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Cucumber production under Chemigation control in greenhouse

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Abstract

This research systematically investigates key determinants influencing crop productivity and quality, specifically centering on the interplay between fertilization methods and irrigation systems. Cucumber production serves as the focal point, with a nuanced examination employing both surface and subsurface drip irrigation systems within distinct greenhouses to elucidate the effects of chemigation—fertilization via irrigation. A controlled environment is established in the first greenhouse devoid of chemigation, while the second greenhouse introduces variable chemigation rates. The outcomes underscore a noteworthy positive influence of chemigation on the growth and yield of cucumbers under both irrigation systems. Quantitative analyses of plant height ratios demonstrate improvements of 26.87% and 39.7% for surface and subsurface irrigation systems, respectively, with chemigation. Moreover, chemigation yields substantial increases in flower abundance, registering percentage ratios of 58.2% and 40.3% for surface and subsurface irrigation systems, respectively. Significant enhancements in fruit characteristics are also attributed to chemigation, notably manifesting in increased length, diameter, and weight. The synergy of chemigation with the subsurface irrigation system produces the most substantial results, yielding the highest fruit dimensions and weight. The findings, therefore, contribute to advancing our comprehension of the intricate dynamics governing chemigation, irrigation systems, and cucumber production. This study holds practical implications for optimizing crop yield and quality, acknowledging and addressing research limitations, and offering valuable insights for sustainable agricultural practices.

Keywords: Chemigation, Cucumber production, Fruit characteristics, greenhouse cultivation, Crop quality, Irrigation systems.

Full length article **Corresponding Author*, e-mail: sohae.a.gad@arc.sci.eg

1. Introduction

Cucumber is a very popular vegetable worldwide. The total cucumber production (including gherkins) in 2018 was 75.2 million tons from 1.984 million cultivated hectares, as reported by [1]. Cucumber (*Cucumis sativus L.)* is one of the most important fresh consumed vegetables worldwide in Egypt cucumber is used to produce under open field conditions and recently is considered as one of the main greenhouse cultivated vegetables. The total greenhouse area for cucumber production increased from 5395 thousand square meters in 2004 up to 11.915 million square meters in 2014, and the production increased from 60 thousand ton in 2004 up to 161 thousand ton in 2014. [2] found significant effects of irrigation methods on various key parameters, including the amount of irrigation, drainage, leakage, nitrogen load from drainage, soil nitrification potential, and ammonia volatilization. They suggest that the choice of irrigation method plays a crucial role in influencing water use, nutrient dynamics, and potential environmental impacts in the studied system. The total cultivated area of open field cucumber in 2013/2014 was 52.67 thousand Fadden and produced about 496.81 thousand tons of fresh fruits. The domestic consumption of fresh cucumbers in 2000 was 428 thousand tons and rose to 540 thousand ton in 2014, giving an increase of 26.20% [3].

The gap between domestic consumption and total production increase in public demand for fresh cucumbers has allowed farmers to produce more to fill that demand, and this can be narrowed by using Greenhouse Technology in cultivation. The greenhouse production of cucumber. Further reported that cucumber yield was linearly related to irrigation amount, however, the yield decreased when irrigation amount increased from 100% to 125% pan evaporation. Therefore, proper irrigation scheduling could further improve cucumber production and irrigation efficiency in greenhouse cultivation [4]. Climate conditions are widely used for determining irrigation amounts. This method is mainly based on the crop variety, growth stage and climatic evaporation potential. For a specific crop, the irrigation amount is estimated based on the reference crop evapotranspiration (ETo) and the crop water requirement (ETc) or pan evaporation. For example, [5] and [6].

We [7] found that the highest vegetative growth and cucumber yield in a greenhouse in Egypt was obtained with 100% ETo irrigation. Pan evaporation, including from Class A pan and 20-cm diameter pans, has also been used to determine irrigation scheduling; generally, the highest irrigation amount was found to in the highest cucumber yield. They [8,9,10,11] found that demonstrate a positive and significant impact of the interaction between fertaliztion on various indicators, including leaf area, number of female flowers, and total yield. The abstract effectively communicates essential details such as nutrient percentages in the leaves and the yield of one plant and its fruit weight. The significant effects of the interaction fertalization on leaf area, number of female flowers, total yield, and leaf nutrient percentages are also highlighted. The cultivation of Cucumber (*Cucumis sativus*, L.) is prevalent in greenhouses, particularly as an offseason vegetable, owing to its substantial yield and economic advantages. Given the sensitivity of cucumber to soil water conditions, there is a recognized potential for improving cucumber yields and water productivity through strategic irrigation scheduling. This underscores the importance of optimizing irrigation practices to align with the specific water needs of cucumber crops, thereby maximizing both agricultural output and resource efficiency [12].

The objectives of this study were to:

1. To investigate parameters affecting the management of chemigation (fertilization integrated with irrigation) for cucumber crops in greenhouses.

2. To compare the performance of surface trickle irrigation systems and subsurface trickle irrigation systems for cucumber production.

