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Potassium Uptake as Influenced by Neem (*Azadirachta indica* L.) Cake, Neem Oil and NPK on Grain Yield of Maize (*Zea mays* L.) in Guinea Savannah Zone of Ghana

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Abstract

The research study was conducted at the experimental farm of University for Development Studies, Nyankpala-Tamale in northern region, Ghana during the 2021 growing season to evaluate the effect of inorganic NPK fertilizer, Neem cake and neem oil as soil amendments on maize P uptake and grain yield. A 3 × 3 × 2 factorial experiment was laid out in a Randomized Complete Block Design with three replications. 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}). Parameters examined were plant height, crop growth rate, chlorophil content (using spad), leaf area index (LAI), K uptake and grain yield. The study revealed plant height, uptake of K, grain yield and biological yield of maize increased with increased rate of neem cake (200 to 400 kg ha^{-1}) when combined with 250 kg NPK/ha. Plant height, growth rate, uptake and uptake efficiency of K and grain yield of the crop decreased with increased rate of neem oil from 10 l/ha to 20 l/ha, when combined with 250 kg NPK/ha. The results showed combining 250 kg NPK/ha with 400 kg/ha neem cake increased K uptake by 34% (from 99 kg/ha to 133 kg/ha) compared to the recommended NPK rate. Application of 250 kg NPK/ha plus 400 kg/ha neem cake gave grain yield of 7637 kg/ha representing 61% increment over the application of only the inorganic fertilizer (4736 kg/ha), .and biological yield of 26873 kg/ha as maximum entries. The results of the study posited important implications for soil health management for enhanced maize production.

Keywords: Nitrogen; Phosphorus; Potassium; Neem cake; Neem Oil and Maize**.**

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1.Introduction

Globally, amongst the numerous cereal crops in the agricultural industry, one of the most momentous is maize (*Zea mays* L.). It is utilized both for man's food and also used to feed animals. No other cereal has such immense potential in food security, earning it the title "Queen of Cereals" [1]. Although Scientists have developed varieties with higher proportions of nutrients, the maize grain has the composition of "9% protein, 4% oil, 70% starch, and 2.7% crude fiber". Maize protein "Zein" contains abundance of two important amino acids, Tryptophan and lysine [2], which are noted for building proteins that improves human health.In Ghana, maize is undisputedly a major staple crop that accounts for over half of the country's grain production and is planted in all "agro-ecological zones" [3]. Maize is often the most popular basic grain, and output has increased since 1965 [3] in the country. Most of the produced maize in Ghana are consumed by households within it and that is why maize production is crucial if Ghana wants to ensure food security in a sustained manner [4]. Average maize yields range between "1.2 and 1.9 metric tons (Mt) per hectare (ha), while field and institutional indicate that economic yields of "4 to 6 Mt/ha of maize are achievable in the country" [5].Maize is farmed and consumed by the totality of the "agro-ecological zones of Ghana". This crop flourishes in loamy soils that are deep and well-drained [6]. The three agro-ecological zones namely: "Guinea savanna, Forest savanna and Transitional zones"; in the country is responsible for over 70% of the maize produced. The (5) five main regions for growing maize are "Northern, Brong-Ahafo, Ashanti, Central, and Eastern Regions" [7]. The attainable yield of well-liked enhanced maize varieties planted in Ghana is 2.2 metric tons per hectare, which is 50% below the yield reported by [8]. For instance, Obatanpa and Mamaba each have a 5.5 and 7.5 Mt/ha potential production, respectively [9]. These figures show that there is enormous potential to raise smallholder income and room for significant increases in maize output.Due to its reputation as a heavy nutrient feeder, maize typically benefits from heavier fertilizer applications [10]. N-P-K:100-40-40 kg/ha is the suggested rate of chemical fertilizer for maize production in Ghana's Guinea savannah zone, indicating significant deficiency of the potassium (K) in the Guinea savannah zone soils. The recommendation of 40 kg K/ha for maize maximum yield speaks volumes of the contribution of K to maize yields in the northern soils. Potassium catalyses most physiological function; regulation of water; aids nitrate absorption from the soil; neutralize organic aids; strengthens plants straw and stalk against lodging, fungal and bacteria attack. Potassium contributes to charge balance, osmotic adjustment, and enzyme catalysis, which are all crucial for plant growth and development as well as cellular homeostasis [11]. The Guinea savannah ecological zone of Ghana being one of the principal maize producers of the country [7] is one of the largest consumers of chemical fertilizers in the country [12]. Despite that, farmers often record low average maize yield of 1.9 t/ha compared to the potential yield of 6.0 t/ha [13;6]. Further investigation into the issues facing the northern Ghanaian agricultural sector reveals that low fertility soils support low crop yields, which are detrimental to the advancement of agriculture [14]. The widespread reduction in soil fertility and the chronically low crop yields is could also be caused by cropping cereal-based culture without sufficient nutrient inputs to the soil [15]. Therefore, continued crop production without proper nutrient uptake from fertilizers could lead to rapid loss of soil nutrients including K and associated diminishing crop growth and yields [16]. In order to attain the highest yields from the application of the necessary doses of fertilizers, strategies for enhancing and maintaining agricultural production could be concentrated on utilizing the available nutrient resources more effectively, efficiently, and sustainably than in the past. However, the escalating price of fertilizers coupled with the frequent shortages in supply in recent years, limit its use in crop production. Limited use of fertilizers (250 kg/ha of NPK 15-15-15 compound fertilizer and topdressing with 250 kg/ha of sulphate of ammonia) in cropping systems is becoming rampant such that crop productivity is low [17]. Where fertilizers are obtained in the midst of the difficulties and applied, most nutrients are lost, through leaching and poor nutrient uptake by crops resulting in low yields [6]. As a result, there is now a lot of interest in increasing nutrient use efficiency (NUE) through optimizing nutrient uptake due to the rising expense of fertilizers and worries about their negative environmental effects. As such, higher crop yields per nutrient input could be achieved, since negative impacts such as nitrogen losses could be minimized [18,19]Exploiting the use of technologies for improving fertilizer uptake and utilization efficiency could be vital in achieving and sustaining high crop yields and reduce losses that can potentially deteriorate environmental quality. Through moderation of soil physico-chemical parameters including pH, cation exchange capacity, nutrient uptake, and water retention capacity, organic materials like neem products could promote soil health [20,21]. According to studies, using both organic and inorganic nutrient sources together improve crop performance overall and nutrient uptake [22]. By enhancing nitrogen uptake and soil health, [23] demonstrated that the combined use of organic and inorganic fertilizer decreased cost and amount of fertilizer required by crops. Therefore, nutrient provision through chemical fertilizers, if complemented with low-cost natural plant resources that could boost nutrient uptake and utilization, would improve NUE and sustainable soil health and crop production [24]. Neem and neem-cake coated urea have been shown in prior investigations to have nitrification-inhibiting capabilities [25,26]. Neem-coated fertilizers, for instance, have been shown to minimize nitrogen losses through leaching and volatilization [27]. Additionally, according to [28], fertilizer coated with neem oil lowers nutrient losses in a rice-wheat cropping system, and nutrients are gradually released to the crop throughout its life cycle. Neem is a good soil conditioner, inhibits nitrification, boosts crop production over time, and has no adverse environmental effects [29].Limited information is available on the reactions of maize to neem and neem products in relation to the recognized poor soil in Ghana's vast Guinea savannah ecological zone, where maize is intensively farmed. The goal of the current study was to determine the potential of neem products as soil amendments to increase the uptake and utilization of potassium in maize production in the Guinea savannah ecological zone of Ghana.

