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Impact of different levels of irrigation and mulches on yield of tomato, water use efficiency, weed density and soil moisture percentage in Northern dry zone of Karnataka

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Abstract
Field experiment was conducted at Vegetable block of College of Horticulture, Bagalkote, University of Horticultural Sciences, Bagalkote to study the effect of different levels of irrigation and mulches on growth and yield of tomato. The experiment with 12 treatment combinations was laid out in split plot design with three replications. Main plot constitutes four irrigation levels (I_1: 100%, I_2: 80%, I_3: 60% and I_4: 40% cumulative pan evapotranspiration) and subplot comprised of three levels of mulches (M_1: Without mulch, M_2: Sugarcane mulch and M_3: Polythene mulch). Irrigation was given based on cumulative pan evapotranspiration following alternate day irrigation schedule using drip irrigation. The treatment combination receiving drip irrigation at 80 per cent CPE along with polythene mulch (I_2M_3) was recorded with highest fruit yield per plant (2.74 kg), yield per plot (60.90 kg) and yield per hectare (51.83 t/ha). The same treatment combination was noticed with highest benefit cost ratio of 3.23. Whereas, highest water use efficiency was noticed under individual treatments of drip irrigation (I_4) provided at 40 per cent CPE (255.44 kg $ha^{-1}mm^{-1}$) and under polythene mulch (204.03 kg $ha^{-1}mm^{-1}$). The highest soil moisture content was observed under the treatment combination with drip irrigation at 100 per cent CPE under polythene mulch (I_2M_3) at 30 and 60 DAT, whereas, at 90 DAT it was highest under I_2M_3. However, lowest weed density was noticed under all the four irrigation levels in combination with polythene mulch at all the monthly intervals.

Keywords: Drip irrigation, cumulative pan evaporation, water use efficiency, yield, soil moisture percentage, weed density and polythene mulch

Introduction
Now a days, human race is witnessing the rapid decline in the irrigation water and increased demand for fresh water from various sectors. In that context, drip irrigation is one such technology that has been introduced to reduce the quantum of water consumption in agriculture sector. It is an efficient irrigation system where water is applied directly to the root zone in some small and frequent intervals which results in substantial reduction in total consumption of water. Drip irrigation is the most effective form of watering the plants (Gonzalez-Cebellada, 2015) [12]. It is more efficient because it uses 40 per cent less water than conventional irrigation methods. As the water is directed only to the root zone, there is considerable control over weed growth and subsequent reduction in engaging labour in weeding and intercultural operations. Drip irrigation, considered as the most potential approach, has created interest among off season vegetable growers because of less consumption of irrigation water, increased water use efficiency, reduced tillage requirement, higher quality products, increased crop yield and higher fertilizer use efficiency.
To combat the problems of water scarcity, mulching has been emerged as potential management practice to maintain favourable soil moisture and temperature at crop root zone. The major portion of water is lost from the soil profile through evaporation, percolation and transpiration. Percolation can be regulated by watering required depth of root zone. Evaporation can be minimized by way of mulching. The microclimatic conditions of soil underneath the mulch are favourably affected by optimum soil moisture level that help in the reducing evaporation and increasing infiltration rate of water (Khurshid *et al*., 2006) [17]..

Mulching operation favours the suppression of weed seed germination and its growth. Hence, it keeps the weed under control Due to the absorption of short wavelength radiations, plastic mulch gets heated which inturn raises the soil temperature by 6 ˚C by conduction. This beneficial effect of polythene mulch induces early harvest and higher yield in tomato and pepper (Hutton and Handley, 2007) [14].

The combination of drip irrigation and plastic mulch has been proven to be best. Under drip irrigation, wetted portion of soil is maintained in continuously moist (though unsaturated hence provide aeration) state and soil volume is never allowed to deplete or to approach wilting point. Along with drip, the use of mulch facilitates in conserving soil moisture in the root zone will further enhance the WUE.

