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RESEARCH ARTICLE

Effects of Split Application of Urea Fertilizer on Soil Chemical Properties, Maize Performance and Profitability in Southwest Nigeria

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Abstract:

Background:

Since N fertilizer applied to maize (*Zea mays* L.) is prone to loss by leaching, it is important to derive an application time during the phenology of maize when the fertilizer is most efficiently and effectively used by the crop with minimal losses.

Objective:

Hence, experiments were carried out in 2014 at two locations in Osogbo southwest Nigeria to determine the effects of split application of N fertilizer on soil chemical properties, maize performance, and profitability.

Methods:

The treatments were: (i) control, (ii) 120 kg N ha^{-1} Applied at Planting (AP), (iii) two split applications (SA) of 120 kg N ha^{-1} {90 kg N ha^{-1} applied AP + 30kg N ha^{-1} at thirty Days After Planting (DAP) [90 + 30]}, and (iv) three SA of 120 kg N ha^{-1} {60 kg N ha^{-1} applied AP + 30 kg N ha^{-1} thirty DAP + 30 kg N ha^{-1} at tasselling[60+30+30]}. The four treatments were arranged in a Randomized Complete Block Design with three replicates.

Results:

Results indicate that at both sites, SA three times (60+30+30) has the most improved soil chemical properties, growth and yield of maize relative to other methods. The yield parameters increased in the order: control < 120 kg N ha^{-1} applied once < 90+30 < 60+30+30. Using the mean of both sites, 60+30+30 increased yield of maize by 15.3%, 37.1% and 138.2%, respectively compared with 90+30, 120 kg N ha^{-1} applied once and the control. Optimum returns were recorded by 60+30+30 with net return of ₦ 227,600 and a benefit cost ratio of 3.67:1 while the application of 120 kg N ha^{-1} applied once has a return of ₦ 157,200 with a benefit ratio of 2.9. These results show that farmers would benefit by making more profit by adopting the method of SA of N fertilizer three times (60+30+30).

Conclusion:

Therefore, for improved soil chemical properties, growth, yield and profitability of maize, N fertilizer application should be structured in accordance with this pattern of uptake to avoid losses by leaching and therefore ensure that N level in the soil is high at the critical stage of N demand.

Keywords: N fertilizer, Maize performance, Profitability, Split application, Soil chemical properties, *Zea mays* L.

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1. INTRODUCTION

Maize (*Zea mays* L.) is an important cereal crop grown worldwide. It is the third most important cereal crop after wheat and rice. Maize has been found growing in the tropical, subtropical and temperate parts of the world [1]. In Nigeria, the crop is fast becoming a staple food, according to Nweke [2], maize has accounted for about 43% calories in the diet of an average Nigerian. The fresh grain may be roasted or cooked and eaten or the grains may be used for the preparation of porridge after undergoing the process of milling and boiling.

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Apart from the direct consumption of maize by man and live stocks, it is also a raw material in the production of alcohol, starch, *etc*. The stocks are also indispensable as they are used for staking, fencing, mulching and livestock fodder.

However, most soils used for maize production in Southwest Nigeria are exhausted due to continuous cropping and needs the addition of an external input like fertilizer to sustain its fertility. Maize, like other cereal crops are a heavy feeder and needs a high amount of nutrients for increased productivity. Among these nutrients, nitrogen (N) is very important because of its role in the growth and development of maize crops [3]. This is also because N fertilized crops have larger root systems for the adsorption of nutrients [4]. N is also a major constituent of chlorophyll, protein and amino acids. N is important for carbohydrate utilization and above ground vegetative growth and stimulation and utilization of other nutrient elements such as K, P and S [5]. Also, under high rainfall condition of southwest Nigeria, N applied as fertilizer may stand the chance of part still retained in the soil or lost from the soil through leaching, erosion [3], or volatilize to the air.

