

DEFICIT IRRIGATION EFFECTS ON SOIL NUTRIENT DYNAMICS AND YIELD PERFORMANCE OF MAIZE (ZEA MAYS L.)

Chike Pius Nwachukwu¹, Chukwuemeka Obumneme Umobi¹, Luke Okwuchukwu Uzoigwe²

¹Department of Agricultural and Bioresources Engineering, Nnamdi Azikiwe University, Awka, Nigeria

²Department of Agricultural Engineering, Imo State University, Owerri, Nigeria

*Corresponding author, email: cp.nwachukwu@unizik.edu.ng

doi: 10.17977/um068.v5.i9.2025.1

Keywords

Deficit irrigation
Maize yield
Crop evapotranspiration (ETc)
Soil chemical properties
Water use efficiency
Irrigation regimes
Randomized complete block design

Abstract

A field experiment was conducted at the Experimental Farm/Workshop of the Department of Agricultural and Bioresources Engineering, Nnamdi Azikiwe University, Awka, Nigeria, to evaluate the effects of deficit irrigation on soil chemical properties, yield, and yield components of maize. The study was laid out in a randomized complete block design with three replications and six irrigation regimes based on crop evapotranspiration (ETc), namely 100% ETc (full irrigation), 80% ETc, 60% ETc, 50% ETc, 40% ETc, and 30% ETc. Measured parameters included maize yield, 1000-grain weight, cob weight, soil electrical conductivity (EC), nitrogen, phosphorus, potassium, and soil pH. Maize yield ranged from 1,420 to 2,580 kg/ha, while 1000-grain weight varied between 162 and 342 g. Cob weight ranged from 352 to 398 g. Soil EC varied between 50.8 and 55.6 $\mu\text{S}/\text{cm}$, nitrogen ranged from 1.08 to 1.86 g/kg, phosphorus ranged from 3.10 to 7.72 mg/kg, potassium ranged from 6.5 to 9.2 ppm, and soil pH ranged from 6.08 to 7.02. Analysis of variance showed significant ($p < 0.05$) effects of irrigation treatments on yield and most soil chemical properties. Moderate deficit irrigation improved water use efficiency and maintained soil fertility within optimal ranges, moderate deficit irrigation is a viable and sustainable strategy for maize production in Awka, as it reduces water use while maintaining high yield and improving nutrient retention.

1. Introduction

Irrigation refers to the deliberate application of water to land in order to maintain adequate soil moisture for crop growth. It supplements natural rainfall, ensuring that agricultural production can be sustained even under conditions of water scarcity (Phocaides, 2007). Sole reliance on rainfed agriculture is often insufficient, particularly in regions where rainfall is irregular or inadequate, making artificial water application essential for achieving sustainable farming systems. Globally, agriculture remains the largest consumer of water resources, accounting for approximately 70% of total withdrawals and more than 80% of consumptive water use (Baudequin & Molle, 2003). This proportion, however, varies significantly across regions, reaching nearly 88% in Africa while dropping below 50% in Europe. Such disparities highlight the dependence of agricultural systems in arid and semi-arid regions on irrigation, where rainfall alone cannot meet crop water requirements. Even in areas with high seasonal rainfall, crops may still suffer short periods of moisture stress, underscoring the critical role of irrigation in stabilizing yields and enhancing food security (USDA, 1984).

Despite its importance, irrigation is not without limitations. Inefficient water use can lead to soil degradation, nutrient leaching, and salinity buildup, making proper calibration and scheduling indispensable for sustainable management. Growing concerns about water scarcity have heightened the need for efficient irrigation practices. Alternative application methods, such as drip irrigation, have emerged as promising solutions, significantly improving water use efficiency and overall irrigation performance (El-Garawany & Albaloushi, 2015). Empirical evidence supports this: Nwachukwu et al. (2019) reported satisfactory drip irrigation performance in their study conducted

in Awka, Nigeria, demonstrating its potential to optimize crop production under constrained water availability.

Building on this context, the present study evaluates the combined effects of deficit irrigation on soil chemical properties, maize yield, and yield components in Awka, Nigeria. By examining both agronomic outcomes and soil quality indicators, the study aims to provide insights into how strategic water management can balance productivity with resource conservation, contributing to sustainable agricultural practices in water-limited environments.

