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Nutrient and Water Use Efficiency of Cucumbers Grown in Soilless Media under a Naturally Ventilated Greenhouse

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ABSTRACT

Cucumbers were planted in soilless media in a split plot design with three replicates under a naturally ventilated greenhouse to study nutrient and water use efficiency in relation to fertigation management. Three fertigation levels (F1-100%, F2-85% and F3-70%) and three varieties (V1-Kafka, V2-Multistar and V3-PBRK-4) were applied to the main and subplots in the experiment. The amount of irrigation water applied for growing cucumbers was computed to be 2559.4 m^3 ha^{-1}. The Nutrient Use Efficiency (NUE) of macro and micro nutrients was computed to be in the order of S> P> Mg> N> Ca> K and Cu≥ Mo> Zn> B> Mn> Fe, respectively. Among the varieties, *NUE* in V2 remained statistically higher than V3 for each level of fertigation. Similarly, among fertigation levels, *NUE* under F3 remained statistically higher than F1 for each variety. Among interactions, *NUE* under treatment F3V2 was statistically higher than F2V3, F1V2, F1V1, and F1V3, respectively. Irrigation Water Use Efficiency (IWUE) was found significantly higher (51.4 kg m^{-3}) under treatment F1V2 than F3V3 (34.5 kg m^{-3}). Crop Water Use Efficiency (CWUE) was also found statistically different both among fertigation levels and varieties, having highest and lowest values of 179.9 and 120.6 kg m^{-3} under treatment F1V2 and F3V3, respectively. Thus, growing offseason seedless cucumbers in soilless media inside a naturally ventilated greenhouse, where the environment was partially under control, helped in improving nutrient and water use efficiency compared to conventional cultivation.

Keywords: Crop water use efficiency, Irrigation water use efficiency, Nutrient use efficiency, Offseason cucumber.

INTRODUCTION

Water and nutrients are two critical inputs for plant growth, particularly in soilless production system, and their uptake by plants are two independent processes (Viets, 1972). Fertigation in soilless media is irrigation where fertilizers are dissolved in water. Soilless cultivation can provide a more efficient use of water and nutrients (Jensen, 1997) as fertigation allows an accurate and uniform application of nutrients directly to the active root system (Rouphael *et al*., 2008). Moreover, protective cultivation may reduce water and nutrient consumption by 22% and 35%, respectively, in cucumber production (Tuzel *et al.*, 1999). The soilless cultivation overcomes the soil borne diseases (Hussain *et al.*, 2014) and allows cultivation of crops in the areas where regular production would not be possible (Jensen, 1999).

Greenhouse cucumber plants have rapid vegetative and reproductive growth rates, high water and nutrient uptake rates, and large root masses (Sutherland, 1988). At the early growth stages, the greenhouse cucumber grows very slowly, so, the requirement for water is also low, and the capacity of water uptake by roots is limited (Zotarelli *et al.*, 2009). Numerous researchers have studied the effect of irrigation amount (Howell *et al.*, 1990; Mao *et al.*, 2003; Amer *et al.*, 2009; Song *et al.*, 2010; Alomran *et al.*, 2013;

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Salcedo *et al.,* 2017) and fertilizer coupled irrigation (Papadopoulos, 2001; Ahmet *et al.*, 2006; Zhang *et al.*, 2011) on cucumber yield and Water Use Efficiency (WUE). Mao *et al.* (2003) reported that *WUE* decreases with increasing level of irrigation water applied from fruiting to the end of the growth stage. However, it increases with increase in irrigation water from cucumber fruit setting to the initial fruit repining stage. After studying the effect of irrigation intervals (2 and 4 days) and plant-pan coefficients (0.75, 1.00, 1.25 and 1.50) on cucumber cultivation in a greenhouse, Cakir *et al.* (2017) reported Irrigation Water Use Efficiency (IWUE) and Crop Water Use Efficiency (CWUE) values of, respectively, 56.0 kg m^{-3} and 42.0 kg m^{-3} with least applied irrigation water amounts. While investigating the effect of deficit irrigation (40, 60, 80, and 100% ET_c) on soil salinity, crop response factor (K_y), Crop Water Productivity (CWP) and yield of cucumber, Alomran *et al*. (2013) reported that the soil salinity increased with decreased applied water and the water used in 100.0% ET_c treatment was much lower compared to that in the traditional drip irrigation as practiced by farmers. According to Yaghi *et al*. (2013), drip irrigation (or fertigation) in the presence of plastic mulch helps in improving cucumber yield and *WUE*. Further, a better irrigation scheduling method in conjunction with drip irrigation may save about 20% irrigation water application in row crops (EU Water Saving Potential, 2007). While studying the effect of water deficit (water potential of 15, 30, 60, and 120 kPa) on production of Japanese cucumber inside a greenhouse, Oliveira *et al*. (2011) reported a decreased yield of cucumber with increasing water potential. Therefore, judicious use of the available water through more efficient methods of water application like drip irrigation under protected cultivation becomes necessary to enhance the yield and water use efficiency (Dunage *et al.,* 2009; Arshad, 2017).