Further, mulching provides the additional benefits like prevention of soil crust formation caused by rain drop splashing and reduction of the surface run off over soil. Thus water and soil erosion are minimized. Because of these properties, mulching retains the best soil structure for crop growth. Tomato is day neutral crop and less tolerant to shade conditions. Crop being tap rooted is moderate in its water requirement.

The crop is less hardy and performs well even under less irrigated condition. The unscientific use of water has negative effects on crop growth, deleterious effect on microorganisms and it also leads to more runoff of water.

Water is limiting factor in this zone. For this effective utilization of water and mulches is necessary to avoid runoff and to conserve soil. However, under this situation use of drip irrigation with different kinds of mulches will definitely lead to increased access to water use efficiency which leads to higher crop growth, yield and quality produce. Hence, the present investigation was conducted with this purpose.

Material and Methods

The present investigation entitled "Studies on different levels of irrigation and mulches on growth and yield of tomato (*Solanum lycoperscicum* L.) in northern dry zone of Karnataka" was carried out at Vegetable block of College of Horticulture, Bagalkote, University of Horticultural Sciences, Bagalkote during the *Rabi* season 2019-2020.

The experimental plot was thoroughly ploughed with disc plough and tilled to fine soil tilth. Raised beds of one meter width and 15-20 cm height were laid with two rows of planting. Each bed was provided with two drip laterals with discharge holes distanced at 40 cm. The four irrigation levels assigned in main plot of size is 9.6 m × 3.6 m and subplots comprising of three mulch treatments of size 3.2 m × 3.6 m. Public sector hybrid Arka Rakshak seeds were sown in portrays to raise seedlings and 30 days old seedlings were transplanted into main field.

Design and treatment details

The experiment was laid in split plot design with four levels of irrigation in main plot and three levels of mulches in sub plots together forming 12 combinations replicated thrice.

Irrigation (I): I_1 = Drip irrigation at 100 per cent cumulative pan evaporation
I_2 = Drip irrigation at 80 per cent cumulative pan evaporation
I_3 = Drip irrigation at 60 per cent cumulative pan evaporation
I_4 = Drip irrigation at 40 per cent cumulative pan evaporation

Mulch (M): M_1 = Without mulch
M_2 = Sugarcane mulch
M_3 = Polythene mulch

Treatment combinations

$I_1 M_1$	Drip irrigation at 100 per cent cumulative pan evaporation under without mulch
I_1M_2	Drip irrigation at 100 per cent cumulative pan evaporation under sugarcane mulch
I_1M_3	Drip irrigation at 100 per cent cumulative pan evaporation under polythene mulch
I_2M_1	Drip irrigation at 80 per cent cumulative pan evaporation under without mulch
I_2M_2	Drip irrigation at 80 per cent cumulative pan evaporation under sugarcane mulch
I_2M_3	Drip irrigation at 80 per cent cumulative pan evaporation under polythene mulch
I_3M_1	Drip irrigation at 60 per cent cumulative pan evaporation under without mulch
I_3M_2	Drip irrigation at 60 per cent cumulative pan evaporation under sugarcane mulch
I_3M_3	Drip irrigation at 60 per cent cumulative pan evaporation under polythene mulch
I_4M_1	Drip irrigation at 40 per cent cumulative pan evaporation under without mulch
I_4M_2	Drip irrigation at 40 per cent cumulative pan evaporation under sugarcane mulch
I_4M_3	Drip irrigation at 40 per cent cumulative pan evaporation under polythene mulch

Scheduling of irrigation

The present investigation comprised of two factors *i.e.* irrigation and mulches.

To conduct the study drip system of irrigation was adopted and the discharge rate of emitters was measured. The quantum of irrigation water to be applied into the treatment plots was based on the cumulative pan evaporation (CPE) data recorded in the meteorological unit situated at University of Horticultural Sciences, Bagalkote.

The obtained CPE value was converted into required pumping hours to discharge water into the plots according to four different irrigation levels *viz.*, 100, 80, 60 and 40 per cent of CPE.

Observations recorded

Plant yield (kg): The total marketable yield of the tagged plants throughout its cropping period is noted and average yield of plant is calculated in kilograms.

