The Pharma Innovation Journal 2023; 12(6): 4753-4757

www.ThePharmaJournal.com

The Pharma Innovation

ISSN (E): 2277-7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2023; 12(6): 4753-4757

www.thepharmajournal.com
Received: 02-04-2023
Accepted: 13-05-2023

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Investigation of irrigation and mulching on yield and water use efficiency of cucumber (*Cucumis sativus* L.) under protected structure

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Abstract
Investigation was taken up to assess the combined effects of drip irrigation and mulches on yield, water-use efficiency and economic return of cucumber. The treatments of the study comprised of different combinations of three drip irrigation levels (100, 80 and 60% of crop water requirement, ETc) and three mulches (white polyethylene sheet, black polyethylene sheet and no mulch). The yield of cucumber increased with the increasing amount of irrigation water in mulched treatment. The yield per plot was 71.93 kg, yield per 1000 square meter 11.07 t and yield per ha 110.70 t ha^{-1} under treatment consisting of 100% crop ET with white plastic mulch as compared to black mulch and without mulch. The average water use efficiency was highest in treatment consisting of drip irrigation at 60% crop ET with white plastic mulch (9.70 t $ha^{-1}cm^{-1}$).
The study thus reveals that drip irrigation with mulch has an explicit role in increasing the land and water productivity of cucumber.

Keywords: Irrigation, mulching, yield, water use efficiency and application efficiency

Introduction
Efficient use of available irrigation water is essential for increasing agricultural production for the alarming Indian population. Water availability for irrigation is going to be a major constraint for agriculture in the near future. Hence, judicious use of the available water resources through more efficient methods of water application like drip irrigation under conditions of protected cultivation becomes necessary to enhance the yield and water use efficiency (Dunage *et al*., 2009) [4]. Protected cultivation of vegetables provides the best way to increase the productivity and quality of vegetables, especially cucurbits. Naturally ventilated greenhouses are highly suitable for year round cultivation of parthenocarpic cucumber varieties. Water management by drip irrigation provides daily requirement of water to the root zone of each plant and maintains a high soil matric potential in the rhizosphere to reduce plant water stress (Nakayama and Bucks, 1986) [10]. Cucumber (*Cucumis sativus* L.) is an important vegetable belonging to the family cucurbitaceae. Cucumber has tremendous economic and dietic importance. The immature fruits are eaten raw as salad. Keeping in view the above facts, the present study was undertaken to determine the most suitable irrigation requirement for salad cucumber grown under naturally ventilated polyhouse.

Material and Methods
The experiment was conducted at Zonal Agricultural and Horticultural Research Station (ZAHRS), Keladi Shivappa Nayaka University of Agricultural and Horticultural Sciences (KSNUAHS) Navile, Shivamogga which is situated at $13^0$58`North latitude and $75^0$34`East longitude with an altitude of 650 meters above mean sea level. It comes under agro-climatic region-4 and zone-VII (Southern Transition Zone) of Karnataka.

The experiment consisted of two factors Factor 1 consisted of irrigation levels (I)
i.e., I_1: Drip irrigation at 60 percent of ET I_2: Drip irrigation at 80 percent of ET and I_3: Drip irrigation at 100 percent of ET. Factor 2 consisted of Mulching levels (M)
i.e., M_1: Mulching with white polythene sheet M_2: Mulching with black polythene sheet and M_3: Without mulching (Control)

Land preparation
The selected experimental land inside the polyhouse was brought to fine tilth and as per the plan 9 beds of 1 m width, 15 m length and 15 cm height (15 m^2 bed) were prepared and 0.5 m distance was maintained in between the beds to facilitate the intercultural operations.

Installation of drip system
In the experimental plot, drip irrigation system was installed after the raised beds preparation. The drip irrigation unit consisted of main line, laterals, valves and filters. The main lateral line having the emitting point at every 50 cm was laid on the centre of the beds connecting to the pumping line. To the pumping line, screen filters were provided to prevent the impurities entering into the drip system. Separate valves were installed to each main line to regulate the water flow. White and Black LDPE sheets of 40 micron thickness were used to cover the beds for mulching treatment. After covering the beds with mulching sheet, 10 cm diameter holes were made on the sheet as per the treatment plan.