A continuous effort has been made in the past to study the performance of cucumber cultivation (Sanchez-Guerrero *et al.,* 2009; Pahlavan *et al*., 2012; Hussain *et al.,* 2014) under different growing conditions. However, the soil borne diseases have limited the crop production in greenhouses (Baysal-Gurel *et al.,* 2012). The soilless cultivation is, therefore, a possible alternative for sustainable vegetable production, which reduces the soil related problems experienced in the conventional crop cultivation (Olympious, 1995; Hussain *et al.*, 2014). Due to this reason, the soilless cultivation has significantly increased during the last couple of decades (Gul *et al.,* 1999; Huber *et al.,* 2005; Al-Mulla *et al.,* 2008; Grewal *et al*., 2011; Zhang *et al.,* 2012; Mazahreh *et al.,* 2015) than soil based cultivation. The soilless growing media are easier to handle and may provide a better growing environment compared to the soil (Mastouri *et al.,* 2005). Soilless cultivation also offers other benefits such as the capability to control water availability, pH, and nutrient concentration in the root zone (Epstein and Bloom, 2005). While studying the effect of eight different compositions of growing media (perlite and its mixture) with organic substrates on cucumber cultivation, Samadi (2011) reported a significant effect on fruit yield, plant height, and leaf area of cucumber with best performance in fine-grade perlite. Among several soilless growing media, cocopeat has high Water Holding Capacity (WHC) and air filled porosity which in turn results in very high seed germination rate and produces stronger and fibrous seedlings (Fornes *et al.*, 2003).

The present study was thus undertaken to explore the nutrient and water use efficiencies of greenhouse seedless cucumber production in soilless media under partially controlled greenhouse conditions.

MATERIALS AND METHODS

Study Site and Climate

An experimental trial was conducted inside a naturally ventilated greenhouse located at research farm of the Department of Soil and Water Engineering, Punjab Agricultural University (PAU), Ludhiana. PAU is situated

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between latitude 30° 56´ N and longitude 75° 52´ E with an altitude of 247 m above mean sea level. The areal extent of the main campus of PAU is about 1510 acres having a general slope from North-East to South-West direction.

Ludhiana district falls in the central part of Indian Punjab and is bounded between latitude 30° 33´´ to 31° 01´´ N and longitude 75° 25´´ to 76° 27´´ E having a geographical area of 3,767 km^2. The climate of the district is categorized as tropical steppe, hot and semi-arid, which mainly remains dry with very hot summer and cold winter climatic conditions, except during monsoon. The rainfall distribution of the district is uneven, contributing to a normal annual rainfall of 680 mm. About 70-80% of annual rainfall is contributed by south-west monsoon, which mainly occurs from June to September (July and August being the wettest months).

Greenhouse Characteristics

The dimensions of the greenhouse along north-south and east-west directions were 28 and 20 m, respectively, with a surface area of the floor 560 m^2. The greenhouse had 200 µm thickness of plastic cover, oriented in a North-South direction, with a height of 6.5 and 3.5 m at center and gutter, respectively. A total 30% area of the greenhouse cover was facilitated with natural ventilation (20% sides and 10% top). The greenhouse included a thermal shade net at 2.84 m height from the greenhouse floor. Foggers were also installed at the height of 2.0 m above the greenhouse floor.

Treatments and Experimental Setup

The experiment was laid in a split plot design with fertigation and cucumber varieties in the main and subplots, respectively. Fertigation included three levels *viz*. F1-100%, F2-85%, and F3-70% of complete nutrient solution required under optimal microclimatic conditions. Three varieties of cucumber *viz.* V1-Kafka, V2-Multistar, and V3-PBRK-4 were planted in three replications. The complete design of the experimental trial including fertigation system is shown in Figure 1.

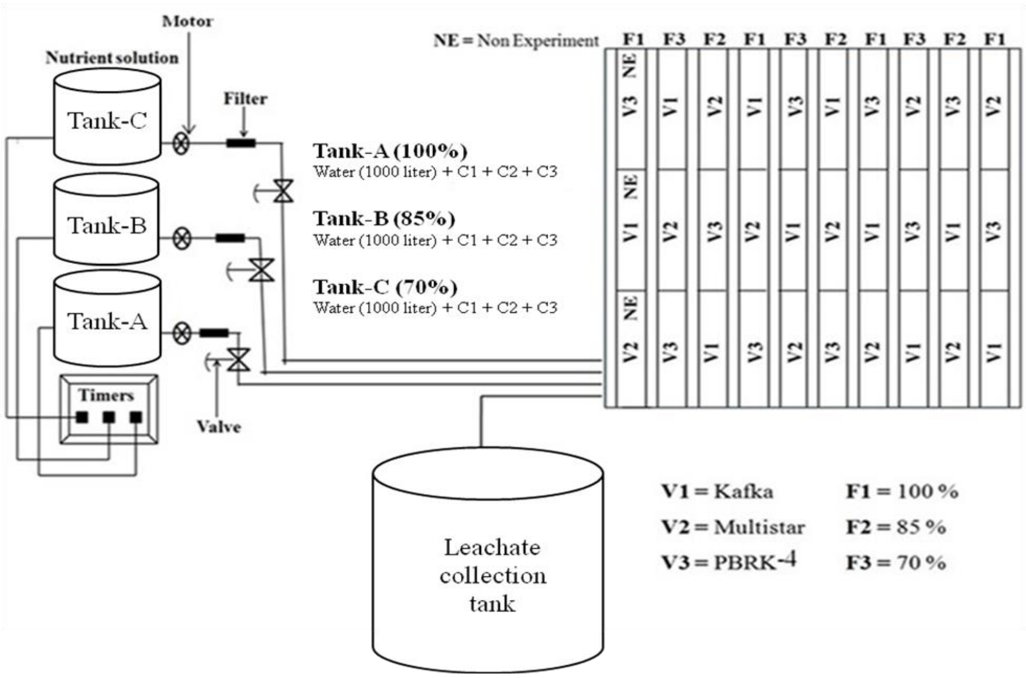

Figure 1. Schematic of experimental trial including fertigation system.

