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RESEARCH PAPER

Drip irrigation as a climate smart agricultural strategy to enhance productivity and water use efficiency in cucumber (*Cucumis sativus* L.)

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Key Message: The study showed that enhancing irrigation frequency rather than increasing water application can significantly improve both the productivity and water use efficiency of cucumbers. Integrating drip irrigation frequency and crop variety showed that cucumber variety CU-999 and irrigation four times a week is a climate-smart production strategy for better performance with excellent water use efficiency.

Abstract

Climate change is already having negative impacts on food security; therefore climate smart agricultural practices such as resilience crop variety and irrigation have become inevitable. A field experiment was carried out to investigate the impact of drip irrigation frequency on the productivity and water use of two cucumber varieties at the Research Station of Ekiti State University, Ado Ekiti, Nigeria during the 2020/2021 dry season. The experiment design was 2-factorial, randomized complete block, arranged in split-plot and replicated three times. The main plot was drip irrigation frequency at three levels: irrigation water application five days a week (I5), irrigation water application four days a week (I4), and irrigation water application three days a week (I3) while the subplot was crop variety consisting of two cucumber varieties: CU-999 (V1) and Morano F1 (V2). The germination rate was significantly higher in Murano variety (96%) compared to CU-999 (83%). Irrigation, variety, and their combination did not influence ($p > 0.05$) cucumber growth parameters. Drip irrigation application four days a week and CU-999 cucumber variety had significantly ($p < 0.05$) highest number of fruits (14), fruit diameter (53.5 cm), water use efficiency (7.5 kg/ha/mm) whereas drip irrigation application five days a week and CU-999 cucumber variety had the highest fruit weight (208.8 g) and yield (3.2 kg/m^2). CU-999 variety grown under four irrigations per week showed more resilience in terms of growth parameters, yield components, and water use efficiency. Therefore, CU-999 cucumber variety and irrigation four days a week is the preferred irrigation-variety combination for optimum productivity and water use of cucumber production in this region.

Keywords: Climate smart agriculture, Cucumber performance, Drip irrigation, Food security, Water use

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Introduction

Cucumber (*Cucumis sativus* L.) is a high-value fruit vegetable cultivated in almost all regions of the world (Vora, 2014). Presently, cucumber production ranked fourth after tomato, onion, and cabbage in Asia (Jamir & Sharma, 2014), ranked second after tomatoes in Europe but it has not been ranked in Africa as a result of limited usage (Eleduma, 2023). Worldwide cucumber production has reached close to 89 million tons, with Asia contributing about 85% in 2019 (FAOSTAT, 2019). Because of its health, nutritional and economic benefits, cucumber has become a highly sought fruit in Nigeria today (Nweke et al., 2013). However, cucumber is produced largely under rainfed agriculture, with limited production during the off (dry) season, making the fruit very expensive during the off season.

Recently, the production of arable crops during the rainy season has been threatened due to climate change caused by erratic, decreased rainfall and elevated temperatures in Nigeria and elsewhere, and the situation getting worse year after year. This has significantly decreased food production, threatening food security (Lipper et al., 2014; Benitez-Alfonso et al., 2023). To mitigate the climate change impacts on food production, various climate-smart agricultural solutions (CSAs) are being advocated to farmers (Mango et al., 2018; Ghosh, 2019). According to Food and Agricultural Organization (FAO, 2013), CSAs are strategies that sustainably increase agricultural productivity, promotes resilience, lock greenhouse gases as possible, with a view to ensuring millennium development goal of food security.

Therefore, there is the need for adoption of improved land cum water management options among other sustainable strategies could help in achieving the above goals (Lipper et al., 2014). Among the sustainable technologies is improved agricultural water management through the use of small-scale irrigation technologies, improved crop cultivars, soil amendments and other innovations that can adapt to the local environment (SciDev.Net, 2014). In this context, the priority is on the use of small-scale irrigation, particularly drip irrigation technology, which currently is very incipient in Nigeria agriculture, compared to other climes. Because of high water saving potential, small wetted area (limited evaporation), no runoff, less deep percolation, uniformity of water distribution, and high fertigation efficiency (Mena, 2014), drip irrigation has become better option for CSA compared to other irrigation methods. The choice of improved crop cultivars will not only increase climate resilience but also will reduce the necessity for excessive irrigation, reduce the cost of production and increase yield in a sustainable manner (Alliance Bioversity-CIAT, 2024).

Different studies have evaluated climate-smart drip irrigation regimes on the performance of cucumber whether under protected structures or open field conditions (Rahil & Qanadilla, 2015; Sonnenberg et al., 2016; Çakir et al., 2017; Zakka et al., 2020., Fasina et al., 2021a; Fasina et al., 2021b; Igbojionu et al., 2024) however there is dearth of information on studies considering the response of different varieties of cucumber to drip irrigation regimes. We hypothesized: i) five times drip irrigation per week gave cucumber with better performance indices, ii) there was significant difference between the two varieties of cucumber, and iii) there is significant interaction between drip irrigation frequency and cucumber cultivars on the performance indices of cucumber. Therefore, the study investigated the impact of climate-smart drip irrigation frequency and two varieties of cucumber in terms of productivity and water use with a view for better understanding of its resilience to climate change.

