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(Research Article)

Nitrogen uptake and grain yield of maize (*Zea mays* L.) as influenced by soil amendments of neem (*Azadirachta indica* L.) cake and oil extracts and NPK fertilizer in Guinea savannah zone of Ghana

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Abstract

Maize (Zea mays L.) has high response to N and the efficient uptake of N is a major factor influencing grain yield. The effect of inorganic NPK fertilizer and Neem cake and neem oil as soil amendments were examined on maize N uptake and grain yield. A 3 × 3 × 2 factorial experiment was laid out in a Randomized Complete Block Design with three replications at the University for Development Studies farms at Nyankpala near Tamale, in northern Ghana. The treatments consisted of combinations of three levels of neem cake (0, 200 and 400 kg ha^{-1}), three levels of neem oil (0, 10 and 20 L ha^{-1}) and two levels of NPK (0 and 250 kg ha^{-1}). The results showed that NPK at 250 kg ha^{-1} combined with neem cake at 400 kg ha^{-1} significantly ($p < 0.05$) increased N uptake in maize by 31% (from 111.3 kg ha^{-1} to 146.9 kg ha^{-1}) compared to the recommended NPK rate. Maize grain yield was significantly maximized by that treatment at 7,471 kg ha^{-1}. Grain yield was significantly associated with N uptake; therefore 250 kg ha^{-1} NPK with 400 kg ha^{-1} neem cake could be recommended for maize farmers in the project area. In contrast, neem oil extracts significantly reduced N uptake. The results of the study posited important implications for soil fertility management and climate change mitigation strategies for enhanced maize production.

Keywords: Nitrogen; Phosphorus; Potassium; Neem cake; Neem oil; Maize

1. Introduction

Maize (*Zea mays* L.) is one of the most important cereal crops in the world's agricultural economy, both as food for human beings and feed for animals. In Ghana, maize is the most important staple and food security crop and it accounts for more than 50% of total cereal production and the second important commodity crop in the country after cocoa (MoFA, 2011a). Maize is a major source of calories provider in Ghana, and report indicated that it has nearly replaced sorghum and pearl millet as traditional staple crops in northern Ghana (SRID-MoFA, 2011). The average yearly maize production was reported to be 1.5 million MT between 2007 and 2010 (Rondon and Ashitey, 2011) with an average yield of about 1.7 t/ha (SRID-MoFA, 2011). It is cultivated in all agro-ecological zones of Ghana and grows best in deep and well-drained loamy soils (MoFA, 2005) but more than 70% of the maize output is from three of the agro-ecological zones (guinea savanna, forest savanna and transitional zones). The five principal maize growing areas are in the Northern, Brong-Ahafo, Ashanti, Central and Eastern Regions (Amanor- Boadu, 2012). Maize is noted to be a heavy nutrient feeder and responds well to higher fertilizer application, particularly nitrogenous in Northern Ghana (CSIR-SARI, 2011). For decades the application rate of chemical fertilizer for maize production in Ghana has been basal

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application of 250 kg/ha of NPK 15-15-15 compound fertilizer and topdressing with 125 kg/ha of sulphate of ammonia (Kombiok *et al.,* 2012).

The exploitative agriculture for a long time in our country has brought down the soil fertility status to a level that necessitates provision of high rate of fertilizer to sustain high crop production. Percent organic matter and nitrogen are particularly low in the savannah and transition zones (FAO 2005). Whilst agricultural production systems absorb nutrients from mineralized soil organic matter and atmospheric deposition, synthetic sources have rapidly evolved as a major source of nutrients in developed countries (Halvin 2005). Smil (2001), concluded that without industrial synthesis of ammonia, the world could not support its current population. It is well documented that maize grain yields in most growing areas including the Guinea savannah zone are low and uneconomical when cultivated without fertilizers (CSIR-SARI, 1996; Gholipoor *et al.,* 2013).

