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Comparative evaluation of drip and sprinkler irrigation systems under varying soil moisture depletion levels for cucumber production

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KEYWORDS

cucumber, drip irrigation, sprinkler irrigation, management allowable depletion, MAD, yield, water management

ABSTRACT

Climate variability continues to pose significant challenges to agricultural productivity, particularly in water-dependent crops such as cucumber (Cucumis sativus L.). Efficient irrigation management is therefore essential to enhance crop yield under changing environmental conditions. This study evaluated the effects of irrigation method (drip and sprinkler) and management allowable depletion (MAD) levels (50% and 70%) on cucumber yield parameters at the experimental farm of the Department of Agricultural and Bioresources Engineering, Nnamdi Azikiwe University, Awka, Nigeria, in 2025. A 2 × 2 factorial experiments arranged in a Completely Randomized Design (CRD) with three replications was used. Data collected included average fruit weight and fruit length, and were analyzed using two-way analysis of variance (ANOVA) at $p \leq 0.05$. Results showed that both fruit weight and fruit length increased as MAD decreased from 70% to 50%, indicating improved yield performance under higher soil moisture availability. Drip irrigation consistently produced higher values of fruit weight and fruit length compared to sprinkler irrigation across all MAD levels. Statistical analysis revealed that MAD had a significant effect on both fruit weight and fruit length ($p < 0.05$), while irrigation method was not significant for fruit weight but showed a marginal effect on fruit length. The interaction between irrigation method and MAD was not significant for both parameters. Overall, the study demonstrates that maintaining lower soil moisture depletion levels (50% MAD) significantly enhances cucumber yield, with drip irrigation offering superior performance in optimizing water use efficiency and crop development.

1. Introduction

Variation and change in climate have become an issue in recent time because of its impact on natural eco-systems, and agriculture is one of the most likely operations affected by this climate change (Adamgbe and Ujoh 2013). Climate variability remains one of the most critical determinants of inter-annual crop output, including high yield (Kang et al, 2009). Changes in temperature and precipitation as a result of global climate change could have severe implication on hydrologic cycle processes, water resources accessibility, irrigation water use and hence upsetting agricultural production and output (Abeysingha et al., 2016).

Irrigation is the application of water to the land to provide adequate moisture for crop production. Phocaides (2007) also defined irrigation as the application of water, supplementary to that supplied by precipitation for the production of crops. Man cannot depend solely on rainfed Agriculture for his activities without supplementary application of water hence the need of artificial application of water cannot be underestimated in achieving a sustainable agriculture. Agriculture is the greatest user of water resources in the world totalling 70% of total withdrawals and over 80% of the consumptive use of water (Baudequine and Molle, 2003).

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Cucumber (Cucumis sativus L.) is a widely cultivated vegetable crop valued for its nutritional and economic importance. Its productivity is highly dependent on adequate soil moisture, making irrigation a critical factor in its cultivation.

Modern irrigation systems such as drip and sprinkler irrigation have been developed to improve water-use efficiency. Drip irrigation delivers water directly to the root zone, reducing evaporation losses, while sprinkler irrigation distributes water over the crop canopy but may result in inefficiencies (Michael, 2008).

Management Allowable Depletion (MAD) is a key irrigation scheduling parameter that determines when irrigation should occur. Lower MAD levels (e.g., 50%) maintain higher soil moisture, whereas higher levels (e.g., 70%) may induce water stress (Allen et al., 1998).

Previous studies have shown that both irrigation method and soil moisture levels significantly influence crop yield (Kirda, 2002; Shock et al., 2007). However, comparative studies under tropical conditions remain limited. This study therefore evaluates the combined effects of irrigation method and MAD on cucumber yield.

2. Method

2.1 Experimental Site

The study was carried out at the farm workshop/experimental site of the department of agricultural and Bioresources Engineering, Nnamdi Azikiwe University, Awka, Anambra State, Nigeria (6°15’11.8N to 6°15’5.3E latitude and 7°7’118N to 7°7’183N longitude, and altitude of 142m) in 2025.

Deficit irrigation was used to compare the effects of sprinkler and drip irrigations on cucumber yield.

2.2 Experimental Design

A 2 × 2 factorial arrangement in a Completely Randomized Design (CRD) was used:
Factor A: Irrigation Method (Drip, Sprinkler)
Factor B: MAD Levels 50% and 70%
In 50% MAD, Irrigation is triggered when half of the available soil water is used.
So,

$$MAD = 0.5\ X\ TAW \qquad 1$$

Where:

TAW = Total available water.

MAD at 70% means, Irrigation is triggered when 70% of available water is depleted.