Materials and Methods

Study area

The field experiment was conducted at the Research Station of Ekiti State University, Ado-Ekiti, Ekiti State in southwestern Nigeria during the 2020/2021 dry season. The area is located within latitude 7.25° to 8.08° N longitude 4.75° to 5.75° E, at about 434 m above the mean sea level. The area is humid, tropical climate, with contrasting wet and dry seasons, receiving about 1,368 mm rainfall annually while the daily temperature averaged around 27 ^{o}C. The soil of the study site is Typic Kandipludalf following Soil Survey Staff classification (2014), mostly sandy-loam texture (Fasina et al., 2005). Prior to this study, the site has been used for the cultivation of crops such as amaranth, musk melon, cassava, maize, okra, pepper, and cucumber and left fallow for two years. Table 1 shows some physico-chemical properties of the 0 - 30 cm soil depth of the experiment field.

Experimental design, treatments and field layout

The experiment design was 2-factorial, in randomized complete block (RCBD), arranged in split-plot and three replicates. The main plot was irrigation frequency comprising three irrigation regimes viz five irrigation water application in a week: I5, four irrigation water application in a week: I4, and three irrigation water application in a week: I3 while cucumber crop variety constituted the subplot namely V1 (CU-999) and V2 (Murano-F1). There were six treatments combination, giving a total of 18 experimental units. There were three (3) blocks, each ridge in a block 11 m long and spaced 1 m from one another. Each block contained the three drip irrigation regimes while each ridge in a block was split into two to constitute the subplot for the two cucumber varieties. Each experimental unit measures 5 m × 1 m, and spaced 1 m apart. The field layout is presented in Fig. 1.

Land preparation and installation of the drip irrigation system

The experimental site was cleared of existing vegetation and debris were packed and burnt before the marking out into plots. Tilling of soil and making of seedbeds (ridges) was done with the use of hoes. Farmyard manure (poultry waste) at the rate of 25 ton/ha was spread evenly on the soil surface, mixed and incorporated manually within the 10 cm soil depth. The drip irrigation system consisted of Netafim drip tapes (pressure-compensating type, 4 L/h discharge rate and 30 cm interval between drip points), 1” polyvinyl chloride (PVC) main line, 1” PVC sub-main lines, control valves, end plugs, and other accessories constituted. There were two (2) drip laterals, spaced 80 cm apart, on each ridge. A storage tank, 3000 L capacity, installed about 1 m above the soil surface, was connected to a borehole to supply water to the field via main line, sub-mains, laterals, and drip emitters (Fig. 1).

Field procedures

Before planting, the field was adequately irrigated for two (2) days. The cucumber varieties (CU-999 and Murano F1) were obtained from Government Accredited Seed Company. One (1) seed of each cucumber variety was sowed about 10 cm from the drip points (spaced 30 cm) along the double drip laterals on each ridge. After planting, the field was irrigated uniformly for 10 days for crop establishment after which the irrigation treatments were imposed. For better water redistribution in the soil and reduce evaporation during the day, water application was performed between 17:00 and 19:00h on scheduled days. Manual weeding by hoeing was done periodically. Two weeks after sowing, soluble fertilizer, KNO_3, at the rate of 50 g KNO_3/25 L H_2O was applied via the irrigation water. Foliar fertilizer, MaxiYield (NPK 20-20-20 + TE) was applied at the rate of 20 mL/16 L H_2O on weekly basis. Insecticide (Laraforce Gold) and fungicide (Red Force) were applied to combat insect pests and control fungal attack, respectively. Staking and training of the vines were done to protect the fruits from contact with the soil and ensure good aeration within the crop canopy.

