FUDMA Journal of Sciences (FJS)
ISSN online: 2616-1370
ISSN print: 2645 - 2944
Vol. 10 No. 16, June, 2026, pp 750 – 758
DOI: https://doi.org/10.33003/fjs-2026-1016-3821

Optimizing Irrigation Regimes and Intervals for Improved Water Productivity and Yield of Cucumber (*Cucumis Sativus*) in a Tropical Agroecological Zone

***[1]Donatus Okwudiri Igbojionu, [1]Valentine Ngozi Ekejiuba, [2]Juliet Nnennaya Igbojionu, [3]Patience C. Ezema, [3]Helen Sampson and [2]Cabrine Ifeoma Chiemeka**

[1]Department of Agricultural & Bio-environmental Engineering Technology, Federal College of Land Resources Technology, Owerri, Imo State, Nigeria.
[2]Department of Soil Science Technology, Federal College of Land Resources Technology, Owerri, Imo State, Nigeria.
[3]Department of Crop Production Technology, Federal College of Land Resources Technology, Owerri, Imo State, Nigeria.

*Corresponding authors' email: igbojionudonatus@gmail.com

ABSTRACT
This study evaluated the effects of four irrigation levels (R_1: 100% ETc; R_2: 75% ETc; R_3: 50% ETc; R_4: 25% ETc) and three irrigation intervals (D_1: daily; D_5: 5-day; D_{10}: 10-day) on cucumber yield, fruit quality, and water productivity under tropical greenhouse conditions in southeastern Nigeria. A randomized complete block design (RCBD) with a 4×3 factorial arrangement and three replications was implemented over two growing seasons (2023–2024). Crop evapotranspiration (ETc) was calculated using the FAO Penman-Monteith equation, with water applied via calibrated drip irrigation. Key results revealed that both irrigation amount (IA) and interval (II) significantly ($p < 0.001$) influenced all parameters. Maximum fruit yield (151 t/ha in 2023; 123.1 t/ha in 2024), fruit weight (17.6 kg/plot), length (36.1 cm), and diameter (5.99 cm) occurred under full irrigation with daily application (R_1D_1). Yield declined progressively with reduced IA and extended II, with R_4D_{10} yielding only 16.3 t/ha (2023) and 11.5 t/ha (2024). Water productivity (WP) peaked at 73 kg/m³ (R_1D_1, 2023) and 43.1 kg/m³ (R_2D_1, 2024), while irrigation water productivity (IWP) reached 81 kg/m³ (R_1D_1, 2023). Crucially, R_2D_1 (75% ETc daily) maintained competitive yields (92 t/ha in 2023; 87.1 t/ha in 2024) and high WP/IWP, indicating potential for significant water savings with minimal yield penalty. Interactions between IA and II were nonsignificant for yield, WP, and IWP but significant for fruit dimensions over time ($p < 0.001$). The study demonstrates that while R_1D_1 maximizes yield, R_2D_1 offers a sustainable compromise for tropical cucumber production, enhancing water efficiency by 25% with only moderate yield reduction. These findings provide evidence-based irrigation strategies to optimize water use in water-scarce tropical agro-ecologies.

Received: 05 Aug. 2026
Accepted: 27 Aug. 2026
Published: 15 Sep. 2026

Keywords: *Cucumis Sativus*, Deficit Irrigation, Water Use Efficiency, Drip Irrigation, Tropical Agriculture, Evapotranspiration, Fruit Quality

INTRODUCTION

Cucumber (*Cucumis sativus* L.) is a widely cultivated horticultural crop valued for its high nutritional and economic importance. In tropical and subtropical regions, particularly in sub-Saharan Africa, cucumber production has gained momentum as a result of increasing consumer demand and the expansion of urban and peri-urban agriculture (Adeleye *et al*., 2021; Ibrahim *et al*., 2023). Despite its potential, the productivity of cucumber in these environments is largely constrained by erratic rainfall patterns, inefficient irrigation practices, and limited access to water resources (Ahmed et al., 2020; Olaoye *et al.*, 2022).

In Nigeria, where agriculture remains heavily rainfed and climate variability is intensifying, sustainable water management is vital to ensure stable crop productivity and food security (NIMET, 2023). Cucumber, being a shallow-rooted and water-sensitive crop, requires frequent and well-regulated watering to avoid physiological stress that negatively affects yield and fruit quality (Oyinlola *et al.*, 2020; Musa *et al*., 2022). Over-irrigation not only leads to nutrient leaching and fungal infections but also contributes to water waste. Conversely, under-irrigation can result in poor flowering, reduced fruit set, and lower yields (Zhao *et al.*, 2020; Hasanuzzaman *et al.*, 2022).

Research on deficit irrigation — a strategy that applies less than full crop water requirement — has shown promise in enhancing water productivity while maintaining acceptable yield levels (Kassaye & Solomon, 2021; Rafiee & Nazari, 2022). However, few studies have evaluated its application for cucumber production under tropical field conditions. Most existing studies are limited to greenhouse trials or Mediterranean climates, which do not adequately reflect the challenges and conditions of sub-Saharan Africa.

Furthermore, the interaction between irrigation amount (IA) and irrigation interval (II) is often overlooked, despite its potential to influence evapotranspiration, soil moisture availability, and crop physiological responses. Studies by Adeboye *et al.* (2022) and Zhang *et al.* (2023) emphasized that both the volume and frequency of irrigation must be jointly optimized to balance yield goals with resource efficiency.

This study therefore aims to bridge this knowledge gap by assessing the impact of multiple irrigation regimes and scheduling intervals on cucumber performance in southeastern Nigeria. Specifically, it evaluates how variations in IA and II affect fruit yield, crop water use (ETc), water productivity (WP), and irrigation water productivity (IWP) over two growing seasons (2023–2024). The outcomes are expected to contribute to developing localized, climate-smart irrigation guidelines for cucumber production under tropical conditions.

MATERIALS AND METHODS

Description of Study Area

The field experiment was conducted in a greenhouse during the growing season, September, 2023 and November, 2024 at the Research Farm of the Federal College of Land Resources Technology, Owerri, Nigeria, situated at latitude 05°24'N and longitude 06°54'E with an average annual rainfall of 2000-2500 mm and temperature range of 27 -31°C. The soil at the experimental site was classified as sandy clay loam with initial physicochemical properties determined before planting.