So,

$$MAD = 0.7\ X\ TAW \qquad 2$$

Each treatment was replicated three times to allow statistical analysis.

2.3 Data Collection

- Average fruit weight (g)
- Average fruit length (cm)

2.4 Statistical Analysis

Data were analyzed using two-way ANOVA:
Model:
Yijk=μ+Ii+Mj+(IM)ij+ϵijkY_{ijk} = \mu + I_i + M_j + (IM)_{ij} + \epsilon_{ijk}Yijk=μ+Ii+Mj+(IM)ij+ϵijk

Where:

- IiI_iIi = irrigation effect
- MjM_jMj = MAD effect
- IMijIM_{ij}IMij = interaction

Significance was tested at $p \leq 0.05$.

3. Results

3.1.1 Cucumber Fruit weight

The data presented in the graph can be organized into the following table:

Table 3.1: Effect of Irrigation Method and MAD on Fruit Weight

MAD (%)	Sprinkler (g)	Drip (g)
70	200	210
50	250	269

Table 3.1 and Figure 3.1 illustrates the variation in average fruit weight as influenced by irrigation method and management allowable depletion (MAD) levels. A clear increasing trend in fruit weight is observed as MAD decreases from 70% to 50% under both irrigation methods, indicating that reduced soil moisture depletion (i.e., higher water availability) promotes greater fruit development. Under sprinkler irrigation, the average fruit weight increased from approximately 200 g at 70% MAD to 250 g at 50% MAD. Similarly, under drip irrigation, fruit weight rose from about 210 g to 269 g across the same MAD levels.

Although drip irrigation consistently produced higher fruit weights compared to sprinkler irrigation at both MAD levels, the overall pattern of increase was similar for both methods. This parallel trend suggests that the effect of MAD on fruit weight is consistent regardless of the irrigation method employed. The larger increase observed under drip irrigation indicates a potential advantage in optimizing water delivery efficiency; however, the dominant factor influencing fruit weight remains the level of soil moisture availability.

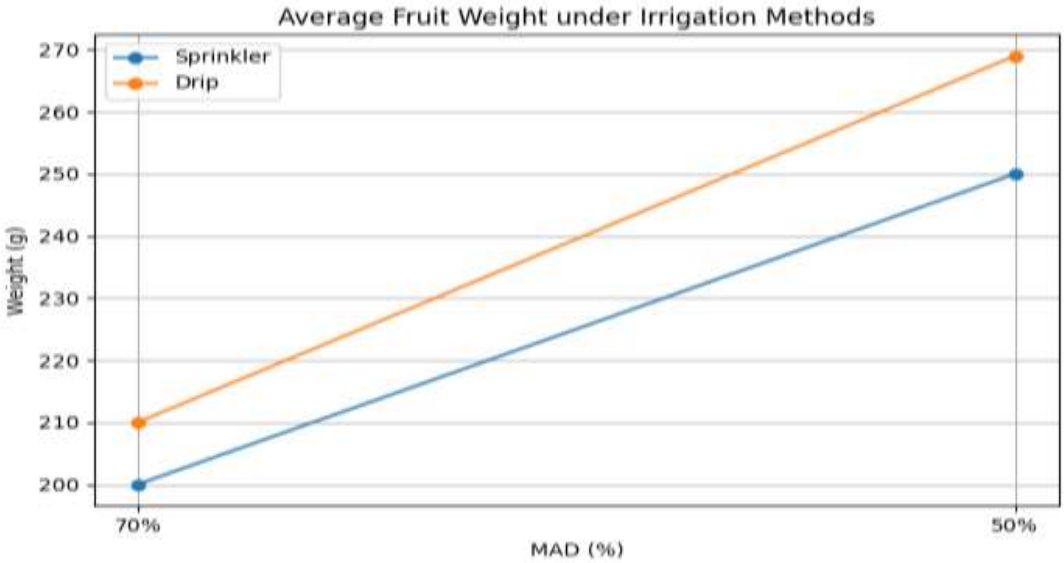

Figure 3.1: Effect of Irrigation Method and MAD on Fruit Weight

Table 3.2: ANOVA for Fruit Weight

Source	SS	df	MS	F	p-value
Irrigation	722.25	1	722.25	8.12	0.065
MAD	3481.00	1	3481.00	39.15	0.008*
Interaction	90.25	1	90.25	1.02	0.372
Error	355.50	4	88.88		
Total	4649.00	7			

The ANOVA results in table 3.2 indicate that the level of soil moisture depletion (MAD) had a statistically significant effect on fruit weight ($p < 0.05$), demonstrating that variations in soil water availability directly influenced the development and final mass of the fruits. In contrast, the irrigation method exhibited only a moderate effect on fruit weight, which was not statistically significant, suggesting that the type of irrigation applied did not play a decisive role under the conditions of the study. Furthermore, the interaction between MAD level and irrigation method was not significant, indicating that their effects operated independently rather than synergistically. Overall, these findings suggest that soil moisture availability is the primary factor governing fruit weight, outweighing the influence of the irrigation method used.