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A gap of 2.0 m was kept around the inside boundary of the greenhouse. The entire surface area of the greenhouse floor was covered with plastic weed mat for the avoidance of weed emergence. Plastic troughs were laid on the beds above weed mat. The spacing trays were then laid on the troughs, above which the coco-peat slabs were placed. The original dimensions (length × width × height) of a coco-peat slab were 97.5×15.0×2.8 cm. The coco-peat slabs were saturated for at least 24 hours before transplanting. After saturation, the dimensions of a coco-peat slab changed to 100.0×15.0×10.0 cm. Thus, after saturation, the volume of each slab was 3.8 times the original volume. The physiochemical properties of the growing media *viz*. particle density, air filled porosity, field capacity, Electrical Conductivity (EC) and pH values were 3.28 g cm^{-3}, 29.05%, 46.11%, 2.80 dS m^{-1}, 5.65, respectively. The experimental set up of the greenhouse before transplanting is shown in Figure 2.

Nursery raising and transplanting

The nursery sowing of cucumber was done on 6^{th} September, 2016, under an insect proof poly net house. The nursery was raised in a coco-peat media fully saturated with a nutrient solution before placement of seeds. The seed was treated before sowing. After emergence, partial shading was given to the plants through operation of shade net. A total of 648 ready cucumber plants were transplanted at 3-4 leaf stage in coco-peat slabs saturated with nutrient solution for at least 24 hours and the planting density was kept as 3 plants m^{-2}. The plants were trained vertically using nylon strings attached to the roller hooks. Pruning of cucumber plants was done at a regular interval by removing older leaves and branching stems, thereby keeping the main stem alone. Fruit thinning was also done to keep a single fruit at each node along with a single leaf.

Irrigation and Fertigation Management

The cucumber crop was fertigated with nutrient solution for a predetermined time on a daily basis throughout the crop growth period through a semi-automated fertigation system (Figure 1). The differential fertigation was started on the day of

Figure 2. Experimental set-up for soilless cucumber cultivation.

transplanting. The complete system included three tanks each having a Capacity≥ 1,000 L for three different levels of fertigation. Three electric motors, each having a power of 1 hp were installed for running the individual fertigation system to deliver nutrient solution (≤ 2.0 L h^{-1} d^{-1}) at an Operating pressure≤ 1.5 kg cm^{-2}. For safe delivery of the nutrient solution, the operating pressure of emitters was regulated using pressure gauge (0 to 7 kg cm^{-2}). The time to operate the fertigation system was set in the timers for a pre-determined time. The nutrient solution was passed through filters to prevent clogging of emitters. An inverter was also provided for running the fertigation system in the absence of electricity.

Preparation of Nutrient Solution

The nutrient solution was prepared by making a common solution of macro and micro nutrients in 1000 L of water each time. The macro nutrients included Nitrogen (N), Phosphorus (P) and potassium (K), Calcium (Ca), Magnesium (Mg) and Sulfur (S). The micro nutrients, included Boron (B), iron (Fe), Manganese (Mn), Copper (Cu), Zinc (Zn) and Molybdenum (Mo). The preparation of the nutrient solution for 100% (F1) level of fertigation is shown in Figure 3.

In Figure 3,

C1= Container-1 having solution of phosphates and sulfates free fertilizers

C2= Container-2 having solution of calcium free fertilizers

C3= Container-3 having phosphoric acid (C3)

Thus, *Nutrient solution= Water (1000 L)+C1+C2+C3*

The pH and *EC* values of nutrient solution and soilless media were monitored using digital waterproof testers (HI 98130 and HI 98331) of HANNA instruments. Phosphoric acid (86 %) was used (0.260 mL L^{-1} of nutrient solution) for adjustment of pH and *EC* value of the nutrient solution.

For safe disposal of the leachate coming out of coco-peat media, a slope of 1% was given to the greenhouse floor along the length in a North-South direction. The leachate was expelled through underground pipeline system and collected outside the greenhouse in a separate tank, which was further filtered and reused for fertigating cucumbers.