Yield per plot (kg): The total marketable yield of all plants of gross plot is noted to work out plot yield and is expressed in kilograms.

Yield per hectare (t/ha): To compute the yield per hectare, convert the gross plot yield on hectare basis.

$$\text{Yield per hectare (t/ha)} = \frac{\text{Fruit yield per plot (t)} \times 10000(\text{m}^2)}{\text{Plot area (m}^2)}$$

Water use efficiency (kg ha^{-1} mm^{-1}): Water Use Efficiency is defined as the ratio of total yield obtained to the applied quantity of irrigation water during the cropping period. It is

calculated from the formula mentioned below and expressed in kg ha^{-1} mm^{-1}.

$$\text{Water use efficiency (kg ha}^{-1}\text{mm)} = \frac{\text{Total yield of crop (kg ha}^{-1})}{\text{Total water used (mm)}}$$

Soil moisture percentage: The moisture content of soil was measured by gravimetric method. Collection of soil samples was done with the help of core sampler at four different depths (0-15, 15-30, 30-45 and 45-60 cm) in each treatment. The sieved composite soil samples were weighed and subjected to dry in hot air oven at 105 ˚C until we get constant dry weight. The formula to calculate soil moisture content is mentioned below and is expressed in percentage.

$$\text{Soil moisture content (\%)} = \frac{\text{Initial weight of soil (g)} - \text{Final weight of soil (g)}}{\text{Final weight of soil (g)}} \times 100$$

Weed density (Number per m^2): The occurance of weed plants in the experimental field is counted as the number of weed plants in m^2 quadrant at any 3 locations in each plot at 30, 60 and 90 DAT. It is converted equivalent to the plot area and is expressed as weed density.

Benefit cost ratio: The benefit cost ratio was worked out by using the formula mentioned below.

$$\text{Benefit cost ratio} = \frac{\text{Net income (₹/ha)}}{\text{Total cost of cultivation (₹/ha)}}$$

Results and Discussion

Effect of irrigation and mulches on yield of tomato

Yield of plant was significantly influenced by both irrigation levels and mulches. Among irrigation levels, highest yield per plant (2.45 kg), yield per plot (56.16 kg) and yield per hectare (46.28 t/ha) was noted under irrigation at 100 per cent CPE (I_1) and was on par with I_2. Similar outcomes were observed in study conducted by Bahadur *et al.* (2009) [6] and Al-Marri *et al.* (2020) [2] where highest fruit yield per plant (2.71 kg) and yield per hectare (847.52 q/ha) in tomato irrigated at 100 per cent Pan Evaporation. When optimum moisture is available for plant, fruits per cluster and total number of fruits per plant increase as flower dropping will be reduced. Though higher irrigation regimes reduce the average fruit weight, higher total number of fruits per plant is responsible for the total yield of crop. Similar findings were reported by Saleh *et al.* (2007) [26], Singh *et al.* (2009) [31], Panigrahi *et al.* (2010) [22], Helyes *et al.* (2012) [13] and Alaoui *et al.* (2014) [1]. Lower irrigation regimes directly affected the growth as well as yield attributing characters which resulted in significantly lower yields. Though earliness with respect to flowering was observed under lower irrigation regimes, due to low availability of moisture and nutrients flower clusters per plant, fruits per cluster and total number of fruits per plant were significantly lower for drip irrigation at 60 per cent CPE (I_3) and drip irrigation at 40 per cent CPE (I_4), hence drastic reduction in the yield was noticed. Least fruit yield per plant (1.87 kg), yield per plot (42.51 kg) and yield per hectare (33.76 t/ha) Similar results were observed in the studies of Dung *et al*. (2016) [9], Cheena *et al*. (2018) [8], El-Labad *et al*. (2019) [10], Ragab *et al*. (2019) [24], Oke *et al*. (2020) [21] and Samui *et al*. (2020) [27].