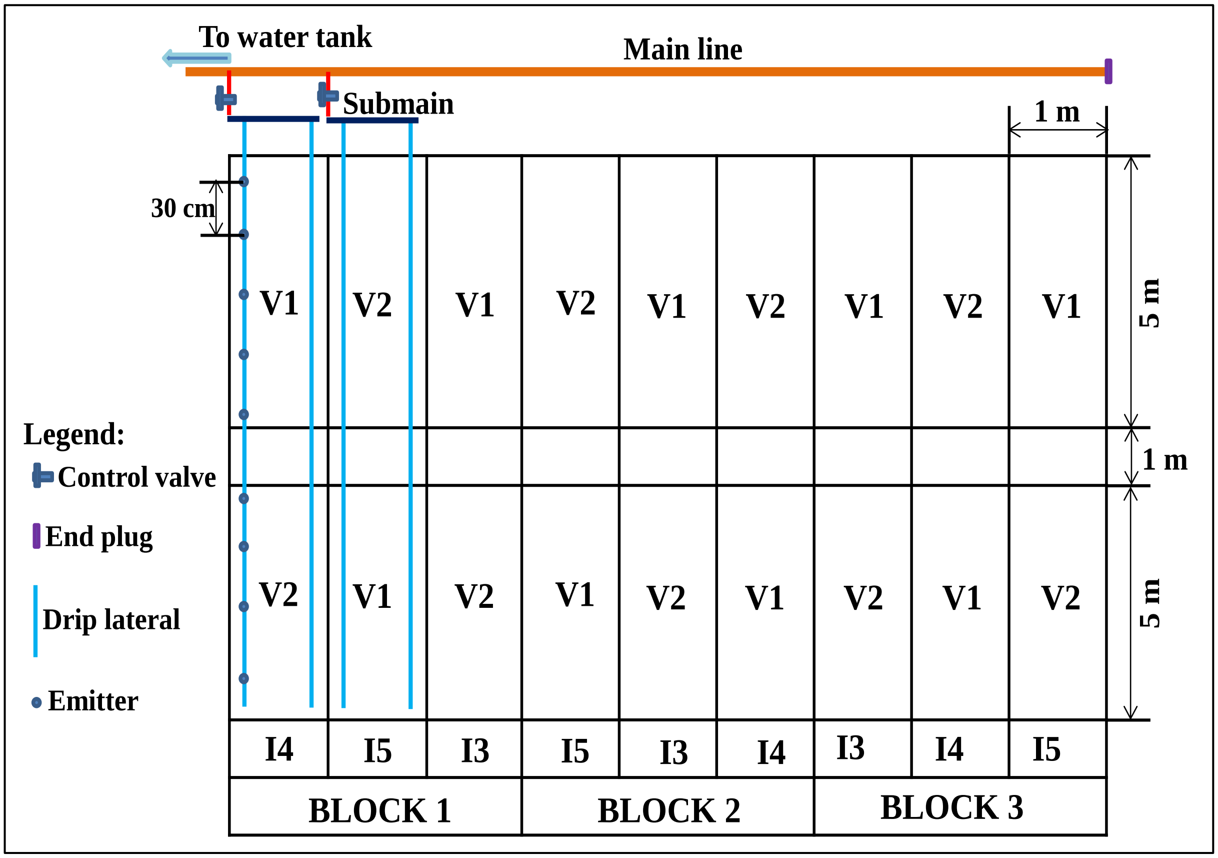

Fig. 1 Field layout of the experiment; I5: irrigation water application five times a week; I4: irrigation water application four times a week; I3: irrigation water application three times a week; V1: Cucumber Variety 1 (CU-999); V2: Cucumber Variety 2 (Murano2)

Soil sampling and laboratory analysis

Shortly after seedbed preparation, a small profile about 50 m × 50 m × 50 cm was dug within the experimental site. Structured soil samples were collected from the middle of 0 – 10, 10 – 20, and 20 – 30 cm soil layers using 57 mm diameter and 40 mm high core samplers. Also collected from same soil layers were disturbed samples. The samples were sealed and moved to the laboratory for preparation and analysis. Sample preparations in the laboratory involved air-drying, crushing, and sieving (2-mm sieve) of the disturbed soil samples while excess soil on the structured samples in cores was trimmed. Samples were thereafter kept in marked, safety boxes for analysis. Soil bulk density was determined following the protocol of Blake and Hartge (1986). The constant-head permeameter was used to measure the soil saturated hydraulic conductivity (Empresa Brasileira de Pesquisa Agropecuária [EMBRAPA], 2011). The pipette method was used to analyze soil texture following Gee & Bauder (1986) and modified by Suzuki et al. (2015). The volumetric flask method was employed to determine the soil particle density following Danielson & Sutherland (1986), modified by Gubiani et al. (2006). The relationship between soil bulk density and particle density was used to obtain the soil total porosity (Danielson & Sutherland, 1986).

A 1: 2 soil-water suspension was made to determine the soil pH. The pH of the solution extract was read using a digital electrode pH meter (Thomas, 1996). The wet oxidation method of Walkley and Black (1934) was used to quantify soil organic matter, while the Bray and Kurtz (1945) method was used to determine the available phosphorus. Total nitrogen was obtained using the Kjeldahl digestion techniques (Bremner & Mulvancy, 1982). The exchangeable bases, K^+, Ca^{2+}, Mg^{2+}, and Na^+, were extracted using ammonium acetate, flame photometry (JENWAY PFP7 Flame Photometer) was used to read K^+, Ca^{2+} and Na^+ while Mg^{2+} was read using the atomic absorption spectrophotometer (AAS) (Perkins Elmer 2280 model). The cation exchange capacity (CEC) was quantified as the sum of the exchangeable bases.

Table 1 Physicochemical characteristics of soil collected from 0–30 cm depth at the experimental site

Soil depth (cm)	pH_{H2O} 1: 2	EC dS/m	OM %	TN g/kg	Av. P mg/kg	Ca Cmol/kg	Mg Cmol/kg	K Cmol/kg	Na Cmol/kg	Ex. Ac
0-10	7.1	906	2.2	0.044	91.7	3.2	1.3	0.95	0.07	0.20
10-20	6.9	314	0.8	0.028	28.5	1.9	1.1	0.16	0.04	0.15
Soil physical properties										
Soil depth (cm)	BD g/cm^3	Pd g/cm^3	Pt cm^3/cm^3	Ksat cm/h	Sand %	Clay %	Silt %	Texture -		
0-10	1.41	2.70	0.4770	105.6	58.0	8.1	34.0	SL		
10-20	1.58	2.60	0.3922	52.6	58.3	8.1	33.6	SL		
20-30	1.66	2.60	0.3604	35.1	56.3	10.3	33.5	SL		

EC: Electrical conductivity; OM: Organic matter; TN: Total nitrogen; Av. P: Available phosphorus; Ca: Calcium; Mg: Magnesium; K: Potassium; Na: Sodium; Ex. Ac: Exchangeable acidity; BD: Bulk density; Pd: Particle density; Pt: Total porosity; Ksat: Saturated hydraulic conductivity. SL: Sandy loam

Germination rate, plant growth and yield indices, and water use efficiency

The germination rate of the two cucumber cultivars under same irrigation was monitored for five days after sowing.
Leaf length and width were measured using a flexible tape rule and the leaf area/plant was computed using the equation (Blanco & Folegatti, 2003):

$$A = 0.85 \times L \times B$$

Where A = Leaf area (cm^2); L = Leaf length (cm); B = Leaf breadth (cm).