Mulching
White and Black LDPE sheets of 40 micron thickness were used to cover the beds for mulching treatment. After covering the beds with mulching sheet, 10 cm diameter holes were made on the sheet as per the treatment plan.

Manure and fertilizer application
During final land preparation, the FYM @ 20 t ha^{-1} (50 kg / 25 m^{-2}) was applied 10 to 15 days prior to sowing. The specific dose of fertilizer for the cucumber under fertigation has not yet been standardized. Hence the RDF for this crop was taken into consideration.

Sowing
The first season sowing of the crop was taken up during June, 2020-21 and the second season sowing of crop during June, 2021-22. The required quantity of seeds was treated with trichoderma and one seed per hill were dibbled manually at 2-3 cm depth. Gap filling or resowing was done after 5-6 days of sowing, where the seeds were not germinated, in order to maintain the optimum plant population in each treatment.
The weight of fruits from tagged plants was recorded in each picking. Finally, yield from the total field in each picking were summed and average yield per plot was worked out and expressed in kg per plot. Total yield obtained from an area of 1000 square meter computed and expressed in tonnes. Total yield obtained from an area of 1 hectare area computed and expressed in t ha^{-1}.

Water use efficiency (WUE)
The WUE of each treatment was estimated by (Ram *et al*., 2013) in kg
ha^{-1} mm^{-1}.

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

Water application efficiency
The application efficiency of drip irrigation was computed using equation given by Nakayama and Bucks (1986) [10].
The equation is expressed as follows.

$$e_a = \frac{e \times q_{min} \times T}{V} \times 100$$

Where,
e_a = Application efficiency in percent
e = Total number of emitters
q_{min} = Minimum emitter flow rate in litres hr^{-1}
T = Total irrigation time in hours
V = Total volume of water applied in litres

Statistical Analysis
The data on the observations made and characters studied were statistically analyzed by using two factorial experiment. Wherever the results are significant, the critical difference at 5 percent level was worked out and presented. The data were analyzed by using 'OPSTAT' software.

Results and Discussion
Yield per plot
The data pertaining to yield per plot of cucumber is provided in Table 1. Among irrigation levels, 100 percent crop ET recorded significantly higher yield per plot (64.42 kg, 74.27 kg and 69.35 kg during 2020-21, 2021-22 and pooled data, respectively) over 80 percent crop ET. Drip irrigation at 60% crop ET recorded lower yield per plot (56.42 kg, 57.49 kg and 56.95 kg during 2020-21, 2021-22 and pooled data, respectively).
Among three levels of mulching, maximum yield per plot was documented under white polythene mulch i.e., 63.12 kg, 69.33 kg and 66.23 kg during 2020-21, 2021-22 and pooled data, respectively. Whereas minimum yield per plot was documented under no mulch conditions i.e., 56.62 kg, 62.43 kg and 59.53kg during 2020-21, 2021-22 and pooled data, respectively.
When the interaction effect was noticed it was found that the yield per plot was maximum in treatment consisting of drip irrigation at 100% crop ET and white polythene mulch i.e., 67.60 kg, 76.27 kg and 71.93kg during 2020-21, 2021-22 and pooled data, respectively. The yield per plot was minimum in treatment consisting of drip irrigation at 60% crop ET and un mulched condition i.e., 52.87 kg, 54.60 kg and 53.73kg during 2020-21, 2021-22 and pooled data, respectively.
Higher yield per plot might be due to adequate moisture availability in the soil which might have increased various crop physiological processes, better plant nutrient uptake, higher rates of photosynthesis, which reflected in more number of fruits and higher fruit weight. (Ngouajio *et al*. 2007). Added to this, the combined influence of irrigation levels and mulching might have significantly affected the fruit yield of cucumber in polyhouse. Fruit yield increases with increase in irrigation level. Irrigation level at 100% CPE was found to be the best for producing higher fruit yield. Similar effect of irrigation levels was reported by Lee *et al*. (2005). Similar results are found by Rincy *et al*. (2017) [15], Dillip Kumar *et al*. (2018) [3], Om Prakash *et al*. (2018) [11], Pawar *et al*. (2018) [12] and Karki *et al*. (2020) [7] in cucumber.