3. To assess irrigation scheduling based on deficit irrigation levels and evaluate cucumber performance under various irrigation regimes, as well as different nitrogen (N) sources, including commercial and manure sources.

In essence, the study aims to improve cucumber production in greenhouses by optimizing irrigation and chemigation practices, which are critical factors in achieving higher yields and resource efficiency.

2. Material and Methods

2.1. Study materials

This study was conducted at the Agricultural Engineering Research Institute, part of the Agricultural Research Center, in Dokki, Giza, Egypt. Two greenhouses were created for the purpose of a research experiment, each measuring 400 cm in width, 350 cm in length, and 250 cm in height, with a north-south orientation. The greenhouses were covered with 5mm-thick plastic during the spring season of 2022. The research aimed to investigate the impact of chemigation management in greenhouse environments located in arid zones, specifically in the mentioned location with coordinates (Latitude 30.1113N, 31.4138E). The study's primary goal was to assess the impact of chemigation management in arid regions, within greenhouse conditions. Cucumber cultivation was the focus, and two irrigation systems were implemented: one free chemigation and the other incorporating chemigation. The central objective was to compare the production outcomes between these two irrigation approaches. In summary, the study aimed to enhance cucumber production in greenhouses by optimizing irrigation and chemigation practices, recognizing their crucial role in achieving improved yields and resource efficiency. The components of the surface drip and subsurface drip irrigation systems used in each greenhouse are illustrated in Figure 1.

Control head (CH): Figure (2) illustrates the components of the control head, which were used to manage the irrigation system in this study. The control head consisted of the following elements:

Water source: A water tank with a capacity of 200 liters was utilized as the water source for the irrigation system.

Ball valves: Four PVC ball valves (1̀) were placed before the tanks to regulate the opening and closing of the water flow.

Pump characteristics: The pump used in the system was powered by a 220V, 50Hz, 2.6A electrical supply. It had a power rating of 0.5 HP (550 watts) and operated at a speed of 2900 rpm, delivering a high flow rate of 40 l/min.

Wash pad: A 16 mm wash pad was incorporated into the system to cleanse the laterals between treatments, ensuring the disposal of salinity and preventing cross-contamination. It was also used to wash the network after completing irrigation.

Non-return valve: To prevent reverse flow and the backflow of fertilizers into the water source, a non-return valve was installed in the system.

Pressure gauges: Fixed pressure gauges were positioned before water entered the lateral line to maintain a consistent pressure throughout the system.

Filtration: A 3/4" disc-type filter with a mesh size of 120 (equivalent to 130 microns) was employed to remove debris and particles from the water. The filter had a flow rate range of 3-5 m^3/hr.

Fertilization unit: The system included an injection pump, powered by electricity (0.45 HP, 370 watts, 2860 rpm, with a head of 35 m and operating at 220V). It was used for injecting fertilizers into the irrigation water.

