Original Research Article

Effects of Irrigation Regimes on Yield and Water Use Efficiency of Cucumber (*Cucumis sativus* L.) in Ogbomoso, Nigeria

ABSTRACT

Agriculture uses over 70% of global freshwater resources, suggesting that deficit irrigation may be essential for sustainable food production and soil health. In Ogbomoso, Nigeria, limited research has been conducted on how deficit irrigation and intervals affect soil thermal properties. An experiment on the effects of irrigation regimes on soil thermal properties under cucumber production was carried out at the Teaching and Research Farm of the Department of Agricultural Engineering, Ladoke Akintola University of Technology, Ogbomoso, Nigeria using a split-plot experimental design with irrigation depth (D1:100% ETc, D2:85% ETc, D3:70% ETc) and irrigation interval (I1:daily, I:-every two days, I3:every three days) arranged in a randomized complete block design with three replications. Soil temperature, thermal conductivity, and thermal resistivity were measured throughout the cucumber growth cycle. Data collection involved weekly soil thermal property measurements at four soil depths (0-5, 5-10, 10-15, and 15-20 cm) using a KD2 Pro thermal analyser. At 15-20 cm depth, significant soil temperature differences ($p \leq 0.05$) were observed throughout most of the growing period 5-7 weeks after planting (WAP) and 9 WAP. D2 reached 32.5°C, approximately 1.9% higher than D1 (31.9°C) and 0.3% higher than D3 (32.4°C). At the 0-5 cm depth, the thermal conductivity at 7-8 WAP under D1 (0.216 W/m·K) was significantly higher ($p<0.05$) than those of D2 (0.118 W/m·K) and D3 (0.104 W/m·K). At 5-10 cm, the thermal conductivity at 6 WAP under I2 (96.765 cm·°C/W) was significantly higher ($p<0.05$) than those of I2 (0.925 W/m·K) and I3 (0.696 W/m·K). At the 5-10 cm depth, the thermal resistivity at 6-7 WAP under I3 (162.249 cm·°C/W) was significantly higher ($p<0.05$) than those of I1 (96.765 cm·°C/W) and I2 (0.104 W/m·K). Irrigation depths and intervals had significant impacts on the above listed soil paramters. However, D.212 displayed an optimum soil thermal balance across the soil layers. So, farmers in Ogbomoso and similar regions are advised to adopt a deficit irrigation of 85% and a two day interval water applicaton as it supports soil thermal stability and optimizes growth without requiring full water allocation.

Keywords: Deficit irrigation, Water use efficiency, Cucumber yield, Irrigation scheduling, Water management

1. INTRODUCTION

Agriculture faces unprecedented challenges in meeting global food demand while confronting increasing water s With agriculture consuming approximately 70% of global freshwater resources and up to 95% in numerous developing countries, efficient water management has become crucial for sustainable crop production (Naganjali *et al.*, 202 challenge is particularly acute in regions experiencing water stress, where water management practices is essential for maintaining agricultural productivity while conserving the water resource.Cucumber (*Cucumis sativus* L.) is a sig

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vegetable crop valued for its nutritional content and economic importance in both local and international markets. As a crop containing approximately 95% water, the growth and yield of cucumber are particularly sensitive to water availability and irrigation management (Ors *et al.*, 2022). Despite its importance, cucumber cultivation faces challenges related to water availability and efficient use, especially in regions with limited water resources or irregular rainfall patterns.Water use efficiency (WUE) has emerged as a critical metric in agricultural water management, representing the relationship between crop yield and water consumption. In the context of increasing water scarcity and climate variability, improving WUE while maintaining acceptable yields has become a primary objective in sustainable agriculture (Kilemo, 2022). This is particularly relevant for cucumber production, where water management directly influences both yield quantity and quality.