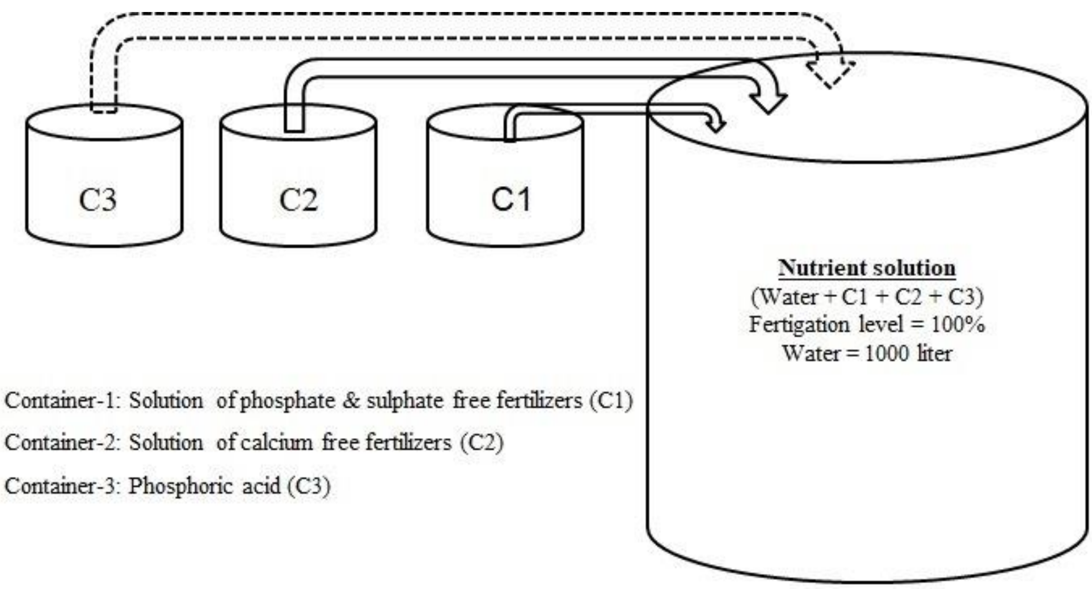

Figure 3. Preparation of nutrient solution for one level of fertigation (100%).

Source of Irrigation Water

The water for irrigation and fertigation was supplied either directly from the ground water through a bore or from water harvested in a pond (10×10×3 m^3) constructed outside the greenhouse. The water supplied from the pond was passed through a filtration system containing primary (sand filter) and secondary filtration units. The pond water was tested for its quality and found fit for irrigation.

Coefficient of Uniformity

The emitters were calibrated for their proper working regarding their discharge rate and coefficient of consistency. For this purpose, at a regular interval, emitters were selected for their discharge measurement at a known operating pressure and coefficient of uniformity was calculated.

Nutrient Use Efficiency (NUE)

The volume of nutrient solution applied per plant was recorded on daily basis and the concentration of each nutrient in the applied nutrient solution was known. The quantity of each applied nutrient per plant was computed by multiplying the mean nutrient concentration in the applied solution with the volume of nutrient solution applied to a plant. *NUE* was calculated according to Jisha Chand (2014) using the equation (1).

$$NUE = \frac{\text{Yield (g plant}^{-1}\text{ or kg ha}^{-1})}{\text{Nutrient applied (g plant}^{-1}\text{ or kg ha}^{-1})} \quad (1)$$

Water Use Efficiency

Water use efficiencies *viz*. Irrigation Water Use Efficiency (IWUE, kg m^{-3}) and Crop Water Use Efficiency (CWUE, kg m^{-3}) were calculated using the methods reported in Cakir *et al*. (2017) and Buttaro *et al*. (2015) (equations 2 and 3).

Irrigation Water Use Efficiency (IWUE)

$$IWUE = \frac{\text{Yield (kg plant}^{-1})}{\text{Irrigation water applied (m}^{3}\text{plant}^{-1})} \quad (2)$$

Crop Water Use Efficiency (CWUE)

$$CWUE = \frac{\text{Yield (kg plant}^{-1})}{\text{Crop water use (m}^{3}\text{plant}^{-1})} \quad (3)$$

Disease Management

The white fly incidence was noticed at 16 Days After Transplanting (DAT). For quicker action, yellow sticky traps were installed and, secondly, a spray of Polo (Diafenthiuron 50% WP) with concentration of 1 g per liter was done for control of white fly prevalence.

Data Analysis

The data on crop growth parameters and yield was analyzed using SAS 9.3 Proc-GLM procedure. Tukey test was used to compare the treatment means at 95.0% level of significance**.**

Greenhouse Micro Climate

The climatic parameters *viz.* temperature, relative humidity, and solar radiation were monitored and evaluated during the crop growth period as suggested by Singh *et al*. (2016) and Singh *et al*. (2017a). The greenhouse was naturally ventilated provided with no artificial heating arrangement throughout the crop growth period. The microclimate was partially controlled and optimum day air temperature for plant growth was in the range of 20-30°C between 10:30 am to 17:30 pm. Three commonly used techniques *viz*. natural ventilation, shading and evaporative

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cooling as reported in Singh *et al*. (2018) were initially used for achieving desired microclimatic conditions inside the naturally ventilated greenhouse and thereafter the microclimate was modeled mathematically (Singh *et al*., 2018c; Singh *et al*., 2018d). The inside temperature was favorable for plant growth till 40 DAT (> 20°C) and was below the optimum range during the rest of the period with a linear decrease. Both inside and outside temperatures were negatively correlated (R^2= 0.86) to DAT through the growth period. Inside the greenhouse, the average maximum and minimum air temperatures during the growing season were 24.4 and 14.0°C, respectively, at 19 and 67 DAT.