However, the escalating price of fertilizers in recent years, limit its use in crop production. Limited use of fertilizers in cropping systems is becoming rampant such that crop productivity is low (Okoboi and Barungi, 2012). Where fertilizers are applied; most of them are lost by leaching and poor nutrient uptake by crops. The integrated use of organic and inorganic nutrient sources has been reported to improve the performance of crops than sole application (Ayoola and Makinde, 2009). Krupnit *et al.* (2004) reported that combined use of organic and inorganic fertilizer reduced cost and amount of fertilizer required by crops. Therefore, nutrient provision through chemical fertilizers, if complimented with low-cost natural plant resources that could boost nutrient uptake would improve nutrient use efficiency and sustainable soil health and crop production (Singh *et al*., 2016). With the increased cost of urea fertilizer and concern about its adverse environmental impact of nitrogen losses, there has been a great interest in improving the Nitrogen Use Efficiency through optimization of nitrogen use. By doing so, higher yields can be achieved with less negative impacts like nitrogen leaching (Agostini *et al*., 2010)

Improving efficiency of fertilizer use is vital to achieve and sustain high crop yields and reduce losses that can potentially deteriorate environmental quality.

Neem (*Azadirachta indica*) has demonstrated activity as a nitrification inhibitor, helping to slow the bacterial activity that is responsible for denitrification, hence decreasing the loss of urea from the soil (Mohanty *et al*., 2008). The neem tree, *Azadirachta indica*, a member of the *Meliaceae* family that originates from the Indian subcontinent and is now valued worldwide as an important source of phytochemicals. *Azadirachta* is a fast-growing small-to-medium sized evergreen tree, with wide and spreading branches. It can tolerate high temperatures as well as poor or degraded soil. Neem contains melicians (generally known as neem bitters) of which Epinimbin, Diacetyl and Azadirachtin are the main fractions, which are responsible for nitrification inhibition action (Devakumar 2016). The plant contains nutrients such as, N (2.0% to 5.0%), P (0.5% to 1.0%), K (1.0% to 2.0%), Ca (Calcium 0.5% to 3.0%), Mg (Magnesium 0.3% to 1.0%), S (Sulphur 0.2% to 3.0%), Zn (Zinc 15 ppm to 60 ppm), Cu (Copper 4 ppm to 20 ppm), Fe (Iron 500 ppm to 1200 ppm), Mn (Manganese 20 ppm to 60 ppm)(Schmutterer, 2002).

The neem products namely; bark, leaves and seeds are very useful for medicinal and agricultural purposes (NRC, 1992; Uyovbisere and Elemo, 2007). Neem seed cake (NSC) is a by-product of Neem oil extraction from the neem seed kernels. Neem seed cake was found to have high manurial value; Indian farmers have traditionally used neem cake (NSC) as fertilizer on their fields (NRC, 1992). It improves the growth and yield of crops because it contains essential nutrients necessary for the growth of crops (Agbenin, 1999).

Neem oil is extracted from the seeds of the neem tree and has insecticidal and medicinal properties due to which it has been used in pest control in rice cultivation. Oil derived from seeds of neem when applied along with urea are capable of enhancing nitrogen use efficiency (NUE) in rice (Agarwal *et al.* 1980; Singh and Singh 1986)

The neem nitrification inhibiting properties and its phenomenon in increasing NUE in rice were also reported by Naresh *et al.* (2003). Scientists at the Indian Agricultural Research Institute (IARI), New Delhi (India) found the nitrification-inhibiting properties of neem (Rao *et al.,* 2000) and neem-cake coated urea (Pushpanathan *et al.,* 2005). Sanjay *et al.* (2015) studied the effect of different organic manures and fertilizers on yield and nutrient uptake of maize (*Zea mays L.*) using three organic manures viz., FYM, vermicompost and poultry manure with fertilizers and neem coated urea. The results indicated neem coated urea significantly increased nutrient availability and uptake. Mangat *G.S.,* (2004) found the application of 100 % recommended dose of nitrogen through neem coated urea (4 ml neem oil/100 g urea) significantly increased both grain and straw yield To evaluate Application of different sources of nitrogen on the yield of wheat the results revealed that the maximum grain yield 42.40 q ha^{-1} was recorded in 100% N through NCU followed by 100% N through urea 37.37 q ha^{-1} and 80% N through NCU 35.36 q/ha over farmer practice, which has recorded minimum grain yield 34.77q ha^{-1}. Because of its bactericidal properties it has been reported that neem inhibit nitrification, gives higher grain yield and fertilizer nitrogen use efficiency. NCU reduces nitrate leaching to groundwater and ammonia and nitrous oxide emissions to the environment. Datt *et al.* (2007) studied nitrogen mineralization and relative efficiency of neem and neem coated urea for wheat and rice. Results showed that 100% neem coated urea produce more grain and straw yield both in rice (9.2% and 6.8% higher yield) and wheat crop.

