | |
| Total | 44 | 9.552 | | | | |
| **4. Days of first flower** | | | | | | |
| Replication | 2 | 8.844 | 4.422 | 1.331 | 6.944 | 0.283 |
| Irrigation levels (I) | 2 | 116.044 | 58.022 | 8.674 | 6.944 | 0.000 |
| Error (a) | 4 | 26.756 | 6.689 | | | 0.125 |
| Mulching methods (M) | 4 | 506.578 | 126.644 | 38.120 | 2.776 | 0.000 |
| I x M | 8 | 45.289 | 5.661 | 1.704 | 2.355 | 0.149 |
| Error (b) | 24 | 79.733 | 3.322 | | | |
| Total | 44 | 783.2444 | | | | |

**Appendix 4 Anova table of growth parameter 2020**

| Source of Variation | DF | SS | MSS | $F_{Cal}$ | $F_{Tab}$ (5%) | Sig. |
|---|---|---|---|---|---|---|
| **1. Plant population** | | | | | | |
| Replication | 2 | 10.133 | 5.067 | 0.291 | 6.944 | 0.750 |
| Irrigation levels (I) | 2 | 285.733 | 142.867 | 32.969 | 6.944 | 0.002 |
| Error (a) | 4 | 17.333 | 4.333 | | | |
| Mulching methods (M) | 4 | 341.200 | 85.300 | 4.907 | 2.776 | 0.005 |
| I x M | 8 | 63.600 | 7.950 | 0.457 | 2.355 | 0.874 |
| Error (b) | 24 | 417.200 | 17.383 | | | |
| Total | 44 | 1135.200 | | | | |
| **2. Plant height 90 days** | | | | | | |
| Replication | 2 | 95.536 | 47.768 | 2.593 | 6.944 | 0.096 |
| Irrigation levels (I) | 2 | 1149.232 | 574.616 | 14.263 | 6.944 | 0.000 |
| Error (a) | 4 | 161.152 | 40.288 | | | 0.101 |
| Mulching methods (M) | 4 | 4432.788 | 1108.197 | 60.151 | 2.776 | 0.000 |
| I x M | 8 | 197.639 | 24.705 | 1.341 | 2.355 | 0.272 |
| Error (b) | 24 | 442.165 | 18.424 | | | |
| Total | 44 | 6478.512 | | | | |
| **3. Number of branches per plant** | | | | | | |
| Replication | 2 | 0.108 | 0.054 | 0.726 | 6.944 | 0.494 |
| Irrigation levels (I) | 2 | 2.183 | 1.092 | 9.233 | 6.944 | 0.000 |
| Error (a) | 4 | 0.473 | 0.118 | | | 0.211 |
| Mulching methods (M) | 4 | 10.270 | 2.568 | 34.387 | 2.776 | 0.000 |
| I x M | 8 | 0.626 | 0.078 | 1.048 | 2.355 | 0.430 |
| Error (b) | 24 | 1.792 | 0.075 | | | |
| Total | 44 | 15.452 | | | | |
| **4. Days of first flowering** | | | | | | |
| Replication | 2 | 20.800 | 10.400 | 6.455 | 6.944 | 0.494 |
| Irrigation levels (I) | 2 | 44.133 | 22.066 | 8.945 | 6.944 | 0.000 |
| Error (a) | 4 | 9.867 | 2.467 | | | 0.211 |
| Mulching methods (M) | 4 | 251.867 | 62.967 | 39.083 | 2.776 | 0.000 |
| I x M | 8 | 17.867 | 2.233 | 1.386 | 2.355 | 0.429 |
| Error (b) | 24 | 38.667 | 1.611 | | | |
| Total | 44 | 383.200 | | | | |

