

Optimizing Water and Nutrient Use Efficiency Through Deficit Irrigation and Fertilization Strategies in Cucumber (*Cucumis Sativus* L.)

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ABSTRACT

Water scarcity and declining soil fertility are major constraints to sustainable vegetable production in sub-Saharan Africa, particularly under rain-fed and poorly managed irrigation systems. This study examined how deficit irrigation, together with integrated fertilization methods, affected water-use efficiency (WUE) and nutrient-use efficiency (NUE) in cucumber (*Cucumis sativus* L.) plants. The study utilized a Randomized Complete Block Design (RCBD) with three replications to conduct experiments in Asaba, Delta State, Nigeria. The study applied three irrigation treatments, including full crop water supply at 100% and reduced supplies at 75% and 50% of crop water need, together with two NPK treatments at 60 and 120 kg/ha, two poultry manure treatments at 3 and 6 t/ha, and control plots. Fruit yield fluctuated drastically over the course of the experiments; it ranged from 2.26 t/ha with I50N0M0 to 4.78 t/ha with I100N6M6, an increase of 111.5%.

Full irrigation (I100) consistently produced the highest yield, with yields reduced by 8.9% to 12.1% under I75, depending on nutrient management. Still, the application of nutrient-rich treatment (N6M6) at I75 achieved a yield of 4.20 t/ha, which was only 0.58 t/ha lower than full irrigation. Water and concordant nutrient management showed significant main and interaction effects on yield in a two-way ANOVA, with highly significant main and interaction effects on fruit yield. Variability is about 5.67%, reflecting high precision in the experiments. This shows that adequate interaction between water and nutrient availability strongly influences cucumber yield, differentiating production and must lead to effective water use; the adoption of such strategies should not substantially hamper production.

The results demonstrated that irrigation at 50%, combined with high manure application at 6 t/ha and high NPK application at 120 kg/ha, produced the best irrigation water use efficiency of 19.49 kg/m³ and water use efficiency of 16.73 kg/m³. Under full irrigation conditions with low NPK and high manure application, the study observed the highest nutrient use efficiency, achieving a yield of 26.00 kg per kilogram of nutrient. Post-harvest soil analysis demonstrated that integrated nutrient applications enhanced soil pH, organic matter content, total nitrogen, and available phosphorus compared with unfertilized controls. The combination of organic amendments and deficit irrigation resulted in significant increases in water productivity while maintaining yield levels. The study establishes that South-South Nigerian sandy loam soils achieve optimal water and nutrient use efficiencies through integrated nutrient management, which combines deficit irrigation with 60 kg/ha NPK and 6 t/ha poultry manure for cucumber production.

Keywords: Deficit irrigation, water use efficiency, nutrient use efficiency, cucumber, fertilization

INTRODUCTION

In developing countries, food security poses a major challenge due to inconsistent rainfall, poor soil fertility, and low levels of agricultural input, resulting in reduced yields (Akinrinde, 2006). Akinrinde *et al.* (2005) highlight that limited soil biodiversity, nutrient deficiencies, financial limitations, moisture stress, erosion, excessive phosphorus fixation, high acidity with aluminum toxicity, and inadequate soil fertility hinder tropical soil productivity and sustainable farming practices. Despite significant oil revenues, agriculture is still one of Nigeria's most vital economic sectors. It accounts for roughly 70% of employment, meets around 80% of the nation's food requirements, and contributes over 40% of the GDP (Adenuga *et al.*, 2013). Enhancing water use efficiency in irrigation is becoming increasingly critical, as agriculture is the largest water consumer worldwide. Vegetable production is significantly threatened by population growth and climate change, particularly in arid and semi-arid regions. Indeed, climate change can result in more frequent, intense, and extended droughts (Jones & van Vliet, 2018). Fertilization not only boosts crop yields but also improves product quality by influencing soil fertility and nutrient levels. However, the overuse of chemical fertilizers can lead to low efficiency, as uneven fertilization may cause micronutrient deficiencies (Souri *et al.*, 2017). Attempts to boost agricultural output through fertilizer overapplication have resulted in soil degradation, groundwater contamination, and various ecological and environmental issues (Li *et al.*, 2023). According to Opara *et al.* (2012), using a combination of organic and inorganic fertilizers enhances fruit yield and nutrient absorption. Cucumber (*Cucumis sativus*), a popular vegetable from the Cucurbitaceae family, is a key global crop known for its nutritional value and economic importance (Amtmann & Blatt, 2009). This succulent plant features broad leaves that shade the fruit and has a high-water content. The plant produces soft, hearty vines that climb supports and develop substantial leaves above the fruits (Wehner & Gunner, 2004). Cucumber is an essential horticultural crop cultivated and consumed worldwide due to its distinctive flavor, health advantages, and significant production. Cucumbers require more water than grain crops, and the amount of irrigation water used at all growth stages significantly impacts cucumber fresh fruit yields. Irrigation regimes with water deficits during the fruiting stages produce the least fruitful results (Mao *et al.*, 2003). Due to the small amount of wet soil, there will be minimal change in the root zone's soil moisture content from the start to the end of the growth season. Deficit irrigation has emerged as an effective water management technique capable of optimizing water use efficiency (WUE) while ensuring satisfactory yields. This method intentionally supplies water below the complete requirements for crops during particular growth phases or over the entire growing season (Yu *et al.*, 2020). Xu *et al.* (2024) note that certain crops can sustain fairly high yields even under moderate water deficits, which substantially enhance WUE. The effectiveness of deficit irrigation, however, relies on several factors, such as crop type, growth phase, environmental conditions, and irrigation scheduling (Zou *et al.*, 2021). Few studies have investigated the combined effects of irrigation depth and frequency on cucumber output, despite many examining each factor individually. This knowledge gap is particularly crucial in locations like Nigeria, where local environmental factors and resource constraints require the adaptation of water management systems. Understanding cucumber responses to limited fertilization and irrigation is critical; however, study on this topic is limited, particularly in the South-South, Nigeria. This study intends to explore Water Use Efficiency (WUE) and Nutrient Use Efficiency (NUE) in cucumber production through deficit irrigation and fertilization strategies to promote sustainable farming in the region.

MATERIALS AND METHODS

Study Area

The study was carried out at the Demonstration Farm of the Federal College of Education (Technical), Asaba, Delta State, South-South, Nigeria during 2025/2026 growing season. Delta State is Nigeria's oil- and agriculture-producing state, located in the South-South geopolitical area of the Niger Delta region, with a population of 4,098,291 (males: 2,674,306; females: 2,024,085) (NPC, 2006). With an area of approximately 762 square kilometers (294 sq mi), the capital city is Asaba, situated at the northern end of the state, while Ogwashi-Uku has the largest land area for industry. Asaba is located on a terrace overlooking the point where the Anambra River flows into it from the lower Niger River. Beyond the river banks, secondary forest vegetation thrives on the high plains

that are much more widespread than the river basins (Federal Republic of Nigeria (FRN) 2013). It is the capital of Delta State, Nigeria, and the headquarters of Oshimili South Local Government Area of the state, which is in the South-South Zone of Nigeria. and it lies between longitudes 6°38'44" and 6°44'00" east of the Greenwich Meridian and latitude 6°08'00" and 6°16'00" North of equator.