2. Metode

2.1. Study Area

A field experiment was carried out at the Department of Agricultural and Bioresources Engineering Experimental Site/Farm Workshop, Nnamdi Azikiwe University, Awka. The study area is located between latitudes 6°15'11.8"N and 6°15'5.3"N, and longitudes 7°07'11.8"E and 7°07'18.3"E, at an altitude of 142 m above sea level. The experiment took place during the dry season, and previous studies indicate that the soil in the area is predominantly sandy loam. The vegetation is characteristic of a savanna, mainly grasses. Geologically, the area is underlain by Imo shale (Odoh et al 2012).

The region is drained by the Anambra River and its tributaries. It experiences two main climatic seasons: the dry season (November to March) and the rainy season (April to October), with a brief rainfall break in August. During the dry season, temperatures range from 20°C to 38°C, leading to increased evapotranspiration, whereas in the rainy season, temperatures range from 16°C to 28°C with comparatively lower evapotranspiration. The experiment was conducted between October 2024 and January 2025

2.2. Experimental Layout

The experiment was conducted using a randomized complete block design, with the experimental field divided into blocks to account for variability in soil and environmental conditions across the site. Each block contained all six irrigation treatments, and the treatments were randomly assigned within each block to minimize bias. This arrangement was replicated three times, resulting in three blocks, each serving as a replicate to improve the reliability and precision of the results.

The six irrigation treatments were imposed at different percentages of crop evapotranspiration (ET_c), which represents the crop's water requirement. The full irrigation treatment received 100% of ET_c, while the deficit irrigation treatments received reduced amounts. The amount of water applied to each treatment was calculated using standard ET_c estimation procedures and was delivered at appropriate intervals to maintain the intended moisture levels throughout the growing period.

Uniform agronomic practices were maintained across all plots to ensure that differences in crop performance could be attributed solely to the irrigation treatments. Fertilizers were applied at recommended rates and at appropriate growth stages to meet the maize crop's nutritional requirements. Weed control was carried out regularly using manual or chemical methods to prevent competition for nutrients, water, and light. Other routine field management practices were also consistently applied across all treatments to maintain optimal growing conditions.

Soil samples were collected from the 0–30 cm depth using a soil auger after harvest. The samples were air-dried, ground, and passed through a 2 mm sieve prior to analysis. Soil pH was determined in a 1:2.5 soil-to-water suspension using a calibrated pH meter. Electrical conductivity (EC) was measured in the same extract using a conductivity meter. Total nitrogen was determined using the Kjeldahl digestion method. Available phosphorus was analyzed using the Olsen extraction method followed by colorimetric determination. Exchangeable potassium was extracted with ammonium acetate and quantified by flame photometry.

Grain yield was determined at harvest and adjusted to kg/ha. Yield components such as cob weight and 1000-grain weight were measured using standard methods.

The experiment was laid out in a randomized complete block design with three replications. Six irrigation treatments were applied at predetermined percentages of crop evapotranspiration (ETc). Irrigation water was applied at the required intervals to meet the specified treatment levels. All plots received uniform agronomic management practices, including recommended fertilizer application rates and manual weed control to minimize external variability.

Grain yield was determined by harvesting maize cobs from the net plot area, shelling, and weighing the grains. The grain weight was adjusted to a standard moisture content and converted to kilograms per hectare (kg ha⁻¹). Cob weight was measured by weighing randomly selected cobs from each plot using a digital balance. The 1000-grain weight was determined by counting and weighing 1000 grains from each treatment sample, ensuring uniform moisture content at the time of measurement.

3. Results and Discussion

3.1. Yield and yield components of maize

Table 1 and Figure 3.1 show how different treatments affect maize yield, 1000-grain weight, and cob weight, key indicators of crop performance and productivity. A clear pattern emerges: the higher-performing treatments produce better results across all three parameters, while the lower-performing treatments show a steady decline.

Table 1. Yield and yield components of maize

Treatment	Grain yield (kg/ha)	1000-grain weight (g)	Cob weight (g)
T1	2,580 a	342 a	398 a
T2	2,460 a	330 a	392 a
T3	2,120 b	298 b	381 b
T4	1,980 bc	276 bc	370 bc
T5	1,760 c	248 c	360 c
T6	1,420 d	162 d	352 c