During this time interval, the radiation level was in the range of 9.0-183.0 W m^{-2}. Likewise, the optimum relative humidity was observed in the range of 39.1-77.4%. There was a significant variation in air temperature vertically within the plant community, under the effect of operating conditions of thermal shade net above plant community and natural ventilation from sides. The root zone temperature of cucumber in soilless media was also negatively correlated (R^2= 0.89) with time (DAT) and decreased linearly as the season progressed. However, the minimum root zone temperature was 13.7°C (at 83 DAT), which was above the optimum range suggested by Salokangas (1973) for plant growth and the maximum root zone temperature was 24.9°C at 20 DAT.

RESULTS AND DISCUSSION

Cucumber Growth Parameters

The height of cucumber plant under treatment F2V2 was significantly higher than F1V1 and F3V1. The leaf area index which ranged from 0.9 to 3.7 followed a trend similar to plant height. Among the varieties, the average number of nodes per plant was highest (42) under V3 and lowest (39) in V1. The number of nodes per plant was statistically different among varieties and similar among fertigation levels, with a non-significant interaction. The fresh fruit yield (Singh *et al*., 2018b) was statistically different both among varieties and fertigation levels with a significant interaction between treatments F1V2 and F3V3. The Fruit Water Content (FWC) varied from 81.2 to 87.1%, with the highest and lowest values in V2 and V3, respectively. However, among the fertigation levels, FWC ranged from 83.3 to 84.6%, with the maximum and minimum values under fertigation level F2 and F1, respectively. Similarly, the Fruit Dry Matter (FDM) content was significantly different among varieties (V2 and V3) and similar among the fertigation levels. FDM varied from 9.2 to 27%, with minimum and maximum values in V2 and V3, respectively, for the same fertigation level (F2). The statistical parameters are presented in Table 1. The microclimatic parameters *viz*. solar radiation, temperature (air, leaf, and growing media) and humidity significantly affected the plant growth and development of greenhouse cucumber (Singh *et al*., 2017b).

Sources of Macro and Micro Nutrients

The water soluble fertilizers *viz*. calcium nitrate (N= 15.5% and Ca= 18.8%), potassium nitrate (N= 13.0% and K= 37.4%), monopotassium phosphate (P= 22.7% and K= 28.2%), potassium sulfate

Table 1. Statistical analysis of growth parameters (SAS-GLM procedure).

Parameter	R^2	*CV* (%)	*RMSE*	Mean
Plant height (ft)	0.79	5.3	0.66	12.5
IWUE (kg m^{-3})	0.75	6.61	2.78	41.99
Nodes $plant^{-1}$	0.68	5.41	2.19	40.41
PWC (%) [a]	0.61	5.93	4.97	83.81
PDM (%) [b]	0.61	30.70	4.97	16.19

[a] Percent water content, [b] Percent dry matter

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(K= 41.5% and S= 17.0%), magnesium sulfate (Mg= 9.6% and S= 13.0%), iron chelate (Fe= 12.0%), manganese sulfate (Mn= 30.5% and S= 17.0%), Zinc EDTA (Zn= 12.0%), borax or boron (B= 10.5%), copper sulfate (Cu= 24.0% and S= 12.0%) and ammonium molybdate (Mo= 52.0%) were used as the source of macro and micro nutrients. The fertilizer doses were calculated according to the growth stage of the crop (Table 2). Their amounts used per plant were 81,712.0, 19,894.4, 17,558.5, 29,792.5, 57,749.0, 515.7, 139.5, 77.4, 193.4, 16.1, and 7.4 mg plant^{-1}, respectively.

Nutrient Application

Among macro nutrients (primary and secondary), the highest (2,4749.4 mg plant^{-1}) and lowest (3,980.9 mg plant^{-1}) application rate per plant was obtained for K and P, respectively (Figure 4a). However, among micro nutrients, the highest (61.9 mg plant^{-1}) and lowest (9.3 mg plant^{-1}) application rate per plant was recorded for Fe and Mo (and Cu), respectively (Figure 4b).

Nutrient Use

The nutrient solution applied to the crop included macro (N, P, K, Ca, Mg, and S) and micro (Fe, Mn, B, Zn, Cu and Mo) nutrients in desired proportion with water. The order of nutrients applied to the crop was obtained as K> Ca> N> S> Mg> P> Fe> Mn> B> Zn> Cu≥ Mo. Table 3 indicates the quantity of macro and micro nutrients applied to cucumber in soilless media.

Nutrient Use Efficiency

Among varieties, *NUE* computed under V2 was statistically higher than V3 for each level of fertigation. However, among fertigation levels, *NUE* obtained under F3 was statistically than F1 for each variety. This implies that *NUE* was positively affected both by varieties and fertigation level and increased statistically with a decrease in fertigation level. The *NUE* of macro and micro nutrients was obtained in the order of S> P> Mg> N> Ca> K and Cu≥ Mo> Zn> B> Mn> Fe, respectively (Table 3). At 95% level of significance, *NUE* was statistically different both among varieties and fertigation levels.