Soil Properties

At the experimental site, a thorough soil evaluation was carried out to determine the baseline physicochemical characteristics of the soil before cucumber seedlings are transplanted and after harvesting of the cucumber. To guarantee a representative profile of the root zone, soil samples were taken from the field using a soil auger at depths varying from 0 to 60 cm. To capture geographic heterogeneity and improve the analysis's accuracy, composite samples were taken from various locations within the experimental region. Soil pH, bulk density, electrical conductivity (EC), particle size distribution, and textural categorization are among the physical and chemical characteristics that need to be ascertained. Total nitrogen (N), accessible phosphorus (P), exchangeable potassium (K), calcium (Ca), magnesium (Mg) and sodium (Na) are among the essential macro- and micronutrients that was also measured.

Climatic Condition

This study concentrates on three crucial meteorological parameters: temperature, precipitation, and relative humidity, and aims to minimize the risk of such associations among independent variables and to ensure the analysis's accuracy and reliability. The Nigerian Meteorological Agency (NIMET) provide climate data for the 2025–2026 season, offering a detailed meteorological profile for the analysis that includes minimum and maximum temperatures, relative humidity, rainfall, wind speed, and sunshine duration.

Land Preparation

The study takes place in a designated area at the Demonstration Farm of the Federal College of Education (Technical) in Asaba. This location was selected for its established effectiveness in vegetable cultivation, as demonstrated by past successful growing attempts. The designated plot measures 36 meters by 72 meters, providing sufficient space for the necessary management techniques and experimental design for cucumber production. Extensive pre-planting procedures were conducted to ensure optimal soil conditions. The area was ploughed thoroughly to a depth of approximately 30 cm using a tractor-mounted disc plough. This step is designed to break up compacted soil layers, enhance root penetration, and improve aeration. Approximately a week after ploughing, the ground was harrowed to further break up large soil clumps and level the soil, creating a finer seedbed better suited for planting.

Experimental Design, Treatments, and Planting

Seeds of *Cucumis sativus* L. (Cucumber Tokyo) were germinated at a constant temperature of 28 °C in sterile Petri dishes lined with two layers of moistened filter paper to maintain optimal moisture levels. Once the acclimatization period is over, the seedlings were transplanted into field plots and were then subjected to the specified combinations of irrigation, NPK fertilizer, and organic manure treatments as set forth in the experimental design. The study utilizes a Randomized Complete Block Design (RCBD), featuring three replications arranged along the natural slope of the field. The experimental treatments include a factorial combination of three irrigation regimes (100%, 75%, and 50% of the crop's water requirement), two levels of NPK fertilizer (60kg/ha and 120kg/ha), and two levels of poultry manure (3 t/ha and 6 t/ha). Additionally, three control treatments were included, each representing an irrigation level without fertilizer or manure amendments, resulting in a total of 15 treatment combinations (Table 1).

Table 1: Treatment for Field Experiment

Treatment	Irrigation (mm)	NPK (kg/ha)	Manure (t/ha)	Description
I ₁₀₀ N ₀ M ₀	100	0	0	Control (Full irrigation, no NPK or manure)
I ₇₅ N ₀ M ₀	75	0	0	Control (75% irrigation, no NPK or manure)
I ₅₀ N ₀ M ₀	50	0	0	Control (50% irrigation, no NPK or manure)
I ₁₀₀ N ₆ M ₆	100	120	6	Full irrigation + High NPK + High manure
I ₇₅ N ₆ M ₆	75	120	6	75% irrigation + High NPK + High manure
I ₅₀ N ₆ M ₆	50	120	6	50% irrigation + High NPK + High manure
I ₁₀₀ N ₆ M ₃	100	120	3	Full irrigation + High NPK + Low manure
I ₇₅ N ₆ M ₃	75	120	3	75% irrigation + High NPK + Low manure
I ₅₀ N ₆ M ₃	50	120	3	50% irrigation + High NPK + Low manure
I ₁₀₀ N ₃ M ₆	100	60	6	Full irrigation + Low NPK + High manure
I ₇₅ N ₃ M ₆	75	60	6	75% irrigation + Low NPK + High manure
I ₅₀ N ₃ M ₆	50	60	6	50% irrigation + Low NPK + High manure
I ₁₀₀ N ₃ M ₃	100	60	3	100% irrigation + Low NPK + Low manure
I ₇₅ N ₃ M ₃	75	60	3	75% irrigation + Low NPK + Low manure
I ₅₀ N ₃ M ₃	50	60	3	50% irrigation + Low NPK + Low manure

Staking was carried out to support cucumber vines while preventing their fruits from direct contact with the soil. The staking process involved using bamboo stakes and white rope, which were available locally for construction work.

Irrigation Systems

The irrigation system aims to improve soil moisture retention and provide adequate water for crop growth, thereby supporting critical physiological processes in plants, such as photosynthesis and nutrient absorption, which will ultimately enhance cucumber growth and yield potential. The experimental design outlines three irrigation levels: full irrigation (100%), which meets all water needs to raise soil moisture content to field capacity (FC). Irrigation will occur when 50% of the available soil water in the root zone has been depleted, as determined through soil moisture monitoring techniques. The deficit irrigation treatments will apply water at 75% and 50% of the total irrigation requirement, respectively, adhering to the same scheduling as the full irrigation treatment.

Irrigation Water Application, Water Use Efficiency and Nutrient Use Efficiency

Irrigation water was applied as per the schedule of the irrigation treatments. Soil moisture was calculated at each stage of the crop by the gravimetric method before irrigation. The depth of irrigation water was calculated by equation 1.

$$d = \left(\frac{FC - M}{100} \right) \times 15 \quad \text{Eqn. 1}$$

Where,

d = Irrigation water depth (cm)

FC = Field capacity (% vol.)