Similarly, highest yield per plant (2.36 kg), yield per plot (53.87 kg) and yield per hectare (44.12 t/ha) was recorded under polythene mulch and was on par with sugarcane mulch. Whereas, lowest fruit yield per plant (1.99 kg), yield per plot (47.10 kg) and per hectare (37.91 t/ha) was observed under without mulch condition. The per cent increase in fruit yield per hectare under polythene and sugarcane mulch was 16.38 and 6.11 per cent, respectively over unmulched condition. Singh and Kamal (2012) [30] also reported that yield in black plastic mulch was greater than bare soil. Kayum *et al.* (2008) [16] noticed higher fruit weight per plant, fruit weight per plot and fruit yield per hectare in tomato grown under water hyacinth mulch. This improvement in yield attributes was due to better soil moisture and nutrients utilization in rhizosphere, higher photosynthesis and negligible weed growth and better soil hydrothermal properties due to black polythene mulching. These findings are in agreement with the earlier works of Singh (2005) [32] and Ashrafuzzaman *et al.* (2011) [3]. Another factor for increased yield under polythene mulch might be due to restricted nitrate leaching under black polyethylene as reported by Romic *et al.* (2003) [25].

Among the combinations, the treatment combination receiving irrigation at 80 per cent CPE along with polythene mulch (I_2M_3) recorded highest yield per plant (2.74 kg), yield per plot (60.90 kg) and yield per hectare (51.83 t/ha) which was on par with I_1M_3. Lowest yield per plant (1.71 kg), yield per plot (38.60 kg) and per hectare (32.19 t/ha) was recorded under I_4M_1. With the saving of 20 per cent irrigation water highest yield was obtained. Hence, treatment combination receiving drip irrigation at 80 per cent CPE along with polythene mulch (I_2M_3) was more remunerable than I_1M_3. Singh *et al.* (2009) [31] also recorded higher yield of tomato when higher irrigation regimes are combined with black polythene mulch. Similar findings were observed by Paul *et al.* (2013) [23] in capsicum and Attia *et al*. (2019) [4] in tomato.

Table 1: Yield parameters in tomato as influenced by different levels of irrigation and mulches

Yield parameters															
	Yield per plant (kg)					Yield per plot (kg)					Yield per hectare(t)				
Treatments	I_1	I_2	I_3	I_4	Mean	I_1	I_2	I_3	I_4	Mean	I_1	I_2	I_3	I_4	Mean
M_1	2.28	2.09	1.88	1.71	1.99	52.57	51.63	45.60	38.60	47.10	43.89	41.50	34.05	32.19	37.91
M_2	2.48	2.30	2.04	1.92	2.18	56.27	54.45	47.13	42.53	50.10	46.00	44.64	36.77	33.53	40.23
M_3	2.60	2.74	2.13	1.97	2.36	59.64	60.90	48.53	46.40	53.87	48.95	51.83	40.13	35.57	44.12
Mean	2.45	2.38	2.02	1.87		56.16	55.66	47.09	42.51		46.28	45.99	36.98	33.76	
	S.Em±		CD @ 5%			S.Em±		CD @ 5%			S.Em±		CD @ 5%		
Main plot(M)	0.06		0.19			1.38		4.76			1.07		3.72		
Sub plot (S)	0.11		0.33			1.61		4.82			1.38		4.13		
M×S	0.06		0.17			0.80		2.41			0.69		2.07		

Effect of different levels of irrigation and mulches on water use efficiency (WUE)