Nitrogen Use Efficiency

Nitrogen use efficiency computed for V2 was found statistically higher (266.7 g plant^{-1}) than V3 (243.1 g plant^{-1}) for each level of fertigation. Among fertigation levels, the nitrogen use efficiency was statistically higher (281.8 g plant^{-1}) in F3 than F1 (229.6

Table 2. Water soluble fertilizers (dose) applied to crop.

Water soluble fertilizer	Slab saturation (mg L^{-1})	28-42 DAT (mg L^{-1})	Normal feed (mg L^{-1})	Heavy fruit load (mg L^{-1})
Calcium nitrate	1121.1	1010.0	1010.0	1010.0
Potassium nitrate	257.2	257.2	257.2	410.0
Monopotassium phosphate	227.0	227.0	220.0	220.0
Potassium sulphate	225.0	500.0	510.0	493.0
Magnesium sulphate	700.0	780.0	670.0	780.0
Iron chelate	6.667	6.667	6.667	6.667
Manganese sulphate	1.803	1.803	1.803	1.803
Zn EDTA	1.000	1.000	1.000	1.000
Borax (boron)	2.500	2.500	2.500	2.500
Copper sulphate	0.208	0.208	0.208	0.208
Ammonium molybdate	0.096	0.096	0.096	0.096

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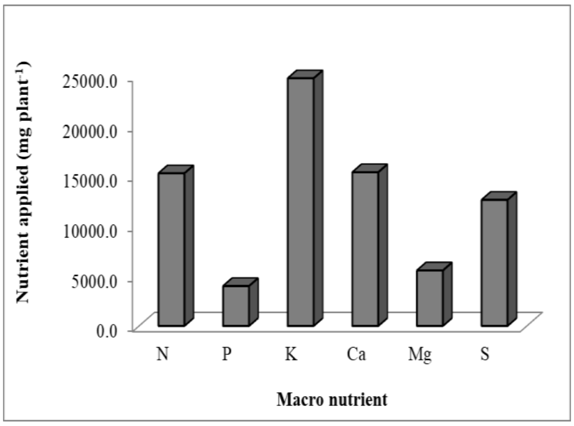
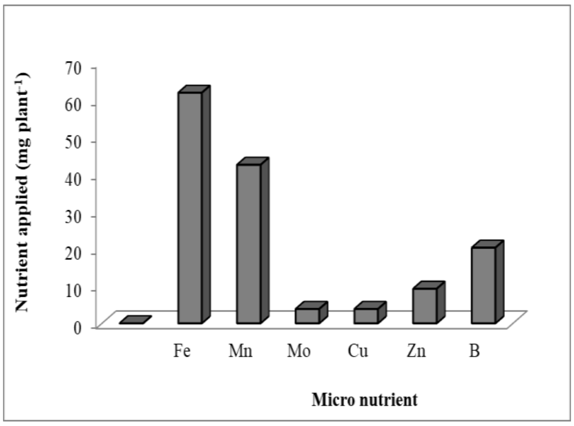
Table 3. Nutrients applied and use efficiency.

Nutrient		Nutrient applied (kg ha^{-1})	*NUE* (g $plant^{-1}$)
Macro nutrient	N	429	253.6
	P	112	971.5
	K	696.1	156.3
	Ca	432.1	251.8
	Mg	155.9	697.6
	S	354.3	8634.5
Micro nutrient	Fe	1.7	62497.8
	Mn	1.2	90924.4
	Mo	0.11	1001616.9
	Cu	0.11	1001616.9
	Zn	0.26	416672.6
	B	0.57	190478.9



a)



b)

Figure 4. Application rate of (a) Macro, and (b) Micro nutrients.

g $plant^{-1}$). However, among interactions, the nitrogen use efficiency obtained under treatment F3V2 was statistically different from F2V3, F1V2, F1V1, and F1V3. The *RMSE* and mean nitrogen use efficiency values were obtained as 18.0 g $plant^{-1}$ and 253.6 g $plant^{-1}$, respectively.

Phosphorus Use Efficiency

Phosphorus Use Efficiency (PUE) was obtained statistically higher in V2 (1,021.9 g $plant^{-1}$) than V3 (931.5 g $plant^{-1}$). Among fertigation levels, *PUE* was recorded significantly higher in F3 (1,079.6 g $plant^{-1}$) than F1 (869.8 g $plant^{-1}$). However, among the interactions, the *PUE* recorded under treatment F3V2 was statistically different from F2V3, F1V2, F1V1, and F1V3. The *RMSE* and mean *PUE* values were obtained as 69.0 and 971.5 g $plant^{-1}$, respectively.

Potassium Use Efficiency

Among varieties, the potassium use efficiency under V2 was statistically higher (164.4 g $plant^{-1}$) than V3 (149.8 g $plant^{-1}$). Among fertigation levels, potassium use efficiency under F3 (173.7 g $plant^{-1}$) was significantly higher than F1 (141.5 g $plant^{-1}$). However, among the interactions, the potassium use efficiency computed under treatment F3V2 was statistically different from F2V3, F1V2, F1V1, and F1V3. The

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RMSE and mean potassium use efficiency were computed as 11.1 and 156.3 g plant^{-1}, respectively.