M = Percent moisture content (volume basis)

Water use efficiency (WUE) was determined as the ratio of the amount of economic crop yield to the amount of water required for growing the crops. WUE was determined to evaluate the benefit of applied water through economic crop production as expressed in equation 2.

$$WUE = \frac{Y}{ET} \quad \text{Eqn. 2}$$

Where;

WUE = field water use efficiency (t/ha-mm)

Y = economic crop yield (t/ha)

ET = Water requirement of the crop (ha-mm)

The volume of nutrient solution applied per plant was recorded daily, and the concentration of each nutrient in the applied solution was known. The quantity of each applied nutrient per plant was computed by multiplying the mean nutrient concentration in the applied solution by the volume of nutrient solution applied to a plant. NUE was calculated according to Jisha Chand (2014) using equation 3.

$$\text{Nutrient Use Efficiency} \left(\frac{g}{\text{plant}} \right) = \frac{\text{Yield} \left(\frac{g}{\text{plant}} \text{ or } \frac{kg}{ha} \right)}{\text{Nutrient Applied} \left(\frac{g}{\text{plant}} \text{ or } \frac{kg}{ha} \right)} \quad \text{Eqn. 3}$$

Crop Evapotranspiration

Crop evapotranspiration (ET, mm) values of different irrigation treatments were calculated based on the soil water budget as expressed in equation 4 (Garrit *et al.*, 1982).

$$ET = I + P - R - D \pm \Delta S \quad \text{Eqn. 4}$$

Where I is the applied irrigation water amount (mm), P is the precipitation, R is the runoff (mm), D is the drainage below the effective root depth (mm), and ΔS is the soil water content difference between two measurements (mm 90 cm⁻¹). The amount of irrigation water was measured by a water meter for each plot. The changes in soil water content between different measurements were calculated by the gravimetric method. In determining the ET, the water content in the 0-60 cm layer of the soil was taken into account (Patane & Cosentino, 2010). The runoff is not taken into consideration in the computation for the soil water budget since irrigation water was administered in a regulated manner using the drip irrigation method.

Statistical Analysis

To evaluate the individual and combined effects of various irrigation strategies and fertilizer application rates on the water use efficiency (WUE) and nutrient use efficiency (NUE) of cucumber (*Cucumis sativus* L.), a comprehensive statistical analysis was conducted. The analysis was performed using Minitab version 19 (Minitab Inc., State College, PA, USA). ANOVA helps deter

mine whether the differences observed among treatment means are statistically significant. When significant differences are identified, Tukey's Honest Significant Difference (HSD) test is applied for multiple comparisons among treatment means to identify specific differences between combinations. All statistical tests were conducted at a 95% confidence level, with differences considered significant at $p \leq 0.05$.

RESULTS AND DISCUSSIONS

Physical and Chemical Properties of the Soil

The physical and chemical properties of soil, such as textural class, bulk density (BD), total porosity (TP), water holding capacity (WHC), field capacity (FC), pH, electrical conductivity (EC), available phosphorus (Av. P), total nitrogen (TN), exchangeable bases (K, Ca, Na, Mg), effective cation exchange capacity (ECEC), organic matter (OM), and total organic carbon (TOC). were determined in each of three blocks at three depth intervals: 0–20 cm, 20–40 cm, and 40–60 cm.

Particles Size Distribution

The classification of soil textural class depends on the amounts of sand, silt, and clay in the soil sample (Table 2). The results showed that sand was the dominant fraction across all blocks and depths, ranging from 63.74% to 79.10%. Silt content ranged from 22.37% to 32.64%, and clay content varied from 10.52% to 13.64%. The sandy loam texture has important implications for soil management. The high sand content promotes good air movement through the soil, making it easier for farmers to till their fields and supporting root development in plants. The soil structure allows water to move quickly, but this trait also causes the soil to lose water and nutrients rapidly. The results align with the findings of Okoh *et al.* (2025), which showed that soils with high sand content and low clay fractions experience increased pollutant leaching because of their larger pore spaces and limited ability to retain contaminants.

Table 2: Physical Properties and Particle Distribution of the Soil at Different Depths

Block	Depth (cm)	pH	Sand (%)	Silt (%)	Clay (%)	Textural Class	BD (g/cm ³)	TP (%)	WHC (%)	FC (%)
1	00-20	6.5	68.3	31.19	11.78	Sandy loam	1.53	42.3	23.5	23.5
	20-40	6.7	74.5	27.1	11.01	Sandy loam	1.57	40.8	22.7	22.7
	40-60	6.8	79.1	22.37	11.45	Sandy loam	1.64	38.1	21	21
2	00-20	6.45	68.4	31.23	11.36	Sandy loam	1.55	41.5	23.6	23.6
	20-40	6.23	70.34	29.44	10.52	Sandy loam	1.61	39.2	23.1	23.1
	40-60	5.71	72.17	28.34	10.86	Sandy loam	1.64	38.1	22.7	22.7
3	00-20	6.52	63.74	32.64	13.42	Sandy loam	1.55	41.5	24.8	24.8
	20-40	5.82	73.71	29.62	13.49	Sandy loam	1.59	40	22.3	22.3
	40-60	6.33	69.71	25.65	13.64	Sandy loam	1.62	38.9	23.3	23.3

* BD = Bulk Density, TP = Total Porosity, WHC = Water Holding Capacity, FC = Field Capacity

Bulk Density (g/cm³)

Bulk density and total porosity are important indicators of soil compaction and structure, directly influencing root development and water availability throughout the soil profile. Bulk density values ranged from 1.53 to 1.64 g/cm³, steadily increasing with depth across all blocks (Table 2). This suggests compaction in subsoil layers, likely due to reduced organic matter and increased overburden pressure. Surface soils (0–20 cm) displayed lower bulk density, indicating better structure and higher biological activity. A clear trend of increasing bulk density with depth was observed in all blocks. The bulk density varied with depth across locations, attributable to soil-forming processes and low OM in the sub-surface horizon. Chaudhari *et al.* (2013) also observed increases in bulk density with depth, which was linked to low organic matter.

Total Porosity

Total porosity ranged from 38.1% to 42.3% and decreased with depth in all blocks (Table 2). This reduction in porosity indicates a less porous medium at greater depths, which can hinder water movement and root growth. This inverse relationship with bulk density is expected, as increased compaction reduces pore spaces. Surface soils showed higher porosity, promoting root development and water infiltration. According to Brady and Weil (2015), total porosity values vary widely across different soil types, ranging from 25% in compacted soils to 60% in well-aggregated soils, depending on soil aggregate size, aeration, and water retention characteristics. The observed porosity falls within this range, with a pattern indicating that subsurface soils are more compacted than surface horizons, which exhibit excellent soil aggregation that supports plant growth (Alaoui *et al.*, 2011).

Water Holding Capacity and Field Capacity

The water-holding capacity (WHC) and field capacity (FC) of soil are key factors in its ability to retain water and supply moisture needed by plants during drought conditions (Table 2). These properties are vital for supporting crop growth under different climatic circumstances. The WHC and FC values across all blocks and depths ranged from 21.0% to 24.8%, decreasing as soil depth increased. This method is widely accepted because researchers studying Nigerian sandy loam soils have successfully employed it (Abdullahi *et al.*, 2025).