**Appendix 5 Anova table of yield parameter 2019**

| Source of Variation | DF | SS | MSS | $F_{Cal}$ | $F_{Tab}$ (5%) | Sig |
|---|---|---|---|---|---|---|
| **1. Number of pods per plant** | | | | | | |
| Replication | 2 | 1.568 | 0.784 | 0.258 | 6.944 | 0.775 |
| Irrigation levels (I) | 2 | 39.526 | 19.763 | 9.605 | 6.944 | 0.006 |
| Error (a) | 4 | 8.230 | 2.058 | | | 0.615 |
| Mulching methods (M) | 4 | 135.225 | 33.806 | 11.110 | 2.776 | 0.000 |
| I x M | 8 | 5.259 | 0.657 | 0.216 | 2.355 | 0.985 |
| Error (b) | 24 | 73.028 | 3.043 | | | |
| Total | 44 | 262.836 | | | | |
| **2. Yield per plant** | | | | | | |
| Replication | 2 | 188.764 | 94.382 | 0.209 | 6.944 | 0.812 |
| Irrigation levels (I) | 2 | 28844.910 | 14422.45 | 58.778 | 6.944 | 0.000 |
| Error (a) | 4 | 981.489 | 245.372 | | | 0.704 |
| Mulching methods (M) | 4 | 68662.640 | 17165.66 | 38.145 | 2.776 | 0.000 |
| I x M | 8 | 14850.410 | 1856.301 | 4.125 | 2.355 | 0.003 |
| Error (b) | 24 | 10800.150 | 450.006 | | | |
| Total | 44 | 124328.400 | | | | |
| **3. Crop yield** | | | | | | |
| Replication | 2 | 3.454 | 1.726 | 0.615 | 6.944 | 0.548 |
| Irrigation levels (I) | 2 | 50.031 | 25.016 | 13.289 | 6.944 | 0.001 |
| Error (a) | 4 | 7.529 | 1.882 | | | 0.618 |
| Mulching methods (M) | 4 | 578.392 | 144.598 | 51.502 | 2.776 | 0.000 |
| I x M | 8 | 13.566 | 1.696 | 0.604 | 2.355 | 0.766 |
| Error (b) | 24 | 67.383 | 2.808 | | | |
| Total | 44 | 720.356 | | | | |
| **4. Water use efficiency** | | | | | | |
| Replication | 2 | 1397.164 | 698.582 | 0.339 | 6.944 | 0.715 |
| Irrigation levels (I) | 2 | 110637.400 | 55318.68 | 48.259 | 6.944 | 0.000 |
| Error (a) | 4 | 4585.091 | 1146.273 | | | 0.695 |
| Mulching methods (M) | 4 | 361224 | 90306 | 43.926 | 2.776 | 0.000 |
| I x M | 8 | 39009.850 | 4876.231 | 2.372 | 2.355 | 0.049 |
| Error (b) | 24 | 49341.09 | 2055.879 | | | |
| Total | 44 | 566194.6 | | | | |

**Appendix 6 Anova table of yield parameter 2020**

| Source of Variation | DF | SS | MSS | $F_{Cal}$ | $F_{Tab}$ (5%) | Sig. |
|---|---|---|---|---|---|---|
| **1. Number of pods per plants** | | | | | | |
| Replication | 2 | 3.811 | 1.906 | 0.783 | 6.944 | 0.469 |
| Irrigation levels (I) | 2 | 86.663 | 43.331 | 39.44 | 6.944 | 0.000 |
| Error (a) | 4 | 4.395 | 1.099 | | | 0.771 |
| Mulching methods (M) | 4 | 115.16 | 28.79 | 11.818 | 2.776 | 0.000 |
| I x M | 8 | 4.945 | 0.612 | 0.254 | 2.355 | 0.975 |
| Error (b) | 24 | 58.466 | 2.436 | | | |
| Total | 44 | 273.440 | | | | |
| **2. Yield per plant** | | | | | | |
| Replication | 2 | 477.532 | 238.766 | 0.573 | 6.944 | 0.571 |
| Irrigation levels (I) | 2 | 37397.250 | 18698.625 | 221.830 | 6.944 | 0.000 |
| Error (a) | 4 | 337.170 | 84.292 | | | 0.935 |
| Mulching methods (M) | 4 | 74257.462 | 18564.365 | 44.540 | 2.776 | 0.000 |
| I x M | 8 | 9954.860 | 1244.358 | 2.985 | 2.355 | 0.018 |
| Error (b) | 24 | 10003.307 | 416.804 | | | |
| Total | 44 | 132427.581 | | | | |
| **3. Crop yield** | | | | | | |
| Replication | 2 | 0.198 | 0.099 | 0.136 | 6.944 | 0.873 |
| Irrigation levels (I) | 2 | 39.074 | 19.537 | 12.743 | 6.944 | 0.000 |
| Error (a) | 4 | 6.133 | 1.533 | | | 0.110 |
| Mulching methods (M) | 4 | 347.653 | 86.913 | 119.762 | 2.776 | 0.000 |
| I x M | 8 | 14.468 | 1.808 | 2.492 | 2.355 | 0.040 |
| Error (b) | 24 | 17.417 | 0.726 | | | |
| Total | 44 | 424.942 | | | | |
| **4. Water use efficiency** | | | | | | |
| Replication | 2 | 151.712 | 75.856 | 0.188 | 6.944 | 0.830 |
| Irrigation levels (I) | 2 | 123271.661 | 61635.830 | 100.908 | 6.944 | 0.000 |
| Error (a) | 4 | 2443.240 | 610.810 | | | 0.231 |
| Mulching methods (M) | 4 | 197349.571 | 49337.393 | 121.957 | 2.776 | 0.000 |
| I x M | 8 | 19889.622 | 2486.203 | 6.146 | 2.355 | 0.000 |
| Error (b) | 24 | 9709.154 | 404.548 | | | |
| Total | 44 | 352814.961 | | | | |