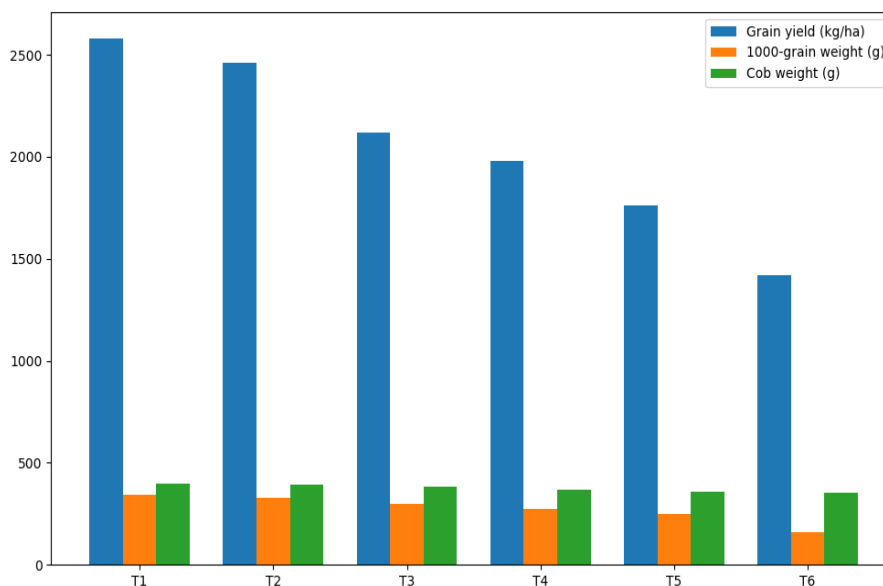


Figure 1. Plot of yield and yield components of maize

The highest grain yield was obtained under treatment T1, with 2,580 kg/ha, followed closely by T2 at 2,460 kg/ha. These two treatments produced comparably high yields, suggesting that they provided the most favorable conditions for maize productivity. As treatments progressed from T3 to T6, grain yield declined steadily, with T3 recording 2,120 kg/ha, T4 at 1,980 kg/ha, T5 at 1,760 kg/ha, and T6 at 1,420 kg/ha. This consistent downward trend indicates a gradual reduction in the

effectiveness of the treatments in sustaining grain production, reflecting the sensitivity of maize yield to water availability and management practices.

A parallel pattern was observed in the 1000-grain weight, a key indicator of grain size and density. Treatment T1 again recorded the highest value at 342 g, followed by T2 at 330 g. These results demonstrate that grains produced under these treatments were larger and heavier, contributing directly to the superior overall yield. From T3 onward, the 1000-grain weight decreased progressively, culminating in a markedly low value of 162 g under T6. The sharp decline in T6 suggests poor grain filling, likely attributable to restricted nutrient uptake or unfavorable growing conditions associated with reduced irrigation. This outcome highlights the critical role of adequate water supply in ensuring proper grain development and maximizing yield potential. Taken together, the results underscore the importance of optimized irrigation strategies for balancing water-use efficiency with crop performance. Treatments T1 and T2 clearly outperformed the others, both in terms of yield and grain quality, while the progressive decline from T3 to T6 illustrates the detrimental impact of deficit irrigation when applied beyond a critical threshold.

Cob weight also follows the same general pattern, though the decline is more gradual than that of grain weight. T1 and T2 produce the heaviest cobs at 398 g and 392 g, respectively, indicating better development and possibly more kernels per cob. As the treatments progress, cob weight decreases to 381 g in T3, 370 g in T4, 360 g in T5, and 352 g in T6. Although the reduction is not as steep as seen in grain weight, it still reflects a consistent decline in crop performance.

Overall, the results demonstrate a strong positive relationship between the treatments and crop productivity. Treatments that increase grain and cob weight also increase grain yield, indicating that improved grain filling and cob development contribute significantly to overall output. T1 and T2 are the most effective treatments, providing the best conditions for both yield and yield components, while T6 is the least effective, resulting in the lowest performance across all parameters. The steady downward trend across treatments indicates a reduction in treatment effectiveness, likely linked to declining input levels or soil fertility.

In Table 1, the lowercase letters (a, b, c, d) represent the results of mean separation following ANOVA, typically using a post hoc test such as the Least Significant Difference (LSD) or Tukey’s test. Means followed by the same letter within a column are not significantly different from each other at the specified probability level, whereas means with different letters differ significantly. When a mean is assigned a combination of letters, such as “bc”, it indicates that the value is not significantly different from means labeled with either “b” or “c” but differs from those assigned other letters. These letter groupings therefore provide a detailed comparison of treatment effects, showing the relative ranking and statistical separation among treatment means.

