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Effects of Water Stress and NPK Levels on Growth and Yield Attributes of Greenhouse-Grown Cucumbers

Muhammad Sadiq Anjum[1]*, Muhammad Asif[2]*, Muhammad Shoaib Munir[1], Muhammad Asim Rafique[2]

[1]Department of Food, Agriculture and Bioresources, School of Environment, Resources and Development, Asian Institute of Technology, Pathum Thani, Thailand

[2]Directorate of Agriculture, On Farm Water Management, 25000, Faisalabad, Punjab, Pakistan

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***Corresponding author**
Anum Rafia Munir
Muhammad Asif
E-mail
a.rafiamunir@gmail.com
drasifpk@gmail.com

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Abstract

Judicious use of water and nutrients is a key factor for successful off-season vegetable production in greenhouses. This experiment was conducted under plastic tunnels to evaluate the effect of water stress and NPK levels on the growth and yield attributes of greenhouse-grown cucumbers. Effect of three irrigation levels *viz*., 100%, 80% and 60% of actual crop evapotranspiration (ETc) and three drip fertigation levels, *viz*., 100%, 80% and 60% of the recommended dose of NPK (RDF) with control (furrow irrigation with 100% RDF) were studied in a randomized complete block design experiment. The study indicated better plant growth, a greater number of fruits per plant and enhancement in the yield under drip irrigation. Among the various treatments, T_5 (W80%ETc.F80% RDF) resulted in the highest mean fresh fruit yield (66.7 ton/ha) while the full irrigation treatments T_1 (W100%ETc.F100% RDF) and T_2 (W100%ETc.F80%RDF) recorded the lowest mean fresh fruit yield of 12.9 t/ha and 13.9 t/ha, respectively, as against 9.6 t/ha for the control plot. Conversely, the fully stressed T_7, T_8 and T_9 treatments reduced the irrigation requirement by 29%, 26% and 21% but the mean cucumber yield was significantly decreased by 40%, 70% and 59%, respectively. These results suggested that drip irrigation has a great scope for the production of off-season vegetables. A water deficit level of 80% ETc with 80% RDF is the most appropriate treatment and optimal level to obtain better yield, quality and profitability of greenhouse-grown cucumbers under scarce water resources.

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Introduction

Pakistan is mainly an agricultural country with about 43% cultivable land of the total area and the agriculture sector is a big user of water resources. Food insecurity is continuing to rise due to rapid population growth. Irrigation water is becoming scarce as water availability in Pakistan has approached about 1000 m^3/capita, categorizing the country as a water deficit country and the water availability will reach 915 m^3/capita in 2025 [1]. The government and farmers are cordially making efforts to increase crop-water productivity. To achieve the goal of maximizing water productivity, water and fertilizer coupling drip irrigation technology is a key technology for the development of high-yield, efficient and high-quality agriculture production in greenhouses [2]. The lack of balanced nutrition and the unsynchronized supply of water are mainly restricting the successful production of vegetables under greenhouse conditions in Pakistan. Therefore, the latest and most efficient water-drip irrigation and fertilization technology can effectively regulate the supply of water and nutrients to crops under greenhouse conditions. Cucumber plays an important role in meeting the vegetable shortage during the scarce period, which ultimately helps to improve the malnutrition problem in Pakistan. Farmers grow cucumber widely under flood irrigation in tunnels for vegetable production in Punjab, which is highly inefficient and causes water logging and salinity. The application of a deficit amount of water combined with fertilizers through a drip irrigation system will be a suitable approach to increase the productivity of water for the greenhouse cucumber production system in Punjab Pakistan.

In Pakistan, especially in Punjab Province, the promotion of vegetable cultivation under greenhouse has been overlooked because of water scarcity. However, the highly productive soils in Punjab can be successfully utilized for vegetable cultivation, like cucumber, tomato, Chili, pumpkin, capsicum, etc. using greenhouse water and fertilizer coupling drip irrigation technology [4]. Greenhouse ensures a safe environment for plants with quality vegetable production. Greenhouse-grown cucumbers are different in smoothness, firmness and often in color. Greenhouse cucumbers are traded at a higher price because consumers are ready to pay exceptionally for the product due to better-quality taste, color, and size. Greenhouse water and fertilizer coupling drip irrigation technology increases crop and water productivity by sustainable use of scarce water resources with balanced use of NPK [5]. The present investigation was planned to determine the effects of different levels of irrigation and fertilizer applications under drip irrigation on the crop and water productivity of greenhouse-grown cucumbers.