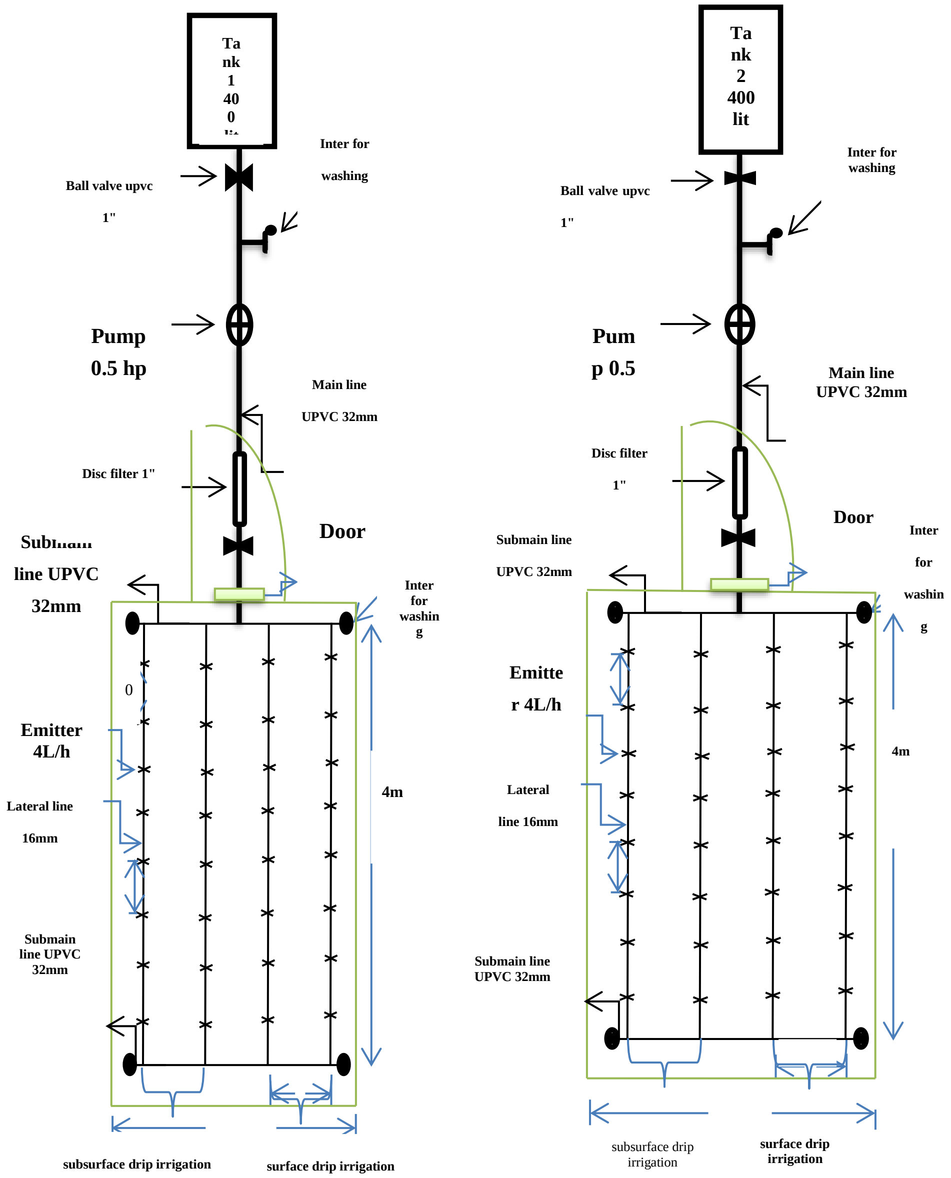

Fig. 1: Experimental components of surface and subsurface drip irrigation systems in greenhouse.

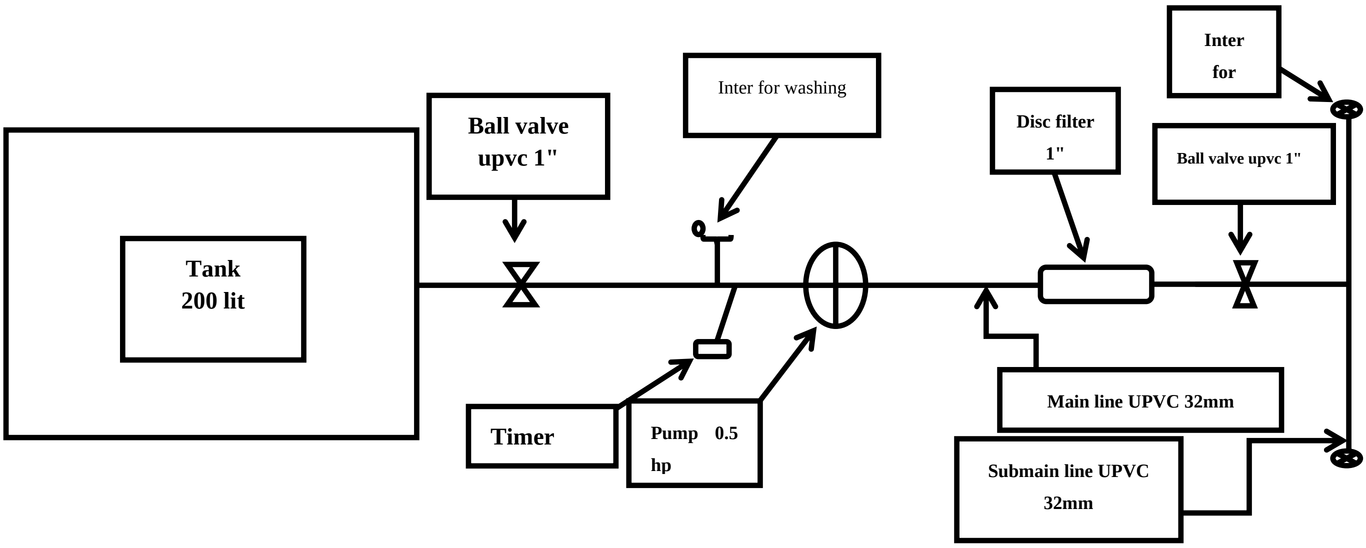

Fig. 2: Experiment components of control head of irrigation system.

Fertilizer tank: A 120-liter capacity tank was connected to the injection pump through a PVC ball valve (1'), allowing control of the quantity of fertilizer injected into the system.

Timer: The experiment was designed as a randomized complete block design with 12 treatments and 3 replications. An irrigation timer (model: YTS-F, 220V-240V, 50Hz, 0-3500W) from China was utilized to regulate the irrigation intervals for all treatments during the plant growth period. The irrigation intervals were set at 15 minutes per hour.