3.1.2 Cucumber Fruit Length

Table 3.3: Effect of Irrigation Method and MAD on Fruit length

MAD (%)	Sprinkler (cm)	Drip (cm)
70	14	15
50	17	20

Table 3.3 and Figure 3.2 shows the effect of irrigation method and management allowable depletion (MAD) on fruit length under sprinkler and drip irrigation systems. At 70% MAD, fruit length values of 14 cm and 15 cm were recorded under sprinkler and drip irrigation, respectively. When MAD was reduced to 50%, fruit length increased to 17 cm under sprinkler irrigation and 20 cm under drip irrigation.

The results indicate that a lower MAD level (50%) was associated with greater fruit length compared to 70% MAD for both irrigation methods. Across both MAD levels, drip irrigation consistently produced higher fruit length values than sprinkler irrigation. This suggests that irrigation scheduling based on lower soil moisture depletion enhances fruit development, and that drip irrigation provides a more favorable moisture regime for improving fruit length relative to sprinkler irrigation.

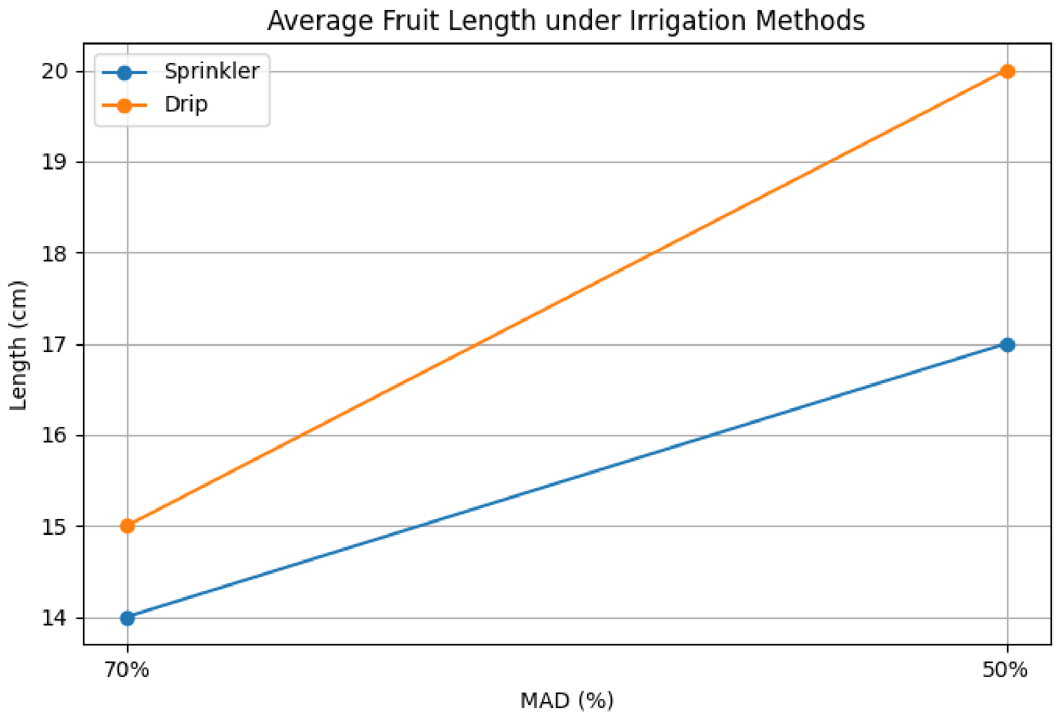

Figure 3.2 Effect of Irrigation Method and MAD on Cucumber fruit length

The analysis of variance (ANOVA) for fruit length in table 3.4 revealed that management allowable depletion (MAD) had a statistically significant effect on fruit length (F = 27.78, p = 0.013), indicating that variations in soil moisture availability strongly influenced fruit elongation. In contrast, the effect of irrigation method was not statistically significant at the 5% level (F = 6.94, p = 0.078), although the relatively low p-value suggests a possible trend that may warrant further investigation.

The interaction between irrigation method and MAD was also not significant (F = 1.11, p = 0.352), indicating that the influence of MAD on fruit length was consistent across both irrigation methods and that the two factors acted independently. The error mean square was relatively low (MS = 0.90), suggesting limited unexplained variability in the data. Overall, these results demonstrate that soil moisture availability, as regulated by MAD, is the primary factor affecting fruit length, while irrigation method plays a less influential role under the conditions of this study.