Yield per 1000 square meter
The data pertaining to yield per 1000 square meter of cucumber is provided in Table 1. Among irrigation levels, 100 percent crop ET recorded significantly higher yield per 1000 square meter (9.91 t, 11.43 t and 10.67 t during 2020-21,2021-22 and pooled data, respectively) over 80 percent

crop ET. Drip irrigation at 60% crop ET recorded lower yield per 1000 square meter (8.68 t, 8.84 t and 8.76 t during 2020-21, 2021-22 and pooled data, respectively). Among three levels of mulching maximum yield per 1000 square meter was documented under white polythene mulch i.e., 9.71 t, 10.67 t and 10.19 t during 2020-21, 2021-22 and pooled data, respectively. Whereas minimum yield per square 1000 meter was documented under no mulch conditions i.e., 8.71 t, 9.60 t and 9.16 t during 2020-21, 2021-22 and pooled data, respectively. When the interaction effect was noticed it was found that the yield per 1000 square meter was maximum in treatment consisting of drip irrigation at 100% crop ET and white polythene mulch i.e., 10.40 t, 11.73 t and 11.07 t during 2020-21, 2021-22 and pooled data, respectively. The yield per 1000 square meter was minimum in treatment consisting of drip irrigation at 60% crop ET and un mulched condition i.e., 8.13 t, 8.40 t and 8.27 t during 2020-21, 2021-22 and pooled data, respectively.

Table 1: Effect of drip irrigation and plastic mulching on yield per plot, yield per 1000 square meter and yield per hectare in cucumber

Treatment details	Yield per plot (kg)			Yield per 1000 square meter (t)			Yield (t ha^{-1})		
	2020-21	2021-22	Pooled	2020-21	2021-22	Pooled	2020-21	2021-22	Pooled
Irrigation treatments (I)									
I_1	56.42	57.49	56.95	8.68	8.84	8.76	86.80	88.40	87.60
I_2	61.39	67.02	64.21	9.44	10.31	9.88	94.40	103.10	98.80
I_3	64.42	74.27	69.35	9.91	11.43	10.67	99.10	114.30	106.70
S.Em. ±	0.64	1.41	0.67	0.09	0.22	0.10	0.90	2.20	1.00
CD @ 5%	1.90	4.23	2.00	0.29	0.65	0.31	2.90	6.50	3.10
Mulching treatments (M)									
M_1	63.12	69.33	66.23	9.71	10.67	10.19	97.10	106.70	101.90
M_2	62.49	67.02	64.75	9.61	10.31	9.96	96.10	103.10	99.60
M_3	56.62	62.43	59.53	8.71	9.60	9.16	87.10	96.00	91.60
S.Em. ±	0.64	1.41	0.67	0.09	0.22	0.10	0.90	2.20	1.00
CD @ 5%	1.90	4.23	2.00	0.29	0.65	0.31	2.90	6.50	3.10
Interaction effect (I×M)									
I_1M_1	58.07	60.67	59.37	8.93	9.33	9.13	89.30	93.30	91.30
I_1M_2	58.33	57.20	57.76	8.97	8.80	8.89	89.70	88.00	88.90
I_1M_3	52.87	54.60	53.73	8.13	8.40	8.27	81.30	84.00	82.70
I_2M_1	63.70	71.07	67.38	9.80	10.93	10.37	98.00	109.30	103.70
I_2M_2	63.27	68.47	65.87	9.73	10.53	10.13	97.30	105.30	101.30
I_2M_3	57.20	61.53	59.37	8.80	9.47	9.13	88.00	94.70	91.30
I_3M_1	67.60	76.27	71.93	10.40	11.73	11.07	104.00	117.30	110.70
I_3M_2	65.87	75.40	70.63	10.13	11.60	10.87	101.30	116.00	108.70
I_3M_3	59.80	71.15	65.48	9.20	10.95	10.07	92.00	109.50	100.70
S.Em. ±	1.10	2.45	1.16	0.169	0.38	0.18	1.69	3.80	1.80
CD @ 5%	NS	NS	NS	NS	NS	NS	NS	NS	NS

I_1:Drip irrigation @ 60% ET	M_1:White polythene mulch
I_2:Drip irrigation @ 80% ET	M_2:Black polythene mulch
I_3:Drip irrigation @100%ET	M_3:Without mulching (Control)

Total yield per hectare

The data pertaining to total yield per hectare of cucumber is provided in Table 1. Among irrigation levels 100 percent crop ET recorded significantly higher total yield per hectare (99.10 t ha^{-1}, 114.30 t ha^{-1} and 106.70 t ha^{-1} during 2020-21, 2021-22 and pooled data, respectively) over 80 percent crop ET. Drip irrigation at 60% crop ET recorded lower total yield per hectare (86.80 t ha^{-1}, 88.40 t ha^{-1} and 87.60 t ha^{-1} during 2020-21, 2021-22 and pooled data, respectively).