Maize needs a large amount of N fertilizer for its growth, in the study area urea fertilizer applied as N could be as high as 260 kg ha^{-1} [6] and since N is prone to loss by either leaching, erosion or denitrification, it is, therefore, important to derive an application time during the phenology of the crop when the fertilizer is most efficiently and effectively used by the crop with minimal losses. Increasing N use efficiency of maize plant is one of the major ways of decreasing N loss through erosion, leaching or volatilization. Moreover, most farmers in southwest Nigeria apply fertilizer anytime since there is little information available on the time and rates of fertilizer to be applied during the phenological growth of maize. Therefore, Tobert *et al*. [7] suggested multiple times of N fertilizer application. This multiple application of N fertilizer in maize becomes imperative because any deficiency in N supply as a result of N loss during the growth of the crop will result in economic losses. Likewise, over-application due to a single application of N fertilizer may result in excessive vegetative growth and reduced grain yield. Therefore, the application of N fertilizer at multiple times during the growth of maize plants may reduce the risk of N losses and increase crop yield especially when the timing is in synchrony with the time of critical need of the crop. Furthermore, multiple applications of N fertilizer may affect soil chemical properties and the profitability of such maize after harvest. This aspect needs investigation especially in southwest Nigeria where N losses due to leaching are high and where data on multiple applications of fertilizer to maize are scarce and the existing ones are conflicting. There is the need to investigate the best time during the phenology of maize plants to apply N fertilizer in southwest Nigeria that will optimise soil chemical properties, increase yield and ensure profitability to farmers. Therefore, the objective of this study was to determine the effects of split application of N fertilizer on soil chemical properties, maize performance, and profitability on Alfisols of Southwest Nigeria.

2. MATERIALS AND METHODS

2.1. Experimental Site

The experiments were carried out in July 2014 at two locations (Site I and Site II) in Osogbo Agricultural Farm Settlement, Osogbo, Osun State, southwest Nigeria. (Latitude 7° 48`N and Longitude 4°37`E). The locations are characterized by a bimodal pattern of rainfall with an annual mean of about 1300 mm with a mean temperature of 27°C and the climate is of the sub humid type. The sites had been under continuous cultivation for many years with maize, the soil at the two locations are Alfisols [8].

2.2. Treatment Application

The treatment involved doses of periods of N (urea) fertilizer applications: (i) 0 kg N ha^{-1} (control), (ii) 120 kg N ha^{-1} applied at planting, (iii) two split applications of 120 kg N ha^{-1} (90 kg N ha^{-1} applied at planting + 30kg N ha^{-1} at thirty days after planting), and (iv) three split applications of 120 kg N ha^{-1} (60 kg N ha^{-1} applied at planting + 30 kg N ha^{-1} thirty days after planting + 30 kg N ha^{-1} at tasselling). The four treatments were arranged in a Randomized Complete Block Design (RCBD) with three replicates.

2.3. Land Preparation, Field Layout and Sowing of Maize Seeds

The experimental plots at both sites were ploughed and harrowed. The field layout was demarcated immediately after harrowing using rope, pegs and tape. Each experimental unit has a dimension of 5 m × 2 m. Plots were separated by 0.5 m apart while blocks were separated by 1m apart at the two sites. Maize seed (Empress 96), a late-maturing cultivar was obtained from the Government Economic Service (GES) in Osogbo, Osun state. The seeds were sown at both sites on the 7th of August 2014 at a depth of 2-3 cm. Two seeds were sown per hole at a spacing of 75 cm × 25 cm which was later thinned to one plant per stand at two weeks after sowing to achieve 53 plants per plot equivalent to about 53,333 plants per hectare. Fertilizer (urea) was applied as required: 0 kg N ha^{-1} (control), 120 kg N ha^{-1} applied at planting, two splits of 120N kg ha^{-1} (90 kg N ha^{-1} applied at planting + 30kg N ha^{-1} at thirty days after planting) and three splits of 120 N kg ha^{-1} (60 kg N ha^{-1} applied at planting + 30 kg N ha^{-1} thirty days after planting + 30 kg N ha^{-1} at tasselling). The first urea was applied at planting on the 7th of August 2014, the second application on the 6th and 7th of September 2014 and the third dose was applied at tasselling. Fertilizer was applied by side placement at about 8-10cm away from the sown seeds at planting and the base of the plant after germination. Weeds were controlled manually at three weeks interval using a hoe.

