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Efficacy of fertigation on yield, water use efficiency and nutrient use efficiency of cucumber (*Cucumis sativus* L.) under protected structure

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Abstract
A field experiment was carried out under naturally ventilated polyhouse during 2020-21and 2021-22 at Zonal Agricultural and Horticultural Research Station (ZAHRS), Keladi Shivappa Nayaka University of Agricultural and Horticultural Sciences (KSNUAHS) Navile, Shivamogga. The experiment consisted of 4 treatment combinations with 6 replications in CRD design. The treatments included four levels of fertilizer application viz. 50%, 75%, 100% RDF through fertigation and 100% RDF through soil application. Water applied was common for all the treatments and it was 100% crop ET. The highest crop yield was recorded in the treatment receiving 100% crop ET with 100% RDF through fertigation. i.e., 111.70 t ha^{-1}. The water use efficiency was highest in treatment consisting of drip irrigation at 60% crop ET and nutrient use efficiency was highest in the treatment receiving 100% crop ET with 100% RDF through fertigation (587.89 kg ha^{-1}).

Keywords: Fertigation, yield, water use efficiency, nutrient use efficiency and nutrient uptake

Introduction
Cucumber is one of the oldest grown vegetable crops possibly originating in India. Cucumber is an incredibly low-calorie food, containing just 15 calories per 100 g. It contains high content of water which makes cucumber an ideal food for hydration and cooling. This is a very good source of potassium, vitamin K and other special antioxidants that are essential for the human body's brain, heart and urinary system (Sikarwar and Hardaha 2016) [22].
Fertigation is the application of water-soluble solid fertilizer applied through drip irrigation directly to the root zone plant. It increases the fertilizer efficiency by saving fertilizer. In polyhouse technique yield of crop increased but proper water and fertilizer management will be necessary. The present work was conducted to study the effect of irrigation and fertigation levels on growth and yield of cucumber crop under NVP in order to find out best combination of water and fertilizer treatment.

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.
The experiment consisted of 4 treatments i.e., T_1:50 percent of RDF through fertigation, T_2:75 percent of RDF through fertigation, T_3: 100 percent of RDF through fertigation and T_4:100 percent of RDF through soil application. The experiment had six replications and the design adopted was RCBD.
The recommended levels of fertilizer for cucumber crop are as follows. N: 60 kg ha^{-1}, P_2O_5: 50 kg ha^{-1} and K_2O: 80 kg ha^{-1}. The liquid fertilizer was applied by using the venturi fitted in the main line.

Land preparation
The selected experimental land inside the polyhouse was brought to fine tilth and as per the plan 8 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.

Mulching
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) [18] in kg ha^{-1} mm^{-1}.

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

Nutrient use efficiency (NUE)
The nutrient use efficiency was calculated for each treatment separately for the macro nutrient components, i.e., N, P, and K (Dobermann, 2007) [7].

$$\text{Nutrient use efficiency (NUE)} = \frac{\text{Crop yield (kg ha}^{-1}\text{)}}{\text{Total nutrient applied (N, P and K) (kg ha}^{-1}\text{)}}$$

Nutrient uptake by the crop
Nutrient uptake by cucumber crop was computed from their respective nutrient concentration and expressed in kg ha^{-1} for major nutrients.

$$\text{Nutrient uptake (kg ha}^{-1}\text{)} = \frac{\text{Nutrient Concentration (\%)} \times \text{Biomass (kg ha}^{-1}\text{)}}{100}$$