Materials and Methods

Description of the study area

The experiment was conducted in the greenhouse of the Department of Food, Agriculture and Bioresources, Asian Institute of Technology, Pathum Thani, Thailand, located at 14° 04′ N latitude and 100° 37′E longitude with 2.27 m elevation from December 2020 to March 2021. The climate of the study area is classified as tropical with an average temperature of 28.1°C, average precipitation of 1426 mm and average relative humidity of 79.9%. The month of April was the warmest month of the year with an average temperature of 30.4 °C during the study period. The soil of the experimental site was a composite of topsoil layer (0-15 cm) that was sandy and silt-clay layer (15-30 cm) with an average bulk density of 1.60 gm/cm^3 and particle density of 2.66 g/$cm^{3.}$

Experimental design and layout

The overall experimental area was 200 m^2 (10m × 20m) with 30 equal blocks and each of the blocks had an area dimension of 3m^2 (1.5m × 2m). The experimental design was the randomized complete block design (RCBD) replicated thrice. The treatments include three irrigation levels of 100%, 80% and 60% of crop water requirement (ETc) and three fertilizer levels of 100%, 80% and 60% of the recommended dose of fertilizer (RDF). In detail, treatments comprised of the following: T1 = W100%ETc F100%RDF, T2 = W100%ETc F80%RDF, T3 = W100%ETc F60%RDF, T4 = W80%ETc F100%RDF, T5 = W80%ETc F80%RDF, T6 = W80%ETc F60%RDF, T7 = W60%ETc F100%RDF, T8= W60%ETc F80%RDF, T9 = W60%ETc F60%RDF and T10 = Furrow F100% (control).

Crop husbandry and fertilizer management practices

Normal cultivation practices involved in cucumber production were observed. Minja (Chia Thai) cucumber variety was sown directly into the soil on December 4, 2020, in the greenhouse. At the maturity stage, the plants were supported vertically with the help of a plastic net. NPK (15:15:15) was used as basal dose and urea (46-0-0) was also applied for the development of plants according to the crop growth stage requirement. The cucumber fruits were harvested when the fruit was still unripe slightly and before the fruit hardened.

Irrigation management for the experimental site

The linear low-density polyethylene (LLDPE) film of 50-micron thickness was used for mulching around the plant. The lateral lines of 12 mm diameter LLDPE pipes were laid along the crop rows and each lateral served two rows of crop. The laterals were provided with a line dripper of 2.40 liter per hour (LPH) discharge capacity. LLDPE pipes of 75 mm diameter were used for the main and 63 mm diameter was used for the sub-main (Fig. 1). The main line was directly connected to a 1.5 HP pump installed to lift water from an open sump. The manifold unit was connected with a screen filter, a pressure gauge and a control valve. The duration of water delivery o each was used for the main and 63 mm diameter was used for the sub-main. The main line was directly connected to a 1.5 HP pump installed to lift water from an open sump. The manifold unit was connected with a screen filter, a pressure gauge and a control valve. The duration of delivery of water to each treatment was controlled with the help of gate valves provided at the inlet end of each lateral. In the case of surface irrigation, irrigation was scheduled weekly.

Crop water requirement

Crop water requirements (CWR) include the total amount of water used in evapotranspiration. The crop water requirement was defined as the depth of water needed to meet the water loss through evapotranspiration of a crop [6]. The CWR is equal to actual evapotranspiration ET_c. The crop water requirement was calculated as ET_c and expressed in mm/day [7]. CROPWAT model was used for the crop water requirement of greenhouse-grown cucumbers for the growing season [8]. Its basic function includes the calculation of reference evapotranspiration and crop water requirement, *i.e.*, for March 2020.

$$ET_c = K_c \times ET_o$$

Where ETc is actual crop evapotranspiration (mm/day), Kc is cropping coefficient and ETo is reference evapotranspiration (mm/day).