Soil pH

Soil pH is a key characteristic that influences various chemical and biological reactions in soil, critically affecting the soil's ability to support plant growth. It determines how nutrients become available to plants through ion exchange and controls microbial processes that decompose organic matter and distribute nutrients throughout the ecosystem. The pH values across the study area ranged from moderately acidic (5.71) to near neutral (6.80), indicating generally favourable conditions for crop production (Table 3). This is likely due to the decomposition of organic matter and the production of organic acids in soils, which is consistent with the findings of Abegunrin *et al.* (2013). The results suggest that proper management, routine assessment, and appropriate soil amendments are necessary to maintain optimal pH levels for sustainable crop growth.

Electrical Conductivity

Soil electrical conductivity (EC), used to estimate salinity, is a measure of the soil's capacity to conduct electricity. EC is directly influenced by the concentration of water-soluble salts and moisture content. The EC values were quite low across all samples (Table 3). The measured EC values ranged from 10.67 to 13.76 mg/kg, which, when converted to equivalent salinity, are acceptable for normal plant growth. This abnormally low EC value is advantageous for sustainable cropping, as salt accumulation could impair water supply to plants and require energy to regulate osmotic conditions (Marschner, 2012).

Organic Matter and Total Organic Carbon

The positive and negative charges in soil organic matter enable the soil to exchange both cations and anions. A decrease in organic matter reduces soil exchange capacity, leading to lower access to minerals and nutrients. The organic matter (OM) content in the sample ranged from 4.46% to 6.78%, while the total organic carbon (TOC) ranged between 1.34% and 2.78%, as shown in Table 3. Surface soils exhibited higher OM and TOC levels, with fluctuations driven by plant residue accumulation and microbial activity. The study found that organic matter content decreased with increasing soil depth because organic matter input declines in the subsoil layers. These results suggest that the soil has either received substantial organic matter inputs from crop residue retention and manure applications or contains conditions that promote organic matter accumulation by reducing decomposition rates (Brady & Weil, 2017). The high organic matter content provides vital benefits for soil fertility by acting as a reservoir for plant nutrients, enhancing cation exchange capacity, improving soil structure, and increasing water retention capacity (Havlin *et al.*, 2016).

Available Phosphorus and Total Nitrogen

The study found that available phosphorus (Av. P) was low, ranging from 0.11 to 0.37 ppm, indicating a potential phosphorus deficiency in the soils (Table 3). Higher phosphorus concentrations in the surface layers, followed by a decline with depth, may be attributed to organic matter mineralization and fertilizer accumulation in the topsoil. The highly weathered tropical soils display low phosphorus levels due to their tendency to fix phosphorus through iron and aluminum oxides. This condition prevents crop production and necessitates the supply of phosphorus through proper fertilization. The micro-Kjeldahl method revealed total nitrogen (TN) results ranging from 0.18% to 0.68%, with topsoil samples showing higher nitrogen content (Table 3). The agricultural soils reach medium to high levels because nitrogen content is directly related to soil organic matter, which serves as the main nitrogen reservoir (Brady & Weil, 2017). Total nitrogen content includes all nitrogen forms in the soil, and mineralization processes determine which forms plants can absorb. Farmers require efficient nitrogen management systems, including split fertilizer application, to maintain productive crops while utilizing adequate TN levels.

Exchangeable Bases (K, Ca, Na, Mg)

The exchangeable bases showed calcium as the most abundant cation, ranging from 12.39 to 16.14 cmol/kg across all sampling depths and locations (Table 3). The fertility rating system from Landon 1991 indicates that calcium levels above 5 cmol/kg are considered high. Calcium, as the primary element, is present in soils developing from base-rich parent materials because it maintains soil structure and promotes optimal root growth through its chemical properties (Havlin *et al.*, 2016). Magnesium (Mg) was the second most common base, with levels between 2.69 and 3.73 cmol/kg. The Ca:Mg ratio ranged from 3.6 to 5.1, which falls within its balanced range, reducing potential negative impacts on plant absorption (Marschner, 2012). The moderate potassium status suggests that, although not severely deficient, regular monitoring and maintenance applications may be necessary to prevent depletion, especially under intensive cropping systems (Havlin *et al.*, 2016). Akinde *et al.* (2025) demonstrated that organic amendments such as poultry manure can enhance potassium availability in Nigerian benchmark soils by improving cation exchange capacity and reducing leaching losses.

Effective Cation Exchange Capacity (ECEC)

The study measured total exchangeable bases, including calcium, magnesium, potassium, and sodium, to determine the effective cation exchange capacity. The ECEC values ranged from 10.52 cmol/kg to 18.57 cmol/kg, which Landon (1991) classifies as medium to high. The study found that nutrient retention capacity is moderate, depending on clay content and exchangeable bases. These findings are consistent with those of Angyu *et al.* (2025), who studied savanna soils treated with organic materials and observed ECEC improvements linked to increased organic carbon.

Climatic Conditions and Their Influence on Soil Properties and Cucumber Production.

The successful growth of crops relies on the complex relationships between soil traits and weather patterns. Studying seasonal weather patterns is essential because they help scientists determine which crops will thrive in specific areas and how to manage those crops. Table 4 presents climatic conditions analysis for the study area, covering the growing season from December 2025 to February 2026, and explains how weather patterns interact with soil traits to support cucumber (*Cucumis sativus* L.) production.

A mean temperature of 30.78 °C during the day supported plant development despite marginal daytime temperatures, especially when soil moisture and nutrients were adequate (Olarewaju *et al.*, 2023). The sandy loam soils, containing 4.44% to 6.67% organic matter, play a crucial role in maintaining temperature stability by enhancing moisture retention and reducing temperature swings. Since cucumber production requires 25-50 mm of water per week across various growth stages and weather conditions, farmers often rely on supplementary irrigation due to insufficient rainfall to meet crop needs. In the study area, cucumber cultivation relies on sandy loam soils with specific water-holding properties that keep moisture content between 21.0% and 24.8% at field capacity. These

soils offer moderate water retention, allowing them to store adequate moisture between rainfall and irrigation events. Khanal and Poudel (2020) found that sandy loam soils support effective cucumber farming through supplementary irrigation because they maintain a balance between drainage and water retention, creating optimal conditions for root growth. Harmattan conditions that cause lower humidity usually occur during the dry season in southern Nigeria and increase water loss through transpiration, leading to wilting when soil moisture becomes insufficient.