Vine length was measured using a flexible tape rule from the base (soil surface) to the apex of the vine. Fruit diameter was measured using a digital Vernier caliper. At each harvest, number of fruits was obtained by manual counting, fruit length and diameter were obtained using a flexible tape rule and digital Vernier caliper, fruit weight was determined using a sensitive, digital weighing scale. At the close of harvesting, fruit yield was obtained as the sum of all fruits harvested in each experimental unit and converted to ton/ha. The ratio between crop yield and total irrigation water applied was used to obtain the water use efficiency (WUE) (kg/ha/mm) as:

$$\text{WUE} = \frac{\text{Crop yield (kg/ha)}}{\text{Water applied (mm)}}$$

Irrigation amount and weather data

Because of the technical issue of installing water meter for each irrigation treatment and replicates, irrigation water was applied based on time of application ($t\,(hr)$) considering the soil field capacity (θ_{FC}, mm), number of emitters per lateral (N_E), plot area (A, mm^2), emitter discharge rate ($Dr, L/h$) and application efficiency (A_E) taken as 95% for drip irrigation system according to the equation (Awe et al., 2020):

$$t\,(hr) = \frac{\theta_{FC} \times A}{Dr \times N_E \times A_E}$$

The total irrigation amount (θ_{FC}, mm) applied was obtained considering the total number of days that irrigation was applied for the different frequencies (I5, I4, and I3). A mini-pan evaporimeter was installed in a free area around the experimental field to measure pan evaporation potential evapotranspiration during the growing period (Awe et al., 2020). A rainguage was also installed to measure rainfall amount.

Statistical analysis

Data collected, except germination rate, was subjected to analysis of variance (ANOVA), where F-value is significant, means were separated using Fisher's Least Significant Difference (LSD) test at 5% level of significance. The germination rate was compared using t-test. All statistics were done in SAS (SAS version 8.0).

Results and Discussion

Evapotranspiration, rainfall and cumulative irrigation amount

The potential evapotranspiration, ETp, during the growing period was 66.5, 177.5, and 98.5 mm for December 2020, January and February 2021, respectively. Less than 15 mm rainfall was received in December 2020 when the project commenced; no rain was received in January 2021 while about 18 mm of rain was received in third week of February. A comparison between rainfall amount and ETp showed irrigation becomes necessary for cucumber cultivation during the period (Fig. 2). The cumulative amount of water received by the irrigation treatments I5, I4, and I3 was 740.0, 6-6.6, and 456.6 mm, respectively. Compared to I5 treatment, I4 and I3 treatments accounted for about 18% and 25% in water saving, respectively (Fig. 3).

Germination rate

The comparison of germination percent of the varieties cucumber under the same soil temperature and moisture is presented in Table 2. The germination rate differed significantly ($p < 0.05$) between the two cucumber varieties, with Murano F1 (V2) having higher germination rate by about 20.0 to 15.0% on the fifth and ninth day after sowing, respectively compared to CU-999 (V1). Other researchers have reported differences in germination rates for varieties of same crop such as maize (Wawo et al., 2020; Omar et al., 2022) and cowpea (Adetumbi et al., 2011). This may be attributed to differences in genetic characteristics during breeding. According to Bewley and Black (1982), genetic factors affect seed germination, emergence and vigour. Grzybowski et al. (2015) also reported that seed germination rate can be influenced by the physiological quality and the plant genotype.

Growth parameters

The cucumber plant growth parameters are presented in Table 3. At 2 WAP, irrigation, variety and the interaction effects were not significant ($p < 0.05$) on the entire plant growth parameters. Similarly, at 5 WAP, irrigation, variety and the interaction effect were not significant ($p < 0.05$) on the plant growth parameters. Numerically, increasing drip irrigation frequency decreased cucumber growth parameters at both early and late growth stages. Interestingly, Murano F1 variety had longer vines than CU-999 F1 variety however the opposite was the case for leaf area. The combination of I4V1 had the numerically highest values of the growth parameters evaluated. Our results with that of Rahil and Qanadillo (2015) who found that reducing irrigation water improved cucumber growth. On the contrary, Masria et al. (2021) reported increased cucumber plant height with increasing irrigation water under greenhouse conditions. These authors attributed the improved performance with increased irrigation to adequate water quantity especially in the early stages of crop growth which gives more soil volume for extensive and deeper root system. Sonnenberg et al. (2016) also reported significant increase in plant height and number of leaves with high irrigation volume during early to late growth stage of the cucumber crop grown hydroponically in glasshouse. In this study, it could be that overwatering cucumbers resulted into stunted growth, and this happens because of a mixture of soil, root, and physiological stresses that come into play when there's too much water. When the soil gets too wet, the pores are filled up with water, leading to anaerobic conditions that hinder root respiration and nutrient absorption (Barickman et al., 2019). Therefore, when the roots stay saturated for too long, they become weaken, reducing their ability to take up water and make them more prone to diseases. Furthermore, excess water could compromise the soil's nutrient balance by leaching important nutrients such as nitrogen, diluting the essential ions around the roots and decreasing the microbial activity required for breaking down nutrients (Pawar et al., 2025). All of these put stress on the plant, resulting in lower stomatal conductance, impaired photosynthesis, and less energy being directed to the growing tissues. Above that, too much irrigation can also lead to shallow root systems, making it harder for the cucumber crop to access nutrients, leaving them more susceptible to changes in water availability (Luo et al., 2024).