The present study therefore looks at the potential of neem products as soil amendments to increase the uptake and utilization of nitrogen in maize production in the Guinea savannah ecological zone of Ghana.

2. Material and methods/ Research methodology

2.1. Description of Study Site

The study was conducted under on-station conditions, during the 2021 cropping seasons, at the UDS farms, Nyankpala near Tamale, in Northern Ghana. The area is within the Guinea savannah agro-ecological zone and lies within latitude 09˚ 25'N and longitude 0˚58'W and at altitude 183 m above sea level. The area is characterized by a mono-modal rainfall with an annual rainfall range of 900–1,000 mm and it usually occurs from July to early November. The average daily temperatures during rainy and dry seasons are 22˚C and 34˚C respectively. The maximum relative humidity of 80% occurs in the area during the rainy season and this decrease to minimum of 53% during the dry season. The soil, which is locally classified as "Nyankpala soil series", is brownish in colour, sandy-loam, free from concretion, very shallow with a hardpan under the top soil (SARI, 2007).

During the period of study (June- November), maximum mean rainfall was recorded in June (28.6 mm) whilst the minimum was recorded in July (9 mm). Maximum temperature was 35 ^{o}C in November whilst the mean minimum temperature of 24 ^{o}C was for all the months as indicated in (Table).

Table 1 Monthly Climatic data during the period of study April-August, 2010

Months	Rainfall (mm)	Temperature (°C)	
		Minimum	Maximum
June	28.6	24	33
July	9.0	24	30
August	15.0	24	30
September	12.0	24	30
October	10.0	24	32
November		24	35

Source: CSIR_SARI weather station. 2021 records, Tamale.

Basal soil samples were collected at 0-20 cm depth from the experimental sites and the physico-chemical properties analysed (Table 1). The chemical analysis was conducted by the soil chemistry laboratory in the CSIR – SARI, Nyankpala -Tamale.

Table 2 Basal physico-chemical properties of the experimental soil at 0 - 20 cm depth

pH	% N	mg/kg P	mg/kg K	Texture			
				% Sand	% Silt	% Clay	Class
5.28	0.24	6.08	58	67.6	22	10.4	Sandy Loam clay

2.2. Experimental Design and Treatment

The experiment was a 3 × 3 × 2 factorial experiment laid in a randomized complete block design (RCBD) with three replications. The planting material used was a hybrid maize, lake. The factorial treatment consisted of three levels of neem cake (0, 200 and 400kg ha^{-1}), three levels of neem oil (0, 10 and 20L ha^{-1}) and two levels (0 and 250 kg ha^{-1}) of inorganic fertilizer. Each plot measured 4.5 m × 4.0 m with an alley of 1 m between plots and 2 m between replications.

2.3. Agronomic practices and data collection

The hybrid maize (Lake 601) was planted (in June 2021 cropping season) at a spacing of 75 cm × 20 cm with one seed per hill. Inorganic compound fertilizer (15-15-15, NPK) was applied at 250 kg/ha 2 weeks after planting (WAP) and sulphate of ammonia fertilizer was applied at 125 kg/ha 6 WAP as side-dressing (Kombiok et al., 2012). Data collected on the maize included bi-weekly plant height, chlorophyll content using the spad, total leaf area and Leaf area index (LAI) were calculated with formulae below, days to 50% tasseling, days to 50% silking, grain yield (economic yield) was calculated by shelling grains from the cob and sun dried to 14% moisture content. Grain weight of sampled plants were measured and converted to kilogram per hectare, total stover biomass yield (dry weight of biological yield) was calculated by adding the weight of the above-ground Stover yield of sampled plants to the corresponding grain weights and then converted to kilogram per hectare, harvest Index (HI) was calculated with formulae below. N Uptake was calculated with formulae below. The maize cobs were harvested in October-November, 2021 cropping season at physiological maturity, dehusked, and oven dried at 65°C to a moisture content of 14% before shelling to measure the grain weight. After harvesting the cobs, the plants were cut at ground level and oven dried at 65°C for 72 h to a constant weight before measuring stover yield.