Among three levels of mulching maximum total yield per hectare was documented under white polythene mulch i.e., 97.10 t ha^{-1}, 106.70 t ha^{-1} and 101.90 t ha^{-1} during 2020-21, 2021-22 and pooled data, respectively. Whereas minimum total yield per hectare was documented under no mulch conditions i.e., 87.10 t ha^{-1}, 96.00 t ha^{-1} and 91.60 t ha^{-1} during 2020-21, 2021-22 and pooled data, respectively.

When the interaction effect was noticed it was found that the total yield per hectare was maximum in treatment consisting of drip irrigation at 100% crop ET and white polythene mulch i.e., 104.00 t ha^{-1}, 117.30 t ha^{-1} and 110.70 t ha^{-1} during 2020-21, 2021-22 and pooled data, respectively. The total yield per hectare was minimum in treatment consisting of drip irrigation at 60% crop ET and un mulched condition i.e., 81.30 t ha^{-1}, 84.00 t ha^{-1} and 82.70 t ha^{-1} during 2020-21, 2021-22 and pooled data, respectively.

Higher soil moisture content maintained under plastic mulched treatments and better control of weeds when compared to un mulched plots had positively reflected on the vegetative and yield parameters. Consequently, use of plastic mulch as soil cover increased the yield of cucumber in the current trial. Mulch is a covering placed over the soil around the plants. Plastic mulch on the surface of the soil causes change in the microclimate around the plants. This results in moisture conservation, less soil compaction and higher CO_2 levels around plants (Mane and Umrani, 1981) [9]. Mulching is an effective method of manipulating the crop growing environment to increase crop yield and improve product quality by controlling soil temperature, retaining soil moisture and reducing soil evaporation Chakraborty *et al*. (2008) [2].

These results are in agreement with the study conducted by Rincy *et al*. (2017) [15], Dillip Kumar *et al*. (2018) [3], Om Prakash *et al.* (2018) [11], Pawar *et al.* (2018) [12] and Karki *et al*. (2020) [7] in cucumber.

Water use efficiency

The data pertaining to water use efficiency of cucumber is provided in Table 2. Among irrigation levels, 60 percent crop ET recorded significantly higher water use efficiency (10.46,

8.19 and 9.33 t $ha^{-1}cm^{-1}$ during 2020-21, 2021-22 and pooled data, respectively) over 80 percent crop ET. Drip irrigation at 100% crop ET (I_3) recorded lower water use efficiency (7.19, 6.35 and 6.77 t $ha^{-1}cm^{-1}$ during 2020-21, 2021-22 and pooled data, respectively).

Among three levels of mulching maximum water use efficiency was documented under white polythene mulch i.e., 9.07, 7.58 and 8.33 t $ha^{-1}cm^{-1}$ during 2020-21, 2021-22 and pooled data, respectively. Whereas minimum water use efficiency was documented under no mulch conditions i.e., 8.16, 6.81 and 7.49 t $ha^{-1}cm^{-1}$ during 2020-21, 2021-22 and pooled data, respectively.

When the interaction effect was noticed it was found that the water use efficiency was highest in treatment consisting of drip irrigation at 60% crop ET and white polythene mulch i.e., 10.76, 8.64 and 9.70 t $ha^{-1}cm^{-1}$ during 2020-21, 2021-22 and pooled data, respectively. The water use efficiency was lowest in treatment consisting of drip irrigation at 100% crop ET and un mulched condition i.e., 6.67, 6.08 and 6.38 t $ha^{-1}cm^{-1}$ during 2020-21, 2021-22 and pooled data, respectively.

