Journal of Agriculture and Agricultural Technology

(JAAT)

Journal of Agriculture and Agricultural Technology 14 (1), 2025

EFFECTS OF TILLAGE AND NITROGEN FERTILIZATION ON NITROGEN USE EFFICIENCY OF MAIZE IN THE SOUTHERN GUINEA SAVANNA OF NIGERIA

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ABSTRACT

The study was to evaluate the effects of tillage and split nitrogen fertilization on nitrogen use efficiency (NUE) of maize in the rainy season of 2022 at Anyigba, southern Guinea savanna agroecological zone of Nigeria. Agronomic efficiency of nitrogen (AEN) and partial factor productivity of nitrogen (PFPN) were used to evaluate the NUE. The treatments were a factorial combination of two tillage practices [manual ridging (MR) and minimum tillage (MT)] and split nitrogen application rates [0, 30 + 60, 45 + 45, 60 + 30 kg N ha^{-1} applied at 2 weeks after planting (WAP) / at tasseling growth stage, and 90 kg N ha-1 applied at 2 WAP] arranged in a Randomized Complete Block Design and replicated three times. The results showed that tillage had a *significant effect on AEN and PFPN. Manual ridging recorded significantly higher AEN, PFPN and maize yield with mean values of 15.7 kg^{-1}, 22.2 kg kg^{-1} and 1.3 Mg ha^{-1}, respectively. There was no significant response of NUE to N fertilization. The split application of N (60 + 30 kg N ha^{-1}) produced the highest grain yield of 2.2 Mg ha^{-1}, significantly higher than that of the split (30 + 60 kg N ha^{-1}) and the 0 N treatment. The interaction between Tillage and Nitrogen on NUE and grain yield was insignificant. Manual ridging and split application of the recommended rate of N is the most appropriate for maize production in the area.*

Key words: Maize, Nitrogen, Tillage, Southern Guinea savanna

INTRODUCTION

Conservation agriculture (CA) is a system of farming that involves minimum soil disturbance (zero and minimum tillage), crop residue retention and crop rotations; this is considered a soil and crop management system that could potentially increase soil quality and crop yield [Food and Agriculture Organization of the United Nations (FAO) 2008]. It offers an opportunity to reverse land degradation that prevails in many parts of sub-Saharan Africa (Fowler and Rockstrom, 2001) due to its positive effects on the enhancement of physical, biological and chemical properties of soil when compared to conventional tillage practices (Wander and Yang, 2000; Madari *et al.,* 2005). Conservation agriculture is an approach that aims to improve farm productivity, profits, and food security sustainably. It has three principles: minimum soil disturbance, crop residue retention, and diversified crop rotations. The three principles increase soil organic carbon, minimize erosion risk, conserve soil water, decrease fluctuations in soil temperature, and enhance soil quality and the soil's environmental regulatory capacity. Ultimately, CA optimizes crop yields and reduces input costs. (Hobbs *et al*., 2008; Wall, 2008).

Soil tillage is the mechanical manipulation of the soil for crop production. It negatively affects water conservation, soil temperature, infiltration and evapotranspiration processes. Derspsch *et al.* (2006) reported that continuous cultivation under tillage agriculture leaves the soil bare and unprotected, thereby promoting accelerated soil erosion, soil nutrient depletion and soil structural deterioration consequent upon the decline in soil organic matter. This decline is due mainly to accelerated microbial decomposition of organic residues due to improved soil aeration from tillage operations and destruction of aggregates that expose the high surface area coupled with the release of aggregated-protected organic matter for mineralization. (Govaerts *et al.*, 2009). Conservation agriculture has been reported to mitigate these problems from continuous soil tillage (Grahmann *et al.,* 2013).