Statistical Analysis
The data on the observations made and characters studied were statistically analyzed by CRD design. 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 parameters
The data pertaining to yield per plot of cucumber are presented in Table 1. Highest yield per plot was observed in the treatment consisting of 100% RDF through fertigation. i.e., 66.78 kg, 78.43 kg and 72.61 kg during 2020-21, 2021-22 and pooled data, respectively. Lowest yield per plot was (54.60 kg, 63.70 kg and 59.15 kg during 2020-21, 2021-22 and pooled data, respectively) in treatment T_4 i.e., 100% RDF through soil application.
The enhanced supply of nutrients through increased fertigation levels at the root vicinity of plant, maintains optimum nutrient concentration in the root zone throughout the crop growth period. This increases the uptake of moisture and nutrients which resulted increased the yield attributes of cucumber. Similar results were also reported by Sharma *et al*. (2009), Dai *et al*. (2011) and Zhang *et al*. (2011) [19, 6, 25]. Chand (2014) [4] who found the significant effect of fertigation levels on fruit number per plant for polyhouse cucumber. Similar result was also reported by Choudhari and More (2002), Surve *et al*. (2002) [5, 23] for cultivation of cucumber in open field.
There is a significant difference in the yield per 1000 square meter during both the years and in pooled data. The data is presented in Table 1. Highest yield per 1000 square meter was observed in the treatment consisting of 100% RDF through fertigation. i.e., 10.27 t, 12.07 t and 11.17 t during 2020-21, 2021-22 and pooled data, respectively. Lowest yield per 1000 square meter was (8.40 t, 9.80 t and 9.10 t during 2020-21, 2021-22 and pooled data, respectively) in treatment T_4 i.e., 100% RDF through soil application.
There is a significant difference in the yield per hectare during both the years and in pooled data. The data is presented in Table 1. Highest yield per hectare was observed in the treatment consisting of 100% RDF through fertigation. i.e., 102.70 t ha^{-1}, 120.70 t ha^{-1} and 111.70 t ha^{-1} during 2020-21, 2021-22 and pooled data, respectively. Lowest yield per hectare was (84.00 t ha^{-1}, 98.00 t $ha^{-1}$and 91.00 t ha^{-1} during 2020-21, 2021-22 and pooled data, respectively) recorded in treatment consisting of 100% RDF through soil application.
The probable reason for enhanced yield might be due to cumulative effects of nutrient on vegetative growth which ultimately led to many physiological activities like increased uptake of nutrients, photosynthetic rate, vigorous growth, efficient translocation and partitioning of assimilates towards

reproductive sink, which might have directly influenced the increase in yield and its characters.

Increased yield could be largely attributed to proper micro climatic condition due to the green-house cover, which led to increased plant growth, which further lead to increased nutrient uptake and its absorption. These results are in agreement with results obtained by Fonsecal *et al*. (2003) [10]. Optimal root zone temperature conditions allow for adequate root function including proper uptake of water and nutrients El-Shinawy (1997) [9].

These findings are similar to the findings of Arinderpal Kaur *et al*. (2019), Pramod Kumar, *et al*. (2020) and Akanksha *et al*. (2020) in cucumber. Prabu *et al*. (2016) in chilly and Vasanthi *et al.* (2017) [3, 16, 1, 15, 24] in tomato.

Water use efficiency

The water use efficiency is the production, per unit cm of water applied. The water use efficiency as influenced by different levels of fertigation is presented in Table 2. Highest water use efficiency was observed in the treatment consisting of 100% RDF through fertigation. i.e., 7.44 t ha^{-1} cm^{-1}, 8.75 t ha^{-1} cm^{-1} and 8.09 t ha^{-1} cm^{-1}during 2020-21, 2021-22 and pooled data, respectively. Lowest water use efficiency was recorded (6.09 t ha^{-1} cm^{-1}, 7.10 t ha^{-1} cm^{-1} and 6.59 t ha^{-1} cm^{-1} during 2020-21, 2021-22 and pooled data, respectively) in treatment consisting of 100% RDF through soil application.

Highest water use efficiency in 100% RDF through fertigation and lowest water use efficiency in 100% RDF through soil application may be due to higher yield levels. For both the treatments, equal quantity of water was applied with similar quantity of RDF applied through different mode of fertilizer application. Application of 100% RDF through fertigation gave higher yield compared to 100% RDF through soil application.

Drip irrigation significantly increased the crop yield of cucumber and improved water use efficiency due to consumption of less irrigation water. However, integrated use of drip irrigation, at 100% RDF through fertigation was more appropriate and profitable. Therefore, drip irrigation in combination with 100% RDF through fertigation and plastic mulch, was found to be more effective method in improving WUE and also increasing the crop yield of cucumber.

Chand (2014) [4] also found the similar water use efficiency results for cucumber in polyhouse. Similar result were documented by Dunage *et al*. (2009) [8] in tomato.