2.4. Soil Analysis

Surface soil samples (0-15 cm depth) were collected randomly from the field at the two sites for physical and chemical analysis before the start of the experiment. The soil sample was air-dried, sieved through a 2-mm sieve and kept for analysis The sand, silt and clay contents were determined by the hydrometer method [9].The soil pH was determined using the pH-meter in a 1:2.5 soil/water ratio, total nitrogen content was by the micro-kjedahl method [10], available phosphorus was by Bray 1 method [11], Calcium (Ca) and Magnesium (Mg) were determined by the Atomic Absorption Spectrophotometer (AAS) and potassium (k) and sodium (Na) by flame emission photometry (Association of Official Analytical Chemists [12]. The organic carbon was according to Walkey and Black using the dichromate wet oxidation method [13] and the present organic matter was estimated by multiplying the percent organic carbon with a factor 1.724. At the end of the experiment at both sites, soil samples were also collected randomly from five different places within a plot and later bulked together to form composite soil sample (on plot basis) and similarly analysed for soil chemical properties as described above.

2.5. Determination of Growth and Yield Parameters

Ten (10) maize plants were tagged in each plot for data collection. Data was collected at fortnight intervals starting from the third week after sowing. The following parameters were measured; plant height, number of leaves, stem girth, and leaf area. Plant height was measured with a tape from the base of the plant to the first tassel, the number of leaves were counted, leaf area was calculated using non-destructive analysis method (length × breath by correction factor 0.75 [14], and stem girth was measured using a vernier caliper. Maize was allowed to dry before harvest. Yield parameters collected at harvest of maize included: the weight of grain/ plant and weight of cob/plant.

2.5.1. Statistical Analysis

Data on growth and yield parameters were subjected to Analysis of Variance (ANOVA) using Statistical Analysis System (SAS) and means were separated using Tukey pairwise comparisons at $P<0.05$.

3. RESULTS

3.1. Soil Fertility Status of the Sites

The fertility status of the sites (I and II) used for the experiments in 2014 are presented in Table **1**. The experimental sites were slightly acidic and sandy loam in texture. Site II has lower sand and greater percentages of silt and clay relative to site I. Soils at both sites were low in organic matter (OM), N and P. The exchangeable bases K, Ca and Mg were adequate according to the critical level of 3.0% OM, 0.20% N, 10.0 mg kg^{-1} P, 0.16 - 0.20 cmol kg^{-1} K, 2.0 cmol kg^{-1}Ca and 0.40 cmol kg^{-1}Mg recommended for crop production in the agroecological zone [15].

3.2. The Effect of Split Application of N Fertilizer on Soil Chemical Properties

The result of the effects of split application of N fertilizer on soil chemical properties is presented in Table **2**. Application of N fertilizer increase soil OM, N and P compared with the control at both sites. Split applications of N fertilizer three times (60+30+30) had the highest values of OM and N. The values of P between two split applications (90+30) and three split applications (60+30+30) was not significantly different. At both sites, although the values of K increase from no application of N fertilizer (control) to 60+30+30 N application, there were no significant differences between these values. There was no consistent pattern of variation in the values of Ca, for site II, 120 kg N ha^{-1} fertilizer applied once at planting had the highest value (2.36 cmol kg^{-1}) and 60+30+30 had the least value(1.15 cmol kg^{-1}). For site I, Ca values were significantly increased from the control up to 60+30+30. At both sites, Mg values were significantly increased with the application of N fertilizer compared with the control. The significant increase was from the control to 60+30+30 treatment. At both sites, the control plots after crop harvest (Table **2**) had lower values of soil OM, N, P, K, Ca and Mg compared with the pre-plant soil (Table **1**).