Blanket fertilizer recommendations, in type and amount, can be assessed using indicators such as agronomic nutrient use efficiency (AEN) and partial factor productivity (PFP) (Ichami *et al*., 2019). The AEN measures the increase in crop yield for a given amount of nutrient added and can be used to evaluate the efficiency of a specific nutrient applied. It indicates how much productivity increase was gained by applying the nutrient and is used as a short-term indicator of the impact of applied nutrients on productivity (Dobermann, 2007; Ichami *et al*., 2019). The PFP is determined by dividing the grain yield by the amount of nutrients applied; therefore, it indicates production per unit of nutrients applied. The PFP addresses how productive the cropping system is compared to its nutrient input. It is considered the most important index for on-farm studies, among the different indices of nutrient use efficiency, as it integrates the use efficiency of both indigenous and applied nutrients (Dobermann, 2007; Mandal *et al*., 2015).

Maize production has increased over the years in both humid rainforests and moist savannas of Nigeria. It is an enormously important crop grown for human consumption and used as animal feed and agro-industrial raw material. However, maize is a heavy feeder that is easily affected by soil degradation [(Badu-Apraku and Fakorede, 2017; The International Institute of Tropical Agriculture (IITA), 2017]. The total annual production has increased from 1.06 M tons in 1976 to 12.75 M tons in 2021 (FAO, 2022). Maize productivity largely depends on nutrient availability, particularly nitrogen, phosphorus, and potassium, as well as management practices (Rasheed *et al.,* 2004). Therefore, this has necessitated the evaluation of the effects of tillage and nitrogen fertilization on selected organic carbon and maize performance in Guinea Savanna of Nigeria.
One of the significant constraints to adopting CA is the poor availability and quality of crop residues essential for mulching to achieve one of the three basic principles of CA and/hence, prevention of soil erosion. The poor quality of the mulching materials in the form of grass or cereal stover with a high C: N ratio results in short-term immobilization of N. These adverse effects can

be offset by applying large amounts of N fertilizer in the early years of CA. This is because net mineralization from grass or cereal stover residues may only be achieved over a long time (Kafesu *et al*., 2018). In Nigeria, there is a dearth of knowledge documented on the effect of N management in the early years of CA on the soil organic carbon and performance of maize. Therefore, this study aimed to assess the impact of tillage and N fertilization application rate on nitrogen use efficiency in the early years of CA at Anyigba, Kogi State, in the southern Guinea savanna of Nigeria.

MATERIALS AND METHODS

Study Site and Characteristics

The study site was the Teaching and Research Farm of Prince Abubakar Audu University, Anyigba, Kogi State, in the Southern Guinea Savanna agro-ecological zone of Nigeria on latitude 7º 10′ 30″ N and longitude 7º 28′ 50″ E, at an altitude of 289 m above sea level. The climate of Anyigba is sub-humid, with average annual rainfall and temperatures of 1360 mm and 27 °C, respectively. The rainfall, minimum and maximum temperature data of the site during the study period were presented in Table 1. The area lies in the derived savanna vegetation zone of Nigeria. Derived savanna evolved from the rain forest through human activities such as regular fire, deforestation, and farming (Adekiya *et al.,* 2018). The site's physical features are flat to gently undulating lowlands filled with Cretaceous and Tertiary rocks over which the rivers have been cut. The soils are Eutric Gleysols and Eutric Fluvisols, mainly developed from a wide range of alluvial materials (Ojanuga, 2006). Before the research, the field was cultivated to sorghum and maize with little fertilizer application over a long period.

The treatments consisted of a factorial combination of two tillage practices (minimum and manual) and five levels of nitrogen fertilizer application (0 kg N ha^{-1}, 90 kg N ha^{-1} applied in the split form of 30 kg N ha $^{-1}$ at 2 WAP and 60 kg N ha^{-1} applied at tasselling growth stage (recommended practice), 45 kg N ha^{-1} applied at 2 WAP and 45 kg N ha^{-1} applied at tasselling growth stage, 60 kg N ha^{-1} applied at 2 WAP and 30 kg N ha^{-1} applied at tasselling growth stage and 90 kg N ha^{-1} applied at once at 2 WAP emerged in a randomized complete block design (RBCD) with three replications to give a total of 30 experimental plots and 10 treatment combinations. The gross plot size was 5 m × 5 m (25 m^2), which consisted of six ridges and five furrows, while the net plot size was 3 m × 3 m (9 m^2) with four inner ridges and three furrows.