3.2. Soil chemical properties

Table 2 and Figure 2 present the effect of different treatments (T1–T6) on key soil chemical properties, including electrical conductivity (EC), nitrogen (N), phosphorus (P), potassium (K), and pH. These parameters collectively describe soil fertility status and its suitability for plant growth.

Table 2 Soil chemical properties after harvest

Treatment	EC (µS/cm)	N (g/kg)	P (mg/kg)	K (ppm)	pH
T1	50.8	1.08	3.10	6.5	6.08
T2	55.6	1.86	7.72	9.2	7.02
T3	54.2	1.65	6.40	8.5	6.85
T4	53.1	1.48	5.80	7.9	6.60
T5	52.6	1.32	4.75	7.2	6.40
T6	51.3	1.20	3.90	6.8	6.22

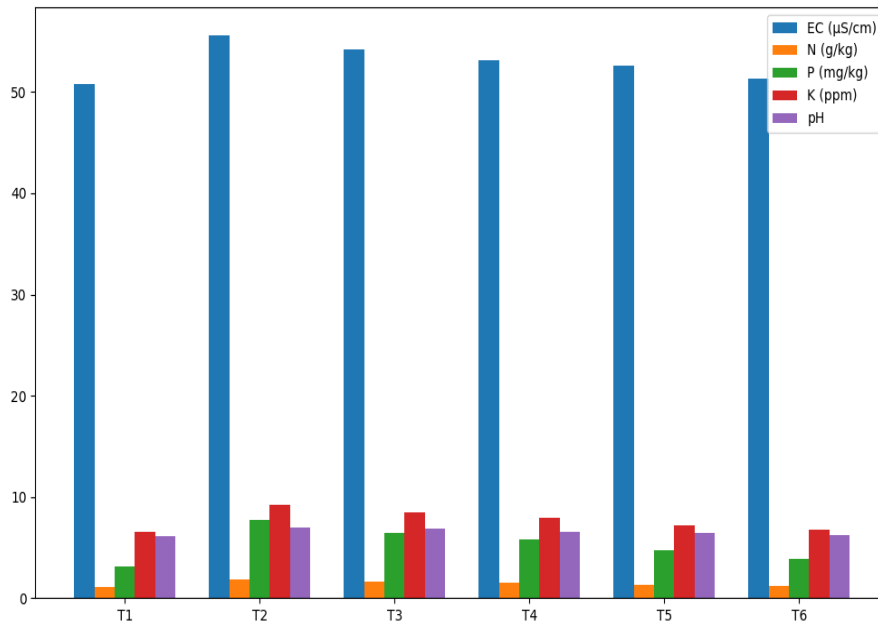


Figure 2. Soil chemical Properties after harvest

A clear pattern emerges: treatment T2 consistently records the highest values for EC, nitrogen, phosphorus, potassium, and pH. The EC value of 55.6 $\mu\text{S}/\text{cm}$ in T2 indicates a greater concentration of soluble ions in the soil, which is directly associated with the higher nutrient levels observed. Nitrogen in T2 reaches 1.86 g/kg, phosphorus 7.72 mg/kg, and potassium 9.2 ppm, all of which are markedly higher than in the other treatments. The pH of 7.02 is close to neutral, a condition known to enhance nutrient availability and plant nutrient uptake. This suggests that T2 provides the most favorable chemical environment for plant growth and likely represents the most effective treatment in improving soil fertility.

Following T2, treatments T3 and T4 show moderately high nutrient levels, though slightly lower than T2. In T3, nitrogen, phosphorus, and potassium decrease to 1.65 g/kg, 6.40 mg/kg, and 8.5 ppm, respectively, while EC drops slightly to 54.2 $\mu\text{S}/\text{cm}$ and pH to 6.85. This still reflects a relatively fertile soil condition, as the pH remains within the optimal range for most crops. T4 continues this gradual decline, with further reductions in nutrient concentrations and EC, indicating that the treatment's effectiveness is diminishing.

Treatments T5 and T6 show a more noticeable reduction in all measured parameters. In T5, nitrogen falls to 1.32 g/kg, phosphorus to 4.75 mg/kg, and potassium to 7.2 ppm, while EC decreases to 52.6 $\mu\text{S}/\text{cm}$ and pH to 6.40. T6 shows even lower values, approaching those of T1, with nitrogen at 1.20 g/kg, phosphorus at 3.90 mg/kg, potassium at 6.8 ppm, and EC at 51.3 $\mu\text{S}/\text{cm}$. Although these values are not extremely low, they indicate reduced nutrient availability compared to the higher treatments, suggesting limited improvement in soil fertility.