## Appendix 7 Irrigation water and irrigation time (minutes/ decade) for the year 2019

| Month | Decade | $ET_0$ (mm/decade) | ETc (mm/decade) | Effective rainfall (mm/decade) | Net water requirement (mm/decade) | Irrigation water, liters/decade | | | Irrigation time, min/decade | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | $I_1$ (1.00ETc) | $I_2$ (0.8ETc) | $I_3$ (0.6ETc) | $T_1$ (1.00ETc) | $T_2$ (0.8ETc) | $T_3$ (0.6ETc) |
| **April** | 2nd* | 40.79 | 28.55 | 31.52 | -2.97 | -17.80 | -14.24 | -10.68 | -9.71 | -7.77 | -5.83 |
| | 3rd | 46.12 | 32.28 | 0.00 | 32.28 | 193.70 | 154.96 | 116.22 | 105.66 | 84.53 | 63.39 |
| **May** | 1st | 45.19 | 32.19 | 5.12 | 27.08 | 162.48 | 129.98 | 97.49 | 88.62 | 70.90 | 53.18 |
| | 2nd | 52.26 | 43.37 | 4.00 | 39.38 | 236.26 | 189.00 | 141.75 | 128.87 | 103.09 | 77.32 |
| | 3rd^ | 55.96 | 46.45 | 12.00 | 34.45 | 206.68 | 165.34 | 124.01 | 112.74 | 90.19 | 67.64 |
| **June** | 1st | 54.33 | 46.97 | 0.00 | 46.97 | 281.82 | 225.45 | 169.09 | 153.72 | 122.98 | 92.23 |
| | 2nd | 56.57 | 57.14 | 0.00 | 57.14 | 342.81 | 274.25 | 205.69 | 186.99 | 149.59 | 112.20 |
| | 3rd | 59.40 | 59.99 | 3.20 | 56.79 | 340.76 | 272.61 | 204.46 | 185.87 | 148.70 | 111.52 |
| **July** | 1st | 63.02 | 63.45 | 0.00 | 63.45 | 380.68 | 304.55 | 228.41 | 207.65 | 166.12 | 124.59 |
| | 2nd | 64.51 | 63.21 | 72.80 | -9.66 | -57.96 | -46.37 | -34.78 | -31.62 | -25.29 | -18.96 |
| | 3rd^ | 62.96 | 61.71 | 48.24 | 13.46 | 80.77 | 64.61 | 48.46 | 44.05 | 35.24 | 26.43 |
| **Total** | | **601.11** | **535.33** | **176.88** | **358.37** | **2150.20** | **1720.16** | **1290.12** | **1172.84** | **938.27** | **703.70** |
| *Nine days in the month of April as sowing date was 12 April | | | | | | | | | | | |
| ^one extra day in third decade of month May and July | | | | | | | | | | | |
| Average discharge per emitters = 3.34 lit/hr, Bed size = 6 $m^2$ Irrigation water ( liters ) = Net water requirement * bed size | | | | | | | | | | | |