2.1.1. Growth parameters

1. Vegetative growth: Stem diameter was measured by Electronic digital calliper with accuracy ± 0.02 mm.

2. Plant height: Measuring tape was used to measuring the height of plant

3. Number of leaves per plant: Numbers of leaves per plant were counted after harvesting.

4. Leaf area :The leaf area was calculated according to the following formula of [13]:

Leaf area (c m^3) = Leaves dry weight (gm) x disk area / Disk dry weight (gm)…... (1)

2.1.2. Fruit characteristics

1. Fruit number measurements were carried out on plants, which were selected randomly from each treatment.

2. Fruit length was measured by Electronic digital calliper with accuracy ± 0.02 mm.

3. Fruit diameter, Fruit length were measured by Electronic digital calliper with accuracy ± 0.02 mm.

4. Fruit weight was measured by digital balance (chyo balance corp, Japan, accuracy of device 0.01 g).

2.1.3. Chemical properties of the soil

The mechanical analysis of the experimental soil was classified as a mix of sandy soil and compost in rate 1:1. It was mixed homogeneously in the laboratory and then placed in the culture trank.

2.1.4. Some chemical properties of irrigation water and the used fertilizers

Table 1 presents a depiction of the chemical characteristics of the utilized water and table 2 present the ratios of fertilizer application in the soil.

2.2. Evaluations

2.2.1. Emission uniformity

To define the uniformity of water application by drip irrigation method, [14,15] suggested two parameters, namely field emission uniformity (EUf) and absolute emission uniformity (EUa). The relations are given as under:

Euf= (qn/qa) *100 ……… (2)

Where,

qn: the average of lowest ¼ of the emitter flow rate, in (l/h), and

qa: the average of all emitter flow rates, in (l/h).

For determination of the crop water requirements (CWR), crop evapotranspiration was calculated under standard conditions (ETc) as follows:

ETc = ETo × Kc ……. (3)

Where:

ETc = crop evapotranspiration [mm/day],

ETo = reference crop evapotranspiration [mm/day],

Kc = crop coefficient.

IR= (ETO*Kc*A) / ((1-LR) * Ea) ………. (4)

Where:

IR= Irrigation water requirements under drip irrigation system, m^3/m^2/day.

ETO= Reference evapotranspiration (mm/day).

Kc= crop coefficient.

A = the irrigated area m^2

Ea= Irrigation efficiency of drip irrigation system, percentage

LR= Leaching requirement

The Food and Agriculture Organization of the United Nations (FAO) recommends computing LR as [16]:

$$LR = ECiw/((5 * ECe - ECiw)) \ldots\ldots\ldots\ldots (5)$$

Where,

EC is the electrical conductivity, iw denotes irrigation water, ECe is the EC of the soil saturated paste extract corresponding to the soil salinity tolerated by the crop.

2.2.2. Water productivity

Water productivity for the tested treatments was calculated according to [17], as follows:

Water productivity (kg/m^3) = (total yield (kg/fed)) / (total water applied (m^3/fed)) ……. (6)

Table 1: Chemical analysis of water irrigation, used in this experiment

Water sample	pH	EC Ppm	Soluble anions and cations (meq/l)							
			Ca^{++}	Mg^{++}	Na^{++}	K^+	Co_3^-	Hco_3^-	So_4^-	Cl^-
S	7.30	219	1.2	0.1	3.31	0.41	0.00	0.5	1.4	3.12

Table 2: The ratios of fertilizer application in the soil

The rate of putting fertilizers	Fertilizers	The age of the seedling
4 times per week	0.5 gm/lit NPK (20-20-20)	first week
twice a week	(1 gm/lit NH_4NO_3 + 0.25 gm/lit $MgSO_4$)	second week until the 25th day
once a week	1gm / lit NPK 20-20-20	
Once every 10 days	0.5 gm/lit ($Ca(NO_3)_2$)	
once a week	Mix of The Micronutrients (fe – mn- zn) and Fulvic Acid at a rate of 0.25 gm/lit	
twice a week	1.5 gm/lit NH_4NO_3+ 0.25 gm/lit $MgSO_4$	After 25 days from the date of transplanting until the beginning of the flowering stage
once a week	1 gm/lit K_2SO_4 + 1gm/lit NH_4NO_3	
once a week	2 gm/lit NPK (0-15-40)	
At the beginning of the flowering stage, phosphorous doses should be increased, especially potassium phosphate compound		

2.2.3 Climatic data

The following meteorological variables were daily estimated from the nearest weather station throughout the crop growing (Central Laboratory of agriculture Climate CLAC, ARC).

2.2.3.1. Maximum and minimum air temperature

Illustrated data in table (3) showed maximum and minimum air temperature at Dokki site during the season of 2021-2022.

2.2.3.2. Maximum and minimum relative humidity

Data in table (3) showed maximum and minimum relative humidity at Dokki site during the season of 2021-2022.

3. Results

3.1. The water requirements

[17]: Climate data for the study location using Penman- Monteith equation and also the values of the yield

coefficient for each stage of the plant using The FAO crop coefficient (Kc) was adjusted according to local climatic conditions, including minimum relative humidity, wind speed and maximum plant height. Data presented in Table (4) show the water requirements for irrigated cucumber crop under surface drip irrigation system and subsurface drip irrigation system) with different chemigation treatment.