T1 represents the lowest overall fertility condition among the treatments, with the lowest EC (50.8 $\mu\text{S}/\text{cm}$), nitrogen (1.08 g/kg), phosphorus (3.10 mg/kg), and potassium (6.5 ppm). Its pH of 6.08 is slightly acidic but still within an acceptable range for many crops. This treatment likely serves as a control or baseline, reflecting soil conditions with minimal or no amendment.

Overall, the data demonstrate a strong positive relationship between EC and nutrient concentrations, with higher EC values corresponding to higher levels of nitrogen, phosphorus, and potassium. The gradual decrease in all parameters from T2 through T6 suggests a systematic reduction in treatment intensity or effectiveness, possibly due to lower fertilizer or organic amendment application rates. Despite these variations, the pH across all treatments remains within a narrow and suitable range, indicating that soil acidity is not a limiting factor in any of the treatments.

T2 provides the most optimal soil conditions, while T1 and T6 reflect comparatively low fertility. The trend across treatments shows that increasing treatment intensity improves soil nutrient status and overall soil quality.

3.3. Analysis of Variance (ANOVA)

Significant differences among treatments were observed for most parameters (Table 3.3), indicating that irrigation levels strongly influenced both yield and soil chemical properties. The relatively high treatment means squares relative to the error mean squares confirm the robustness of the treatment effects.

In Table 3, the asterisks (* and **) denote the level of statistical significance of the treatment effects as determined by the analysis of variance. A single asterisk (*) indicates that the treatment effect is significant at the 5% probability level ($p < 0.05$), implying that the observed differences among treatments are unlikely to have occurred by chance. A double asterisk (**) indicates significance at the 1% probability level ($p < 0.01$), reflecting a higher degree of confidence in the treatment effect. Parameters marked with ** therefore exhibit stronger statistical evidence of treatment influence than those marked with *.

Table 3. Mean squares for maize yield and soil properties

Source	df	Grain yield	1000-grain weight	Cob weight	EC	N	P	K	pH
Replication	2	12,540	210.3	85.6	1.12	0.021	0.45	0.62	0.08
Treatment	5	185,600*	2,845.7**	1,245.3**	8.56*	0.312*	6.84**	4.25*	0.64*
Error	10	8,420	165.2	62.8	0.95	0.018	0.52	0.48	0.05

4. Conclusion

The study clearly demonstrates that regulating water supply through deficit irrigation has a pronounced effect on both maize productivity and soil chemical status in Awka, Nigeria. The observed variation in grain yield, which ranged from 1,420 kg/ha under severe water stress (30–40% ETc) to 2,580 kg/ha under full irrigation (100% ETc), shows that maize performance is highly sensitive to moisture availability in the study area, where rainfall distribution is often irregular and evapotranspiration demand is relatively high during the growing season. This yield reduction under increasing water deficit was also reflected in yield components, such as 1000-grain weight and cob weight, indicating that water stress particularly affected assimilate accumulation during grain filling. Soil chemical properties responded differently to irrigation levels. The results showed that moderate deficit irrigation improved soil nutrient retention, with higher nitrogen, phosphorus, and potassium levels observed particularly in the 80–85% ETc treatments compared to both full irrigation and severe deficit conditions. This suggests that excessive irrigation may have promoted nutrient leaching in the sandy loam soils of the experimental site, while severe water deficit likely limited nutrient mobility and microbial activity necessary for nutrient availability. Soil pH and electrical conductivity remained within acceptable ranges across treatments, indicating that deficit irrigation did not negatively alter overall soil reaction within a single cropping season. Overall, the findings indicate that applying irrigation at about 85% ETc provides an optimal balance between water savings and crop productivity under local agroecological conditions. At this level, maize yield remained statistically close to full irrigation while improving soil nutrient conservation and reducing unnecessary water use. However, when irrigation was reduced beyond this threshold, particularly below 60% ETc, yield and yield components declined sharply, confirming that severe water stress is unsuitable for maize production in the study area. Therefore, moderate deficit irrigation is recommended as a sustainable water management strategy for maize production in Awka, Anambra State, Nigeria, where water scarcity and rainfall variability are key agricultural constraints.

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