## Appendix 8 Irrigation water and irrigation time (minutes/ decade) for the year 2020

| Month | Decade | $ET_0$ (mm/decade) | ETc (mm/decade) | Effective rainfall (mm/decade) | Net water requirement (mm/decade) | Irrigation water, liters/decade | | | Irrigation time, min/decade | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | $I_1$ (1.00ETc) | $I_2$ (0.8ETc) | $I_3$ (0.6ETc) | $T_1$ (1.00ETc) | $T_2$ (0.8ETc) | $T_3$ (0.6ETc) |
| June | 1st | 59.14 | 41.40 | 11.04 | 30.36 | 182.15 | 145.72 | 109.29 | 99.35 | 79.48 | 59.61 |
| | 2nd | 57.26 | 40.08 | 0.00 | 40.08 | 240.49 | 192.39 | 144.30 | 131.18 | 104.94 | 78.71 |
| | 3rd | 63.02 | 45.77 | 6.72 | 39.05 | 234.30 | 187.44 | 140.58 | 127.80 | 102.24 | 76.68 |
| July | 1st | 64.54 | 53.57 | 1.12 | 52.45 | 314.69 | 251.75 | 188.81 | 171.65 | 137.32 | 102.99 |
| | 2nd | 63.69 | 52.86 | 25.20 | 27.66 | 165.98 | 132.78 | 99.59 | 90.53 | 72.43 | 54.32 |
| | 3rd^ | 69.44 | 61.18 | 35.36 | 25.82 | 154.94 | 123.95 | 92.96 | 84.51 | 67.61 | 50.71 |
| Aug | 1st | 61.69 | 62.31 | 16.80 | 45.51 | 273.04 | 218.43 | 163.82 | 148.93 | 119.15 | 89.36 |
| | 2nd | 60.24 | 60.84 | 67.92 | -7.08 | -42.47 | -33.97 | -25.48 | -23.16 | -18.53 | -13.90 |
| | 3rd^ | 61.80 | 61.93 | 32.80 | 29.13 | 174.76 | 139.80 | 104.85 | 95.32 | 76.26 | 57.19 |
| Sept | 1st | 53.20 | 52.14 | 5.36 | 46.78 | 280.66 | 224.52 | 168.39 | 153.09 | 122.47 | 91.85 |
| | 2nd* | 32.56 | 31.91 | 0.00 | 31.91 | 191.45 | 153.16 | 114.87 | 104.43 | 83.54 | 62.66 |
| Total | | **646.58** | **563.98** | **202.32** | **361.66** | **2169.99** | **1735.99** | **1301.99** | **1183.63** | **946.90** | **710.18** |
| *seven days in the second decade of month September | | | | | | | | | | | |
| ^one extra day in third decade of month July and August | | | | | | | | | | | |
| Average discharge per emitters = 3.34 lit/hr, Bed size = 6 $m^2$ Irrigation water ( liters ) = Net water requirement * bed size | | | | | | | | | | | |