Water saving was determined by dividing the yield by seasonal evapotranspiration and total irrigation water applied and calculated by the following equation:

Water use efficiency (kg/m^3) = Actual yield (kg/m^2) / total volume of water for the season (ETc, m^3/m^2)

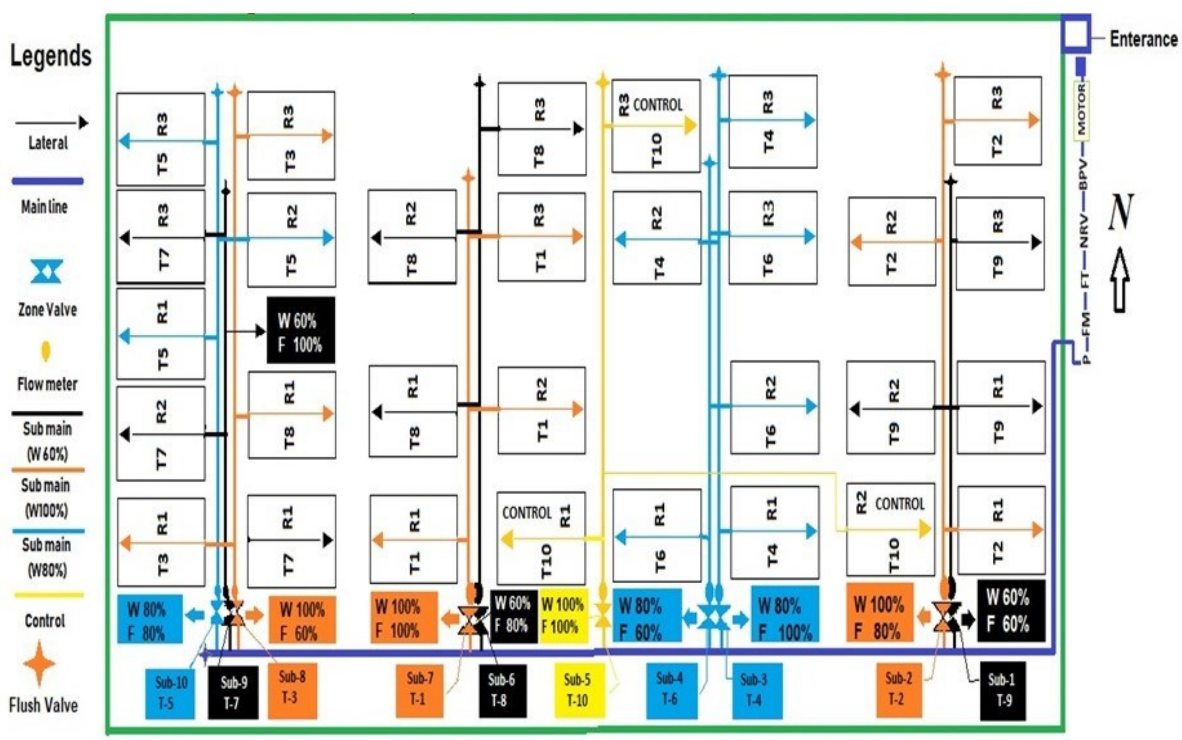

Fig. 1 Experiment layout and irrigation scheme of greenhouse-grown cucumbers.

The plant height was recorded in meters (m) for two plants of each replication from the bottom of the plant to the farthest leaf of the plant and started on 25 DAS, 50 DAS, 75 DAS and 87 DAS. Actual yield was collected (kg/m^2) from each replication respective area ($3m^2$) and then was determined for each treatment area ($9m^2$). The yield was measured in g/ m^2, then it was converted to kg/ha and finally, it was denoted in t/ha.

Crop yield (kg/m^2) = (Weight of individual fruit (g) × numbers of fruits) / area of replicated blocks (m^2)

The yield per hectare was expressed as follows.