The sandy loam soils in this area can tolerate brief water shortages when farmers use proper irrigation practices. The moderate humidity in February (62.02%) provides ideal conditions for continuous plant growth and fruit development. Combined with increasing rainfall, this humidity level supports cucumber production while reducing the risk of foliar diseases linked to very high humidity (Iwe, 2025). The daily average sunshine hours, based on these totals, are around 4.1 hours per day in December, 6.5 hours in January, and 3.8 hours in February. These figures are below the essential minimum of 8 to 10 hours per day needed for successful cucumber cultivation (Craufurd & Wheeler, 2005). The sunshine duration in January, at 6.5 hours per day, offers favourable conditions for plant growth by supporting flower development and fruiting. In contrast, the sunshine durations in December and February, at 4.1 and 3.8 hours per day respectively, create less suitable conditions for the early and late stages of growth. Ikkonen *et al.* (2021) found that cucumber varieties grown in soils enriched with organic matter showed improved light use efficiency, which partly offsets the effects of lower light levels.

Table 3 Chemical Properties of Soil at Different Depths

Bloc k	Dept h (cm)	pH	EC (mg/K g)	Av.P (ppm)	TN (%)	K (cmol/k g)	Ca (cmol/k g)	Na (cmol/k g)	Mg (cmol/k g)	ECEC (cmol/k g)	OM (%)	TOC (%)
1	00- 20	6.5	13.34	0.37	0.6 6	0.29	14.93	0.66	3.42	16.28	5.9 4	1.79
	20- 40	6.7	13.76	0.19	0.6 8	0.27	14.91	0.68	3.31	13.67	6.3 1	2.18
	40- 60	6.8	10.67	0.17	0.2 2	0.38	13.48	0.82	3.33	18.57	6.7 8	1.96
2	00- 20	6.4 5	12.71	0.31	0.3 6	0.28	16.14	0.87	3.16	17.44	5.6 7	1.76
	20- 40	6.2 3	12.67	0.12	0.2 4	0.37	14.52	0.69	3.73	14.22	5.1 8	2.45
	40- 60	5.7 1	11.78	0.13	0.1 8	0.45	13.25	0.95	2.96	18.32	6.2 6	2.78
3	00- 20	6.5 2	11.51	0.17	0.3 5	0.24	12.87	0.71	2.69	13.44	5.6 2	1.34
	20- 40	5.8 2	11.86	0.18	0.3 1	0.21	14.31	0.62	3.49	10.52	4.4 6	1.78
	40- 60	6.3 3	12.88	0.11	0.3 8	0.27	12.39	0.73	3.16	11.67	6.4 7	2.38

***Electrical Conductivity (EC), Available Phosphorus (Av. P), Total Nitrogen (TN), Potassium(K), Calcium (Ca), Sodium (Na), Magnesium (Mg), Organic matter (OM), Total Organic Carbon (TOC), Effective Cation Exchange capacity (ECEC).**

Table 4 Climatic Conditions of the Study Area during Growing Season

Parameter	December 2025	January 2026	February 2026
Average High Temperature (°C)	35.12	29.23	30.22
Average Low Temperature (°C)	23.01	23.01	25.42

Average Temperature (°C)	29.14	29.34	30.78
Precipitation(mm/month)	8.78	10.65	33.02
Humidity (%)	68.87	54.66	62.02
Sunshine (hrs/day)	128	202	105

***Sunshine values are presented as total monthly sunshine hours, indicating the cumulative sunshine duration for each month.**

Irrigation Water Applied and Crop Evapotranspiration

Evapotranspiration (ET) involves both soil evaporation and plant transpiration, which together represent the primary measure of water consumption in agricultural systems. Accurate determination of ET is essential for irrigation planning, estimating crop water needs, and assessing integrated water and nutrient management (Igbadun *et al.*, 2012). The number of irrigation events varied with irrigation frequency and crop duration, with 13, 14, and 16 applications recorded under a 4-day interval schedule.

Full irrigation (I100) had the highest irrigation frequency, whereas deficit irrigation reduced the number of irrigation periods throughout the cropping cycle. Table 5 demonstrated a clear positive relationship between the amount of water applied and actual crop evapotranspiration across all nutrient regimes. Under the control treatment (N0M0), ET decreased from 415.02 mm under full irrigation (I100) to 323.65 mm under I75 (a 22.0% reduction), and further to 231.56 mm under I50 (a 44.2% reduction relative to I100). Water supply is the main factor influencing crop water consumption because ET declines when water resources are limited, even under ideal growth conditions. During peak growth periods, crop water demand increased, resulting in a larger decrease in ET because plants required more water. These findings align with recent studies conducted in Nigeria. Abegunrin *et al.* (2025) reported that irrigation at 70% ETc improved water-use efficiency by 15% compared with full irrigation in cucumber production, while Onwuegbunam *et al.* (2024) observed that deficit irrigation at 60% ETo maintained optimal water productivity in tomato.

Table 5 Components of water balance and crop evapotranspiration across irrigation and nutrient management treatments.

Treatments	Irrigation (mm)	ΔS	Rainfall(mm)	Runoff (mm)	Deep Percolation (mm)	ET (mm)
I ₁₀₀ N ₀ M ₀	384.89	26.86	3.27	0	0	415.02
I ₇₅ N ₀ M ₀	288.67	31.71	3.27	0	0	323.65
I ₅₀ N ₀ M ₀	192.45	35.84	3.27	0	0	231.56
I ₁₀₀ N ₆ M ₆	384.89	33.94	3.27	0	0	422.10
I ₇₅ N ₆ M ₆	288.67	25.78	3.27	0	0	317.72
I ₅₀ N ₆ M ₆	192.45	28.45	3.27	0	0	224.17
I ₁₀₀ N ₆ M ₃	384.89	30.75	3.27	0	0	418.91
I ₇₅ N ₆ M ₃	288.67	32.27	3.27	0	0	324.21
I ₅₀ N ₆ M ₃	192.45	24.89	3.27	0	0	220.61
I ₁₀₀ N ₃ M ₆	384.89	26.76	3.27	0	0	414.92
I ₇₅ N ₃ M ₆	288.67	31.11	3.27	0	0	323.05
I ₅₀ N ₃ M ₆	192.45	35.34	3.27	0	0	231.06
I ₁₀₀ N ₃ M ₃	384.89	32.99	3.27	0	0	421.15

I ₇₅ N ₃ M ₃	288.67	24.28	3.27	0	0	316.22
I ₅₀ N ₃ M ₃	192.45	28.54	3.27	0	0	224.26

* ΔS = soil water depletion

Effects of irrigation application and nutrient management on fruit yield (t/ha)

The ultimate measure of crop productivity at cucumber farms depends on fruit yield per hectare, which growers consider their most important agricultural requirement. The method evaluates how different agricultural management techniques for irrigation and nutrient distribution impact the success of farming operations. Developing productivity recommendations requires understanding how irrigation and nutrient management systems affect total agricultural output. The fruit yield per hectare data across all treatment combinations are presented in Figure 1. The data show that yields range between two extremes, reaching their lowest point at 2.26 t/ha for the I₅₀N₀M₀ treatment and their highest at 4.78 t/ha for the I₁₀₀N₆M₆ treatment. Cucumber productivity varies substantially between the highest and lowest treatment results, with a 111.5% difference, as water and nutrient management systems both affect productivity. The yield data have important practical implications for irrigation management. The highest crop yields were achieved with the full-irrigation method I₁₀₀, but the moderate-deficit irrigation method I₇₅ yielded 8.9% to 12.1% less than I₁₀₀, depending on the nutrient regime used. Moderate deficit irrigation I₇₅ under N₆M₆ produced 4.20 t/ha, while I₁₀₀ produced 4.78 t/ha, resulting in a 0.58 t/ha difference between the two methods. Farmers facing water shortages can reduce their irrigation needs to 75% of their requirements when they optimize all nutrient management methods. The study by Zakka *et al.* (2020) demonstrated that cucumber yields depend on the performance of the drip irrigation system.