Nutrient use efficiency of cucumber

The results on nutrient use efficiencies are depicted in Table 3. Highest nutrient use efficiency was observed in the treatment consisting of 100% crop ET with 100% RDF through fertigation. i.e., 540.53 kg ha^{-1}, 635.26 kg ha^{-1} and 587.89 kg ha^{-1} of nutrients applied during 2020-21, 2021-22 and pooled data, respectively. The lowest nutrient use efficiency was (442.11 kg ha^{-1}, 515.79 kg ha^{-1} and 478.95 kg ha^{-1} of nutrients applied during 2020-21, 2021-22 and pooled data, respectively) in treatment consisting of 100% crop ET with 100% RDF through soil application.

When fertilizer was applied through drip irrigation, it was observed that the yield has been increased and about 30 percent of the fertilizer could be saved (Sivanappan and Ranghaswami 2005) [21]. Fertigation is one of the most effective method of supplying nutrients and water according to the specific requirements of the crop to maintain optimum soil fertility and to increase the quality of the produce. (Shirgure *et al.*, 1999) [20]. Fertilizer application, ensures application of the fertilizers directly to the plant roots (Rajput and Patel 2002) [17]. Fertigation allows nutrient placement directly into the plant root zone during critical periods of nutrient demand.

Similer trends in irrigation and fertigation was also observed by AI-Wabel *et al*. (2002), Haltlgl *et al*. (2002), Chand (2014) and Mangal and Gadge (2016) [2, 11, 4, 13] in cucumber.

Nutrient uptake (N, P and K) of cucumber

The results on nutrient uptake (N, P and K) are depicted in Table 4. Highest nitrogen uptake was observed in the treatment consisting of 100% crop ET with 100% RDF through fertigation. i.e., 47.53 kg ha^{-1}, 49.07 kg ha^{-1} and 48.30 kg ha^{-1} of nitrogen applied during 2020-21, 2021-22 and pooled data, respectively. Lowest nitrogen uptake was (36.40 kg ha^{-1}, 34.43 kg ha^{-1} and 35.41 kg ha^{-1} of nitrogen applied during 2020-21, 2021-22 and pooled data, respectively) was recorded in treatment consisting of 100% crop ET with 100% RDF through soil application.

Highest phosphorus uptake was observed in the treatment consisting of 100% crop ET with 100% RDF through fertigation. i.e., 9.20 kg ha^{-1}, 8.43 kg ha^{-1} and 8.82 kg ha^{-1} of phosphorus applied during 2020-21, 2021-22 and pooled data, respectively. Lowest phosphorus uptake was (6.88 kg ha^{-1},7.50 kg ha^{-1} and 7.19 kg ha^{-1} of phosphorus applied during 2020-21, 2021-22 and pooled data, respectively) was recorded in treatment consisting of 100% crop ET with 100% RDF through soil application.

Similarly, highest potassium uptake was observed in the treatment consisting of 100% crop ET with 100% RDF through fertigation. i.e., 44.47 kg ha^{-1}, 45.23 kg ha^{-1} and 44.85 kg ha^{-1} of potassium applied during 2020-21, 2021-22 and pooled data, respectively. The lowest potassium uptake was (34.38 kg ha^{-1}, 33.13 kg ha^{-1} and 33.75 kg ha^{-1} of potassium applied during 2020-21, 2021-22 and pooled data, respectively) was recorded in treatment consisting of 100% crop ET with 100% RDF through soil application

When fertilizers are applied through drip irrigation, it was observed that the yield increased and about 30 percent of the fertilizer could be saved (Sivanappan and Ranghaswami., 2005) [21]. Fertigation is one of the most effective convenient methods of supplying nutrients and water according to the specific requirements of the crop to maintain optimum soil fertility and to increase the quality of the. Fertigation allows nutrient placement directly into the plant root zone during critical periods of nutrient demand.

Similar results for nutrient uptake were documented by Hashem *et al*., (2011) and Chand (2014) [12, 4] in cucumber.