Table 1: Monthly Climatic Data Observed in Anyigba during Experiment

Month	Rain (mm)	Temperature	
		Min	Max
June	400.00	24.70	34.10
July	400.20	25.00	35.10
August	598.50	24.80	33.20
September	500.60	23.90	35.00
Total	1898.70		

Source: National Agency for Space and Research Development Authority (NASRDA).

Treatments and Experimental Design

Soil Sampling and Analysis

To characterize the whole field before the study commenced in 2022, surface soil (0-20 cm) samples were collected using an auger from three diagonal transects at 5 m regular intervals; each bulked together to give three composite samples for the routine analysis. Samples were also collected along three diagonal transects from each plot and bulked together to provide one sample for determining soil organic carbon at various growth stages.

The samples were air-dried, gently crushed using a porcelain mortar and pestle and then sieved with a 2 mm mesh. The routine physical and chemical analysis was determined according to the procedure described by Okalebo *et al.* (2002). Briefly, particle size analysis was performed using the Bouyoucos hydrometer method. Soil reaction determined potentiometrically in 1:2.5: Soil to water suspension using the glass electrode pH meter. Organic carbon was determined by the Walkley and Black wet oxidation method, and total nitrogen was determined by the Kjeldahl digestion method. Bray P-1 extracted available phosphorus, and the P concentration in the extract was determined colourimetrically using a spectrophotometer. Exchangeable bases (Ca2+, Mg2+, K+ and Na+) was extracted using 1 NH4OAC buffered at pH 7.0. Ca2+ and Mg2+ were determined using an atomic absorption spectrophotometer, while K+ and Na+ were determined using a flame photometer. Exchangeable acidity was determined by titration method using 1N KCl extract. Effective cation exchange capacity (ECEC) was estimated by calculation by summing the exchangeable bases and exchangeable acidity.

Agronomic Practices

The field was manually cleared and ridged 75 cm apart, with the litter and weeds incorporated into the soil, making the surface bare. The minimum tillage plots had the land prepared using a hoe to make small heaps 75 cm apart along the planting lines. The minimum tillage plots were then sprayed with Atrazine at 0.25 kg ha^{-1} as pre-emergence three days after planting using a 16 L knapsack sprayer with a flat fan nozzle. The resulting debris and other surface soil litter were left on the soil as mulch; the test crop was yellow maize variety, SAMMAZ 52 (PVA SYN 13) medium maturing between 110 and 120 days, tolerant to maize streak virus, rust, leaf blight and auricularia leaf spot. Three seeds were planted per hole at 25 cm intra-row spacing and thinned to one seed at 2 WAP, giving a total plant population of about 53,333 plants ha^{-1}. All the plots had basal fertilizer application of 60 kg P_2O_5 ha-1 using single superphosphate and 60 kg K_2O ha^{-1} using muriate of potash fertilizer; both were applied at 2 WAP. Urea fertilizer was used to supply N for plots requiring N fertilizer and plots requiring split application. The first dose was applied at 2 WAP, while the second was applied at the tassel growth stage of maize. All fertilizer applications were split in placement about 5 cm away, and 5 cm deep at the base of each plant stand and covered with soil. Weeding was done manually with hoe where necessary at 2 WAP and 4 – 5 WAP before fertilizer application where required. All residues from weeding were left on the surface of the soil.

Yield and Yield Component

At harvest, maize ears and stalk in the net plot were collected, and maize cobs were manually separated from stover and hand-threshed. After threshing, the total fresh weight of maize was separately taken in the field. Thereafter, five plants were taken after the removal of grains, cut into small pieces and weighed to form a sub-sample whose fresh weight was weighed. The sub-samples were oven-dried at 75 °C for 48 h to a constant weight before weighing. The grains were further dried in the sun until a moisture content of 12 % was reached using a Dickey-john grain moisture tester.

Calculation and Statistical Analysis

The nitrogen use efficiency (NUE) of the maize plant was determined using the agronomic efficiency of nitrogen (AEN) and partial factor of productivity of nitrogen (PFPN). They were calculated using the formula below.