Table 3: Maximum and minimum air temperature and relative humidity at Dokki site during season of 2021 – 2022.

Month	Max. Temperature °C	Min. Temperature °C	Max. Humidity (%)	Min. Humidity (%)
October	28.20	21.64	80.1	34.4
November	25.24	17.28	83.87	38.9
December	19.46	11.77	77.87	40.65
January	17.13	9.41	74.74	39.94
February	19.19	12.65	79.21	37.96
March	22.27	10.81	74.06	30.42
April	31.48	17.63	72.73	17.23
May	31.83	20.46	72.39	19.10
June	34.21	26.12	76.8	24.63
July	31.51	27.06	82.03	25.84
August	32.29	28.22	80.68	31.32
September	30.63	26.37	78.3	28.6

Table 4: Irrigation Requirement for each irrigation treatment under growing seasons.

Stage	**Initial**	**Development**	**Development**	**mid**	**mid**	**Late**
	25	6	30	31	31	30
Kc FAO	0.6	0.6	1	0.75	0.75	0.3
ETo (mm)	8.7	8.7	9.5	9.3	8.8	7.6
ETo under the plastic greenhouse	6.09	6.09	6.65	6.51	6.16	5.32
ETc (mm/day)	3.654	3.654	6.65	4.8825	4.62	1.596
Etc(mm/ day/gowth period)	91.35	21.924	199.5	151.3575	143.22	47.88
Total(Etc(m3/fed/ Growth period)	383.67	929.9808		1237.2255		201.096
Total Etc (m^3/fed /season)	2751.9723					
Ea%	90%					
LR%	20%					
IR(m^3/fed)	3822.18375					

3.2. The effect of chemigation on plant specific factors, namely plant height, number of leaves, leaf area, plant stem diameter and number of flowers

Figure 3 present the results indicating that chemigation treatment positively impacted various aspects of cucumber plant growth. Here are the key findings:

3.2.1. Plant Height: Chemigation treatment led to an increase in plant height, with measurements of 177.08 cm for surface irrigation systems and 206.9 cm for subsurface irrigation systems, compared to 129.5 cm and 124 cm for non-chemigated plants in surface and subsurface irrigation systems, respectively. This represented a percentage increase of 26.87% for surface irrigation and 39.7% for subsurface irrigation.

3.2.2. Number of Leaves: Plants subjected to chemigation treatment had a higher number of leaves (28.5 for surface irrigation and 34.1 for subsurface irrigation) compared to non-chemigated plants (18 for surface irrigation and 18.9 for subsurface irrigation). This resulted in percentage increases of 37% for surface irrigation and 44.6% for subsurface irrigation.

3.2.3. Leaf Area: Chemigation treatment also positively affected leaf area, with measurements of 366.8 cm² for surface irrigation and 380.1 cm² for subsurface irrigation, compared to 267.75 cm² and 282.5 cm² for non-chemigated plants in surface and subsurface irrigation systems, respectively. This represented a percentage increase of 27% for surface irrigation and 25.7% for subsurface irrigation.

3.2.4. Plant Stem Diameter: Chemigation treatment resulted in an increase in plant stem diameter, with measurements of 10.85 mm for surface irrigation and 12.2 mm for subsurface irrigation, compared to 9.7 mm and 10.8 mm for non-chemigated plants in surface and subsurface irrigation systems, respectively. This represented a percentage increase of 10.5% for surface irrigation and 11.9% for subsurface irrigation.

3.2.5. Number of Flowers: The number of flowers increased with chemigation treatment, with measurements of 47 for surface irrigation and 43 for subsurface irrigation, compared to 19.7 and 25.7 for non-chemigated plants in surface and subsurface irrigation systems, respectively. This resulted in percentage increases of 58.2% for surface irrigation and 40.3% for subsurface irrigation.