Leaf Area Index was calculated as in equation 1:

$$Leaf\ area\ index\ (LAI) = \frac{Total\ leaf\ area\ of\ plant}{Land\ area} x\ 0.72 \quad \dots\dots\dots\dots\dots\dots\dots .Eqn. 1.$$

Where 0.72 is a constant in Watson formula

Harvest Index was calculated as in equation 2:

$$Harvest\ Index = \frac{Economic\ yield}{Biological\ yield} \qquad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots ..Eqn. 2$$

Nutrient (N) uptake was calculated as in equation 3

$$\text{N uptake (kg } ha^{-1}) = \frac{N\ content\ (\%)\ X\ Yield\ (kg\ ha^{-1})}{100} \quad \dots\dots\dots\dots\dots\dots\dots .\ Eqn. 3$$

2.4. Description of hybrid maize (Lake 601)

Lake 601 hybrid maize seed was produced in South Africa and tried, tested and released by the Varietal Release Committee of the Ministry of Food and Agriculture (MoFA) for use in the 2021 planting season. Ghana's maize production now stands at a little over 3 m tonnes per annum, with 1.7 metric tonnes per hectare as the average yield, but this could rise to more than 15 million metric tonnes with the new seed. The General Manager of Newage Agric Solutions, said that the new variety, which "has come at a time when the demand for maize continues to outstrip supply, thereby impacting prices", was aimed at promoting food security in the country. He said the new seed variety was expected to help farmers guarantee a good yield, as well as provide jobs for the mass of the people who would venture into maize farming. He said the Lake 601 Hybrid Maize Seed could produce far higher yields than the normal open-pollinated maize varieties (OPVs) used in the country. He explained that the seed was a resplendent hybrid which was able to perform well in the environment from hot, humid lowlands to dry mid-altitudes and high potential wet highlands. It was also noted that the variety performed well in all soil types across the country and even performed better in acidic soil with exceptional nitrogen use efficiency (NUE). "It is also tolerant to striga, the most dangerous weed to maize. It is the best option for commercial and small farming because the high yield potential is guaranteed when planted," Mr Nartey said. He added that although both the new variety and the old OPVs attracted the same labour and cost in cultivation, the hybrids gave far higher yields (Graphiconline.com)

2.5. Data Analysis

Data was individually subjected to analysis of variance technique and the means compared by LSD test using GENSTAT version 12 (GenStat, 2008). The analysis of variance (ANOVA) procedure for 3 factor RCBD model was used to determine whether there was significant difference among treatment. Least significant difference (LSD) was also used to separate treatment means of significant difference at 5% probability level.

3. Results

3.1. Effect of NPK fertilizer, neem cake (NC) and neem oil (NO) on maize grain yield

Grain yield was significantly ($p < 0.05$) determined by treatments. The treatment with 400 kg/ha NC with 250 kg NPK/ha recorded the highest yield of 7,471 kgha^{-1} and the lowest yield was recorded in the control with 4,306 kg ha^{-1}. Grain yield was significantly ($p < 0.05$) higher in the 400 kgha^{-1} NC with 250 kgha^{-1} NPK (7471 kg ha$^{-1)}$ than in entries with 250 kg ha^{-1} and the other NC and NO combinations except for the 10 lha^{-1} with 250 kgha^{-1} NPK. Similarly, it was also observed that the 10 l ha^{-1} with 250 kg ha^{-1} NPK treatments was significantly ($p < 0.05$) higher than other plots with NC and NO treatments except the 250 kg ha^{-1} NPK. There were however no significant differences ($P>0.05$) among the control, 200 kg ha^{-1} NC, 400 kg ha^{-1} NC, 250 kg ha^{-1} NPK, 200 kg ha^{-1} NC×250kg ha^{-1} NPK, 10 liters ha^{-1} NO, 20 liters ha^{-1} NO (Table 1).

Table 3 Effect of NPK fertilizer, Neem cake and Neem oil on maize grain yield

Treatment	**Grain yield in Kg**ha^{-1}
Control	4306 c
200 kg/ha neem cake	5291 bc
400 kg/ha neem cake	5043bc
250 kg/ha NPK	5815b
200 kg/ha neem cake × 250 kg/ha NPK	4787bc
400 kg/ha neem cake ×250 kg/ha NPK	7471a
10 liters/ha neem oil	5065bc
20 liters/ha neem oil	4825bc
250 kg/ha NPK	6625ab
10 liters/ha neem oil × 250 kg/ha NPK	6654ab
20 liters/ha neem oil × 250 kg/ha NPK	4794bc
Lsd (0.05)	1378.6

Mean values followed by the same letters in each column are not significantly different from one another.