Deficit irrigation has gained attention as a water management strategy that can potentially optimize WUE while maintaining acceptable yields. This approach deliberately applies water below full crop water requirements during specific growth stages or throughout the growing season (Yu *et al.,* 2020). Research has shown that some crops can maintain relatively high yields under moderate water deficit conditions while significantly improving WUE (Cheng et al., 2021; Xu et al., 2024). However, the success of deficit irrigation strategies depends on various factors, including crop type, growth stage, environmental conditions, and irrigation scheduling (Comas et al., 2019; Zou *et al.,* 2021).
Irrigation scheduling, encompassing both the depth and frequency of water application, plays a crucial role in determining crop response to water availability. The timing and amount of water application can significantly influence soil moisture dynamics, plant water relations, and ultimately, crop productivity (Todorović, 2019; Zakka *et al*., 2020; Zhao *et al.,* 2023). Understanding these relationships is essential for developing efficient irrigation strategies that balance water conservation with yield optimization.
In cucumber production, the relationship between irrigation management and crop performance is complex and influenced by multiple factors. Previous studies have shown varying responses to different irrigation regimes, with some reporting yield reductions under deficit irrigation (Cantuário *et al.,* 2021), while others have found minimal yield impacts with significant water savings (Parkash *et al.,* 2021). These varied responses highlight the need for location-specific research to determine optimal irrigation strategies under local conditions.
The interactive effects of irrigation depth and interval on cucumber yield and WUE remain inadequately understood, particularly in tropical regions. While several studies have examined either irrigation depth or frequency independently, few have investigated their combined effects on cucumber production. This knowledge gap is particularly relevant in regions like Nigeria, where water management strategies must be adapted to local environmental conditions and resource constraints.
In Nigeria, cucumber production faces challenges related to water availability and management, particularly in regions with distinct wet and dry seasons. The growing season in Ogbomoso, characterized by variable rainfall patterns and high evapotranspiration rates, presents unique challenges for irrigation management (Abegunrin *et al.,* 2013). Understanding crop response to different irrigation regimes under these conditions is crucial for developing sustainable production practices.
This study aims to evaluate the effects of different irrigation depths and intervals on cucumber yield and water use efficiency in Ogbomoso, Nigeria. The findings will contribute to developing more efficient irrigation strategies for cucumber production in similar tropical environments while addressing the broader challenge of agricultural water conservation.

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2. MATERIAL AND METHODS

Study Site Description

The study was conducted at the Teaching and Research Farm of the Agricultural Engineering Department, Ladoke Akintola University of Technology, Ogbomoso, Nigeria (8°10'06" N and 4°16'12" E, 341 m above mean sea level). The region experiences a tropical climate characterized by distinct wet and dry seasons. The dry season typically spans from November to March, while the wet season extends from April to October. Annual rainfall averages 1200 mm with a bimodal distribution peaking in June and September. The mean annual temperature ranges from 18°C to 36°C, with an average relative humidity of 74% during the wet season.
Initial soil analysis revealed a sandy loam texture throughout the experimental profile (0-30 cm), with sand content ranging from 61.9% to 65.9%, clay from 15.8% to 19.8%, and silt from 16.3% to 22.3%. Bulk density varied between 1.49 and 1.70 g cm^{-3}, while saturated hydraulic conductivity ranged from 13.35 to 43.97 cm/hr, indicating good drainage characteristics suitable for cucumber cultivation.

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Experimental Design and Treatments

The experiment employed a split-plot randomized complete block design with irrigation depth as the main plot factor and irrigation interval as the subplot factor. The irrigation depth treatments comprised three levels: D_1 (100% ETc, control), D_2 (85% ETc), and D_3 (70% ETc), where ETc represents crop evapotranspiration. Irrigation intervals were established at

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three levels: I_1 (daily irrigation), I_2 (2-day interval), and I_3 (3-day interval). The experimental layout consisted of nine treatment combinations replicated three times, resulting in 27 experimental units.