Yield (kg/ha) = Total weight of replication (kg) / area of the replicated block (ha)

Ultimately, the yield was converted to t/ha.

Statistical analysis

The statistical analysis was performed using analysis of variance (ANOVA) and the differences between the treatment means were determined using least significant difference (LSD) [9].

Results and Discussion

Growth and yield attributes

The average yield attributing characters such as days taken to seed germination, first leave, first flowering, No. of leaves/plant, no. of flowers/plant, no. of fruits /plant, average single fruit weight and the yield of cucumber are presented in Table 1. The results revealed that these characteristics and yield are significantly superior in treatment T5 (80% irrigation requirement through drip irrigation with 80% recommended dose of NPK) as compared to the rest of the treatments. The height of the plant under treatment T5 (492.9 cm) was found to be significantly higher among all other treatments and was 12% higher than the height of plant under surface irrigation (T10). The seed germination was recorded 3.5 days late under full irrigation and 100%RDF as compared to treatment T_5 (W80%ETc F80%RDF). A similar trend was reported by other researchers who observed three days early germination under deficit irrigation [8, 9]. Days required for early leaf development were observed 11.1% higher than a control treatment for treatments T_5 and T_9, which showed a positive effect of deficit irrigation and fertigation on leaf formation. These results are in harmony with the previously reported findings [8,9]. Similarly, treatment T5 showed minimum days (26) required for flowering, 10.3% earlier than the control treatment [10]. However, the days required for early flowering were decreased with a decrease of fertilizer under full irrigation while under deficit irrigation, overall days taken to first flowering were recorded as minimum as compared to control irrigation.

As regards the number of leaves per plant, the maximum value was recorded in treatment T5 (268.33) followed by treatment T3 (268) and the lowest value was found in treatment T6 (104.7). The results shown in Table 1 indicate that the number of leaves per plant increased with the decrease of fertilizer under deficit irrigation. Similar studies found that the number of leaves per plant increased considerably with the decrease of irrigation level to 80% of ET_c [11, 12]. So, irrigation and fertigation level of ($W_{80\%ETc}.F_{80\%RDF}$) was suitable for maximum plant growth of greenhouse-grown cucumber. All the yield attributing characters were found to be significantly higher in treatment T5 than in other treatments. The treatment T5 recorded 67%, 79% and 31% higher number of flowers per plant, number of fruits per plant and single fruit weight, respectively, than the control (T_{10}). Water stress was observed to

Table 1 Growth and yield attributes of greenhouse-grown cucumbers as influenced by water stress and NPK levels.

Treatment	Plant height (cm)	Days to first germination	Days to first leaf	Days to first flowering	Leaf / plant	Flowers / plant	Fruits / plant	Fruit weight (g)	Yield (t/ha)
$T_1=W_{100\%}F_{100\%}$	458.68 ab	11.3 ab	9.7 ab	31.3 a	263.3 e	55.6 h	1.0 h	301.3 g	12.7 e
$T_2=W_{100\%}F_{80\%}$	464.67 ab	11.7 a	10.0 ab	30.0 ab	208.0 d	83.3 d	0.8 i	326.8 f	13.6 e
$T_3=W_{100\%}F_{60\%}$	431.9 b	10 ab	10.3 a	30.3 ab	268.3 a	68.4 f	3.0 e	344.5 e	21.3 d
$T_4=W_{80\%}F_{100\%}$	365.60 c	11.3 ab	10.0 ab	29.7 ab	245.3 b	79.2 e	4.9 c	416.8 d	40.8 b
$T_5=W_{80\%}F_{80\%}$	492.93 a	8.7 b	8.0 c	26.0 c	268.3 a	102.8 a	8.9 a	440.1 a	66.7 a
$T_6=W_{80\%}F_{60\%}$	455.80 ab	10.7 ab	9.0 bc	29.0 abc	104.7 f	55.1 h	4.9 c	439.2 b	39.1 b
$T_7=W_{60\%}F_{100\%}$	382.43 c	10.3 ab	9.0 bc	30.3 ab	151.3 d	62.6 g	5.5 b	293.1 h	40.1 b
$T_8=W_{60\%}F_{80\%}$	431.17 b	11 ab	9.0 bc	28.7 abc	125.3 e	86.2 c	2.6 f	431.1 c	20.5 d
$T_9=W_{60\%}F_{60\%}$	432.73 b	9.7 ab	8.0 c	27.7 bc	125.7 e	96.0 b	3.5 d	441.9 b	27.9 c
$T_{10}=W_{100\%}F_{100}$	436.40 b	11.3 ab	9.0 bc	29.0 abc	195.3 c	33.7 i	1.8 g	217.1 i	9.9 f
LSD	11.14	0.84	0.33	0.97	5.26	37.65	0.01	1.91	0.12