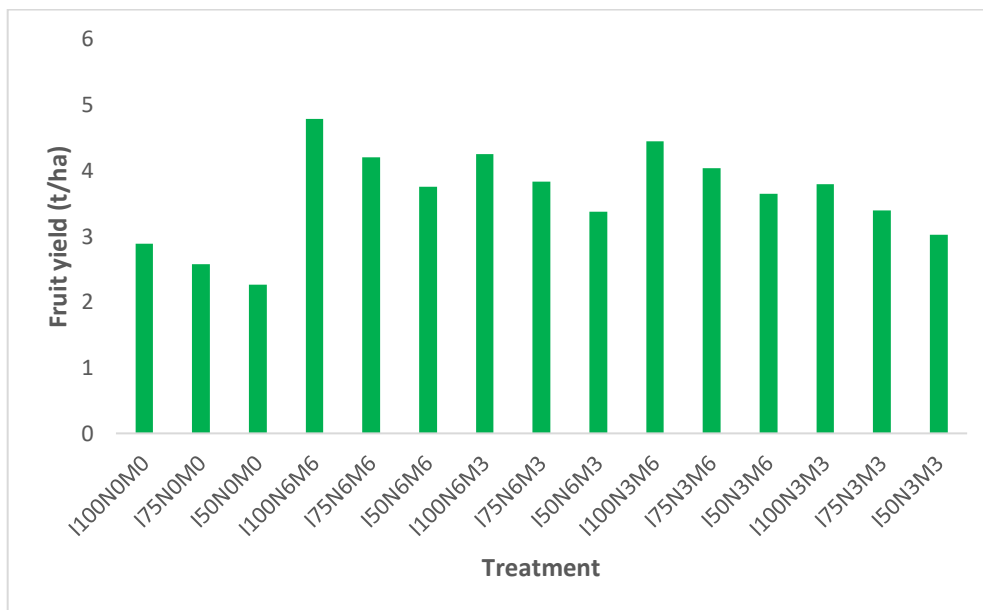


Figure 1: Fruit yield (t/ha) of cucumber as influenced by irrigation and nutrient management

Interactive Effects of Irrigation and Nutrient Management on Fruit Yield (t/ha)

Table 4.6 shows the results of a two-way ANOVA for fruit yield (t/ha). The analysis revealed a significant interaction ($p \leq 0.01$) between irrigation and nutrient management effects on fruit yield. The coefficient of variation was as low as 5.67%, which indicates good experimental precision. This low value suggests that the experimental procedures were properly followed, and the differences observed in the mean values among treatments were mainly due to the treatment types rather than experimental error. Additionally, the highly significant interaction effect ($p \leq 0.01$) highlights that the crop's response to nutrition is largely influenced by water availability. The highly

significant main effects ($p \leq 0.01$) of both irrigation and nutrient management for fruit yield further confirm the crucial roles of these factors in cucumber production. The interaction effect signifies that the extent of yield improvement from nutrient application depends on water availability, and vice versa. Practitioners should take this into account and adjust their nutrient management plans according to water supply predictions. These findings are consistent with the work of Opara *et al.* (2012), who reported significant main and interaction effects of irrigation frequency and poultry manure rates on cucumber yield

Table 4.6 Two-way ANOVA summary for fruit yield (t/ha) of cucumber

Source of Variation	DF	Sum of Squares	Mean Square	F-value	Significance
Irrigation (I)	2	8.234	4.117	45.67	**
Nutrient (N)	4	15.678	3.920	78.34	**
I $\times$ N	8	3.456	0.432	8.45	**
Error	30	1.534	0.051		
Total	44	28.902			

******, Significant at $p \leq 0.01$; CV = 5.67%

Irrigation Water Use Efficiency (IWUE) and Water Use Efficiency (WUE)

Table 7 shows the Irrigation Water Use Efficiency (IWUE) and Water Use Efficiency (WUE) values obtained from testing various irrigation methods combined with fertilizer (N) and poultry manure (M) applications. The results reveal that all treatments yielded different outcomes because both irrigation patterns and nutrient management strategies affected cucumber water productivity. IWUE values ranged from 7.48 kg/m³ (I₁₀₀N₀M₀) to 19.49 kg/m³ (I₅₀N₆M₆), indicating a 160.6% difference between the highest and lowest treatments. WUE values ranged from 6.94 kg/m³ (I₁₀₀N₀M₀) to 16.73 kg/m³ (I₅₀N₆M₆), showing a 141.1% variation. Both IWUE and WUE responded similarly to the different systems. Treatment I₅₀N₆M₆ had the highest IWUE (19.49) and WUE (16.73) because deficit irrigation combined with increased nitrogen and manure improved water efficiency. The treatments I₅₀N₃M₆ and I₅₀N₆M₃ also showed high IWUE and WUE because the additional nutrients helped the crop use water more effectively. The full irrigation treatment under I₁₀₀N₀M₀ resulted in the lowest IWUE (7.48) and WUE (6.94), as water was applied without fertilizer or manure. These findings suggest that the system wasted water by applying excess amounts while neglecting nutrient application.