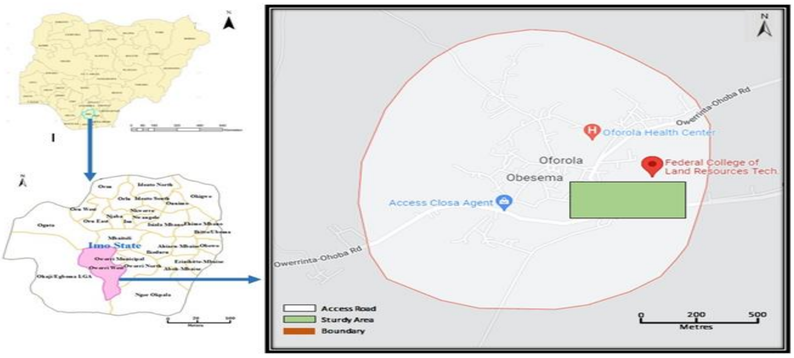

Figure 1: Map of the study area

Data Generation

Daily Crop Evapotranspiration Determination

The treatments were based on the daily crop evapotranspiration (ET_c) which was calculated as a product of the reference evapotranspiration (ET_o) and the stage-specific crop coefficient (K_c). The FAO 56 Penman-Monteith method recommended as the standard method for ET_o estimation (Qui *et al*., 2013) and presented as equation 1 was used. ET_c for the cucumber plant was then calculated using the equation proposed by (Allen *et al*., 1998) and applied by (Al-Kalifa *et al.*, 2013).

$$ET_c = ET_o \times K_c \quad (1)$$

Where:

ET_c = crop evapotranspiration (mm/day)

ET_o) = reference evapotranspiration (mm/day K_c = crop coefficient (dimensionless)

R_1 (100%) received 186mm, R_2 (75%) received 139.5mm, R_3 (50%) received 93mm and R_4 (25%) received 46.5mm.

Time to Apply Depth of Water Per Irrigation

Time to apply the irrigation treatment was calculated thus:

$$T\ (h) = \frac{Depth\ of\ water\ per\ irrigation\ (mm)}{Emitter\ precipitation\ (\frac{mm}{h})} \quad (2)$$

Where:

$$\text{Depth of water (mm)} = \frac{Irrigation\ treatment\ (mm)}{Number\ of\ irrigations} \quad (3)$$

$$\text{Emitter precipitation (mm)} \frac{emitter\ discharge\ (\frac{l}{h})}{Area\ occupied\ by\ an\ emitter (m2)} \quad (4)$$

Yield Parameters

At each harvest total number of fruits per plant, fruit weight (g), fruit diameter (cm), fruit length (cm) per treatment were determined by means weighing balance, counting, digital venier caliper and meter rule respectively. Total yield per plot was extrapolated to hectares

Water Productivity

Water use efficiency or crop productivity was determined using the following equation (Wang *et al*., 2009; Wang *et al.*, 2011):

$$WUE = \frac{Y}{ET_c} \quad (5)$$

Irrigation water efficiency (IWUE) or irrigation water productivity (IWP) was estimated using the following equation (Howell 2001; Ali and Talukder 2008):

$$IWUE \text{ or } IWP = \frac{Y}{IR} \quad (6)$$

Where:

WUE or CWP = water use efficiency or crop water productivity (kg/m^3);

Y = total yield for a particular treatment (kg/ha);

ET_c = crop water consumption for that particular treatment (mm).

IR = amount of irrigation applied for that treatment (mm)

Experimental Design and Treatments

The Cucumber plant (*Cucumis sativus*) (African Giant variety) was used as test crop in the experiment in the greenhouse located at the Federal College of Land Resources Technology, Owerri Students' Research and Demonstration Farm during two cropping seasons of September – November, 2023 and December, 2023 – March, 2024. In this study, a randomized block design (RBD) with three irrigation regimes and three irrigation intervals, replicated three times was used. The treatment used for this study comprised four irrigation levels (R_1: 100% ETc-full irrigation; R_2: 75% ETc-moderate deficit irrigation; R_3: 50% ETc- severe deficit irrigation; R_4: 25% ETc – very severe deficit) and three irrigation intervals (D_1: every day; D_5: every 5 days; D_{10}: every 10 days). The experiment consisted of 12 treatments (Table 1). Water was applied using a drip irrigation system calibrated to deliver precise volumes based on daily crop evapotranspiration (ETc) values calculated using the FAO Penman-Monteith equation (Allen *et al.,* 1998) with lateral diameter of 12 mm, emitter spacing of 33 cm, a head flow of 0.86 l/h and an operating pressure of 1.5 bar with the treatments was laid out in a greenhouse of dimensions 25.8 m long, 7.4 m wide and 2.5 m high. The greenhouse was divided into 3 blocks separated by 0.6 m gap and each consisting of 12 plots. There was a total of 36 plots/treatments. Each treatment represented by a lateral appeared once per block. Each plot measured 0.4 m (width) x 8 m (length) with 0.2 m spacing between them as buffer zone.

Table 1: Description of Treatment

Treatment No.	Treatment Tag	Treatment Combination
T1	R1D1	Irrigating with 100% ETc daily
T2	R1D5	Irrigating with 100% ETc every five days
T3	R1D10	Irrigating with 100% ETc every ten days
T4	R2D1	Irrigating with 75% ETc daily
T5	R2D5	Irrigating with 75% ETc every five days
T6	R2D10	Irrigating with 75% ETc every ten days
T7	R3D1	Irrigating with 50% ETc daily
T8	R3D5	Irrigating with 50% ETc every five days
T9	R3D10	Irrigating with 50% ETc every ten days
T10	R4D1	Irrigating with 25% ETc every day
T11	R4D5	Irrigating with 25% ETc every five days
T12	R4D10	Irrigating with 25% ETc every ten days

Statistical Analysis

The data collected for various variables were subjected to statistical analysis using two-way Analysis of Variance (ANOVA) by means of SAS analytical software technique to evaluate the effect of different irrigation treatments on growth parameters, yield and yield components of cucumber at ($p<0.05$)

RESULTS AND DISCUSSION

Effects of Different Irrigation Regimes and Irrigation Intervals on Fruit Yield of Cucumber (t/ha)

Based on the data from the 2023 and 2024 growing seasons displayed in Table 2, the fruit yield of cucumber is profoundly and consistently influenced by both the amount and frequency of irrigation. The highest yields were achieved with the most frequent and generous irrigation treatment (R1D1), producing 151.0 t/ha in 2023 and 123.1 t/ha in 2024. Conversely, the most restrictive treatment (R4D10) resulted in the lowest yields, at just 16.3 t/ha and 11.5 t/ha for the respective years. The data demonstrates a clear and direct positive correlation: yield increases with both a higher irrigation amount (from regime R4 to R1) and a shorter irrigation interval (from D10 to D1). For instance, within the same irrigation amount (R1), yield systematically decreased as the interval between watering increased from 1 day (D1) to 10 days (D10). This pattern held true across all regimes and in both years, indicating it is a robust finding.