2.Materials and Methods

Description of study site

The study was conducted under on-station conditions, during the 2021 cropping seasons, at the University for Development Studies farms, Tamale, in Northern Ghana. The area is within the Guinea savannah agro-ecological zone. 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, is brownish in colour, loamy sand, free from concretion, very shallow with a hardpan under the top soil [30].

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 ºC in November whilst the mean minimum temperature of 24 ºC was for all the months as indicated in (Table 1).

Table 1: Monthly Climatic data during the period of study April-August, 2021

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 2). The chemical analysis was conducted by the soil chemistry laboratory in the CSIR – SARI, Nyankpala -Tamale.

Table 1: Basal physio-chemical properties of the experimental soils at 0 - 20 cm depth

PHYSICAL PROPERTIES	
Texture	
% Sand	67.6
% Silt	22
% Clay	10.4
Class	Sandy Loam
CHEMICAL PROPERTIES	
P^H	5.28
%N	0.2
mg/kg P	6.08
mg/kg K	58

3. Experimental Design and Treatment

The experiment was a 3 × 3 × 2 factorial experiments 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 × 5.0 m with an alley of 1 m between plots and 2 m between replications.

4. 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 [31]. Data collected on the maize included bi-weekly plant height, chlorophyll content using the spad reading, 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. Nutrient uptake and uptake efficiency were 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.

Plant height

Ten maize plants from the central rows per treatment were randomly selected and tagged and measured from the soil level to the topmost visible node at two weeks' interval. The arithmetic mean was computed for the determination of growth rate.

Growth rate

The growth rate (GR) between times T1 and T2 was determined using the relation:

$$\text{Growth rate (GR)} = \frac{\text{Height of maize at time T2} - \text{Height at time T1}}{\text{Height at time T1}} \qquad eqn. 1$$

Growth rate was estimated in centimeters per week.

Chlorophyll content

The chlorophyll content of two leaves each below the ear, at the ear and above the ear was measured respectively at tasselling by using a chlorophyll meter (Model: Minolta SPAD, Japan). Ten randomly selected plants per plot were used.