3.2. Effect of neem cake and three levels of neem oil on maize grain yield

Grain yield was significantly ($p < 0.05$) different among the treatments. The treatment with 400 kg neem cake recorded the highest yield of 6,693 kg ha^{-1} and the lowest yield was recorded in the 200 kg ha^{-1} neem cake combined with 20liters ha^{-1} neem oil plots with a value of 4,176 kg ha^{-1}. Grain yield was significantly ($p < 0.05$) higher in the 400kg ha^{-1} neem cake than in plots with 20 liters ha^{-1} neem oil, 200 kg^{-1} neem cake combined with 20 liters ha^{-1} neem oil but it wasn't significantly ($p > 0.05$) different from the 400kg ha^{-1} neem cake combined with 20 liters ha^{-1} neem oil, 400 kg ha^{-1} neem cake combined with 10liters ha^{-1} neem oil, 200kg ha^{-1} neem cake combined with 10 liters ha^{-1} neem oil, 200 kg ha^{-1} neem cake, 10 liters ha^{-1} neem oil (Figure 1).

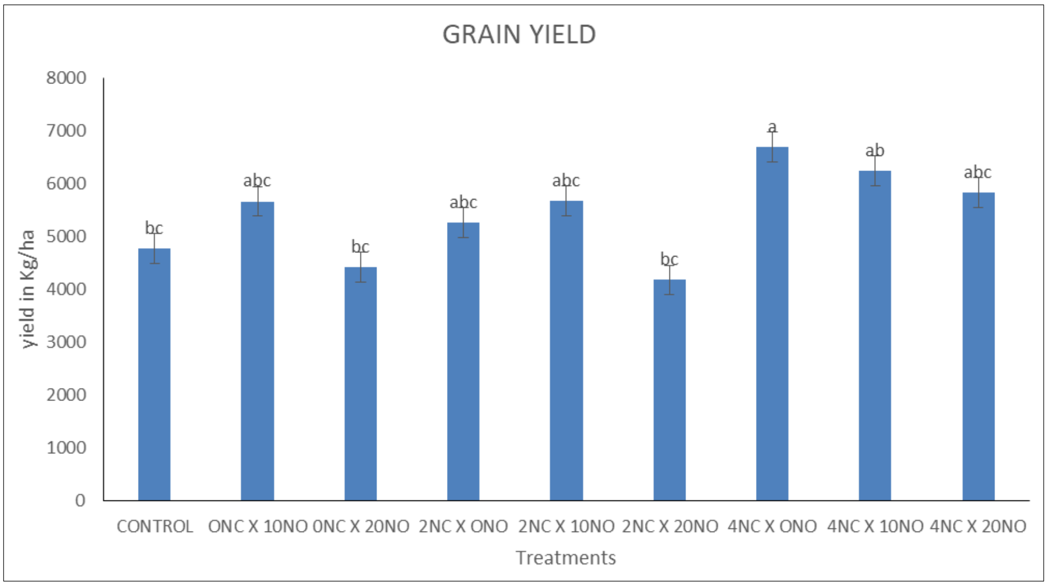

Figure 1 Effect of Neem cake (NC) and three levels of Neem oil (NO) on maize grain yield

3.3. Effect of NPK Fertilizer, Neem cake and Neem oil On Maize grain N Uptake

N Uptake in maize grain was significantly ($p < 0.05$) determined by treatments. The treatment with 400 kg/ha NC combined with 250 kg NPK/ha recorded the highest N Uptake of 146.9 kgha^{-1} and the lowest N Uptake was recorded in the control with 79.2 kg ha^{-1}. N Uptake was significantly ($p < 0.05$) higher in the 400 kgha^{-1} NC with 250 kgha^{-1} NPK (7471kg ha^{-1}) than in 250kg ha^{-1} NPK and the other NC and NO combinations except for the 10 l ha^{-1} with 250 kgha^{-1} NPK. Similarly, it was also observed that the 10 l ha^{-1} with 250 kg ha^{-1} NPK treatments was significantly ($p < 0.05$) higher than other treatments of NC, NO and the 250kg ha^{-1} NPK. There were however no significant differences ($P>0.05$) among the control, 400 kg ha^{-1} NC, 200 kg ha^{-1} NC with 250kg ha^{-1} NPK, 10 liters ha^{-1} NO, 20 liters ha^{-1} NO (Table 2).