Different levels of irrigation and mulches significantly influenced the water use efficiency of tomato and the statistically analysed data presented in Table 2. Significantly higher water use efficiency of 255.44 kg $ha^{-1}mm^{-1}$ was recorded in lowest irrigation regime *i.e.* drip irrigation at 40 per cent CPE (I_4) followed by I_3. Significant least water use efficiency of 140.06 kg $ha^{-1}mm^{-1}$ was recorded under highest irrigation regime *i.e.* I_1. Tomato plants produced substantially higher yield at very low amount of irrigation water with least loss of water by evaporation and percolation as studied by Ayars *et al.* (1999) [5]. Hence with least amount of irrigation treatment receiving drip irrigation at 40 per cent CPE (I_4) could result in highest WUE. Bahadur *et al.* (2009) [6] reported higher WUE under irrigation at 50 per cent Pan Evaporation (49.60 kg ha^{-1} mm^{-1}). However, contrast results were reported by Panigrahi *et al.* (2010) [22] where irrigation at 100 per cent ET resulted in highest WUE. However, contrast reports of higher WUE at moderately higher supply of irrigation water at 75 per cent ET were seen in the reports of Attia *et al.* (2019) [4].

Application of mulches exhibited significant difference on water use efficiency in tomato. Among mulches, highest water use efficiency of 204.03 kg $ha^{-1}mm^{-1}$ was recorded under polythene mulch (M_3) and was on par with sugarcane mulch (M_2). Least significant water use efficiency of 176.24 kg $ha^{-1}mm^{-1}$ was recorded under without mulch (M_1) condition. Use of mulch materials enabled greater water use efficiency over no mulch condition. Both polythene and sugarcane mulch were at par on WUE but significantly different over no mulch condition. Application of mulches reduced the loss of water through evaporation from upper soil layer, thus WUE is higher in mulches compared to no mulch condition. Bahadur *et al.* (2009) [6] and Mukherjee *et al.* (2010) [20] recorded higher WUE under black polythene (46.03 kg ha^{-1} mm^{-1}) over bare soil (no mulch). Goel *et al.* (2020) [11] also reported higher WUE under various organic mulch substances over bare soil condition.Interaction effects of different irrigation levels and mulches on water use efficiency did not show significant difference in tomato.

Table 2: Water use efficiency in tomato as influenced by different levels of irrigation and mulches

Water use efficiency (kg $ha^{-1}mm^{-1}$)					
Treatments	I_1	I_2	I_3	I_4	Mean
M_1	132.81	157.10	171.82	243.21	176.24
M_2	139.22	168.99	185.53	253.83	186.89
M_3	148.15	196.20	202.49	269.28	204.03
Mean	140.06	174.10	186.61	255.44	
	S.Em±		CD @ 5%		
Main plot (M)	5.00		17.29		
Sub plot (S)	7.54		22.61		
M×S	3.77		NS		

Effect of different levels of irrigation and mulches on soil moisture content: Soil moisture percentage was greatly influenced by different levels of irrigation and mulches. The statistically analysed data recorded on soil moisture percentage at 30, 60 and 90 DAT presented in Table 3. Soil moisture percentage in tomato field differed significantly due to various levels of irrigation. Among the irrigation levels, maximum soil moisture percentage of 14.16, 15.86 and 15.38 were recorded in highest irrigation regime *i.e.* drip irrigation at 100 per cent CPE (I_1) at 30, 60 and 90 DAT, respectively and was found to be on par with I_2. Lowest soil moisture contents of 7.52, 8.63 and 11.13 per cent were observed in I_4 at all growth stages, respectively. Similar results were observed by Goel *et al.* (2020) [11]. Panigrahi *et al.* (2010) [22] and Kishore *et al.* (2018a) [18] also reported highest soil moisture content when irrigated at 100 and 120 per cent ET_c, respectively.

The variation in the soil moisture percentage among the irrigation levels at all monthly intervals is mainly due to quantum of irrigation supplied to the plant. Another factor responsible for increased soil moisture content with the growing period is due to plant canopy. As the plant canopy spreads in both East-West and North-South directions with growing period, it reduces the exposure of soil to direct solar radiations. Therefore soil will not get directly heated up and soil temperature is kept low, thereby soil moisture content available in rhizosphere is generally high at later stages of growth.