Table 2 Comparison of germination percent of the varieties of cucumber

	Days after germination				
Variety	13/12/2020	14/12/2020	15/12/2020	16/12/2020	17/12/2020
V1	78.3	81.1	82.8	83.3	83.3
V2	93.9	95.6	95.6	95.6	95.6
$Sig_{(p<0.05)}$	S	S	S	S	S

V1: CU 999 F1; V2: Morano F1; S: Significant at 5% level of probability by t-test

Table 3 Comparison of plant growth parameters of the varieties of cucumber grown under various irrigation regimes

		Vine length (cm)		Stem girth (cm)		Leaf area (cm^2)	
Irrigation	Variety	2 WAP	5WAP	2 WAP	5WAP	2 WAP	5WAP
I5	V1	17.0	159.9	7.5	8.9	158.2	305.0
	V2	16.1	169.9	7.1	8.5	154.6	291.0
I4	V1	19.2	177.9	7.9	10.2	167.3	340.9
	V2	21.1	178.3	7.6	9.5	168.2	297.3
I3	V1	19.1	176.5	8.1	10.0	175.9	345.7
	V2	22.1	182.2	7.1	9.8	182.3	317.2
I effect (p<0.05		NS	NS	NS	NS	NS	NS
V effect (p<0.05)		NS	NS	NS	NS	NS	NS
I × V (p<0.05)		NS	NS	NS	NS	NS	NS

I5: Irrigation water application five times a week; I4: Irrigation water application four times a week; I3: Irrigation water application three times a week; I: Irrigation; V: Variety; V1: CU-999 F1; V2: Morano F1; NS: No significant difference at 5% level of probability by Fisher's Least Significant Difference (LSD) test