Statistical analysis of the data reveals that the main effects of Irrigation Amount (IA) and Irrigation Interval (II) were highly significant (***) for both seasons, meaning the observed differences in yield due to these factors are very unlikely to be due to random chance. However, the interaction between these two factors (IA:II) was not significant (NS), indicating that the effect of changing the irrigation interval is consistent across the different irrigation amounts, and vice-versa.

Furthermore, a notable year-to-year variation is present, with yields in 2024 being generally lower across all treatments compared to 2023, suggesting that environmental factors such as climate (e.g., temperature, humidity, solar radiation) also played a significant role in determining the ultimate crop yield.

Table 2: Effects of Different Irrigation Regimes and Irrigation Intervals on Fruit Yield of Cucumber (t/ha)

Treatment	2023 Y (t/ha)	2024 Y (t/ha)
R1D1	151.0	123.1
R1D5	115.0	103.5
R1D10	102.0	81.9
R2D1	92.0	87.1
R2D5	76.0	75.2
R2D10	63.0	58.1
R3D1	52.9	50.0
R3D5	46.3	43.3
R3D10	35.0	30.6
R4D1	24.9	23.1
R4D5	20.1	15.8
R4D10	16.3	11.5
IA	***	***
II	***	***
IA:II	NS	NS

Effects of Different Irrigation Regimes and Intervals on Average Weight of Cucumber Fruit per Plot (kg)

Based on the data presented in Table 3, the average fruit weight of *Cucumis sativus* (cucumber) is profoundly and consistently influenced by both irrigation amount and irrigation interval throughout the growing season, as measured from 43 to 70 days after planting (DAP) over the 2023 and 2024 seasons.

A clear and direct positive correlation is evident: fruit weight increases significantly with both a higher irrigation amount (from regime W4 to W1) and a shorter irrigation interval (from D10 to D1). The treatment received that the most water most frequently (W1D1) consistently produced the heaviest fruits, with peak weights of 17.6 kg/plot at 67 DAP in 2023 and 10.9 kg/plot at 70 DAP in 2024. Conversely, the most water-stressed treatment (W4D10) resulted in the lightest fruits, with minimum weights as low as 0.23 kg/plot at 58 DAP in 2024.

Statistical analysis confirms that the main effects of both Irrigation Amount (IA) and Irrigation Interval (II**)** were highly significant ($p < 0.001$) at every single measurement date across both years. This indicates that the differences in fruit weight caused by varying the quantity and frequency of water are extremely robust and not due to random chance. However, the interaction between these two factors (IA: II) was not significant (NS) at any date, meaning that the effect of changing the irrigation interval (from 1 to 10 days) on fruit weight is consistent across all different irrigation amounts, and vice-versa.

Table 3: Effects of Different Irrigation Regimes and Intervals on Average Weight of Cucumber Fruit per Plot (kg)

2023											2024									
Treatment	**43 D**	**46 D**	**49 D**	**52 D**	**55 D**	**58 D**	**61 D**	**64 D**	**67 D**	**70 D**	**43 D**	**46 D**	**49 D**	**52 D**	**55 D**	**58 D**	**61 D**	**64 D**	**67 D**	**70 D**
R_1D_1	5.8	2.5	6.0	4.4	8.0	11.7	6.8	5.2	4.6	17.6	5.0	2.3	5.6	3.9	6.5	9.9	5.7	5.1	4.3	10.9
R_1D_5	1.3	1.6	5.8	3.7	6.8	10.8	5.3	5.2	4.6	7.2	4.4	1.6	6.0	3.4	5.5	8.4	4.7	4.6	4.1	7.0
R_1D_{10}	4.0	2.0	5.1	2.9	4.9	10.3	4.0	5.1	4.0	6.4	3.5	2.0	4.1	2.3	3.5	6.7	4.6	3.1	3.5	6.0
R_2D_1	3.7	1.9	4.4	3.0	4.7	7.0	2.8	4.9	3.6	8.1	3.4	1.7	4.5	2.8	4.3	6.4	3.6	4.5	3.3	7.4
R_2D_5	3.2	1.6	4.6	2.7	3.7	5.8	3.5	4.0	3.2	5.9	3.0	1.5	4.4	2.6	3.5	5.5	3.3	3.8	3.0	5.6
R_2D_{10}	2.6	1.6	3.1	1.7	2.2	3.8	3.2	4.1	2.7	5.4	2.3	1.4	2.8	1.5	2.0	3.4	2.9	4.2	2.4	4.9
R_3D_1	2.0	1.1	2.9	1.7	2.8	3.8	2.1	3.1	2.0	3.8	1.9	1.1	2.8	1.6	2..3	3.7	2.1	2.9	2.0	3.6
R_3D_5	1.8	1.0	2.5	1.4	2.1	3.4	1.9	2.6	1.8	3.8	1.6	0.87	2.3	1.4	1.7	3.4	1.8	2.5	1.4	3.8
R_3D_{10}	1.2	0.7	1.7	1.1	1.8	2.8	1.5	2.1	1.4	3.1	0.88	0.44	0.94	1.4	2.5	1.9	1.1	2.2	0.88	2.5
R_4D_1	0.8	0.4	1.4	0.7	0.8	2.0	1.1	1.5	1.0	2.2	0.73	0.73	0.80	1.0	1.5	1.2	0.83	0.86	1.5	1.1
R_4D_5	0.8	0.4	1.3	0.8	0.8	1.6	0.8	1.1	0.6	2.1	0.37	0.60	0.50	0.66	0.96	0.86	0.56	0.56	0.92	0.66
R_4D_{10}	0.6	0.3	1.2	0.6	0.6	0.9	0.6	0.4	0.4	2.4	0.28	0.50	0.23	0.53	0.97	0.53	0.53	0.47	0.63	0.77
IA	•••	•••	•••	•••	•••	•••	•••	•••	•••	•••	•••	•••	•••	•••	•••	•••	•••	•••	•••	•••
II	•••	•••	•••	•••	•••	•••	•••	•••	•••	•••	•••	•••	•••	•••	•••	•••	•••	•••	•••	•••
IA-II	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