Calcium Use Efficiency

Similar to primary macro nutrients (N, P, and K), the *NUE* of the secondary macro nutrients (Ca, Mg and S) also followed the same trend. The *NUE* of secondary macro nutrients was statistically different among both varieties and fertigation levels, with a significant interaction. The highest and lowest calcium use efficiencies were obtained as 264.8 and 241.4 g plant^{-1} in V2 and V3, respectively. Among fertigation levels, the maximum and minimum calcium use efficiencies were recorded to be 279.8 and 220.0 g plant^{-1} in F3 and F1, respectively.

Magnesium Use Efficiency

The highest and lowest values of magnesium use efficiency were obtained as 733.8 and 668.8 g plant^{-1} under V2 and V3, respectively. However, among fertigation levels, the highest and lowest magnesium use efficiency was computed as 775.2 and 631.8 g plant^{-1} in F3 and F1, respectively.

Sulfur Use Efficiency

Similarly, the highest and lowest values of sulfur use efficiency were computed as 9,081.8 and 8,278.3 g plant^{-1} in V2 and V3, respectively. However, among fertigation levels, the maximum and minimum values were obtained as 9,595.2 and 7,819.5 g plant^{-1} in F3 and F1, respectively.

Measurement of Irrigation Water and Nutrient Supply

Cylinders, each having a Capacity≥ 2.0 L were installed at various locations for collection and analysis of water applied per plant on daily basis. For this purpose, surplus emitters were installed for collection of irrigation water. Before applying differential fertigation, the coefficient of uniformity of emitter discharge was calculated (≥ 90.0%). The optimal gauge pressure and emitter discharge for safe application of nutrient solution were 1.25 to 1.5 kg cm^{-2} and 1.7 to 2.0 L h^{-1}, respectively. The measurement of leachate coming out of the coco-peat slabs was also done on a daily basis by the installation of collection containers at different locations. The pH and EC values of the nutrient solution were kept in the ranges of 6.0-6.40 and 2.5-3.0 dS m^{-1}. Phosphoric acid (86%) was used for lowering pH of nutrient solution

The cucumber crop was irrigated as per requirement on daily basis during the four respective growth stages. The season was divided into four stages of durations of 20, 30, 40 and 15 days, respectively (Figure 5). The average amount of irrigation water applied per plant during the growing season was 91 L, excluding nursery planting and saturation of growing media. Buttaro *et al*. (2015) also reported the irrigation water application of 71-140 L plant^{-1} to cucumber crop with an average amount of 105.5 L plant^{-1}. Nursery planting and saturation of growing media required an additional amount of 9.7 L. On average, the water applied per plant was highest during mid-season stage (44 L) followed by plant development stage (24 L) and minimum during end season stage (9 L). Figure 5 shows the irrigation water applied per plant in transplanted cucumber excluding that implemented in nursery raising and media saturation. A total of 2,559.4 m^3 ha^{-1} water was applied to cucumbers.

Irrigation and Crop Water Use Efficiency

Among varieties, the computed Irrigation Water Use Efficiency (IWUE) under V2 was statistically higher (44.1 kg m^{-3}) than V3 (40.3 kg m^{-3}). Similarly, among the fertigation levels, *IWUE* obtained under F1 was significantly higher (45.3 kg m^{-3}) than F3 (38.9

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kg m^{-3}). However, among interactions, *IWUE* computed under treatment F1V2 was significantly higher (51.4 kg m^{-3}) than F3V3 (34.5 kg m^{-3}). Cakir *et al*. (2017) obtained the *IWUE* value of about 56 kg m^{-3} with least quantity of applied irrigation water. Similar to *IWUE*, *CWUE* was also significant both among varieties and fertigation levels with a significant interaction between F1V2 and F3V3. The highest and lowest *CWUE* values were obtained to be 179.9 and 120.6 kg m^{-3} under F1V2 and F3V3, respectively. However, Buttaro *et al*. (2015) reported the *WUE* of cucumber cultivation in the range of 22.9-45.1 kg m^{-3} with an average value of 34.0 kg m^{-3}, which is lower than that obtained in the present study. On the other hand, Cakir *et al*. (2017) reported the highest *CWUE* value of about 42 kg m^{-3} with the least quantity of applied irrigation water, which is much lower than that obtained in the present case. *IWUE* and CWUE are indicated in Figures 6a and 6b, respectively.

CONCLUSIONS

Both water and nutrient use efficiencies were positively affected by fertigation level as well as varieties, with a significant interaction. Among varieties, the water and nutrient use efficiencies in Multistar remained statistically higher than PBRK-4. Growing seedless cucumbers in soilless media inside a naturally ventilated greenhouse, where the microclimate was partially controlled, helped in improving nutrient and water use efficiencies along with significant saving in nutrient and water use. Further improvements in nutrient and water use efficiencies may be achieved by growing cucumbers in soilless media under a fully controlled greenhouse environment. Besides, when the micro climate is not entirely controlled, keeping a single fruit

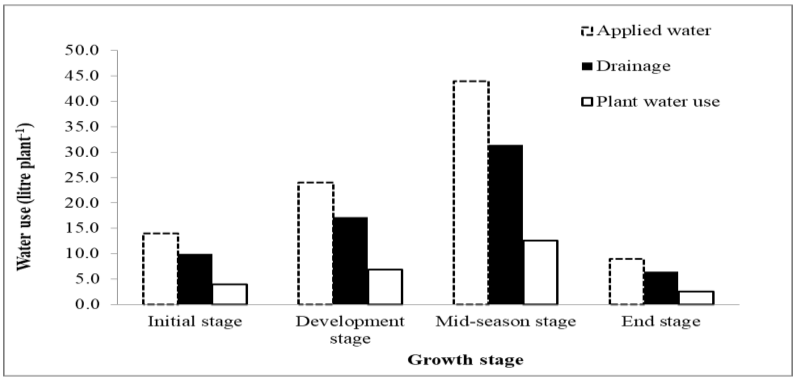

Figure 5. Stage-wise plant water use in drip fertigated soilless cucumber.