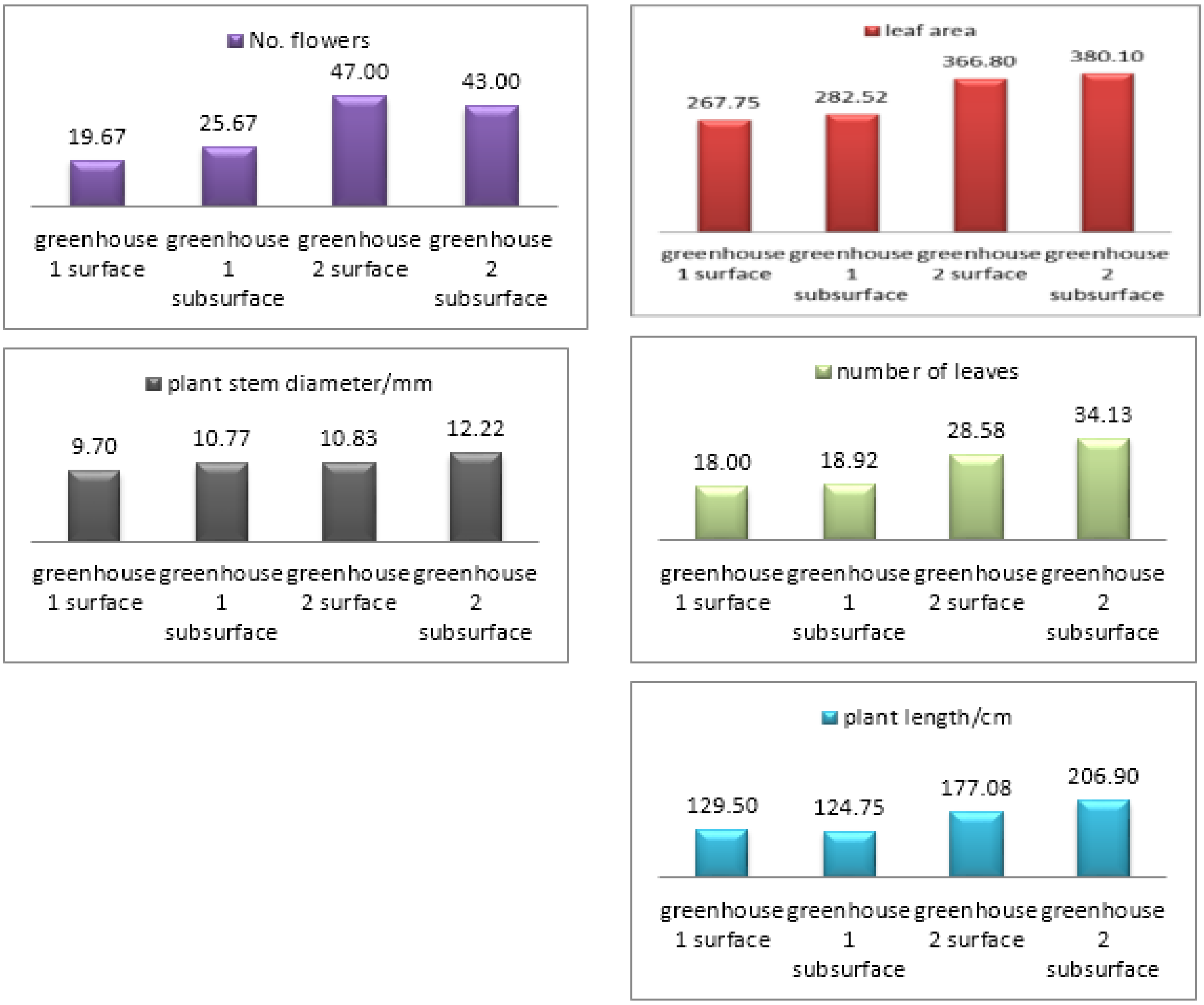

Fig. 3: The effect of chemigation on plant specific factors, namely plant height, number of leaves, leaf area, plant stem diameter and number of flowers.

3.3. Fruit characteristics

The data presented in Figure 4 highlight the positive effects of chemigation treatment on various cucumber fruit characteristics. Here are the key findings:

3.3.1. Fruit Length: Chemigation treatment led to an improvement in fruit length. Cucumbers subjected to chemigation treatment had lengths of 13.04 cm for surface irrigation systems and 13.37 cm for subsurface irrigation systems, compared to 12.33 cm and 12.73 cm for non-chemigated plants in surface and subsurface irrigation systems, respectively. The highest fruit length (13.37 cm) was achieved with chemigation treatment in the subsurface irrigation system, while the lowest value (12.3 cm) was observed in the surface irrigation system without chemigation.

3.3.2. Fruit Diameter: Chemigation treatment also positively influenced fruit diameter. Cucumbers treated with chemigation had diameters of 2.89 cm for surface irrigation systems and 3.06 cm for subsurface irrigation systems, compared to 2.67 cm and 2.91 cm for non-chemigated plants in surface and subsurface irrigation systems, respectively. The highest fruit diameter (3.06 cm) was obtained with chemigation treatment in the subsurface irrigation system, while the lowest value (2.67 cm) was observed in the surface irrigation system without chemigation.

3.3.3. Fruit Weight: Fruit weight increased significantly with chemigation treatment. Chemigated cucumbers weighed 76.91 gm for surface irrigation systems and 80.18 gm for subsurface irrigation systems, compared to 62.33 gm and 72.52 gm for non-chemigated plants in surface and subsurface irrigation systems, respectively. The highest fruit weight (80.18 gm) was achieved with Chemigation treatment in the subsurface irrigation system, while the lowest value (62.33 gm) was observed in the surface irrigation system without chemigation.