3.3. Effect of Split Application of N Fertilizer on the Growth and Yield of Maize

Results of the effects of split application of N fertilizer on maize growth and yield are respectively presented in Figs. (**1** and **2**). Application of N fertilizer increased the growth of maize at both sites (except the number of leaves and leaf area for site II) compared with the control. The values of maize growth parameters increased in the order: control < 120 kg N ha^{-1} applied once < 90+30 < 60+30+30. The values of the number of leaves, stem girth and leaf area were not significantly different between 90+30 and 60+30+30 Fig. (**1**). Yield parameters (maize yield (t ha^{-1}), weight of grain/ plant and weight of cob/plant) increased significantly with the application of N fertilizer compared with the control. The yield parameters also increased in the order: control < 120 kg N ha^{-1} applied once < 90+30 < 60+30+30. Using the mean of both sites, 60+30+30 increased yield of maize in t ha^{-1} by 15.3%, 37.1% and 138.2%, respectively compared with 90+30, 120 kg N ha^{-1} applied once and the control

3.4. The Profitability of Maize Production Under Different Split N Application Methods

Table **3** shows the data on the profitability of maize produced under a split application of N fertilizer. The monetary gain from the sales of one (1) ha of dried maize was lowest (₦ 121,600) with the control and highest (₦289,600) with 60+30+30. The order was: control < 120 kg N ha^{-1} applied once < 90+30 < 60+30+30. The production increase value was highest (₦ 89, 600) with 120 kg N ha^{-1} applied once. For this experiment, the cost of fertilizer application was highest with 60+30+30 and lowest with 120 kg N ha^{-1} applied once. All other costs were assumed to be constant for all treatments. Net returns over each fertilizer were highest (₦ 227,600) with 60+30+30 and lowest with control. With the fertilizer application times, optimum returns were recorded by 60+30+30 with a net return of ₦ 227,600 and a benefit cost ratio of 3.67:1 while application of 120 kg N ha^{-1} applied once have a return of ₦ 157,200 with a benefit ratio of 2.9. These results show that farmers would benefit by making more profit by adopting the method of split application of N fertilizer three times (60+30+30).