D is days after planting. IA is irrigation amount, II is irrigation interval, IA:II is interaction between irrigation amount and irrigation interval, "***" means $p < 0.001$, "**' means $0.001 < p < 0.01$, *' means $0.01 < p < 0.05$, NS means not significant

Effects of Different Irrigation Regimes and Intervals on Average Length of Cucumber Fruit (cm)

Based on the data presented in Table 4, the average fruit length of Cucumis sativus (cucumber) is significantly and complexly influenced by both irrigation amount and irrigation interval throughout the fruit development period, from 43 to 70 days after planting (DAP) over the 2023 and 2024 seasons.

A general trend indicates that more generous and frequent irrigation (treatments W1 and D1) tends to produce longer fruits, while more restrictive and infrequent irrigation (treatments W4 and D10) results in shorter fruits. For example, the W1D1 treatment consistently maintained fruit lengths above 35.0 cm for most of the 2023 season, while the most stressed treatment, W4D10, produced fruits as short as 28.0 cm at 58 (DAP) in 2023.

Statistical analysis confirms that the main effects of both Irrigation Amount (IA**)** and Irrigation Interval (II) were highly significant ($p < 0.001$) at every single measurement date across both years. This means that both the quantity of water applied and the frequency of its application are critically important determinants of final fruit length.

Crucially, and in contrast to the findings for fruit weight, the interaction between irrigation amount and interval (IA:II) was also highly significant ($p<0.001$) at every measurement date. This indicates that the effect of changing the irrigation interval (from 1 to 10 days) is not consistent across all irrigation amounts, and vice-versa. For instance, the negative impact of a long irrigation interval (D10) on fruit length is likely much more severe under a low irrigation amount (W4) than it is under a high irrigation amount (W1). The significant interaction effect reveals that these two factors do not work in isolation; the optimal irrigation interval is dependent on the application amount, and the optimal amount is dependent on the chosen interval. Therefore, a balanced and consistent irrigation strategy is essential to avoid compromising fruit dimensions.

Table 4: Effects of Different Irrigation Regimes and Intervals on Average Length of Cucumber Fruit (cm)

2023											2024									
Treatment	**43 D**	**46 D**	**49 D**	**52 D**	**55 D**	**58 D**	**61 D**	**64 D**	**67 D**	**70 D**	**43 D**	**46 D**	**49 D**	**52 D**	**55 D**	**58 D**	**61 D**	**64 D**	**67 D**	**70 D**
R_1D_1	35.3	36.1	35.0	35.0	35.5	35.7	35.5	35.3	35.1	36.0	34.57	34.74	34.17	34.28	34.67	34.67	34.53	34.43	34.52	34.87
R_1D_5	34.5	34.7	34.7	34.5	34.3	34.3	34.5	34.7	34.7	34.7	33.80	33.90	33.77	33.63	33.53	33.57	33.67	33.80	33.80	33.80
R_1D_{10}	33.3	34.0	33.3	33.7	33.5	34.0	33.7	34.0	33.7	33.6	32.82	33.12	32.83	33.90	32.98	33.12	33.08	33.18	33.02	32.90
R_2D_1	35.70	35.5	35.0	35.25	35.6	35.6	35.4	35.2	35.55	36.0	33.13	33.12	32.83	32.95	33.27	35.60	33.17	33.13	33.22	33.22
R_2D_5	34.60	34.7	34.6	34.4	34.3	34.4	34.6	34.7	34.7	34.7	32.43	32.43	32.40	32.30	32.20	32.47	32.50	32.50	32.43	32.53

	2023										2024									
Treatment	**43 D**	**46 D**	**49 D**	**52 D**	**55 D**	**58 D**	**61 D**	**64 D**	**67 D**	**70 D**	**43 D**	**46 D**	**49 D**	**52 D**	**55 D**	**58 D**	**61 D**	**64 D**	**67 D**	**70 D**
R_2D_{10}	31.50	31.7	31.7	31.4	31.7	31.5	31.7	31.7	31.7	31.5	31.72	31.12	31.40	31.67	31.52	31.12	31.95	31.85	31.62	31.62
R_3D_1	32.7	32.7	32.5	32.6	32.9	32.7	32.7	32.8	32.6	32.9	33.27	32.93	32.93	33.03	33.27	33.40	33.13	33.10	33.37	32.77
R_3D_5	32.3	32.3	32.0	32.0	32.0	32.0	31.9	32.0	32.0	32.0	32.47	32.40	32.23	32.27	32.20	32.50	32.53	32.00	32.43	32.07
R_3D_{10}	31.5	31.7	31.7	31.4	31.7	31.5	31.7	31.7	31.7	31.5	31.83	31.00	31.47	31.63	31.60	31.07	32.00	31.80	31.60	30.80
R_4D_1	31.0	31.1	31.0	31.0	31.2	32.0	31.4	31.4	31.2	31.2	34.22	33.70	33.75	34.03	34.17	34.30	33.97	34.02	34.40	33.43
R_4D_5	30.4	30.2	30.2	30.5	30.3	31.0	31.0	30.8	30.6	30.9	33.27	33.17	33.03	33.03	33.00	33.37	33.47	33.40	33.33	32.62
R_4D_{10}	30.0	28.0	29.0	30.0	29.1	28.0	30.3	30.0	29.5	30.1	32.55	31.60	32.10	32.42	32.32	31.85	32.72	32.45	32.23	30.10
IA	•••	•••	•••	•••	•••	•••	•••	•••	•••	•••	•••	•••	•••	•••	•••	•••	•••	•••	•••	•••
II	•••	•••	•••	•••	•••	•••	•••	•••	•••	•••	•••	•••	•••	•••	•••	•••	•••	•••	•••	•••
IA-II	•••	•••	•••	•••	•••	•••	•••	•••	•••	•••	•••	•••	•••	•••	•••	•••	•••	•••	•••	•••