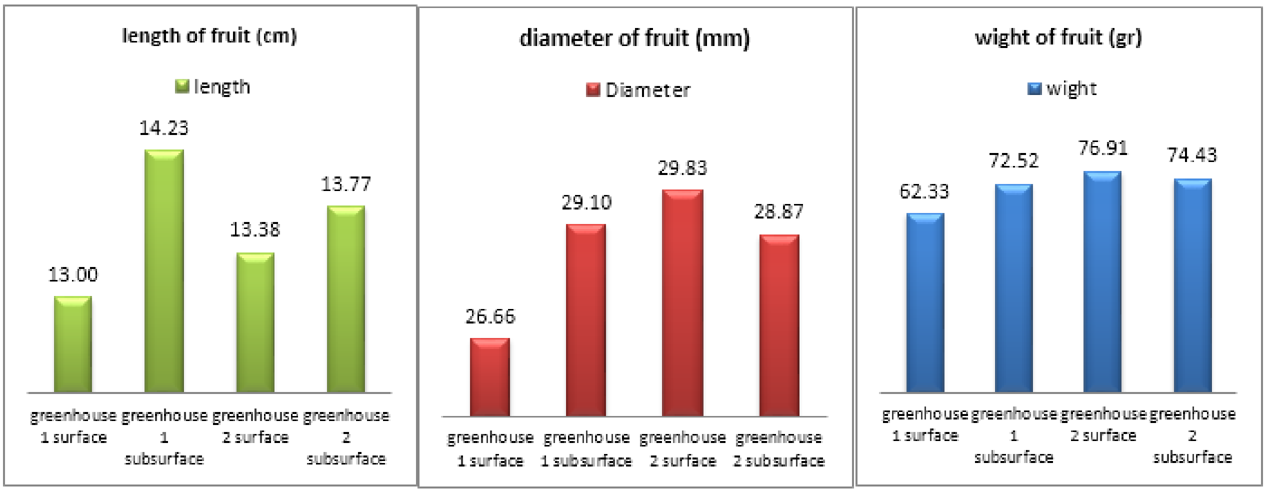

Fig. 4: fruit characteristics were fruit length(cm), fruit diameter(cm) and fruit weight(g).

3.4. Effect of chemigation treatment and no chemigation with surface, subsurface irrigation systems on total yield and WUE

The data presented in Figure (5) reveal the significant impact of chemigation treatment on cucumber fruit yield and water productivity. Here are the key findings:

3.4.1. Fruit Yield: Chemigation treatment led to a remarkable improvement in fruit yield. Cucumbers subjected to chemigation treatment yielded 64.4 tons per feddan (a unit of land area) for the surface irrigation system and 40.22 tons per feddan for the subsurface irrigation system, compared to only 6.16 tons per feddan and 4.57 tons per feddan for non-chemigated plants in the surface and subsurface irrigation systems, respectively. The percentage yield increase was 25.86% for the surface irrigation system and 37.55% for the subsurface irrigation system when chemigation was applied.

3.4.2. Water Productivity: Water productivity, which represents the efficiency of water use in relation to yield, was significantly affected by chemigation treatment. The highest water productivity was achieved under chemigation treatment in the surface irrigation system, with a value of 60.88 kg/m³. In contrast, the lowest water productivity was observed in the subsurface irrigation system without chemigation, with a value of 3.44 kg/m³.

3.5. The quality of the fruit of the cucumber product

Figure (6) illustrates the impact of chemigation treatment on the quality of cucumber fruits. Here are the key findings:

3.5.1. Fruit Quality Improvement: Chemigation treatment resulted in improved fruit quality for cucumber plants compared to those without chemigation treatment. The percentage ratios of water content in cucumber fruits were higher for chemigated plants, with values of 97.9% for the surface irrigation system and 98.08% for the subsurface irrigation system. In contrast, cucumber fruits from plants without chemigation had slightly lower water content, with values of 97.03% for the surface irrigation system and 97.72% for the subsurface irrigation system.

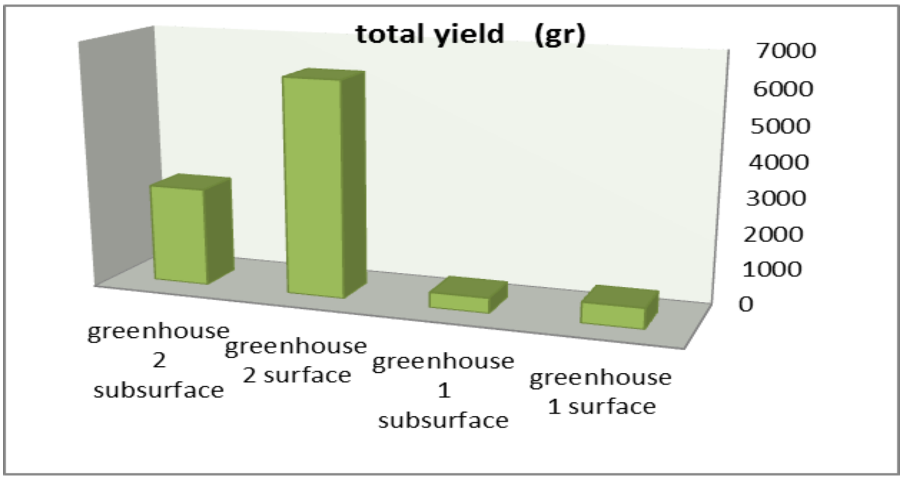

Fig. 5: Effect of chemigation treatment and no chemigation treatment with surface, subsurface irrigation systems on total yield.