AEN = $Y_1 - Y_0/N$ (Ichemi *et al.,* 2019) Eq. 1

Where: AE_N = Agronomic efficiency of N, Y_1 = Yield in mega gram of fertilized crop, Y_0 = Yield in mega gram of control crop

N = Nitrogen applied in kilogram, $PFP_N = Y_1/N$ (Doberman, 2007) Eq 2

where, PFP_N = Partial factor of productivity of nitrogen, Y_1 = Yield in kilogram of fertilized crop

N = Nitrogen applied in kilogram

Data collected were subjected to analysis of variance (ANOVA), and mean separation was carried out using Duncan's New Multiple Range Test (DNMRT) at a 5 % level of probability, using the GenStat analytical tool (19th edition)

RESULTS AND DISCUSSION

Initial Soil Properties

The soil's initial properties at the experiment's commencement are shown in Table 2. The sand was the dominant fine earth fraction in the soil, with a value of 831 g kg-1. The textural class of the soil was loamy sand. The coarse nature of the soil indicates low water holding capacity and availability. The sandy nature of the soil allows for tillage, even at high moisture content, with less damage to the structure of the soil. The pH of the soil was 6.1. This value falls within a slightly acidic pH range, which is optimum for most crops. The pH range of 6.0 – 7.0 is the most suitable for releasing many plant nutrients for uptake and optimum growth and development of most plants (Tan, 2000).

The soil chemical properties were rated based on Chude *et al.* (2011). The soil organic carbon content was 6.8 g kg^{-1}, and the total N content was 0.70 g kg^{-1}, within moderate and low range classes. The available phosphorus of the soil falls within the low class and is 6.0 mg kg^{-1}. The moderate organic carbon with consequent low N and P are characteristics of savanna soils, partly due to rapid decomposition in tropical climates, making it challenging to build soil fertility (Androen e*t al.,* 2007). The result from the determination of exchangeable cations showed that Ca concentration was 4.02 mol kg^{-1} (low), Mg was 2.26 cmol kg^{-1} (moderate), K was 2.02 cmol kg^{-1} (very high), and Na was 0.33 cmol kg-1 (moderate). The low content of Ca and Mg reflects the soil's low clay and moderate organic matter contents. In tropical soils, organic matter is the primary source of negative charges that these nutrients are adsorbed to, which prevents them from being leached down the soil profile beyond the root zone (Brady and Weil, 2010). The exchangeable acidity (Al3++ H+) was low (1.02 $cmol^{-1}$). The soil is thus low in potential acidity and will not contribute to the active acidity; therefore, it may not cause adverse effects on crop growth, including root development (Adeboye *et al.*, 2020). The high amounts of aluminium are toxic to roots and cause roots to swell, impeding their ability to absorb water and nutrients from the soil (Brady and Weil, 2010). Adequate cation exchangeable capacity (ECEC) was moderate (9.65 cmol kg^{-1}), which reflects the moderate organic carbon content.

Grain Yield

The effects of tillage and N fertilization on the grain yield of maize are presented in Table 3. Tillage had a significant impact on grain yield. Manual ridging produced a significantly higher grain yield (1.3 Mg ha^{-1}) than MT. The lowest yield observed in the minimum tillage may be attributed to soil surface crusting, resulting in surface runoff, nutrient loss, reduced infiltration, and hence greater plant-water stress than manual ridging. Similar results have been reported by Khattak *et al.* (2005). A significant effect of N fertilization was observed on both grain yields, confirming N as the most limiting nutrient for maize production in the southern Guinea savanna of Nigeria (Adeboye *et al*., 2020). The split N fertilization (60 + 30 kg N ha^{-1}) recorded a significantly higher grain yield, which was significantly higher than that of the control treatment, having the lowest grain yield of 0.6 Mg ha-1. Similarly, Singh and Sharma (2001) also observed that grain yield increased significantly with increasing nitrogen levels up to 150 kg N ha^{-1}.