Table 4 Effect of NPK fertilizer, Neem cake and Neem oil on maize grain N uptake

Treatments	N uptake grain
CONTROL	79.2 c
200 kg/ha Neem Cake	101.1 bc
400 kg/ha Neem Cake	92.7 bc
200 kg/ha Neem Cake X 250kg NPK	89.3 bc
400 kg/ha Neem Cake X 250kg NPK	146.9 a
10 liters/ha Neem Oil	91.5 b
20 liters/ha Neem Oil	95.1 b
250 kg NPK	121.7 b
10 liters/ha Neem Oil X 250kg NPK	130.8 a
20 liters/ha Neem Oil X 250kg NPK	84.6 b
LsD 0.05	26.24

Mean values followed by the same letters in each column are not significantly different from one another.

3.4. Effect of neem cake and three levels of neem oil on maize grain n uptake

N Uptake was significantly ($p < 0.05$) different among the treatments. The treatment with 400kg neem cake combined with 10 liters ha^{-1} neem oil recorded the highest % N Uptake of 128.3 kg ha^{-1} and the lowest N Uptake was recorded in the 200 kg ha^{-1} neem cake combined with 20liters ha^{-1} neem oil plots with a value of 7 kg ha^{-1}. N Uptake was significantly ($p < 0.05$) higher in the 400 kg ha^{-1} neem cake than in plots with 20liters ha^{-1} neem oil, 200 kg^{-1} neem cake combined with 20 liters ha^{-1} neem oil and the control but it wasn't significantly ($p > 0.05$) different from the 400 kg ha^{-1} neem cake combined with 20 liters ha^{-1} neem oil, 400 kg ha^{-1} neem cake combined with 10liters ha^{-1} neem oil, 200 kg ha^{-1} neem cake combined with 10 liters ha^{-1} neem oil, 200 kg ha^{-1} neem cake, 10 liters ha^{-1} neem oil (Figure 2).

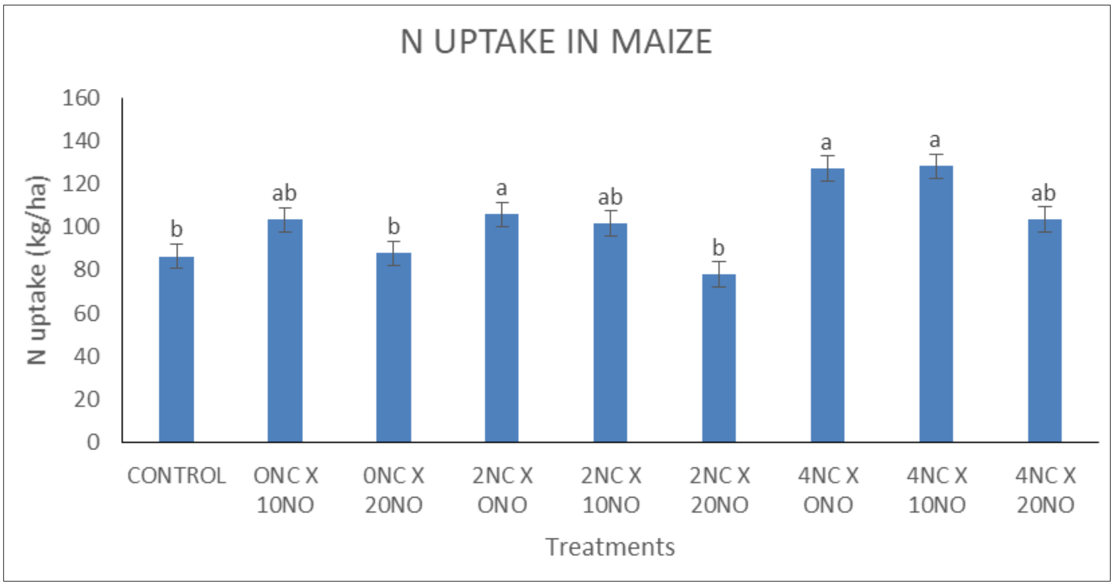

Figure 2 Effect of Neem cake (NC) and three levels of Neem oil (NO) on maize grain N Uptake