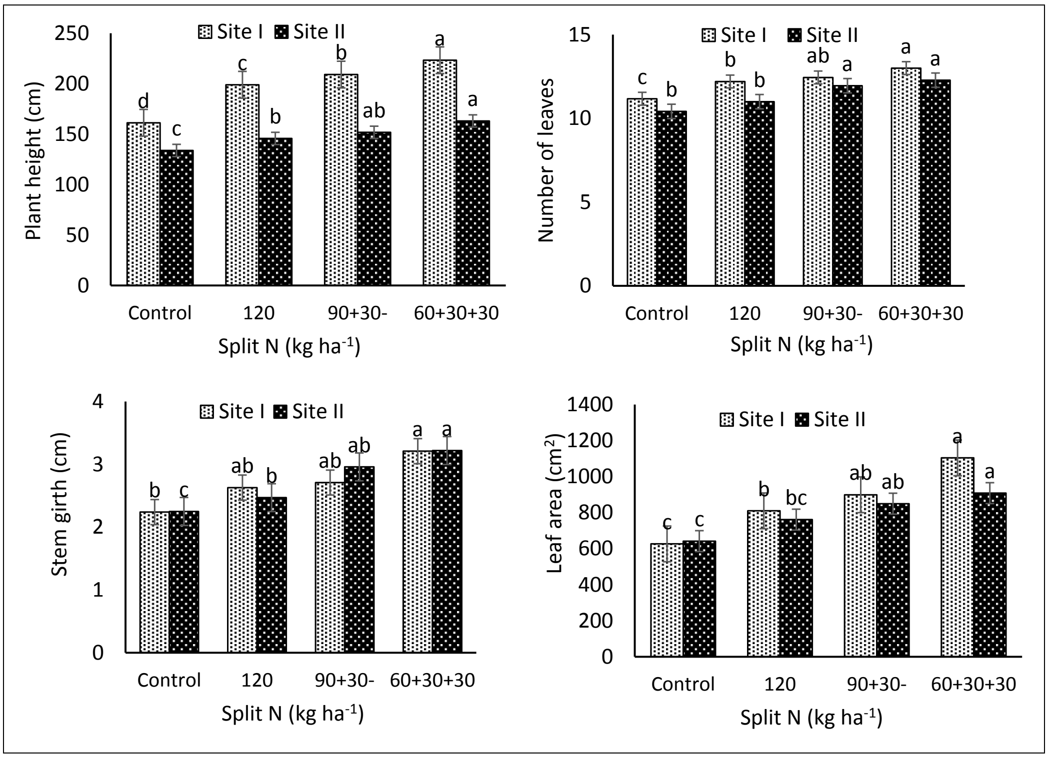

Fig. (1). Effect of split N application on growth parameters of maize from site I and site II. Vertical bars show standard error of paired comparisons; bars marked with different letters show means significantly different at 5% level using Duncan's multiple.

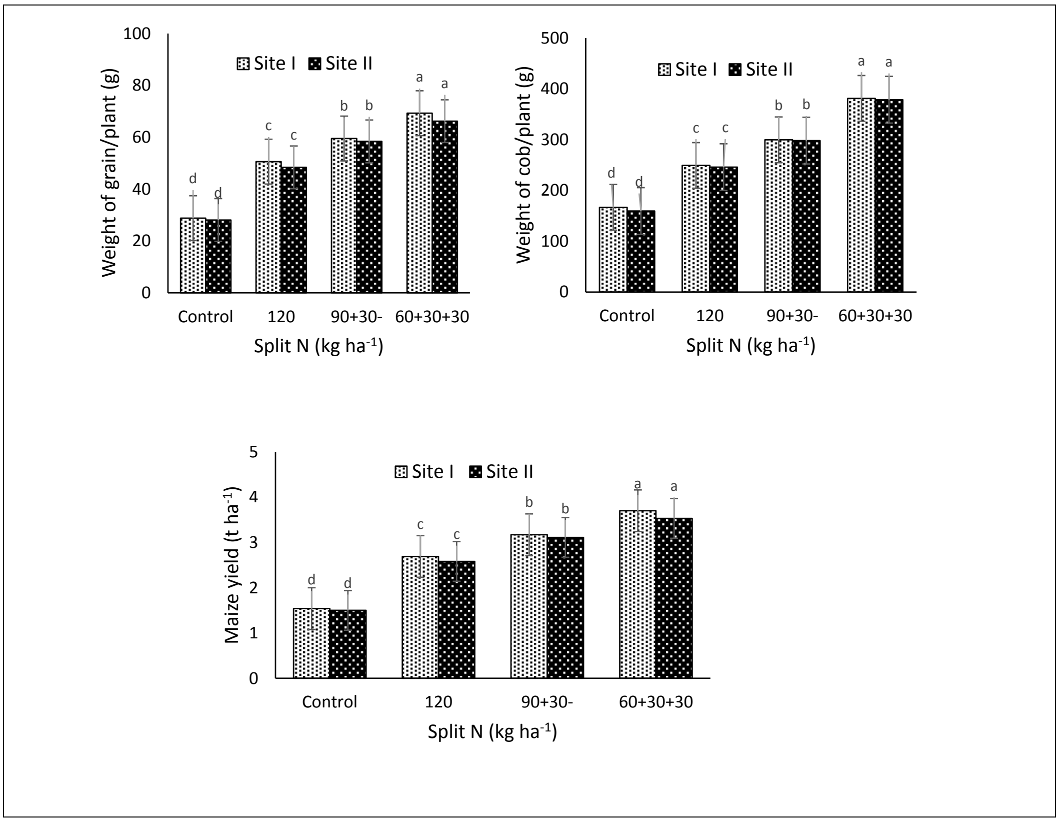

Fig. (2). Effect of split N application on yield parameters of maize from site I and site II. Vertical bars show standard error of paired comparisons; bars marked with different letters show means significantly different at 5% level using Duncan's multiple.