The variation in soil moisture contents due to different mulch materials was significant at 30, 60 and 90 DAT. Among mulches highest soil moisture contents of 14.44, 16.10 and 15.98 per cent were observed under polythene mulch (M_3) treatment followed by sugarcane mulch (M_3) at all growth stages. Least soil moisture contents of 8.27, 8.69 and 10.77 per cent were recorded under without mulch (M_1) condition at 30, 60 and 90 DAT, respectively. Under polythene mulch soil is completely devoid of solar interception and due to evaporation, vapours trapped within mulches turned into fog and dropped over the soil layer hence soil moisture content available under black polythene mulch. These findings corroborate with that of Ashrafuzzaman *et al.* (2011) [3]. In case of sugarcane mulch part of the soil is exposed to direct solar radiation hence evaporation occurs and soil moisture available in this treatment is lesser than polythene mulch. Dung *et al.* (2016) [9] also concluded similar results.

Combined effects of different irrigation levels and mulches on soil moisture percentage were significant at 30, 60 and 90 DAT. At 30 and 60 DAT, soil moisture per cent of 18.67 and 20.29 per cent were significantly higher under the treatment combination receiving drip irrigation at 100 per cent CPE along with polythene mulch (I_1M_3) and at 90 DAT, higher soil moisture content of 19.10 per cent was observed in treatment combination with drip irrigation at 80 per cent CPE along with polythene mulch (I_2M_3). This might be due to higher irrigation levels in conjugation with polythene mulch reduced evaporation thus increased the moisture availability at root zone. Similar results were noticed in the study conducted by Kishore *et al.* (2018a) [18] in tomato. Lowest significant soil moisture contents of 4.83, 5.77 and 9.17 per cent were recorded in treatment combination receiving drip irrigation at 40 per cent CPE under no mulch condition (I_4 M_1) at 30, 60 and 90 DAT, respectively.

Table 3: Soil moisture content (%) at various stages as influenced by different levels of irrigation and mulches

Soil moisture content (%)															
	30 DAT					60 DAT					90 DAT				
Treatments	**I_1**	**I_2**	**I_3**	**I_4**	**Mean**	**I_1**	**I_2**	**I_3**	**I_4**	**Mean**	**I_1**	**I_2**	**I_3**	**I_4**	**Mean**
M_1	10.60	10.00	7.63	4.83	8.27	11.67	9.60	7.73	5.77	8.69	13.10	11.46	9.33	9.17	10.77
M_2	13.20	12.97	11.07	7.00	11.06	15.63	13.13	11.60	8.73	12.28	15.47	14.20	11.33	10.77	12.94
M_3	18.67	15.07	13.30	10.73	14.44	20.29	16.87	15.83	11.39	16.10	17.57	19.10	13.80	13.47	15.98
Mean	14.16	12.68	10.67	7.52		15.86	13.20	11.72	8.63		15.38	14.92	11.49	11.13	
	S.Em±		CD @ 5%			S.Em±		CD @ 5%			S.Em±		CD @ 5%		
Main plot(M)	0.53		1.84			0.35		1.20			0.23		0.81		
Sub plot (S)	0.31		0.93			0.73		2.18			0.92		2.76		
M×S	0.15		0.46			0.36		1.09			0.46		1.38		

Effect of different levels of irrigation and mulches on weed density (Number per m^2)

The variation in both different irrigation levels and mulches exhibited significant influence on weed density at all growth stages. The statistically analysed data presented in the Table 11 and depicted in Fig. 8. Irrigation levels had significant effects on weed density at 30, 60 and 90 DAT. Significantly least weed density of 23.09, 15.79 and 7.76 per m^2 was recorded in drip irrigation treatment at 40 per cent CPE (I_4) at all the growth stages. Highest weed density of 43.07, 30.98 and 13.74 per m^2 was recorded in drip irrigation treatment at I_1 at 30, 60 and 90 DAT, respectively which was significantly higher over other irrigation levels. Readily available moisture available under unmulched higher irrigation regimes promotes the germination and growth of weed seeds in bed. Hence, higher weed population was noticed in higher irrigation regimes and vice-versa. Similar results observed by Bahadur *et al.* (2009) [6]. Similar results were observed in study conducted by Kishore *et al.* (2018b) [18] and Jayalalitha *et al.* (2020).