Table 7 Irrigation water use efficiency (IWUE) and water use efficiency (WUE) of cucumber as influenced by irrigation and nutrient management

Treatment	IWUE (kg/m ³)	WUE (kg/m ³)
I ₁₀₀ N ₀ M ₀	7.48	6.94
I ₇₅ N ₀ M ₀	8.90	7.94
I ₅₀ N ₀ M ₀	11.74	9.76
I ₁₀₀ N ₆ M ₆	12.42	11.32
I ₇₅ N ₆ M ₆	14.55	13.22
I ₅₀ N ₆ M ₆	19.49	16.73
I ₁₀₀ N ₆ M ₃	11.04	10.15
I ₇₅ N ₆ M ₃	13.27	11.81
I ₅₀ N ₆ M ₃	17.51	15.28
I ₁₀₀ N ₃ M ₆	11.54	10.70

I ₇₅ N ₃ M ₆	13.96	12.47
I ₅₀ N ₃ M ₆	18.91	15.75
I ₁₀₀ N ₃ M ₃	9.85	9.00
I ₇₅ N ₃ M ₃	11.74	10.72
I ₅₀ N ₃ M ₃	15.69	13.47

The mean comparison across irrigation levels further revealed that I₅₀ recorded the highest mean IWUE (16.67) and WUE (14.20), followed by I₇₅, while I₁₀₀ recorded the lowest values (Table 4.8). The increase in IWUE and WUE under deficit irrigation (I₅₀) may be attributed to the crop's better utilization of limited water, leading to improved water productivity. The application of nitrogen fertilizer and manure to the soil resulted in improved plant growth and yield by increasing soil fertility and nutrient availability. The results demonstrate that cucumber production achieves better water efficiency through the combination of moderate deficit irrigation and proper nutrient management. Water-limited regions benefit from these agricultural practices because they enable farmers to achieve higher crop yields per liter of water used. The trend indicates that deficit irrigation improved water-use efficiency because plants used their limited water supply more effectively to grow and produce crops. The highly significant ($p \leq 0.01$) main effects of both irrigation and nutrient management on IWUE and WUE confirm that both factors are critical determinants of water productivity in cucumber. Water use efficiency responds to nutrient application through significant interaction effects that depend on water availability, and vice versa. The application of nitrogen fertilizer combined with manure to the soil resulted in better plant growth and yield through improved soil fertility and nutrient availability, compared with the amount of water used for irrigation. The findings demonstrate that cucumber production achieves higher water productivity through the combination of deficit irrigation and proper nutrient management, which is critical in areas with limited water resources. The increased water-use efficiency under deficit irrigation results from two factors: decreased water loss through evaporation and improved crop water use through physiological processes. The results of our research match the findings of Zakka *et al.* (2020) and Igbojonu *et al.* (2024), who showed that moderate deficit irrigation increased water productivity in cucumber production systems.

Table 8 Mean IWUE (kg/m³) and WUE (kg/m³) across irrigation levels

Irrigation Level	IWUE (kg/m ³)	WUE (kg/m ³)
I ₅₀	16.67 a	14.20 a
I ₇₅	12.48 b	11.23 b
I ₁₀₀	10.47 c	9.62 c

Nutrient Use Efficiency (NUE)

Nutrient Use Efficiency (NUE) is an essential agricultural indicator that assesses the effectiveness of nitrogen applications in producing crop yields. The calculation involves measuring fruit yield in kilograms and dividing it by the total nutrients applied in kilograms. A high NUE indicates efficient nutrient use, while a low NUE indicates losses through volatilisation, leaching, denitrification, or immobilisation. Table 9 displays the NUE results for three irrigation levels (I₁₀₀, I₇₅, I₅₀) and four fertiliser treatments (N₆M₆, N₆M₃, N₃M₆, N₃M₃). Control treatments (N₀M₀) received no nutrients, so NUE could not be calculated. The values ranged from 9.25 kg/kg in I₅₀N₆M₃ to 26.00 kg/kg in I₁₀₀N₃M₆, representing a difference of 181.1%, indicating that irrigation and nutrient management systems had a major impact on NUE. Under N₆M₆, NUE decreased from 15.83 kg/kg at I₁₀₀ to 13.58 kg/kg at I₇₅ (a 14.2% decrease) and 12.42 kg/kg at I₅₀ (a 21.5% decrease). N₆M₃ decreased from 11.42 to 10.50 kg/kg at I₇₅ and 9.25 kg/kg at I₅₀. N₃M₆ showed smaller decreases. The N₃M₃ treatment decreased from 15.17 to 13.67 kg/kg (9.9%) and then to 12.67 kg/kg (16.5%). The declines under deficit irrigation are due to water stress, which restricts root development, nitrogen uptake, and water movement through transpiration, as well as all biological functions. The N₃M₆ treatment exhibited the smallest decrease in NUE during periods of water stress, with an 11.5% reduction, indicating that high manure application protects against the effects of water shortage. This study

demonstrates that irrigation practices, together with nutrient management systems, strongly determine NUE levels. The combination of moderate nitrogen and high manure (N3M6) is optimal because it maximizes nitrogen efficiency while reducing both costs and environmental damage. The findings are in line with those of Singh *et al.* (2019), who reported that nutrient use efficiencies were positively affected by fertigation level as well as varieties, with a significant interaction.

Table 9 Nutrient Use Efficiency (NUE) of cucumber as influenced by irrigation and nutrient management

Treatment	NUE (kg yield/kg nutrient)
I ₁₀₀ N ₀ M ₀	
I ₇₅ N ₀ M ₀	
I ₅₀ N ₀ M ₀	
I ₁₀₀ N ₆ M ₆	15.83
I ₇₅ N ₆ M ₆	13.58
I ₅₀ N ₆ M ₆	12.42
I ₁₀₀ N ₆ M ₃	11.42
I ₇₅ N ₆ M ₃	10.5
I ₅₀ N ₆ M ₃	9.25
I ₁₀₀ N ₃ M ₆	26
I ₇₅ N ₃ M ₆	24.33
I ₅₀ N ₃ M ₆	23
I ₁₀₀ N ₃ M ₃	15.17
I ₇₅ N ₃ M ₃	13.67
I ₅₀ N ₃ M ₃	12.67

*NUE = Nutrient Use Efficiency

Post-Planting Soil Analysis

Table 10 summarizes soil chemical properties measured after cucumber harvest under various irrigation and nutrient management treatments. All treatments significantly affected soil pH, available phosphorus, total nitrogen, potassium, calcium, magnesium, organic matter, and total organic carbon at $P \leq 0.05$. Soil pH ranged from 5.12 to 5.44, indicating that soil acidity remained moderate across treatments. Treatment I100N6M3 produced the highest pH (5.44), while I50N0M0 had the lowest (5.12). Treatments combining mineral fertiliser and manure had higher pH values than the controls because nutrient amendments acted as buffering agents, reducing soil acidity. Available phosphorus varied significantly between treatments, ranging from 0.33 to 0.57 ppm. The highest phosphorus content (0.57 ppm) was recorded in I100N6M6, followed by I75N6M6 (0.52 ppm) and I100N6M3 (0.52 ppm), with the lowest (0.33 ppm) in I50N0M0. The combined use of inorganic fertiliser and manure increased phosphorus availability after harvest. Total nitrogen showed significant variation, ranging from 0.39% to 0.67%. The highest value was in I100N6M6 (0.67%), followed by I75N6M6 (0.65%) and I100N6M3 (0.63%). The control treatments (I50N0M0, I75N0M0, I100N0M0) had lower nitrogen levels, between 0.39% and 0.41%. The addition of nutrients, including manure, improved soil nitrogen status. Exchangeable potassium ranged from 0.42 to 0.55 cmol/kg, with the highest in I100N6M6 (0.55 cmol/kg) and the lowest in I75N0M0 (0.42 cmol/kg). Exchangeable calcium ranged from 14.31 to 17.45 cmol/kg, with I100N6M6 highest and I50N0M0 lowest. Exchangeable magnesium ranged from 3.21 to 4.91 cmol/kg, with I100N6M6 showing the highest values. Organic matter (OM) ranged from 4.22% to

6.98%, and total organic carbon (TOC) from 1.22% to 3.34%. The highest OM and TOC were in I100N6M6, while I50N0M0 and I75N0M0 showed the lowest values.