Table 2: Initial Properties of the Soil Prior to Land Preparation

Soil properties	**Values**
Sand (g kg^{-1})	831
Silt (g kg^{-1})	66
Clay (g kg^{-1})	103
Textural Class	Loamy Sand
pH (H2O) 1:2.5	6.1
Organic Carbon	6.8
Total Nitrogen (g kg^{-1})	0.70
Available Phosphorus (mg kg^{-1})	6.0
Exchangeable Cations (cmol kg^{-1})	
Ca	4.02
Mg	2.26
K	2.02
Na	0.33
Exchangeable Acidity	1.02
ECEC (cmol kg^{-1})	9.65

Table 3: Effects of Tillage and Nitrogen Fertilization Application on Maize Yields

Treatments Tillage (T)	Grain Yield (Mg ha^{-1})
Manual Ridging	1.3^{a}
Minimum Tillage	1.2^{b}
SE±	0.01
N rate (kg N ha^{-1})	
0	0.6^{c}
30 + 60	1.6^{b}
45 + 45	1.8^{ab}
60 + 30	2.2^{a}
90	1.8^{ab}
SE±	0.22
Interaction	
T * N	NS

All means within a column (for each factor) followed by same letter (s) are not significantly different at 5 % level of significance, SE = Standard error, NS = Not significant

Table 4: Effects of Tillage and Nitrogen Fertilization Application on Agronomic Efficiency of Nitrogen and Partial Factor Productivity of Nitrogen on Maize

Treatments **Tillage (T)**	AEN (kg grain kg N^{-1})	PFP_N (kg grain kg N^{-1})
Manual Ridging	15.7[a]	22.2[a]
Minimum Tillage	11.4[b]	18.7[b]
SE±	1.87	1.91
N rate (kg N ha^{-1})		
30 + 60	11.0[b]	18.0[b]
45 + 45	13.1[a]	20.1[a]
60 + 30	17.6[a]	24.5[a]
90	13.5[a]	20.5[a]
SE±	2.69	2.68
Interaction		
T * N	NS	NS

All means within a column (for each factor) followed by same letter (s) are not significantly different at 5 % level of significance, AEN = Agronomic efficiency of nitrogen, PFPN = Partial factor productivity of nitrogen, SE = Standard error, NS = Not significant

The effects of tillage and nitrogen application rate on agronomic efficiency and partial factor productivity of nitrogen are shown in Table 4. Both agronomic efficiency of nitrogen use (AEN) and partial factor productivity of nitrogen (PFPN) were significantly affected by tillage practice and nitrogen fertilizer application rate. The AEN and PFPN were significantly higher when maize was grown under MR than MT. This result was in agreement with those obtained by Huggins *et al.* (1993) and Lopez-Bellido *et al.* (2001), who attributed the higher AEN and PFPN under MR to an increase in yield or as a result of N fertilizer immobilization through crop residue in MT plots. The values of AEN and PFPN recorded in this study were lower than 18 kg kg^{-1} reported in smallholder maize farms in SSA (Lehami *et al.,* 2019). The low values of AEN and PFPN recorded reflect the low grain yield obtained in the control plots (Table 3). Also, some soils may be naturally fragile and P-fixing, leading to challenges for increased nutrient use efficiency (Chikowo *et al.,* 2010). The NUE is a function of maize grain yield in the control plots (Lehami *et al.,* 2019). Significantly lower AEN and PFPN recorded under 30 + 60 kg N ha^{-1} may be attributed to the fact that the N requirement at that stage of maize growth seems to be higher than 30 kg N ha^{-1} supplied, which resulted in lower grain yield and subsequent reduction in AEN and PFPN values. The highest values of AEN and PFPN (17.6 and 24.5 kg kg^{-1}, respectively) were recorded in the treatment with an application rate of 60 + 30 kg N ha^{-1}, suggesting that split application rates enhanced the nitrogen use efficiency of maize.

CONCLUSION

This study evaluated the effects of tillage and nitrogen fertilization rates on the nitrogen use efficiency of maize as part of a broad study to promote conservation agriculture in the southern Guinea savanna of Nigeria. The study's findings indicated manual ridging enhanced the nitrogen use efficiency of maize and produced the highest NUE. Thus, it is the most appropriate for maize cultivation in the agroecological zone. The results showed that the highest AEN and PFPN were recorded under split nitrogen fertilizer application of 60 + 30 kg N ha^{-1}, which suggests that N fertilizer application is best applied in split form in the zone.

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