Table 1. Initial soil characteristics at the sites before experimentation.

Property	Site I	Site II
Sand (%)	82.4	61.4
Silt (%)	3.28	17.3
Clay (%)	14.32	21.3
Textural class	Sandy loam	Sandy loam
Soil organic matter (%)	2.84	2.14
pH (water)	5.78	5.60
Total N (%)	0.18	0.14
Available P (mg kg^{-1})	6.56	5.46
Exchangeable K (cmol kg^{-1})	0.36	0.48
Exchangeable Ca (cmol kg^{-1})	2.10	2.30
Exchangeable Mg (cmol kg^{-1})	0.75	0.50

Table 2. Effect of split application of N fertilizer on soil chemical properties

Split N (kg ha^{-1})	OM (%)		N (%)		P (mg kg^{-1})		K (cmol kg^{-1})		Ca (cmol kg^{-1})		Mg (cmol kg^{-1})	
	Site I	Site II	Site I	Site II	Site I	Site II	Site I	Site II	Site I	Site II	Site I	Site II
Control	2.08d	2.02d	0.14d	0.13d	3.30c	4.22c	0.21a	0.26a	0.76d	2.12b	0.24d	0.43d
120	2.18c	2.21c	0.23c	0.20c	3.51b	4.68b	0.25a	0.29a	0.98c	2.36a	0.38c	0.82c
90 + 30	2.41b	2.68b	0.25b	0.25b	3.93a	5.25a	0.28a	0.30a	1.17b	1.75c	0.51b	0.99b
60+30+30	2.72a	3.18a	0.28a	0.29a	3.96a	5.25a	0.29a	0.32a	1.29a	1.15d	0.71a	1.44a

Means followed by the same letters are not significantly different according to Turkey pairwise comparisons. (P<0.05).

Table 3. Profitability of producing maize under different Split N application times (Data from site I and site II pooled).

	Monetary Gain	Production Increase value	Production Increase	Cost of Fertilizer Application	Net Return Over Each Fertilizer Time	Return Rate or Benefit/cost Ratio
Split N (kg ha^{-1})	(₦ ha^{-1})		(%)	(₦ ha^{-1})		
Control	121,600	-	-	-	-	-
120	211,200	89,600	73.7	54,000	157,200	2.90
90 + 30	251,200	40,000	32.9	58,000	193,200	3.33
60 + 30 + 30	289,600	38,400	31.6	62,000	227,600	3.67

Note: In 2018, the price of one (1) tonne of dried maize was ₦ 80,000. ₦360.00 is equivalent to 1.00 US$ in 2018.

4. DISCUSSION

The reduction in OM at both sites in the control plots compared with the pre-plant soils could be due to oxidation of the soil OM during land preparation (ploughing and harrowing). When tillage is performed, the amount of OM exposed to oxidation is high throughout the ploughed layers and therefore OM is easily depleted [16; 17]. Also there was a reduction in the values of N, P, K, Ca and Mg in the control plots compared with the pre-plant soil due to uptake by maize crop. Application of N fertilizer increased soil OM, N, P and Mg contents of the soil relative to the control. Increased soil organic matter and nutrients caused by urea fertilizer could be due to the rapid vigorous growth of maize plants as a result of N fertilizer application which resulted in addition of carbon through maize root biomass and maize residues decay [18]. These increases in soil OM, N, P and Mg could also be probably due to increased microbial activities as a result of N application which led to enhanced production and mineralization of OM from the soil [19]. Split application of N fertilizer three times (60+30+30) significantly had the highest values of nutrients in the soil after the experiment. This was adduced to proper application/time scheduling that minimized N losses. Split application of N fertilizer three times (60+30+30) ensures that only small amount of nutrient applied is lost. Some nutrient elements, such as N is a mobile element and as such can easily be lost in so many ways such as leaching, this is especially true of the soil of the sites (Table **1**) that are low in silt and clay and high in sand and couple with the high rainfall of the area (1300mm). For such soils, during heavy rainfall, when the amount of moisture in the soil is greater than its field capacity, water drains rapidly through the soil and leach any soluble nutrient element [20]. Leaching losses are related to the time of application of fertilizer, soil permeability and quality of rainfall in the ecological zone [21]. It had been reported that nitrogen and phosphorus losses from soil increase during rainy seasons when precipitation and runoff were high [22]. The 120 kg N ha^{-1} applied once resulted in low nutrients because most of it would have been lost before the end of the gestation of the maize, whereas due to split application some nutrients were still retained in the soil. It was reported [23] that greater than 50% of higher doses of applied N are unavailable in the soil to crop due to losses through leaching. Also, Haile *et al* [24] reported that 58 - 70% of applied N may be secured in the soil due to the efficient time of N application.