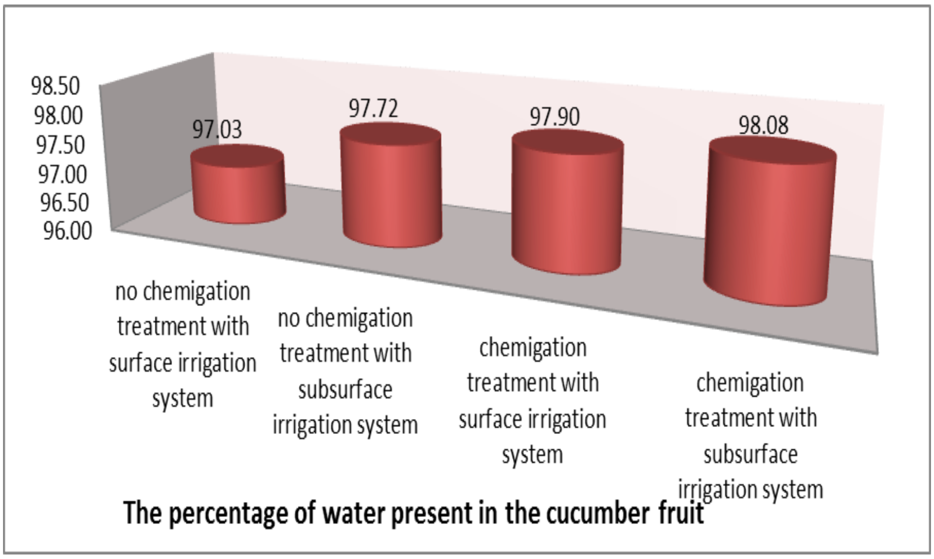

Fig 6: The percentage of water present in the cucumber fruit.

4. Discussion

The effect of chemigation on plant specific factors, namely plant height, number of leaves, leaf area, plant stem diameter and number of flowers, the irrigation with chemigation treatment had improved the plant height compared with no chemigation treatment the percentage ratios were (26.87%, 39.7%) for (surface irrigation system, subsurface irrigation system). Also improved the number of leaves for the plants irrigated with chemigation compared to no chemical treated The percentage ratios were (37%, 44.6%) for (surface irrigation system, subsurface irrigation system) respectively.,and improved the leaf area for the plants irrigated with chemigation treatment but there are variation within treatment this result agree with [18] where, the leaf area for plants increased with chemigation treatment (366.8, 380.1 cm^2 for surface irrigation system, subsurface irrigation system) respectively compared with no chemigation treatment (267.75, 282.5 cm^2 for surface irrigation system, subsurface irrigation system) respectively , also the plant stem diameter/mm increased with chemigation treatment compared to no chemigation treatment while the percentage ratios were (10.5%, 11.9%) for (surface irrigation system, subsurface irrigation system) respectively., also caused increase in leaf area. the percentage ratios were (27%, 25.7%) for (surface irrigation system, subsurface irrigation system) respectively. Chemigation treatment caused increase in number of flowers. the percentage ratios were (58.2%, 40.3%) for (surface irrigation system, subsurface irrigation system) respectively. this result agrees with [19]. Chemigation treatment caused increases in fruit length. The highest length (13.37cm) was obtained with chemigation treatment for subsurface irrigation system, while low value was observed with no chemigaion treatment (12.3 cm) for surface irrigation system., the irrigation water with chemigation treatment caused increases in fruit diameter, the highest diameter (3.06 cm) was obtained with chemigation treatment for subsurface irrigation system, while low value was observed with no chemigation treatment (2.67cm) for surface irrigation system., chemigation treatment had improved the fruit weight for the plants irrigated with no chemigation treatment but there are variation within treatment. Where, chemigation treatment caused increases in fruit weight. the highest fruit weight (80.18gm) was obtained with chemigation treatment for subsurface irrigation system, while low value was observed with no chemigation treatment (62.33 gm) for surface irrigation system these results agree with [20]. Chemigation treatment had improved the fruit yield for the plants irrigated with no chemigation treatment the percentage of yield increasing were (25.86%, 37.55%) for surface irrigation system, subsurface irrigation system respectively, The highest water productivity was achieved under chemigation treatment for surface irrigation system 60.88 kg/m^3 , and the less water productivity was achieved under no chemigation treatment for subsurface irrigation system 3.44 kg/m^3 ,these results agree with [21].

5. Conclusions

The findings highlight the positive effects of chemigation on cucumber production, emphasizing its potential to enhance fruit characteristics, yield, water efficiency, and fruit quality. Growers and agricultural practitioners can consider implementing chemigation practices to improve cucumber cultivation and maximize resource utilization.

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