D is days after planting. IA is irrigation amount, II is irrigation interval, IA: II is interaction between irrigation amount and irrigation interval, "***" means $p < 0.001$, "**' means $0.001 < p < 0.01$, *' means $0.01 < p < 0.05$, NS means not significant

Effects of Different Irrigation Regimes and Intervals on Average Fruit Diameter of Cucumber (cm)

Based on the comprehensive data presented in Table 5, the average fruit diameter of Cucumis sativus (cucumber) is determined by a highly complex and dynamic interplay between irrigation amount, irrigation interval, and the developmental stage of the fruit, as measured from 43 to 70 days after planting (DAP) across the 2023 and 2024 seasons. A clear general trend establishes that both a higher irrigation amount (from regime W4 to W1) and a shorter irrigation interval (from D10 to D1) promote a larger fruit diameter. The most generously and frequently irrigated treatment (W1D1) consistently resulted in some of the largest diameters, reaching up to 5.99 cm, while the most restrictive treatment (W4D10) often produced the smallest diameters, dipping as low as 5.11 cm.

Statistical analysis confirms that the main effects of both Irrigation Amount (IA) and Irrigation Interval (II) were highly significant ($p < 0.001$) at every measurement date. This means that both the quantity and the timing of water application are fundamental, independent factors influencing fruit diameter.

Furthermore, the significant interactions between each irrigation factor and time (IA:ID and II:ID) show that the influence of both water quantity and application frequency on fruit diameter is not constant but changes substantially throughout the fruit's development and maturation. Most notably, the highly significant three-way interaction between amount, interval, and time (IA: II:ID) reveals that this interdependent relationship itself evolves over the growing season. This creates an intensely complex, stage-specific dynamic, meaning the impact of a particular water management strategy on fruit diameter is precisely dependent on the developmental stage at which it is applied.

Table 5: Effects of Different Irrigation Regimes and Intervals on Average Fruit Diameter of Cucumber (cm)

	2023										2024									
Treatment	**43 D**	**46 D**	**49 D**	**52 D**	**55 D**	**58 D**	**61 D**	**64 D**	**67 D**	**70 D**	**43 D**	**46 D**	**49 D**	**52 D**	**55 D**	**58 D**	**61 D**	**64 D**	**67 D**	**70 D**
R1D1	5.95	5.99	5.93	5.96	5.90	5.91	5.98	5.93	5.95	5.99	5.88	5.75	5.77	5.78	5.81	5.80	5.82	5.88	5.93	5.93
R1D5	5.87	5.87	5.88	5.81	5.87	5.81	5.83	5.85	5.87	5.88	5.87	5.74	5.77	5.77	5.72	5.81	5.74	5.77	5.84	5.78
R1D10	5.77	5.75	5.73	5.78	5.78	5.75	5.73	5.71	5.78	5.71	5.75	5.73	5.75	5.76	5.70	5.78	5.43	5.46	5.43	5.11
R2D1	5.80	5.50	5.60	5.60	5.70	5.70	5.83	5.70	5.80	5.88	5.75	5.55	5.62	5.60	5.68	5.66	5.80	5.65	5.70	5.74
R2D5	5.70	5.60	5.65	5.72	5.61	5.80	5.65	5.69	5.80	5.68	5.62	5.58	5.60	5.63	5.57	5.67	5.59	5.63	5.67	5.68
R2D10	5.36	5.32	5.52	5.40	5.40	5.38	5.43	5.20	5.15	5.10	5.61	5.54	5.50	5.60	5.57	5.62	5.43	5.46	5.43	5.11
R3D1	5.69	5.60	5.63	5.60	5.65	5.61	5.60	5.60	5.60	5.61	5.58	5.45	5.48	5.47	5.55	5.47	5.31	5.60	5.46	5.46
R3D5	5.55	5.55	5.55	5.53	5.55	5.53	5.53	5.50	5.55	5.52	5.55	5.43	5.40	5.43	5.38	5.53	5.56	5.38	5.37	5.37
R3D10	5.43	5.42	5.45	5.44	5.43	5.44	5.43	5.41	5.41	5.40	5.43	5.42	5.38	5.35	5.35	5.38	5.43	5.28	5.28	5.26
R4D1	5.31	5.31	5.32	5.33	5.31	5.33	5.31	5.30	5.31	5.30	5.29	5.30	5.20	5.23	5.18	5.18	5.45	5.81	5.52	5.79
R4D5	5.24	5.23	5.23	5.24	5.23	5.23	5.22	5.22	5.23	5.22	5.38	5.40	5.33	5.27	5.26	5.38	5.56	5.38	5.37	5.37
WR4D10	5.11	5.11	5.12	5.13	5.12	5.13	5.15	5.14	5.15	5.11	5.35	5.54	5.25	5.20	5.21	5.36	5.43	5.46	5.43	5.11
IA	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
II	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
IA:II	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***

	2023										2024									
Treatment	**43 D**	**46 D**	**49 D**	**52 D**	**55 D**	**58 D**	**61 D**	**64 D**	**67 D**	**70 D**	**43 D**	**46 D**	**49 D**	**52 D**	**55 D**	**58 D**	**61 D**	**64 D**	**67 D**	**70 D**
IA:ID	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
II:ID	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
IA:II:ID	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***

D is days after planting. IA is irrigation amount, II is irrigation interval, IA:II is interaction between irrigation amount and irrigation interval, "***" means $p < 0.001$, "**' means $0.001 < p < 0.01$, *' means $0.01 < p < 0.05$, NS means not significant

Crop Water Use and Irrigation Water Use Eficiencies under Different Water Regimes and Irrigation Intervals

The data from both the 2023 and 2024 seasons presented in Table 6 demonstrate that yield (Y) increased significantly with greater irrigation amounts (IR) and more frequent watering (shorter intervals), corroborating the yield data from Table 2. However, the Crop Water Productivity (CWP), which measures yield per unit of water consumed by the plant (ETc), and Irrigation Water Productivity (IWP), which measures yield per unit of irrigation water applied (IR), tell a more nuanced story.