The increase in growth and yield of maize with the application of N fertilizer in relative to no application showed that the sites of the experiment were deficient in nutrients. Maize response well to the application of N fertilizer if all other conditions apply such as adequate moisture, good variety, weed control, and plant population, high yield of maize is a function of N in the soil.

The increased growth and yield of maize under 60+30+30 N fertilizer application could be due to superior soil chemical properties of this treatment, suggesting that there was better availability of soil nutrients for plant use when fertilizer was split applied three times compared with other methods. Compared with split application methods, the values of growth and yield of maize under120 kg N ha^{-1} applied once were low because the N applied at planting was more susceptible to leaching losses at the time when the plant was still young and N uptake rate was very low. Maize plant needs about 2 - 3weeks after sowing to develop leaves and roots needed for nutrient absorption. The nodal roots developed after the germination of maize seed are not yet absorbing nutrients. The seedlings at this stage depend solely on the kernel food reserve [25, 26]. Any fertilizer applied at planting will, therefore, be subjected to leaching losses since absorption by the maize up to 10 - 15 days after sowing maize seed is rare [27]. Gehi *et al* [28] reported that maize grain yield increased with the split application of fertilizer compared to one single application at planting. The increased growth and yield of maize under 60+30+30 fertilizer application could also be attributed to better utilization of N at the proper time of the growth stage of the maize plant. It has been reported [29] that split application of fertilizer has a significant effect on maize fodder yield. Mariga *et al* [30] reported that maize yield increased when N was applied up to the tassel stage. At the early stage of growth of maize, the rate of utilization of N is usually very low but gradually increases and reaches the maximum just before tasseling [31]. During this stage, N utilization by maize can be as high as 4 kg N ha day^{-1} [32]. Therefore, for better growth and yield of maize, N fertilizer application should be structured in accordance with this pattern of uptake to avoid losses by leaching and therefore ensure that N level in the soil is high at the critical stage of N demand. Maintaining substantial levels of N in the soil during tasseling is important in spikelet differentiation and also for kernel formation [33, 34]. Bhattarai *et al*. [35] also reported that the application of N fertilizer at equal doses of 60 kg ha^{-1} at sowing, earthing up and silking stages maximized the yield of maize.

CONCLUSION

N (urea) fertilizer either applied once at planting or split applied improved soil chemical properties, growth and yield of maize compared with the control. Split application three times (60+30+30) had the most improved soil chemical properties, growth, yield and also the profitability of maize relative to other methods. Therefore, for better growth, yield and profitability of maize, N fertilizer application should be structured in accordance with this pattern of uptake to avoid losses by leaching and therefore ensure that N level in the soil is high at the critical stage of N demand. There is a need for further studies to show actual absorption and assimilation of urea applied and bio-safety for product

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Not applicable.

HUMAN AND ANIMAL RIGHTS

No animals/humans were used for studies that are the basis of this research.

CONSENT FOR PUBLICATION

Not applicable.

AVAILABILITY OF DATA AND MATERIALS

The data supporting the findings of the article are available in this manuscript.

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CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

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