4. Discussion

4.1. Effect of NPK fertilizer, neem cake and neem oil on maize grain yield

The grain yield is the weight of grains harvested from the crops on the field per plot or treatments as used in the experiment. The treatments where the recommended NPK at 250 kg/ha content was supplied with neem cake at 400 kg/ha significantly ($p<0.05$) recorded higher grain yield than plots with only the recommended NPK and the controls, probably due to the longer availability of nitrogen in the plots. Pushpanathan *et al*., (2000). reported that neem-cake help reduce leaching and volatilization of N. The findings also conform to that of Ayoola and Makinde, (2009) where it was found that integrated use of organic and inorganic nutrient supply improve the performance of crops than their sole application. Sanjay et al., (2015) studied the effect of different organic manures and fertilizers on yield and nutrient uptake of maize (*Zea mays L.*) using three organic manures viz., farm yard manure (FYM), vermicompost and poultry manure with fertilizers and neem coated fertilizer also indicated that neem coated urea significantly increased nutrient availability, uptake and subsequently grain yield.

4.2. Effect of neem cake and three levels of neem oil on maize grain yield

Plots with neem cake at 400 kg/ha and treatments at 10 liters/ha significantly ($p<0.05$) recorded higher grain yield more than plots with neem oil at 20 liters/ha and its combinations. However, there was no significant ($p>0.05$) differences between the neem cake at 400 kg/ha and the 10liters/ha treatments. It was also observed that beyond the 10liters/ha threshold grain yield dropped. This finding conforms to Devakumar and Goswami (1992) which showed dose-dependent nitrification inhibition action of neem oil. It has been established that neem products when applied along with fertilizers are capable of enhancing nitrogen use efficiency (NUE) in rice (Agarwal *et al.* 1980; Singh and Singh 1986). Agbenin, (1999), also found that neem cake improves the growth and yield of crops because it contains essential nutrients necessary for the growth of crops.

4.3. Effect of NPK fertilizer, neem cake and neem oil on maize grain N uptake

There was a direct relationship between the grain yield and the maize grain N uptake, which was the higher the N uptake the greater the grain yield. The treatments where the recommended NPK at 250 kg/ha content was combined with neem cake at 400 kg/ha significantly ($p<0.05$) recorded higher maize grain N uptake. The performance there was more than plots with only the recommended NPK and the controls, probably due to the longer availability of nitrogen in the plots. The findings conform with that of Sanjay *et al.,* (2015) who studied the effect of different organic manures and fertilizers on yield and nutrient uptake of maize (*Zea mays L.*) using three organic manures viz., FYM, vermicompost and poultry manure with fertilizers and neem coated fertilizer. He indicated that neem coated fertilizer significantly increased nutrient availability, uptake and subsequently grain yield. Kumar *et al.* (2011), Upadhyay and Tripathi (2000) and Kumar *et al.* (2007) also found superiority of neem coated fertilizer over ordinary fertilizer in N uptake and nitrogen use efficiencies.

4.4. Effect of Neem cake and three levels of Neem oil on maize grain N uptake

Plots with neem cake at 400 kg/ha and treatments at 10 liters/ha significantly ($p<0.05$) recorded higher maize grain N Uptake more than plots with neem oil @ 20 liter/ha and its combinations. It was equally observed that beyond the 10 liters/ha threshold grain yield dropped. This finding conforms to Devakumar and Goswami (1992) who showed dose-dependent nitrification inhibition action of neem oil. It has been established that neem products when applied along with fertilizer are capable of enhancing nitrogen use efficiency (NUE) in rice (Agarwal *et al.* 1990; Singh and Singh 1986).

5. Conclusion

The study showed that balanced use of both organic amendments and inorganic fertilizer improved the maize grain yield and maize N Uptake compared to sole application of either of them. Coupled with the results obtained, it can be inferred that the soils amended with 400 kg/ha Neem cake with 250 kg/ha NPK significantly ($p< 0.05$) increased the maize grain yield and N uptake while amongst neem oil, 10liters/ha outperformed the 20 liters/ha. The neem oil was observed to be dose-dependent effective. The threshold of 10 liters/ha was almost comparable to the 400 kg/ha neem cake whereas the 20 liters was even worse than the control plots. The results of the study posited important implications for soil fertility management and climate change mitigation strategies for enhanced maize production.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors state no conflict of interest.

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