Land Preparation and Crop Management

The experimental site was initially cleared manually to remove existing vegetation, followed by deep ploughing to a depth of 30 cm using a tractor-mounted disc plough. Poultry manure was incorporated into the soil to enhance fertility. Ridges were constructed manually to facilitate seed sowing and drip lateral installation.
Darina F1 cucumber variety was selected as the test crop and sown manually at a depth of 2-3 cm. Plant spacing was maintained at 90 cm between rows and 30 cm within rows. Two seeds were initially planted per stand and later thinned to one seedling per stand at 14 days after germination. Bamboo stakes were installed to support the trailing vines. Standard agronomic practices, including weed control, fertilizer application, and pest management, were implemented uniformly across all treatments.

Irrigation System Design and Management

A drip irrigation system was designed and installed, comprising a 1000-liter elevated water storage tank, 50.8 mm diameter main pipeline, sub-main pipes, and 16 mm laterals fitted with pressure-compensating emitters. The emitters had a factory-rated discharge of 3 L/h. A filtration unit was installed on the mainline to prevent emitter clogging. The system was regularly monitored for uniform water distribution and maintenance of designed operating parameters.
During the initial two weeks post-planting, all treatments received uniform irrigation of 10 mm daily to ensure proper crop establishment. Subsequently, irrigation was applied according to treatment specifications. The irrigation volume (V_I) for each application was calculated using the following equation:

$$V_I = ETc \times Ii \times Dl \times Ac$$

Where: V_I = irrigation volume (m³); ETc = crop evapotranspiration (mm/day); Ii = irrigation interval (days); Dl = deficit level (decimal); Ac = crop area (m²)

The duration of each irrigation event was determined using:

$$t = V_I / (d \times Ne)$$

Where: t = irrigation time (hr); d = emitter discharge rate (L/hr); Ne = number of emitters

Data Collection and Analysis

Yield

The yield per hectare was calculated using:

$$Y = W / A$$

Where: Y = yield (kg/ha); W = weight of harvested fruits (kg); A = harvested area (ha)

Water Use Efficiency

Water use efficiency (WUE) was evaluated using:

$$WUE = Y/IR$$

Where: IR = total irrigation water applied (mm)

Statistical Analysis

The collected data were subjected to analysis of variance (ANOVA) using SPSS version 20 software. Treatment means were separated using Fisher's Least Significant Difference (LSD) test at 5% probability level.

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3. RESULTS AND DISCUSSION

Effects of Irrigation Depth on Cucumber Yield

Analysis of the yield data showed notable variations among different irrigation depth treatments. The highest yield of 8,738.79 kg/ha was achieved under full irrigation (D_1, 100% ETc), followed by D_3 (70% ETc) with 8,025.20 kg/ha, while D_2 (85% ETc) produced 7,801.37 kg/ha (Table 1). Although these differences were not statistically significant at $p \leq 0.05$, the full irrigation treatment (D_1) demonstrated superior performance, producing approximately 12% higher yield than D2 and 9% higher than D_3.
The yield response to irrigation depth exhibited a non-linear pattern, with the moderate deficit treatment (D_2) showing the lowest yield despite receiving more water than D_3. This unexpected response might be attributed to the plant's ability to adapt more effectively to severe water stress conditions through enhanced root development and improved water use efficiency mechanisms. This finding aligns with research by Abdelraouf *et al.,* (2020), who found that cucumber plants can develop adaptive strategies under consistent water stress conditions.
The superior yield under full irrigation (D_1) can be attributed to optimal soil moisture conditions that enhanced nutrient uptake and physiological processes. These results support findings by Liu *et al.,* (2019), who reported that adequate water availability is crucial for maximizing cucumber productivity. However, the relatively small yield reduction under severe deficit irrigation (D3) suggests that cucumber possesses considerable drought tolerance mechanisms, making it suitable for water-limited conditions.