have a significant effect on yield attributing characters than full irrigation treatments. The highest increase in vegetative growth in treatment T_5 might be due to the availability of soil moisture as well as temperature at the optimum level [13, 14]. The lowest value of vegetative growth in T10 might be because of an unfavorable moisture regime (excess moisture) in the soil through surface irrigation and more NPK uptake at higher fertigation doses under full irrigation [15, 16]. The increased growth attributes might have supplied water and nutrients in adequate proportion, which resulted in triggering the production of plant growth hormone, viz. indole acetic acid (IAA) and a higher number of leaves throughout the cropping period [17]. Therefore, the impact of deficit irrigation through drip irrigation and fertigation on fruits per plant was significant. This could be due to the continuous supply of nutrients in small quantities around the root zone through drip irrigation, facilitating better nutrient uptake and photosynthesis, leading to luxurious crop growth reflected in the yield-attributing characteristics of the cucumber plant. The above results are also akin to the outcome of other researchers who got significantly higher growth and yield attributing characters at 80% RDF than other doses [18-20].

Crop yield

The deficit irrigation and NPK levels significantly increased the yield of capsicum as compared to furrow irrigation (Table 1). Among various treatments, the highest fruit yield (66.71 t/ha) was recorded under treatment T5 ($W_{80\%}$ETc.F80$_{\%RDF}$} which increased by 86% over surface irrigation (T_{10}). This might be due to that the optimum moisture in the vicinity of the root zone throughout the crop growth period enhanced the vegetative growth in the form of higher plant height, number of leaves plant^{-1} and dry matter production of the crop thereby increasing the photosynthesis and efficient translocation of photosynthesis towards the reproductive organ which increased the fruit diameter, weight plant^{-1} finally resulted into increased fruit yield of cucumber. Other researchers also reported a significant increase in yield with every increment in NPK fertigation level from 0 to 80% recommended dose of NPK [21, 22]. Full irrigation with 100% RD of NPK treatments (T1) reduced the percent yield by 81%, followed by 80% in T2 and 68% in T3. The lowest yield was recorded under the surface irrigation method (9.9 t/ha). This might be due to water stress during the critical growth period, coupled with aeration problems in the first few days immediately after irrigation. Another reason for getting low yield by surface irrigation might be due to less availability of nutrients for crop growth due to leaching with high weed infestation between the crops [23, 24]. In the drip irrigation system, water is applied at a low rate for a longer period at frequent intervals near the plant root zone through a lower-pressure delivery system, which increases the availability of nutrients near the root zone with a reduction in leaching losses. More nutrient availability, especially near the root zone might have increased the translocation of photosynthates to the storage organ of cucumber resulting in an increased weight of the cucumber. These results corroborated previous studies [25]. A perusal of Table 1 revealed that the drip irrigation treatments (T5, T4, and T6) increased yield by 86%, 76% and 42%, respectively, compared to surface irrigation (T_{10}). Therefore, the study revealed that even if 20% less quantity of water and fertilizer was supplied through drip irrigation, an 86% higher yield of cucumber was established as compared to surface irrigation. The beneficial effect of yield characters advantage vis-à-vis better efficiency through drip irrigation is attributed to the

Table 2 Water-saving and water-use-efficiency (WUE) of greenhouse-grown cucumbers as influenced by water stress and NPK levels.