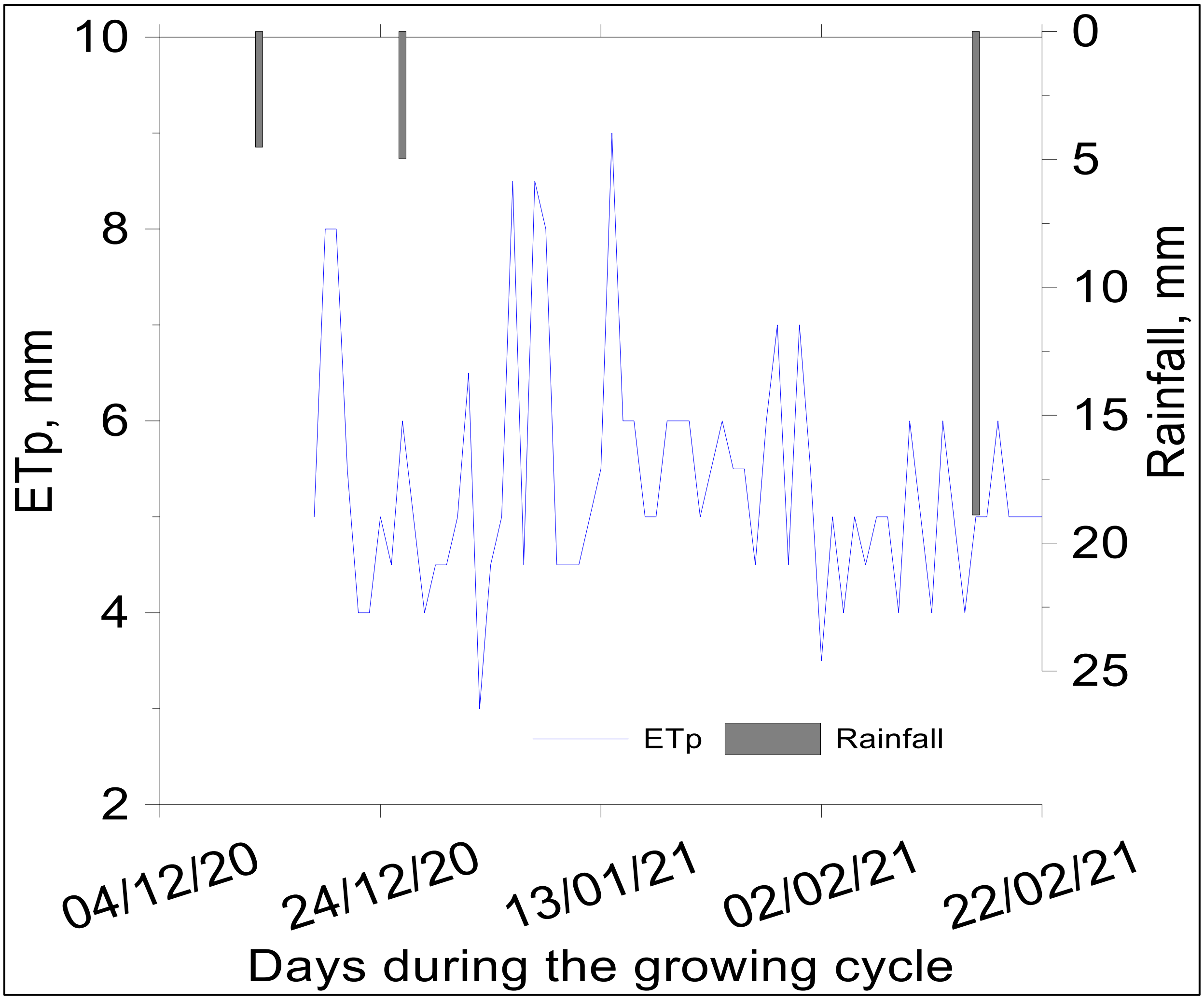

Fig. 2 Temporal pattern of pan evaporation and rainfall during the cucumber growing cycle. ETp: Pan evaporation

Table 4 Comparison of yield components of cucumber varieties grown under three different irrigation regimes

Irrigation	Variety	No. Frt	FrtDia (mm)	FrtLngth (cm)	FrtWt (g)	Yield (kg/m^2)
I5	V1	11.3	51.6	26.8	208.8	3.2
	V2	6.3	46.2	18.7	160.1	1.5
I4	V1	14.0	53.5	26.8	202.7	4.0
	V2	7.3	49.8	20.4	127.8	1.4
I3	V1	9.3	52.3	25.7	193.5	2.6
	V2	5.0	50.1	20.5	180.5	1.4
$V1_{mean}$		11.5	52.4	26.4	201.7	3.3
$V2_{mean}$		6.2	48.7	19.9	156.1	1.4
$I5_{mean}$		8.8	48.9	22.8	184.5	2.3
$I4_{mean}$		10.7	51.6	23.6	165.3	2.7
$I3_{mean}$		7.2	51.2	23.1	186.9	2.0
I effect (p<0.05		S	NS	NS	NS	NS
V effect (p<0.05)		S	S	S	S	S
I × V (p<0.05)		S	S	NS	S	S

I5: Five irrigations per week; I4: Four irrigations per week; I3: Three irrigations per week; V1: Variety 1 (CU999); V2: Variety 2 (Murano F1); No. Frt: Number of fruits; FrtDia: Fruit diameter; FrtLngth: Fruit length; FrtWt: Fruit weight; NS: Not significant difference; S: Significant difference at 5% level of probability by Fisher's Least Significant Difference (LSD) test