Table 3.4: ANOVA for Fruit Length

Source	SS	df	MS	F	p-value
Irrigation	6.25	1	6.25	6.94	0.078
MAD	25.00	1	25.00	27.78	0.013*
Interaction	1.00	1	1.00	1.11	0.352
Error	3.60	4	0.90		
Total	35.85	7			

The results clearly indicate that a lower management allowable depletion (MAD) level of 50% leads to higher cucumber yield compared to higher MAD levels. This improvement in yield can be attributed primarily to better soil moisture conditions, which reduce plant water stress and allow for more stable physiological functioning throughout the growth period. When water is more readily available in the root zone, plants are able to maintain higher turgor pressure, which supports continuous cell expansion and overall vegetative and reproductive development.

In addition, adequate soil moisture enhances nutrient uptake by facilitating the movement of dissolved nutrients toward plant roots. This improves nutrient absorption efficiency and supports stronger plant growth and fruit development. The improved water availability also contributes to higher rates of photosynthesis, as well-watered plants maintain open stomata for gas exchange, enabling efficient carbon assimilation and energy production required for fruit formation.

Across both MAD levels, drip irrigation consistently produced higher yields than sprinkler irrigation. This performance advantage is likely associated with the more precise application of water directly to the root zone, which minimizes water loss through evaporation and runoff while improving water-use efficiency. This finding is consistent with the report of Shock et al. (2007), who also observed that drip irrigation enhances crop yield due to its ability to deliver water more efficiently and maintain optimal soil moisture conditions for plant growth..

4. Conclusion

The results of the study indicate that management allowable depletion (MAD) has a significant influence on cucumber yield, confirming that soil moisture regulation is a critical factor in crop productivity. Lower MAD levels, particularly 50%, were found to be most effective in enhancing both fruit weight and fruit length, suggesting that maintaining higher soil moisture availability supports better physiological development and fruit expansion in cucumbers. This is likely because reduced water stress allows for uninterrupted cell division and enlargement, which are essential processes in fruit growth.

Furthermore, the findings show that drip irrigation consistently outperforms sprinkler irrigation in terms of yield performance. This superiority can be attributed to the more efficient and targeted delivery of water directly to the root zone, which reduces water loss and improves water-use efficiency. As a result, plants under drip irrigation are better able to maintain optimal moisture conditions, leading to improved growth and yield characteristics. The combined effect of irrigation method and MAD levels suggests that the most effective treatment combination is drip irrigation at 50% MAD. This combination provides a balance of efficient water delivery and adequate soil moisture availability, creating favorable conditions for maximum cucumber growth and yield development.

References

Abeysingha, N.S., Singh, N.S., Islam A. and Sehgal, V.K. (2016). Climate change impacts on irrigated rice and wheat production in Gomti River Basin of India: a case study. *SpringerPlus*, 5: 1250

ACPC (Economic Commission for Africa) (2011). Climate change and Agriculture: Analysis of Knowledge gaps and needs. *United Nations Economic Commission for Africa*, Working paper 7.

Adamgbe, E.M., and Ujoh, F. (2013). Effect of variability in rainfall characteristics on maize in Gboko, Nigeria. *Journal of Environmental Protection*, 4: 881-887

Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (1998). *Crop evapotranspiration: Guidelines for computing crop water requirements*. FAO Irrigation and Drainage Paper 56.

Anyadike, R.N.C. (2009). Climate change and sustainable development in Nigeria: Conceptual and Empirical issues. Enugu forum policy paper 10 African Institute for Applied Economics.

Baudequin, D. and Molle, B. (2003). Is standardisation a solution to improve the Sustainability of irrigated agriculture. French national committee of the international commission on irrigation and drainage, France.

Kang, Y., Khan, S. and Ma, X. (2009). Climate change impacts on crop yield, crop water productivity and food security. A review. *Progress in Natural Science* 19: 1665 – 1674

Kirda, C. (2002). Deficit irrigation scheduling based on plant growth stages. *Deficit Irrigation Practices*, 3–10.

Michael, A. M. (2008). *Irrigation: Theory and Practice*. Vikas Publishing House.

Phocaides, A. (2007). Handbook on pressurised Irrigation techniques. Natural resources management and environment department. Rome, Food and Agriculture Organisation of the United Nations. 2nd Ed.

Shock, C. C., Feibert, E. B. G., & Saunders, L. D. (2007). Onion yield and quality affected by irrigation method and nitrogen rate. *HortScience*, 42(3), 563–567.