Treatments	Average volume of water applied (m^3)	Total water applied (m^3ha)	Yield (kg/ha)	Water saved w.r. to control (%)	WUE (Kg/m^3)
T_1=$W_{100\%}F_{100\%}$	1.59 b	5140 b	12673.3 e	32.00 e	2.47 h
T_2=$W_{100\%}F_{80\%}$	1.54 b	5133 b	13647.0 e	36.36 d	2.66 g
T_3=$W_{100\%}F_{60\%}$	1.49 d	4966 d	21387.8 d	40.94 c	4.32 f
T_4=$W_{80\%}F_{100\%}$	1.44 c	4800 c	40841.8 b	45.83 b	8.51 b
T_5=$W_{80\%}F_{80\%}$	1.38 e	4601 e	66711.9 a	53.17 ab	14.51 a
T_6=$W_{80\%}F_{60\%}$	1.4 d	4666 d	39173.3 b	50.00 b	8.39 c
T_7=W60$_{\%}F_{100\%}$	1.28 g	4266 g	38133.7 b	64.06 a	8.94 b
T_8=$W_{60\%}F_{80\%}$	1.3 f	4333 f	20570.7 d	61.54 a	4.76 e
T_9=$W_{60\%}F_{60\%}$	1.33 f	4433 f	27970.4 e	57.89 a	6.32 d
T_{10}=Furrow $F_{100\%}$	2.1 a	7000 a	9940.0 f	-	1.42 gh
LSD	0.84	6.26	0.19	27.5	0.46

WUE = Water use efficiency; w.r.= with respect to continuous supply of water in the required quantity at the right time without flooding to cause hypoxia [26]. Therefore, the roots remain well aerated resulting in more rapid growth through the maintenance of adequate moisture supply and better nutrient mobilization which manifested in higher plant height and a greater number of leaf plant^{-1} and ultimately higher dry matter production [27]. Based on the results, the yield of cucumber was increased considerably under deficit irrigation and fertilizers in optimally combined irrigation and fertigation levels of $W_{80\%ETc}.F_{80\%RDF}$.

Water saving during experimental study

Water use efficiency (yield per unit area per unit depth of water used) decreased with an increase in irrigation levels for all the treatments of the drip irrigation system. The results shown in Table 2 revealed that the water use efficiency was statistically significant in deficit treatments. The maximum water use efficiency (14.47 kg/m^3) was obtained from treatment T_5 ($W_{80\%ETc}.F_{80\%RDF}$) while the minimum water use efficiency (1.42 kg/m^3) was recorded in furrow irrigation treatment T_{10} followed by T_1 (2.47 kg/m^3) and T_1 (2.66 kg/m^3), respectively. The analysis showed that water use efficiency was decreased under full irrigation, *i.e.*, in treatments T_1, T_2, and T_3 where water application was 100% of ET_c. On the other hand, water use efficiency was also decreased under the irrigation level of 60%ET_c, but increased with the increase of fertilizer by 382.1% as compared to control. This result is in close agreement with another finding [28] which conducted similar experiments and found a maximum water productivity of 18.22 kg/m^3. The results shown in Table 2 indicate that maximum water was saved under an irrigation level of 60%ETc as compared to 100%ETc, 80%ETc and control irrigation levels. The treatment T7 showed maximum water saving with the increase of fertilizer which was measured 64.06% higher as compared to the control treatment. Water saving (52.17) was recorded under an irrigation level of 80%ETc with 80% RD of fertilizer for treatment T_5. These results are quite in line with previous findings [26, 29-32].

Conclusions

The drip irrigation system is observed to be most economical and cost-effective as compared with conventional surface irrigation. As a result, the adoption of drip irrigation and fertigation systems can efficiently reduce the water and fertilizer requirement with increased yields with better quality and net return in greenhouse cucumbers. However, the water deficit level at 80% ETc under drip irrigation with 80%RD of NPK is most appropriate as it enhanced plant performance to obtain better yield, quality and profitability of cucumber under plastic tunnel and scarce water resources.

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Conflict of Interest

The authors declare that there is no conflict of interests regarding the publication of this paper.

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