## Appendix 9 Treatment wise expenditure (Rs/ha)

| Particular | Treatments | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $I_1M_1$ | $I_1M_2$ | $I_1M_3$ | $I_1M_4$ | $I_1M_5$ | $I_2M_1$ | $I_2M_2$ | $I_2M_3$ | $I_2M_4$ | $I_2M_5$ | $I_3M_1$ | $I_3M_2$ | $I_3M_3$ | $I_3M_4$ | $I_3M_5$ |
| **A) Total fixed cost (Rs/ha)** | 24472 | 24472 | 24472 | 24472 | 24472 | 24472 | 24472 | 24472 | 24472 | 24472 | 24472 | 24472 | 24472 | 24472 | 24472 |
| **B) Total variable cost ( a + b + c)** | | | | | | | | | | | | | | | |
| **a) Inputs** | | | | | | | | | | | | | | | |
| **Seed (kg/ha)** | 9600 | 9600 | 9600 | 9600 | 9600 | 9600 | 9600 | 9600 | 9600 | 9600 | 9600 | 9600 | 9600 | 9600 | 9600 |
| **Fertilizer ( kg/ha)** | 5530 | 5530 | 5530 | 5530 | 5530 | 5530 | 5530 | 5530 | 5530 | 5530 | 5530 | 5530 | 5530 | 5530 | 5530 |
| **Plant protection** | 1750 | 1750 | 1750 | 1750 | 1750 | 1750 | 1750 | 1750 | 1750 | 1750 | 1750 | 1750 | 1750 | 1750 | 1750 |
| **Plastic mulch** | 45000 | 45000 | 2500 | | | 45000 | 45000 | 2500 | | | 45000 | 45000 | 2500 | | |
| b) **Land preparation** | | | | | | | | | | | | | | | |
| **Ploughing** | 2550 | 2550 | 2550 | 2550 | 2550 | 2550 | 2550 | 2550 | 2550 | 2550 | 2550 | 2550 | 2550 | 2550 | 2550 |
| **Harrowing** | 2550 | 2550 | 2550 | 2550 | 2550 | 2550 | 2550 | 2550 | 2550 | 2550 | 2550 | 2550 | 2550 | 2550 | 2550 |
| **Bed preparation** | 4800 | 4800 | 4800 | 4800 | 4800 | 4800 | 4800 | 4800 | 4800 | 4800 | 4800 | 4800 | 4800 | 4800 | 4800 |
| **Trench preparation** | | | | 4800 | | | | | 4800 | | | | | 4800 | |
| **c) Labor requirement** | | | | | | | | | | | | | | | |
| **Mulch spreading** | 4800 | 4800 | 1500 | | | 4800 | 4800 | 1500 | | | 4800 | 4800 | 1500 | | |
| **Sowing** | 3840 | 3840 | 3840 | 3840 | 3840 | 3840 | 3840 | 3840 | 3840 | 3840 | 3840 | 3840 | 3840 | 3840 | 3840 |
| **Weeding** | | | 9600 | 9600 | 9600 | | | 9600 | 9600 | 9600 | | | 9600 | 9600 | 9600 |
| **Plant protection** | 960 | 960 | 960 | 960 | 960 | 960 | 960 | 960 | 960 | 960 | 960 | 960 | 960 | 960 | 960 |
| **Harvesting** | 24000 | 24000 | 24000 | 24000 | 24000 | 24000 | 24000 | 24000 | 24000 | 24000 | 24000 | 24000 | 24000 | 24000 | 24000 |
| **Total variable cost ( a + b + c)** | 105380 | 105380 | 69180 | 69980 | 65180 | 105380 | 105380 | 69180 | 69980 | 65180 | 105380 | 105380 | 69180 | 69980 | 65180 |
| **Total cost of cultivation ( A+B)** | **129852** | **129852** | **93652** | **94452** | **89652** | **129852** | **129852** | **93652** | **94452** | **89652** | **129852** | **129852** | **93652** | **94452** | **89652** |

**Appendix 10 Anova table of benefit-cost ratio for 2019 and 2020**

| Source of Variation | DF | SS | MSS | $F_{Cal}$ | $F_{Tab}$ (5%) | Sig |
|---|---|---|---|---|---|---|
| **1. Benefit cost ratio 2019** | | | | | | |
| Replication | 2 | 0.187 | 0.093 | 0.694 | 6.944 | 0.511 |
| Irrigation levels (I) | 2 | 3.175 | 1.588 | 16.042 | 6.944 | 0.000 |
| Error (a) | 4 | 0.396 | 0.099 | | | 0.571 |
| Mulching methods (M) | 4 | 3.510 | 0.878 | 6.519 | 2.776 | 0.001 |
| I x M | 8 | 1.127 | 0.141 | 1.046 | 2.355 | 0.430 |
| Error (b) | 24 | 3.230 | 0.135 | | | |
| Total | 44 | 11.625 | | | | |
| **2. Benefit cost ratio 2020** | | | | | | |
| Replication | 2 | 0.002 | 0.001 | 0.031 | 6.944 | 0.974 |
| Irrigation levels (I) | 2 | 2.359 | 1.179 | 11.190 | 6.944 | 0.000 |
| Error (a) | 4 | 0.422 | 0.105 | | | 0.056 |
| Mulching methods (M) | 4 | 1.746 | 0.436 | 11.152 | 2.776 | 0.000 |
| I x M | 8 | 1.025 | 0.128 | 3.274 | 2.355 | 0.013 |
| Error (b) | 24 | 0.939 | 0.039 | | | |
| Total | 44 | 6.493 | | | | |