Impact of Irrigation Intervals on Yield

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The irrigation interval treatments showed interesting effects on cucumber yield. The two-day irrigation interval (I_2) produced the highest yield of 8,281.18 kg/ha, followed by the three-day interval (I_3) with 8,147.86 kg/ha, and daily irrigation (I_1) with 8,043.20 kg/ha. While these differences were not statistically significant, they reveal important patterns in cucumber's response to irrigation frequency. The I_2 treatment produced approximately 3% higher yield than I_3 and 2.9% higher than I_1.
The slight yield advantage with I_2 might be attributed to improved soil aeration between irrigation events and potentially better root development stimulated by mild periodic water stress. This finding corresponds with research by Zakka *et al.,* (2020), who found that allowing slight soil moisture depletion between irrigation events can promote deeper root growth and improve overall plant resilience.
The slightly lower yield under daily irrigation might be attributed to possible soil saturation effects that could impact root respiration and nutrient uptake. These results indicate that cucumber plants can adapt effectively to less frequent irrigation without substantial yield penalties, potentially through physiological adaptations that enhance water uptake and utilization efficiency.

Interaction Effects of Irrigation Depth and Interval on Yield

The interaction between irrigation depth and interval (D × I) revealed significant variations in yield response (Table 1). The yield in $D_1 \times I_1$ combination was significantly higher than the yields in $D_2 \times I_1$ and $D_1 \times I_2$ combinations. The yield was in order ($D_1 \times I_1$) > $D_2 \times I_1$> $D_1 \times I_2$. Thus, $D_1 \times I_1$ combination represents a yield advantage of approximately 37% and 39% over $D_2 \times I_1$ and $D_1 \times I_2$ combination, respectively.
Notable interaction patterns revealed that under full irrigation (D_1), daily application (I_1) significantly outperformed other intervals. In the case of moderate deficit irrigation (D_2), the two-day interval (I_2) showed superior performance. However, under severe deficit conditions (D_3), longer irrigation intervals (I_2 and I_3) yielded better results than daily irrigation. These findings suggest that the best irrigation interval is a function of irrigation depth, indicating the need for synchronized management of both parameters for optimal yield outcomes.
The results align with (Al-Mehmdy and Fal-Issawi, 2023), who reported that irrigation frequency should be adjusted based on the total water application depth to optimize cucumber productivity. This interaction effect demonstrates the complexity of irrigation management and the importance of considering both parameters in irrigation scheduling decisions.

Water Use Efficiency Response to Irrigation Depth

Water use efficiency showed significant responses to irrigation depth treatments, with D_3 (70% ETc) achieving the highest WUE of 155.30 kg/m³. This was approximately 15% and 18% higher than WUE under D_1 and D_2, respectively. This indicates that in this study, reducing irrigation depth by 30% of ETc is most efficient in terms of water usage by cucumber plants.
The enhanced WUE under deficit irrigation suggests that cucumber plants can optimize their water uptake and productivity under water-limited conditions, possibly through several physiological adaptations, including enhanced root

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exploration of soil volume and improved stomatal regulation. This finding supports research by Shani and Musa (2019), who reported that moderate water stress could trigger adaptive responses that enhance water use efficiency.
The relationship between irrigation depth and WUE showed an inverse trend compared to yield, with lower irrigation depths generally resulting in higher WUE values. This pattern indicates a trade-off between maximizing yield and optimizing water use efficiency, an important consideration for irrigation management in water-scarce regions.

Effects of Irrigation Intervals on Water Use Efficiency

The impact of irrigation intervals on WUE revealed a clear trend favouring more frequent irrigation. The WUE in terms of interval is in order: $I_1 > I_2 > I_3$. This substantial difference in WUE across irrigation intervals suggests that more frequent irrigation allows for better water utilization by maintaining optimal soil moisture conditions and reducing water losses through deep percolation and evaporation.
The declining WUE with increasing irrigation intervals indicates that longer periods between irrigation events may lead to less efficient water use, possibly due to increased water stress and reduced photosynthetic efficiency. These findings align with research by Liu et al. (2019), who found that frequent irrigation helps maintain stable soil moisture conditions, leading to better water utilization by plants.