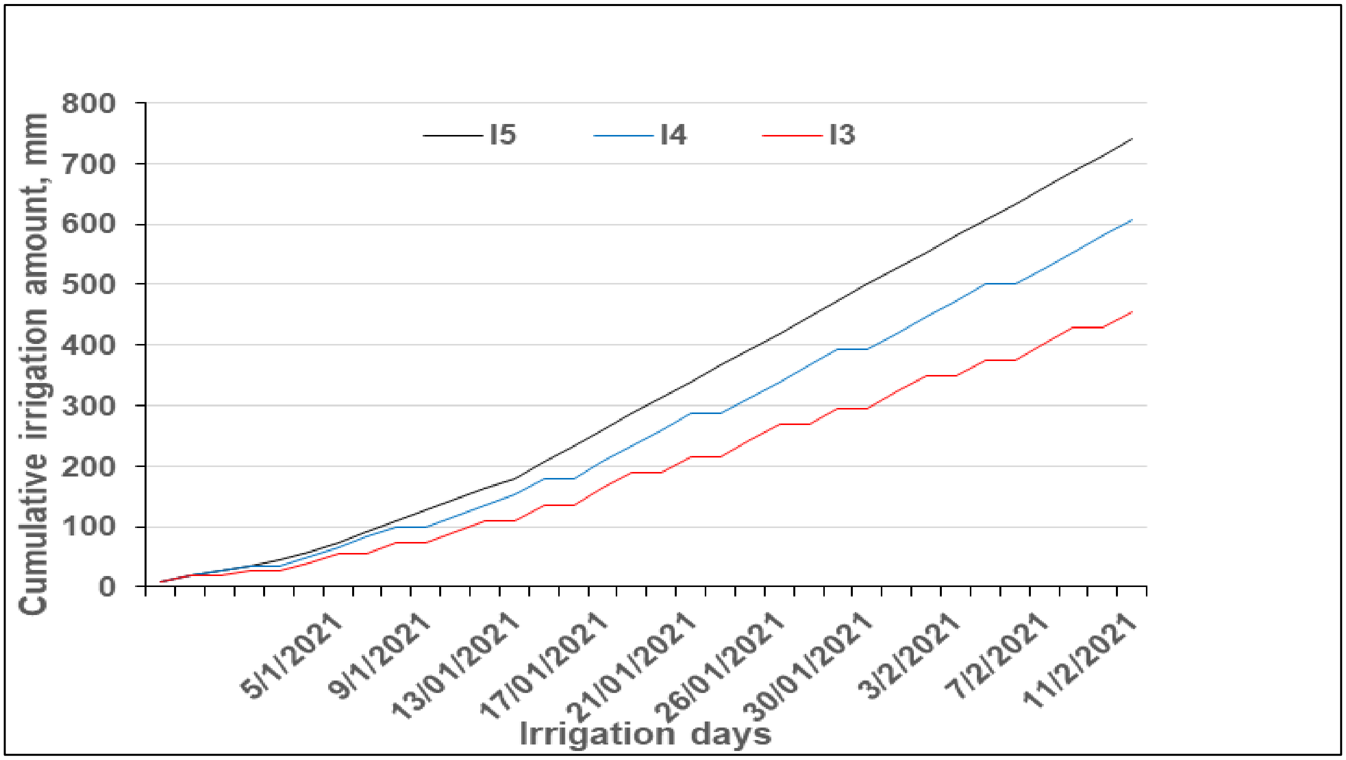

Fig. 3 Cumulative irrigation water depth application by the three irrigation frequencies during the cucumber growing cycle. I5: irrigation water application five times a week; I4: irrigation water application four times a week; I3: irrigation water application three times a week

Yield components

Irrigation had significant ($p < 0.05$) effect only on the number of fruits, with I4 treatment having the highest number of fruits. Although the effect of drip irrigation was not significant ($p > 0.05$) on cucumber yield, but numerically the yield was in the order: I4 > I5 > I3 (Table 4). The two cucumber varieties differed significant ($p < 0.05$) with respect to all the yield components with CU-999 F1 variety having higher number of fruits, fruit diameter, fruit length, fruit weight, and yield than Murano F1 by 46, 7, 25, 23, and 58%, respectively. There was significant interaction effect ($p < 0.05$) of drip irrigation frequency and variety on cucumber yield components, with treatment I4V1 having the highest values of the yield components except fruit length (Table 4). Two scenarios were obtained in this study, first, cucumber yield first increased with increased irrigation frequency from I3 to I4 and later decreased with increased irrigation frequency from I4 to I5.

The first scenario contradicts Rahil and Qanadillo (2015) who found increase in cucumber yield when drip irrigation water was decreased from full (100%) to 80%. Reducing irrigation level was by 50% resulted in low cucumber yield (Abdul Hakkim & Jisha Chand, 2014). However, the second scenario agrees with the findings of El-Hady and Wanas (2006) who found decreased cucumber yield with increased irrigation amount. However, Fasina et al. (2021b) found cucumber yield decreased with increasing irrigation application. It shows in this study that the optimum irrigation scheduling for the cucumber crop is I4. Yuan et al. (2006) had stated that increasing irrigation water to a certain level significantly influenced cucumber growth and yield. In other words, frequent and consistent-managed drip irrigation plays a vital role in keeping soil moisture stable in the root zone, a condition shown to enhance cucumber growth and productivity (Callau-Beyer et al., 2024). This stability in moisture supports a steady uptake of water and nutrients, helps maintain high levels of stomatal conductance and photosynthetic activity, and promotes fruit set and development, resulting in increased number of fruits, size, and overall yield (Sonnenberg et al., 2016; Parkash et al., 2021). On the other hand, deficit water supply (low-frequency irrigation) leads to an imbalance between wetting and drying cycles, which can hinder root water uptake, limit nutrient availability and movement, and restrict the supply of essential resources to developing fruits as plants experience moisture stress (Anjum et al., 2022; Kaman et al., 2023). Consequently, this results in reduced fruit quantity and smaller sizes, hence lower yields. Additionally, different cucumber varieties exhibit distinct characteristics such as root system architecture, drought tolerance, and sink strength that influence how effectively they can absorb water and nutrients based on the irrigation frequency (Balliu et al., 2021). This explains the variations in yield components that arise from the interplay between irrigation frequency and cucumber variety.

Water use efficiency

Fig. 4 shows the water use efficiency (WUE) of the two cucumber varieties under different drip irrigation frequency. The two cucumber varieties differed significantly ($p < 0.05$) with regards to WUE, with variety CU-999 F1 (V1) having the higher WUE compared to Murano F1 (V2). Similarly, the effect of drip irrigation frequency was significant ($p < 0.05$) on cucumber WUE, with I5 having the lowest WUE while I4 had higher WUE but did not differ from I3 treatment. The treatment combination I4V1 had the highest ($p < 0.05$) WUE (data not shown). Studies have also established high WUE for the cucumber crop under reduced irrigation water applications (Hashem et al. 2011; Abdul Hakkim & Jisha Chandy, 2014; Zakka et al., 2020; Fasina et al., 2021a; Fasina et al., 2021b). Nevertheless, the water saving strategy from I3 (40% less water applied compared to I5) did not translate to the highest WUE as expected. When it comes to maximizing water use efficiency in cucumbers, the right drip irrigation frequency paired with the right variety could make the difference. This is largely due to how well the soil moisture is managed and the unique traits of each cucumber variety that help them absorb and use water effectively. By applying drip irrigation four days a week (I4) maintains a stable moisture levels in the root zone and keep a consistent wetting and drying cycles. This stable moisture condition could have promoted the plants' ability to take up water, improves nutrient absorption, and keeps photosynthesis steady along (Navyashree, 2023). Under this close to ideal conditions, plants can turn a greater share of the water they absorb into growth and fruit formation, which in turn raises their water use efficiency (WUE). Moreover, varietal traits such as root system architecture, stomatal regulation, osmotic adjustment, and sink strength determine how efficiently a given cultivar converts available water into biomass and fruit (Basu et al., 2016; Zahedi et al., 2025), explaining why one variety may show significantly higher WUE than another under the same irrigation frequency (Awe et al., 2016; Singh et al., 2019). It follows that the CU-999 has better traits to direct resources toward growth and fruit development. In other words, even when moisture levels fluctuate a bit, the CU-999 variety can keep functioning well, making the most out of every drop of water it gets. Consequently, the combination of optimal irrigation frequency and these adaptive traits leads to a significant boost in WUE for the CU-999 cucumber variety, underscoring its exceptional ability to capture, transport, and convert water into productive growth.