Table 10 Effects of irrigation regime and Nutrient Management on chemical properties of soils of the experimental site after harvesting

Treatment	pH	Av. P (ppm)	TN (%)	K (cmol/kg)	Ca (cmol/kg)	Mg (cmol/kg)	OM (%)	TOC (%)
I100N0M0	5.23c	0.40ef	0.41h	0.45de	14.98fg	3.49f	4.43f	1.23g
I75N0M0	5.22c	0.35fg	0.41h	0.42e	14.88fg	3.22g	4.34f	1.22g
I50N0M0	5.12d	0.33g	0.39h	0.43e	14.31g	3.21g	4.22f	1.35g
I100N6M6	5.42ab	0.57a	0.67a	0.55a	17.45a	4.91a	6.98a	3.34a
I75N6M6	5.37ab	0.52b	0.65ab	0.52b	17.44a	4.88a	6.88a	3.22ab
I50N6M6	5.34b	0.50bcd	0.55efg	0.51bc	17.34a	4.67ab	6.77ab	3.14bc
I100N6M3	5.44a	0.52b	0.63bc	0.49cd	17.11ab	4.87a	6.78ab	3.22ab
I75N6M3	5.43a	0.51bc	0.62bcd	0.49cd	16.22cd	4.45bc	6.54bc	3.11bc
I50N6M3	5.40ab	0.49bcd	0.61bcd	0.48cd	16.78bc	4.34cd	6.55bc	3.12bc
I100N3M6	5.41ab	0.49bcd	0.59cde	0.52b	16.78bc	3.98de	5.59cd	3.01cd
I75N3M6	5.39ab	0.47cde	0.58def	0.49cd	16.44cd	3.67ef	5.66cd	2.98cd
I50N3M6	5.43a	0.47cde	0.52fg	0.48cd	16.01de	3.66ef	5.13e	2.88de
I100N3M3	5.34b	0.39ef	0.55efg	0.49cd	15.23f	3.78ef	5.34de	2.76ef
I75N3M3	5.40ab	0.39ef	0.53fg	0.49cd	15.44ef	3.78ef	5.44de	2.77ef
I50N3M3	5.38ab	0.38f	0.51g	0.48cd	15.33ef	3.67ef	5.45de	2.56f
LSD (0.05)	0.08	0.06	0.06	0.05	1.12	0.45	0.67	0.34
CV (%)	2.34	8.45	6.78	6.23	4.56	6.89	7.23	7.89

***Available Phosphorus (Av. P), Total Nitrogen (TN), Potassium(K), Calcium (Ca), Magnesium (Mg), Organic matter (OM), Total Organic Carbon (TOC)**

Higher organic matter content in manure-treated plots indicates that organic amendments enhance soil carbon status and fertility. Fisher's LSD test confirmed that nutrient management significantly affected all soil chemical properties. Treatments with high manure application rates (N6M6 and N6M3) generally produced the highest values, whereas the control treatment (N0M0) yielded the lowest, highlighting the importance of nutrient application for soil fertility. The results also suggest that irrigation water application during the study had no impact on soil chemical attributes, likely due to the short duration and lack of nutrient contribution from water. The N6M6 and N6M3 treatments performed better at improving soil chemical properties because they supplied nutrients directly from poultry manure, thereby boosting microbial activity. Overall, the research demonstrates that integrated nutrient management is crucial in maintaining soil fertility and sustaining cucumber production (Opara *et al.*, 2012).

CONCLUSION

The study established that deficit irrigation, together with integrated nutrient management practices, significantly improves water, irrigation water, and nutrient use efficiency in cucumber plants grown on sandy loam soils in Asaba, South-South Nigeria. Maximum water use efficiency occurred when deficit irrigation provided 50% of the crop water demand, particularly when paired with high poultry manure application at six tons per hectare and NPK

application at 120kg/ha, yielding irrigation water use efficiency of 19.49kg/m³ and water use efficiency of 16.73kg/m³. The system achieved 160% higher results than complete irrigation without any fertilization. The study found that nutrient use efficiency peaked at 26.00kg/yield per kg of nutrient used when full irrigation was coupled with low NPK application at 60kg/ha and high manure application at 6 t/ha, demonstrating that organic amendments improve nitrogen recovery while decreasing nitrogen losses.

The study found that the integrated application of inorganic fertilizer and poultry manure significantly improved soil chemical properties, including pH, total nitrogen, available phosphorus, organic matter, and exchangeable bases, with I₁₀₀N₆M₆ (full irrigation + high NPK + high manure) yielding the highest values. Deficit irrigation alone (without nutrient amendments) reduced evapotranspiration and yield, but when combined with manure and NPK, it maintained acceptable productivity while substantially improving water productivity.

The study confirms that both irrigation and nutrient management play critical and interdependent roles in determining cucumber fruit yield. Maximum yield was achieved under full irrigation combined with optimal nutrient application (I₁₀₀N₆M₆), while the lowest yield occurred under severe water and nutrient limitations. The significant interaction between irrigation and nutrient management indicates that the effectiveness of nutrient application depends on water availability. Importantly, moderate deficit irrigation (I₇₅) can be adopted as a watersaving strategy with minimal yield reduction when supported by adequate nutrient supply.

These findings highlight the need for integrated water nutrient management practices to optimize productivity, particularly in water-scarce environments. The study revealed that the interaction between irrigation regimes and nutrient treatments was statistically significant at $p \leq 0.05$, demonstrating that simultaneous management of both resources was necessary for optimal water and nutrient use efficiency, which could not be achieved through their separate optimization.

The study recommends that water-limited environments in South-South Nigeria use deficit irrigation at 50% of crop water needs, together with 60kg of NPK per hectare and 6t of poultry manure per hectare, to achieve sustainable cucumber production. The integrated approach enables better resource utilization, decreases environmental damage from fertilizer runoff, enhances soil quality, and contributes to climate change adaptation.

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