Combined Effects of Irrigation Depth and Interval on WUE

The interaction between irrigation depth and interval produced significant variations in WUE (Table 1). The combination of 70% ETc with daily irrigation ($D_3 \times I_1$) achieved the highest WUE, followed closely by $D_1 \times I_1$. These results demonstrate that daily irrigation consistently produced higher WUE across all irrigation depths, and deficit irrigation combined with appropriate intervals can achieve WUE comparable to full irrigation.
The lowest WUE was observed in the $D_2 \times I_3$ combination, indicating that moderate water stress combined with extended intervals may be detrimental to water use efficiency. This finding supports research by Al-Mehmdy and Fal-Issawi (2023), who reported that the combination of irrigation depth and frequency significantly influences water use efficiency in cucumber production.

Practical Implications for Irrigation Management

The interaction effects between irrigation depth and interval provide valuable insights for practical irrigation management. The combination of full irrigation with daily application ($D_1 \times I_1$) produced the highest yield (9,774.54 kg/ha), while moderate deficit irrigation with daily application ($D_3 \times I_1$) achieved the highest WUE (210.18 kg/m³). This presents farmers with flexible options depending on their primary objectives and resource constraints.
In water-scarce regions, the $D_3 \times I_1$ combination might be the most practical approach, as it achieves high WUE while maintaining acceptable yield levels. The relatively small yield penalty under this treatment (approximately 24% compared to $D_1 \times I_1$) could be offset by water savings and reduced irrigation costs. This strategy aligns with sustainable agricultural practices and could be particularly relevant in regions facing increasing water scarcity.

Table 1: Effects of irrigation regimes on cucumber yield and water use efficiency

Treatments	Yield (kg/ha)	WUE (kg/m³)
Irrigation Depth (D)		
D_1 (100% ETc)	8,738.79 a	139.89 b
D_2 (85% ETc)	7,801.37 a	133.50 a
D_3 (70% ETc)	8,025.20 a	155.30 c
Irrigation Interval (I)		
I_1 (Daily)	8,043.20 a	196.52 c
I_2 (2-day)	8,281.18 a	123.47 b

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I_3 (3-day)	8,147.86 a	108.69 a
Interaction (D × I)		
$D_1 \times I_1$	9,774.54 a	207.18 e
$D_1 \times I_2$	7,051.68 b	95.76 a
$D_1 \times I_3$	9,258.81 ab	116.73 b
$D_2 \times I_1$	7,144.88 b	172.21 d
$D_2 \times I_2$	9,232.36 ab	138.09 c
$D_2 \times I_3$	6,812.01 b	90.19 a
$D_3 \times I_1$	7,464.05 ab	210.18 e
$D_3 \times I_2$	8,228.14 ab	136.55 c
$D_3 \times I_3$	8,403.08 ab	119.15 b

Note: Means followed by the same letter(s) within columns are not significantly different at p≤0.05.

4. CONCLUSION

This study demonstrates that irrigation management significantly influences both cucumber yield and water use efficiency in tropical conditions. While full irrigation (100% ETc) with daily application produced the highest yield (9,774.54 kg/ha), moderate deficit irrigation (70% ETc) with daily intervals achieved the highest water use efficiency (210.18 kg/m³), suggesting viable options for different production objectives. The findings indicate that cucumber can maintain relatively stable yields under deficit irrigation, with only a 9% yield reduction at 70% ETc compared to full irrigation, while simultaneously improving water use efficiency. Daily irrigation intervals consistently outperformed longer intervals in terms of water use efficiency, though two-day intervals showed comparable yield results. Based on these findings, it is recommended that farmers in water-scarce regions consider adopting moderate deficit irrigation (70% ETc) with daily application intervals as an optimal strategy to balance yield and water conservation. However, where water availability is not constrained, full irrigation with daily intervals remains the most productive approach.

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