Table 1: Yield per plot, yield per 1000 square meter and yield per hectare of cucumber as influenced by different levels of fertigation

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
T_1	60.23	68.47	64.35	9.27	10.53	9.90	92.70	105.30	99.00
T_2	62.70	71.07	66.89	9.65	10.93	10.29	96.50	109.30	102.90
T_3	66.78	78.43	72.61	10.27	12.07	11.17	102.70	120.70	111.70
T_4	54.60	63.70	59.15	8.40	9.80	9.10	84.00	98.00	91.00
S.Em. ±	0.91	1.23	0.87	0.14	0.19	0.13	1.40	1.90	1.30
C.D.@5%	2.71	3.66	2.58	0.42	0.56	0.40	4.20	5.60	4.00

T1: 50% RDF through fertigation T2: 75% RDF through fertigation
T3: 100% RDF through fertigation T4:100% RDF through soil application

Table 2: Water use efficiency of cucumber as influenced by different levels of fertigation

Treatment details	Water use efficiency (t ha^{-1}cm^{-1})		
	2020-21	2021-22	Pooled
T_1: 50% RDF through fertigation	6.72	7.63	7.17
T_2: 75% RDF through fertigation	6.99	7.92	7.46
T_3: 100% RDF through fertigation	7.44	8.75	8.09
T_4:100% RDF through soil application	6.09	7.10	6.59
S.Em. ±	8.48	10.68	11.26
C.D. @ 5%	25.19	31.73	33.47

T1: 50% RDF through fertigation T2: 75% RDF through fertigation
T3: 100% RDF through fertigation T4:100% RDF through soil application

Table 3: Nutrient use efficiency of cucumber as influenced by different levels of fertigation

Treatment details	N+P+K (kg ha^{-1})		
	2020-21	2021-22	Pooled
T_1	487.89	554.21	521.05
T_2	507.89	575.26	541.58
T_3	540.53	635.26	587.89
T_4	442.11	515.79	478.95

T1: 50% RDF through fertigation T2: 75% RDF through fertigation
T3: 100% RDF through fertigation T4:100% RDF through soil application

Table 4: Nutrient uptake NPK (kg ha^{-1}) in cucumber as influenced by different levels of fertigation

Treatment details	N (kg ha^{-1})			P (kg ha^{-1})			K (kg ha^{-1})		
	2020-21	2021-22	Pooled	2020-21	2021-22	Pooled	2020-21	2021-22	Pooled
T_1	37.25	36.63	36.94	6.90	6.59	6.75	41.40	42.17	41.78
T_2	42.90	41.68	42.29	8.13	7.82	7.97	44.47	42.93	43.70
T_3	47.53	49.07	48.30	9.20	8.43	8.82	44.47	45.23	44.85
T_4	36.40	34.43	35.41	6.88	7.50	7.19	34.38	33.13	33.75

T1: 50% RDF through fertigation T2: 75% RDF through fertigation
T3: 100% RDF through fertigation T4:100% RDF through soil application

Conclusions

Highest crop yield was recorded in the treatment receiving 100% crop ET with 100% RDF through fertigation. i.e., 102.70 t ha^{-1}, 120.70 t ha^{-1} and 111.70 t ha^{-1} during 2020-21, 2021-22 and pooled data, respectively. Maximum water use efficiency was observed in treatment consisting of 100% crop ET with 100% RDF through fertigation. i.e., 7.44 t ha^{-1} cm^{-1}, 8.75 t ha^{-1} cm^{-1} and 8.09 t ha^{-1} cm^{-1} during 2020-21, 2021-22 and pooled data, respectively. Highest nutrient use efficiency was recorded in the treatment receiving 100% crop ET with 100% RDF through fertigation. i.e., 540.53 kg ha^{-1}, 635.26 kg ha^{-1} and 587.89 kg ha^{-1} of nutrients applied during 2020-21, 2021-22 and pooled data, respectively. Highest nitrogen uptake was observed in the treatment consisting of 100% crop ET with 100% RDF through fertigation. i.e., 47.53, 49.07 and 48.30 kg ha^{-1} of nitrogen applied during 2020-21, 2021-22 and pooled data, respectively. Highest phosphorus uptake was observed in the treatment consisting of 100% crop ET with 100% RDF through fertigation. i.e., 9.2, 8.43 and 8.82 kg ha^{-1} of phosphorus applied during 2020-21, 2021-22 and pooled data, respectively. Similarly, highest potassium uptake was observed in the treatment consisting of 100% crop ET with 100% RDF through fertigation. i.e., 44.47, 45.23 and 44.85 kg ha^{-1} of potassium applied during 2020-21, 2021-22 and pooled data, respectively.

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