Mulches significantly influenced the weed population at 30, 60 and 90 DAT. Least weed density of 2.22, 1.69 and 1.49 per m^2 was noticed in polythene mulch (M_3). Highest weed density of 59.67, 39.49 and 17.10 per m^2 was recorded under without mulch treatment (M_1) at 30, 60 and 90 DAT, respectively and was followed by sugarcane mulch (M_2). Polythene mulch increased the soil temperature which is detrimental for germination of weed seeds and also higher puncture resistance capacity of polythene mulch inhibits the emergence of weed plants except few emerged from the planting holes Schonbeck (1998) [27]. Black polythene mulch reflects 90per cent of incident solar radiation hence PAR is not available for weeds under the mulch. Use of black polythene mulch reduced weeds upto 89 per cent over unmulched control was recorded by Bahadur *et al.* (2009) [6]. Similarly less weed population was seen by Shrivastava *et al.* (1994) [29] and Jayalalitha *et al.* (2020) [15] with the use of polythene mulch in tomato.

Table 4: Weed density at various growth stages as influenced by different levels of irrigation and mulches

Weed density (Number per m^2)															
	30 DAT					60 DAT					90 DAT				
Treatments	**I_1**	**I_2**	**I_3**	**I_4**	**Mean**	**I_1**	**I_2**	**I_3**	**I_4**	**Mean**	**I_1**	**I_2**	**I_3**	**I_4**	**Mean**
M_1	75.60	64.13	62.33	36.60	59.67	54.07	43.23	33.77	26.90	39.49	23.37	19.00	14.17	11.87	17.10
M_2	51.37	44.73	41.17	30.50	41.94	36.80	33.00	27.63	18.90	29.08	16.30	11.27	11.37	10.10	12.26
M_3	2.23	2.37	2.10	2.17	2.22	2.07	1.50	1.63	1.57	1.69	1.57	1.47	1.63	1.30	1.49
Mean	43.07	37.08	35.20	23.09		30.98	25.91	21.01	15.79		13.74	10.58	9.06	7.76	
	S.Em±		CD @ 5%			S.Em±		CD @ 5%			S.Em±		CD @ 5%		
Main plot(M)	1.40		4.84			0.69		2.40			0.32		1.10		
Sub plot (S)	4.07		12.20			2.08		6.24			1.06		3.18		
M×S	2.03		6.10			1.04		3.12			0.53		1.59		

The combined effects of irrigation levels and mulch materials significant influenced weed density at all growth stages. The treatments receiving polythene mulch in combination with all the four levels of irrigation resulted in lowest weed densities at all monthly intervals. Weed density of 75.60, 54.07 and 23.37 per m^2 was recorded at 30, 60 and 90 DAT, respectively in treatment combination receiving drip irrigation at 100 per cent CPE under without mulch (I_1M_1) which was significantly higher than other treatment combinations which was followed by I_2M_1 and I_3M_1 of which both were at par. Among the treatment combinations, all the four irrigation levels in combination with polythene mulch recorded least weed density and were at par with each other. Highest weed density was recorded under without mulch condition followed by sugarcane mulch irrespective of irrigation levels at all the monthly intervals. Shrivatsava *et al.* (1994), Biswas *et al.* (2015) [7], Kishore *et al.* (2018b) [19] and Jayalalitha *et al.* (2020) [15] also reported that the combination of lower irrigation regime and polythene mulch is more efficient in suppression of weed plants.

Effect of different levels of irrigation and mulches on benefit cost ratio

The data pertaining to the cost economics of different levels of irrigation and mulches was worked out and presented in Table 5. Interaction effects of irrigation levels and mulches exhibited significant difference on yield. The maximum fruit yield of 51.83 t/ha was found in treatment combination receiving drip irrigation at 80 per cent CPE along with polythene mulch (I_2M_3) followed by treatment combination receiving drip irrigation at 100 per cent CPE along with polythene mulch (I_1M_3). Whereas, minimum fruit yield of 32.19 t/ha was obtained in treatment combination receiving drip irrigation at 40 per cent CPE under without mulch condition (I_4M_1).