The most water-efficient treatment was often a moderate one. For instance, in 2023, the R2D1 treatment (moderate amount, frequent interval) achieved a high CWP of 59 kg/m³ and an IWP of 66 kg/m³, significantly more efficient than the high-yielding R1D1 treatment (CWP: 73 kg/m³, IWP: 81 kg/m³) despite a lower total yield. This indicates that the additional water applied in the R1 regime was used less efficiently by the crop. The most extreme water-saving treatment (R4D10) predictably had the lowest efficiencies due to severe stress severely limiting yield.

Statistical analysis confirms that both the main effects of Irrigation Amount (IA) and Irrigation Interval (II) were highly significant ($p<0.001$) for all water use efficiency parameters, meaning both how much and how often water is applied are crucial determinants of efficiency. However, the interaction between these factors (IA: II) was not significant (NS), indicating that the effect of changing the irrigation interval on efficiency is consistent across the different irrigation amounts.

A notable year-to-year variation is evident, with higher irrigation inputs and lower yields in 2024 leading to substantially reduced CWP and IWP values across all treatments compared to 2023. This highlights the significant influence of seasonal climatic factors on overall water efficiency.

The most efficient use of water is achieved under more moderate, well-managed irrigation regimes (R2D1), which balance a strong yield with superior water productivity. This presents a key consideration in water-scarce environments, where optimizing efficiency may be a higher priority than pursuing absolute yield maxima.

Table 6: Crop Water Use and Irrigation Water Use Efficiencies under Different Water Regimes and Irrigation Intervals

Treatment	**2023**					**2024**				
	IR (mm)	**ETc (mm)**	**Y (t/ha)**	**CWP (kg/m³)**	**IWP (kg/m³)**	**IR (mm)**	**ETc (mm)**	**Y (t/ha)**	**CWP (kg/m³)**	**IWP (kg/m³)**
R1D1	206.82	186.30	151.0	73	81	269.41	242.46	123.1	46.7	50.8
R1D5	206.82	186.30	115.0	56	62	269.41	242.46	103.5	38.4	42.7
R1D10	206.82	186.30	102.0	49	55	269.41	242.46	81.9	30.4	33.8
R2D1	155.12	139.73	92.0	59	66	202.06	181.85	87.1	43.1	47.9
R2D5	155.12	139.73	76.0	49	54	202.06	181.85	75.2	37.2	41.35
R2D10	155.12	139.73	63.0	41	45	202.06	181.85	58.1	28.8	31.9
R3D1	103.40	93.15	52.9	51	57	134.71	121.23	50.0	32.1	41.2
R3D5	103.40	93.15	46.3	45	50	134.71	121.23	43.3	32.1	35.7
R3D10	103.40	93.15	35.0	34	38	134.71	121.23	30.6	22.7	25.2
R4D1	51.71	46.57	24.9	48	54	67.35	60.62	23.1	34.3	38.1
R4D5	51.71	46.57	20.1	39	43	67.35	60.62	15.8	23.5	26.1
R4D10	51.71	46.57	16.3	31	34	67.35	60.62	11.5	17.1	19.0
IA	***					***				
II	***					***				
IA:II	NS					NS				

D is days after planting. IA is irrigation amount, II is irrigation interval, IA: II is interaction between irrigation amount and irrigation interval, "***" means $p < 0.001$, "**' means $0.001 < p < 0.01$, *' means $0.01 < p < 0.05$, NS means not significant

Discussion

The results presented in Table 2 revealed that both irrigation amount (IA) and interval (II) significantly ($p < 0.001$) influenced cucumber fruit yield across both cropping seasons. The highest yields were obtained under R_1D_1 (highest water amount and shortest interval), recording 151 t/ha and 123.1 t/ha in 2023 and 2024, respectively. Yield progressively declined with reduced irrigation frequency and amount, with R_4D_{10} (lowest water and longest interval) yielding only 16.3 and 11.5 t/ha.

These findings align with those of Igbadun et al. (2012), who observed that higher irrigation frequency and quantity enhanced fruit yield in cucurbits due to sustained water availability during critical growth stages. Similarly, Kadayifci *et al.* (2020) emphasized the need for optimal water supply to maximize fruit set and development in cucumber, noting yield penalties under deficit irrigation. This also reinforces the findings of Jensen *et al.* (2020), who noted that cucumber yield is highly sensitive to both water volume and timing due to its shallow root system and rapid fruiting cycle.

However, excessive irrigation may lead to waterlogging and nutrient leaching, justifying the moderate yield declines under intermediate treatments such as R_2D_5.

The effects of IA and II on fruit weight (Table 3) followed a similar trend to yield, with R_1D_1 producing the heaviest fruits (up to 17.6 kg/plot in 2023 and 10.9 kg/plot in 2024). The lowest weights were recorded under R_4D_{10}. The effect of irrigation amount and interval was highly statistically significant ($p < 0.001$), while the interaction (IA × II) was not significant, suggesting that each factor independently influenced fruit weight.

This corroborates the findings of Hassan *et al.* (2021), who demonstrated that frequent and adequate irrigation enhances assimilate translocation and cell expansion, resulting in increased fruit biomass. Water stress, especially during the fruiting phase, limits photosynthesis and fruit bulking, as noted by Akhoundnejad *et al.* (2019) in cucumber under drip irrigation in arid regions.

Similarly, Table 4 showed that irrigation regimes highly significantly affected cucumber fruit length ($p < 0.001$). R_1D_1 produced the longest fruits consistently (35.3–36.1 cm in 2023; 34.57–34.87 cm in 2024), while R_4D_{10} recorded the shortest (as low as 28.0–30.0 cm). Unlike fruit weight, fruit length showed strong interactions between IA, II, and ID ($p < 0.001$ for IA×II, IA×ID, II×ID, and IA×II×ID), indicating that temporal water application patterns intricately influenced elongation processes.

This result supports the report of Ajayi and Olasantan (2022), who found that cucumber fruit elongation is highly sensitive to moisture stress, particularly during early and mid-development stages. Similarly, El-Mageed et al. (2023) highlighted that water deficits impair cell division and elongation, reducing final fruit dimensions.

Furthermore, Table 5 revealed that fruit diameter responded highly significantly to irrigation amount, interval, and their interaction ($p < 0.001$). The maximum diameter (5.95–5.99 cm) was recorded under R_1D_1, while the smallest (5.11–5.26 cm) occurred under R_4D_{10}. The interaction effects of IA×II×ID were also highly significant, indicating complex responses influenced by timing and consistency of water supply.