Drip irrigation significantly increased the crop yield of cucumber and there by improved WUE due to consumption of less water. However, integrated use of drip irrigation and plastic mulch was more appropriate and profitable. Therefore, drip irrigation in combination with plastic mulch was found to be more effective in improving WUE and increasing crop yield of cucumber. Mulches reduced the rate of water loss through evaporation from soil surface. So, the soil-water-plant relationship was better in low irrigation regime than high irrigation regime that might have helped to produce higher yield and thereby higher WUE. In general, the trends for the WUE related to the total water use showed that lower the amount of water use, higher was the WUE. Besides, low irrigation regime reduced deep percolation and increased water use from soil root zone (Ayars *et al.*, 1999) [1].

These results are also in agreement with the results of Jain *et al.* (2000) [6], who concluded that drip irrigation and plastic mulch markedly affects applied water and water use efficiency. The percent of water use reduction was 65%, 64% and 57% for the transparent mulched drip irrigation, black mulched drip irrigation and no mulch drip irrigation, respectively compared to the furrow surface irrigation. Dunage *et al.* (2009) [4], Huimeng *et al.* (2017) [5], Parameshwarareddy *et al.* (2018) [13] and Yaghi *et al.* (2013) [16], recorded similar results in cucumber.

Table 2: Effect of drip irrigation and plastic mulching on water use efficiency in cucumber

Treatment details	Water use efficiency (t $ha^{-1}cm^{-1}$)		
	2020-21	2021-22	Pooled
Irrigation treatments (I)			
I_1: Drip irrigation @ 60% ET	10.46	8.19	9.33
I_2: Drip irrigation @ 80% ET	8.59	7.16	7.88
I_3: Drip irrigation @ 100% ET	7.19	6.35	6.77
S.Em. ±	0.09	0.17	0.15
CD @ 5%	0.26	0.50	0.44
Mulching treatments (M)			
M_1: White polythene sheet	9.07	7.58	8.33
M_2: Black polythene sheet	9.00	7.30	8.15
M_3: Without mulching (Control)	8.16	6.81	7.49
S.Em. ±	0.09	0.17	0.15
CD @ 5%	0.26	0.50	0.44
Interaction effect (I×M)			
I_1M_1	10.76	8.64	9.70
I_1M_2	10.81	8.15	9.48
I_1M_3	9.80	7.78	8.79
I_2M_1	8.91	7.59	8.25
I_2M_2	8.85	7.31	8.08
I_2M_3	8.00	6.57	7.29
I_3M_1	7.54	6.52	7.03
I_3M_2	7.35	6.44	6.90
I_3M_3	6.67	6.08	6.38
S.Em. ±	0.15	0.29	0.25
CD @ 5%	NS	NS	NS
I_1:Drip irrigation @ 60% ET	M_1:White polythene mulch		
I_2:Drip irrigation @ 80% ET	M_2:Black polythene mulch		
I_3:Drip irrigation @100%ET	M_3:Without mulching (Control)		

Application efficiency

The data pertaining to water application efficiency of cucumber is provided in Table 3. The application efficiencies were higher in 80% ET i.e., 94.68, 95.00 and 94.84 during 2020-21, 2021-22 and pooled data, respectively. This was followed by 60% ET and 100% ET.

The application efficiencies were on par with each other in all the drip irrigation treatments, I_1, I_2 and I_3. The above findings of application efficiency under the present study agree with the earlier findings of Nakayama and Bucks (1986) [10]. The higher application efficiency in drip irrigation may be due to the fact that through drip irrigation, water is applied as required by plant, thus the percolation losses will be zero, below the crop root zone and the surface runoff losses would be very negligible.

Table 3: Effect of drip irrigation and plastic mulching on water application efficiency in cucumber

Treatment details	Water application efficiency (%)		
	2020-21	2021-22	Pooled
Irrigation treatments (I)			
I_1: Drip irrigation @ 60% ET	94.45	94.50	94.48
I_2: Drip irrigation @ 80% ET	94.68	95.00	94.84
I_3: Drip irrigation @ 100% ET	93.80	94.00	93.90

Summary and conclusions

The yield per plot, yield per 1000 square meter and yield per ha was higher with drip irrigation at 100% crop ET and white polythene mulch. The water use efficiency was highest in treatment consisting of drip irrigation at 60% crop ET with white polythene. The water application efficiencies were higher with 80% ET.

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