Among 12 different treatment combinations, maximum net returns of `3,96,014 and highest benefit cost ratio of 3.23 was found in the treatment combination I_2M_3. It is slightly higher

than I_1M_3. Though total production cost was same for both treatment combinations, higher fruit yield of 51.83 t/ha was obtained in I_2M_3 which in turn increased the gross returns to `5,18,300 and net returns to `3,96,014 was the cause for its highest benefit cost ratio. This was due to the fact that, treatment combination I_2M_3 besides saving 20 per cent irrigation water increased the yield up to 5.88 per cent than I_1M_3 which raised the net returns as well as benefit cost ratio. Similar reports of highest benefit cost ratio was observed in the findings of Singh *et al.* (2009) [31], Biswas *et al.* (2015) [7] and Subba Reddy *et al*. (2015) [33] in tomato.

Without mulch condition at all the four levels of irrigation resulted in lower total production cost of `1,15,546. The lowest irrigation level *i.e.* drip irrigation at 40 per cent CPE (I_4) in combination with all the three levels of mulch resulted in lower benefit cost ratio than all other combinations. Lowest benefit cost ratio of 1.78 was noticed under drip irrigation at 40 per cent CPE under without mulch condition (I_4M_1) than I_4M_2 and I_4M_3. Though total cost of production was lowest under I_4M_1 than I_4M_2 and I_4M_3, the lowest yield of tomato resulted in lowest net return as well as least benefit cost ratio of 1.78. The reports of Tegen *et al.* (2016) [34] implied that the use of grass mulch increased the benefit cost ratio over unmulched condition.

Table 5: Benefit cost ratio in tomato as influenced by different levels of irrigation and mulches

Treatment combinations	Yield (t/ha)	Cost of mulch material (`/ha)	Cost of manual weeding (`/ha)	Other production cost (`/ha)	Total cost of cultivation (`/ha)	Gross Returns (`/ha)	Net Returns (`/ha)	Benefit cost ratio
I_1 M_1	43.89	-	11,260	1,04,286	1,15,546	4,38,900	3,23,354	2.79
I_1 M_2	46.00	7,000	8,345	1,04,286	1,19,631	4,60,000	3,40,369	2.84
I_1 M_3	48.95	18,000	-	1,04,286	1,22,286	4,89,500	3,67,214	3.00
I_2 M_1	41.50	-	11,260	1,04,286	1,15,546	4,15,000	2,99,454	2.59
I_2 M_2	44.64	7,000	8,345	1,04,286	1,19,631	4,46,400	3,26,769	2.73
I_2 M_3	51.83	18,000	-	1,04,286	1,22,286	5,18,300	3,96,014	3.23
I_3M_1	34.05	-	11,260	1,04,286	1,15,546	3,40,500	2,24,954	1.94
I_3 M_2	36.77	7,000	8,345	1,04,286	1,19,631	3,67,700	2,48,069	2.07
I_3 M_3	40.13	18,000	-	1,04,286	1,22,286	4,01,300	2,79,014	2.28
I_4M_1	32.19	-	11,260	1,04,286	1,15,546	3,21,998	2,06,452	1.78
I_4 M_2	33.53	7,000	7,300	1,04,286	1,18,586	3,35,932	2,17,346	1.83
I_4 M_3	35.57	18,000	-	1,04,286	1,22,286	3,55,700	2,33,414	1.90

Conclusion

The interactive effects of irrigation and mulches were found to be superior over their individual effects. The treatment combination receiving drip irrigation at 80 per cent CPE along with polythene mulch (I_2M_3) was recorded with highest tomato yield per plant, per plot and per hectare and also highest benefit cost ratio of 3.23. Both lowest irrigation level (I_4) and polythene mulch were known to exhibit highest water use efficiency. Whereas, highest irrigation level with polythene mulch recorded maximum soil moisture content. However, weed density was kept low under all the four irrigation levels combined with polythene mulch.

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