These findings are consistent with those of Ahmed *et al*. (2021), who observed that cucumber fruit girth is optimized under frequent irrigation due to enhanced turgor pressure and nutrient uptake. Reduced irrigation frequency induces water stress, limiting fruit expansion and metabolic activity.

The data presented in Table 6 show that both irrigation amount (IA) and irrigation interval (II) had significant effects ($p < 0.001$) on crop evapotranspiration (ETc), yield (Y), water productivity (WP), and irrigation water productivity (IWP) for *Cucumis sativus* in both 2023 and 2024. However, their interaction (IA × II) was not significant, indicating that each factor independently influenced water use dynamics and efficiency.

Crop evapotranspiration (ETc) increased consistently with irrigation amount. The highest ETc values (186.3 mm in 2023 and 242.46 mm in 2024) were recorded under the R_1 treatments, corresponding to the highest irrigation application (206.82 mm and 269.41 mm, respectively). The lowest ETc occurred under R_4D_{10} (46.57 mm and 60.62 mm), following the least irrigation application (51.71 mm and 67.35 mm).

This trend is consistent with findings by Palanisami et al. (2021), who observed that increased water availability correlates with increased actual crop evapotranspiration due to better canopy development and stomatal activity. Similarly, Farre and Faci (2009) reported that crop water use increases linearly with irrigation depth until a threshold where soil field capacity is met.

Water productivity (CWP), defined as the ratio of yield to total evapotranspiration (Y/ETc), was highest under R_1D_1 in 2023 (73 kg/m³) but peaked under R_2D_1 in 2024 (43.1 kg/m³), despite its lower water use compared to R_1D_1. This indicates that moderate irrigation with shorter intervals can optimize the balance between water use and yield in certain seasons, especially under fluctuating climatic conditions.

These observations agree with those of Fereres and Soriano (2007), who emphasized the role of deficit irrigation strategies in improving CWP by avoiding excessive irrigation losses while maintaining acceptable yield levels. Zwart and Bastiaanssen (2004), in a global review, noted that WP values for cucumber range between 25–60 kg/m³, placing these findings within the upper performance range.

Under deficit treatments (R_4), WP dropped significantly, with the lowest recorded under R_4D_1 (31 and 17.1 kg/m³ in 2023 and 2024, respectively), attributed to severely limited water supply, which constrained both ETc and biomass accumulation.

Irrigation water productivity (IWP), which quantifies yield per unit of irrigation water applied (Y/IR), followed a similar pattern to WP. The highest IWP was recorded under R_1D_1 (81 kg/m³ in 2023; 50.8 kg/m³ in 2024), but notably, R_2D_1 also showed competitive IWP (66 kg/m³ in 2023; 47.9 kg/m³ in 2024), suggesting water savings potential without drastically compromising productivity.

This aligns with the findings of Ahmed *et al*. (2020), Chukwuka *et al*. (2019) and Kharrou *et al*. (2011), who advocated for moderate irrigation under shorter intervals to enhance water use efficiency in vegetable crops. The decline in IWP under extended intervals (D_{10}) reflects the inability of cucumber to compensate for long dry spells, resulting in stress-induced yield reduction and inefficient water use (El-Mageed *et al*., 2023; Hassan *et al*., 2022; Kadayifci *et al*., 2020).

Statistical analysis confirms that both irrigation amount and interval had highly significant ($p < 0.001$) effects on WP and IWP in both seasons. However, the interaction term (IA × II) was not significant (NS), indicating that the effects of amount and frequency operate independently rather than synergistically.

This supports the assertion by Geerts and Raes (2009) that optimizing irrigation practices involves identifying independent contributions of volume and timing, as their joint interactions are often minimal, particularly under controlled irrigation systems.

CONCLUSION

The results of this study underscore the importance of adequate and frequent irrigation (R_1D_1) for optimizing cucumber yield and quality attributes such as fruit weight, length, diameter, and number of fruits. The significant effects of both irrigation amount and interval, and their complex interactions with planting days, emphasize the need for location-specific irrigation scheduling, and provide practical implications for improving water productivity and yield under varying agro-climatic condition

It also clearly demonstrates that cucumber yield and water use efficiencies respond sensitively to irrigation amount and interval. The highest water productivity and irrigation efficiency were achieved under the R_1D_1 and R_2D_1 regimes, with sharp declines under R_4D_{10} due to inadequate moisture. These findings suggest that while maximum yield is obtained under full irrigation and short intervals, moderate regimes like

R_2D_1 offer a sustainable compromise, enhancing water use efficiency with only slight yield reductions.
These insights are critical in the context of increasing water scarcity and support strategic irrigation planning for water-smart cucumber production in tropical agro-ecologies.

REFERENCES

Adeleye, O. A., Ayeni, L. S., and Olatunji, A. T. (2021). Evaluation of irrigation scheduling for optimal yield and water productivity in cucumber (*Cucumis sativus* L.). *Journal of Agronomy and Crop Science*, *207*(3), 551–561. https://doi.org/10.1111/jac.12498

Adeboye, A. O., Akintoye, H. A., and Aladesanmi, O. T. (2022). Water use efficiency and growth response of cucumber under regulated deficit irrigation in southwest Nigeria. *African Journal of Agricultural Research*, *17*(1), 1–10.

Ahmed, F. E. M., Abd El-Mageed, T. A., and Awad, Y. M. (2021). Enhancing water productivity and fruit quality of cucumber via deficit irrigation strategies. *Horticultural Plant Journal*, *7*(3), 150–158.

Ahmed, M., Hussain, S., and Hammad, H. M. (2020). Deficit irrigation strategies for water-scarce regions: Review and implications. *Agricultural Water Management*, *238*, 106238. https://doi.org/10.1016/j.agwat.2020.106238

Ahmed, A., Oyebode, M.A., Igbadun, H.E. and Oiganji,E. (2020). Assessment of Tomato Farmers Irrigation Practices in Pampaida Millennium Villge Ikara Local Government Area, Kaduna State, Nigeria. FUDMA Journal of Sciences (FJS), 4(2), 499-509. https://doi.org/10.33003/fjs-2020-0402-232

Akhoundnejad, Y., Ashrafzadeh, A., and Gohari, A. (2019). Response of cucumber yield and quality to different irrigation levels under drip irrigation. *Iranian Journal of Horticultural Science*, *50*(2), 185–195.