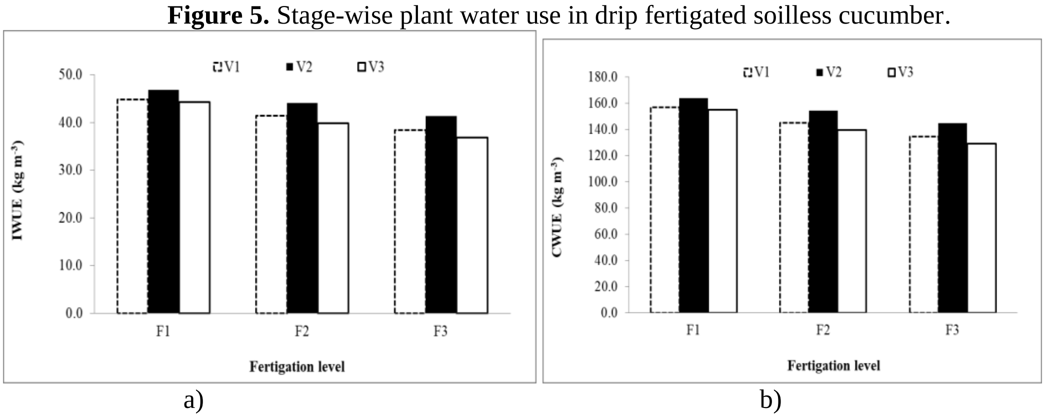

Figure 6. Water use efficiency of (a) Irrigation water applied, and (b) Crop water use.

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at each node along with a single leaf may significantly reduce cucumber yield, irrespective of the shape and quality. Under the present climate change scenarios and the problems associated with conventional cucumber cultivation (soil borne diseases) in both greenhouse and open field environments, the soilless cultivation aided with optimal greenhouse microclimatic conditions may offer the year-round cultivation to increase income through increased productivity. Thus, selection of a suitable growing media, crop management practices, irrigation or fertigation method, and optimal microclimatic conditions of a greenhouse are strongly recommended for successful cucumber cultivation in terms of highly improved water and nutrient use efficiencies.

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کارآیی مصرف عناصر غذایی و آب خیار گلخانه ای در محیط بدون خاک و تهویه طبیعی

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چکیده

به منظور بررسی کارآیی مصرف عناصر غذایی و آب در مدیریت کودآبیاری (fertigation) در یک طرح کرت های خرد شده با سه تکرار، خیار در محیطی بدون خاک که تهویه طبیعی داشت کاشته شد. کود آبیاری در سه سطح (F1-100%، F2-85%، و F3-70%) و سه رقم (V1-Kafka، V2-Multistar، و V3-PBRK-4) در کرت های اصلی و فرعی پیاده شد. مقدار آب آبیاری برای رشد خیار در حد ۲۵۵۹/۴ متر مکعب در هکتار محاسبه شد. کارآیی مصرف عناصر غذایی (NUE) برای عناصر پرمصرف به ترتیب S>P>Mg>N>Ca>K و برای عناصر کم مصرف به ترتیب Cu≥Mo>Zn>B>Mn>Fe محاسبه شد. در میان رقم ها، NUE در رقم V2 در همه سطوح کود آبیاری به طور معناداری بیشتر از V3 بود. همینطور، در میان سطوح کود آبیاری، NUE در هر ر قم در تیمار F3 به طور معناداری بیشتر از F1 بود. از نظر برهمکنش (اثرمتقابل)، NUE در تیمار F3V2 به ترتیب از تیمارهای F2V3، F1V2، F1V1، و F1V3 بیشتر بود. کار آیی مصرف آب (WUE) در تیمار F1V2 ($51.4\ kg\ m^{-3}$) به طور معناداری بیشتر از F3V3 ($34.5\ kg\ m^{-3}$) بود. کارآیی مصرف آب گیاه (CWUE) هم در میان سطوح کودآبیاری و هم در رقم های مختلف به طور معناداری تفاوت داشت و مقادیر بیشینه و کمینه آن به ترتیب در F1V2 و F3V3 برابر ۱۷۹/۹ و ۱۲۰/۶ کیلو گرم بر متر مکعب بود. به این قرار، پرورش خیار بی تخم در خارج فصل در محیط بدون خاک در گلخانه ای با تهویه طبیعی که در آن شرایط محیط تا حدودی تحت کنترل بود به بهبود کارآیی مصرف عناصر غذایی و آب در مقایسه با کشت معمول کمک کرد.

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