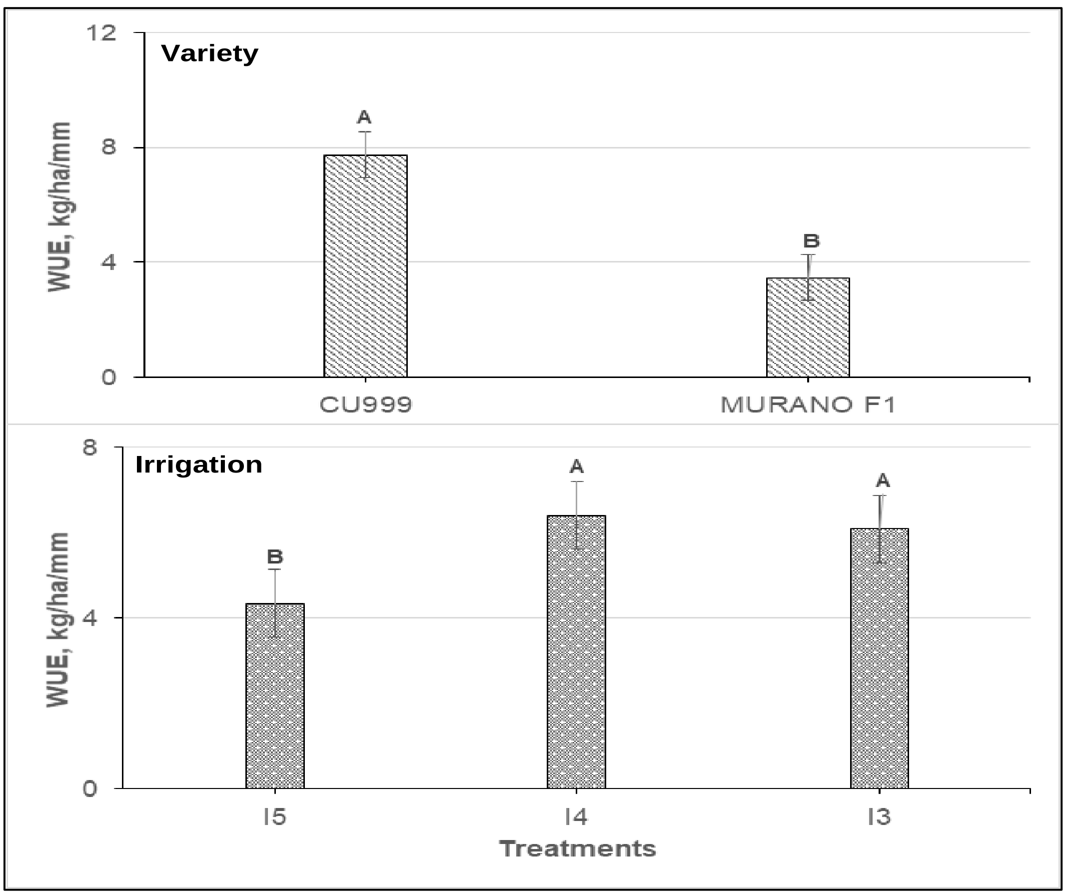

Fig. 4 Water use efficiency of two cucumber varieties under different drip irrigation frequency. I5: Five irrigations per week; I4: four irrigations per week; I3: three irrigations per week

Conclusion

Irrigation, variety and the interaction effects were not significant on cucumber plant growth parameters. The main effect of irrigation frequency was significant on the number of fruits only. The two cucumber varieties differed significantly with respect to all the yield components and water use efficiency, with CU-999 F1 variety more resilience by having the better performance indices than Murano F1 variety. Increasing drip irrigation frequency beyond four times a week did not increase cucumber yield components. The combination of four irrigations per week and CU-999 F1 variety gave the best growth parameters and yield components. Therefore, four irrigations per week and CU-999 F1 variety could be a suitable irrigation-variety combination for climate-smart strategy and resilience for cucumber production in this locality and similar agro-ecological zone.

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Declarations

i. Ethics approval and consent to participate: The study did not involve any human or animal. All authors gave their consent to participate in the study.

ii. Conflict of Interest: The authors declare no conflict of interest.

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