Ajayi, A. O. and Olasantan, F. O. (2022). Influence of irrigation and planting date on growth and yield of cucumber. *Nigerian Journal of Horticultural Science*, 27(1), 56–66.

Allen, R.G., Pereira, L.S., Raes, D and Smith M. (1998). Crops evapotranspirtation: guideline for computing crop water requirements. *FAO irrigation and Drainage Paper* 56, FAO, Rome, *300* (9), DO5109.

Ali M.H. and Talukder M.S.U (2008). Increasing water productivity in crop production – A synthesis. *Agricultural Water Management*, *95*, 1201 – 1213.

Chukwuka, K. S., Ajayi, A. O., and Adegbite, K. A. (2019). Effect of irrigation interval on the growth and yield of cucumber (*Cucumis sativus*) in derived savannah zone of Nigeria. *Nigerian Agricultural Journal*, *50*(1), 135–141.

El-Mageed, T. A., Semida, W. M., and Rady, M. M. (2023). Deficit irrigation strategies to enhance fruit quality and water productivity in cucurbits: A review. *Irrigation Science*, *41*, 117–134.

Farre, I., and Faci, J. M. (2009). Deficit irrigation in maize for reducing water use. *Agricultural Water Management*, *96*(3), 508–514.

Fereres, E., and Soriano, M. A. (2007). Deficit irrigation for reducing agricultural water use. *Journal of Experimental Botany*, 58(2), 147–159.

Geerts, S., and Raes, D. (2009). Deficit irrigation as an on-farm strategy to maximize crop water productivity in dry areas. *Agricultural Water Management*, *96*(9), 1275–1284.

Hasanuzzaman, M., Bhuyan, M. H. M. B., and Al Mahmud, J. (2022). Water stress in vegetables: A review on physiological responses and management. *Horticulturae*, *8*(9), 826. https://doi.org/10.3390/horticulturae8090826

Hassan, M. M., Baset Mia, M. A., and Rahman, M. S. (2021). Effects of irrigation interval and mulching on growth and yield of cucumber. *Journal of Horticultural Research*, *29*(2), 23–30.

Howell T.A. (2001). Enhancing Water use efficiency in irrigated agriculture. *Agron. J.*, *93* (2), 281 – 287.

Ibrahim, R. Y., Fajoye, M. O., and Usman, A. B. (2023). Irrigation scheduling and water management for cucumber cultivation in northern Nigeria. *Nigerian Journal of Horticultural Science*, *28*(1), 102–110.

Igbadun, H. E., Ramalan, A. A., and Oiganji, E. (2012). Effects of regulated deficit irrigation and mulch on yield, water use and crop water productivity of onion in Samaru, Nigeria. *Agricultural Water Management*, *109*, 162–169.

Jensen, C. R., Battilani, A. & Plauborg, F. (2020). Deficit irrigation based on drought tolerance and root signalling in potatoes. *Agricultural Water Management*, *222*, 13–24.

Kadayifci, A., Tuylu, G. I., Ucar, Y. & Cakmak, B. (2020). Crop water stress index for watermelon. *Agricultural Water Management*, *36*(1), 105–112.

Kassaye, A. & Solomon, K. (2021). Effect of deficit irrigation on yield and water productivity of cucumber in Ethiopia. *International Journal of Agricultural Research*, *16*(2), 47–53.

Kharrou, M. H., Er-Raki, S., Chehbouni, A. & Duchemin, B. (2011). Water use efficiency and yield of olive trees under different irrigation regimes. *Agricultural Water Management*, *98*(10), 1489–1496.

Musa, Y. M., Sani, B. M. & Adamu, M. (2022). Comparative analysis of drip and sprinkler irrigation systems for cucumber production in dry regions of Nigeria. *Irrigation Science and Technology*, *9*(1), 11–22.

NIMET (Nigerian Meteorological Agency). (2023). *2023 Seasonal Climate Prediction for Nigeria*. Abuja, Nigeria.

Olaoye, M. O., Ojo, F. T. & Adebisi, A. O. (2022). Evaluation of water productivity under different irrigation schedules in humid tropical vegetables. *Tropical Agriculture*, *99*(2), 120–129.

Oyinlola, E. Y., Adeyemi, O. A. & Balogun, K. S. (2020). Water use efficiency and yield response of cucumber under varying irrigation intervals in Nigeria. *African Journal of Plant Science*, *14*(8), 355–363.

Palanisami, K., Kumar, D. S. & Ramalingam, K. (2021). Improving water productivity through deficit irrigation: A study on cucumber. *Water Resources Management*, *35*(3), 1015–1028.

Qiu, R. & T. Du (2013). Response of evapotranspiration and yield to planting density of solar greenhouse grown tomato in Northwest China. *Agricultural Water Management*, *130*, 44 – 51.

Rafiee, M. & Nazari, M. (2022). Improving crop water productivity through optimized irrigation scheduling in open field cucumber production. *Water Resources Management*, *36*(4), 1191–1205

Wang, F., Kang, S., Du, T., Li, F. & Qiu, R. (2011). Determination of comprehensive quality index for tomato and its response to different irrigation treatments. *Agricultural Water Management*, *98* (8), 1228-1238.

Wang, Z. and Liu, Z., Zhang, Z. & Liu, X. (2009). Subsurface drip irrigation scheduling for cucumber (*cucumis sativus*). Grown in solar greenhouse based on 20cm standard pan evapotranspiration in Northeast China. *Scientia Horticulture*, *123* (1), 51-57.

Zhang, T., Wang, J. & Li, S. (2023). Interactive effects of irrigation frequency and amount on cucumber yield and water productivity. *Agricultural Water Management*, 281, 108305. https://doi.org/10.1016/j.agwat.2023.108305

Zhao, Y., Liu, Y. & Shen, Y. (2020). Deficit irrigation strategies for water-saving agriculture: A global review. *Agronomy*, *10*(12), 1929. https://doi.org/10.3390/agronomy10121929

Zwart, S. J. & Bastiaanssen, W. G. M. (2004). Review of measured crop water productivity values for irrigated wheat, rice, cotton, and maize. *Agricultural Water Management*, *69*(2), 115–133.