Leaf Area Index was calculated as in equation 1

$$Leaf\ area\ index\ (LAI) = \frac{Total\ leaf\ area\ of\ plant}{Land\ area}\ x\ 0.72 \qquad Eqn. 2.$$

Where 0.72 is a constant in Watson formula

Nutrient (N) uptake was calculated as in equation 3 (Xu and his colleagues. 2020)

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

The Nutrient uptake efficiency (NUptE) was determined as in equation 4 (Xu and his colleagues. 2020)

$$\text{NUptE (kg/kg)} = \frac{\text{Nutrient accumulation in plant}}{\text{Nutrient applied}} \qquad Eqn. 4$$

Grain Yield Increase

The yield increase was calculated using the relation,

$$\text{Yield increase } = \frac{Yield\ from\ treated\ plot\ (kg\ ha^{-1})}{Yield\ from\ control\ plot\ (\text{kg } ha^{-1})}\ X\ 100 \qquad eqn. 5$$

Maize grain yield (economic yield)

From the cob, grain was shelled, then dried in the sun. The grain weight of the plants in the sample was calculated as kilograms per hectare.

Total stover biomass yield (Biological yield)

The sampled plants' above-ground Stover output was dried in the oven at 70 °C to a consistent weight. The total dry matter yield per hectare was calculated by averaging the corresponding grain weights.

Data Analysis

Data was subjected to analysis of variance technique using GENSTAT version 12. The analysis of variance (ANOVA) procedure for 3 factors in RCBD 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.

5.Results and Discussion of Finding

Results

Plant Height

At 6 and 8 WAP, plant height was significantly affected (P < 0.001) by NPK rate. All other interactions did not statistically (P >0.05) affect plant height.

250 kg/ha NPK recorded the maximum plant height at both timings, while the control supported lower values. (Figure 1). Plant height at 8 WAP was higher (156.6, 172.18) than at 6 WAP (137.08, 172.13) but values for the fertilizer application for two intervals were similar.

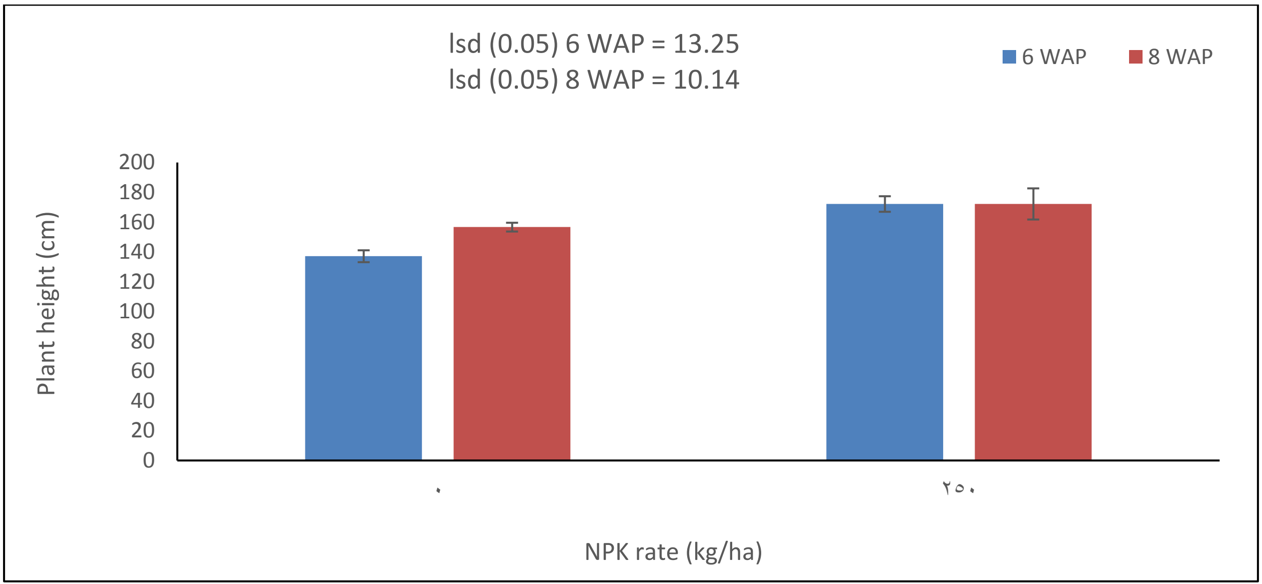

Figure1: Effect of NPK rate on plant height at 6 and 8 weeks after planting of maize. Bars represent SEM

Growth Rate

The results at 2 – 4 and 6 – 8 WAP, growth rate showed no significant effect (P > 0.05) by the treatment application (Appendix 21 and 23). At 4 – 6 WAP growth rate was significantly affected (P < 0.01) by the NPK fertilizer application with 250 kg/ha NPK supporting the maximum growth rate of 0.173 while the control had minimum growth rate 0.081 (Figure 2).

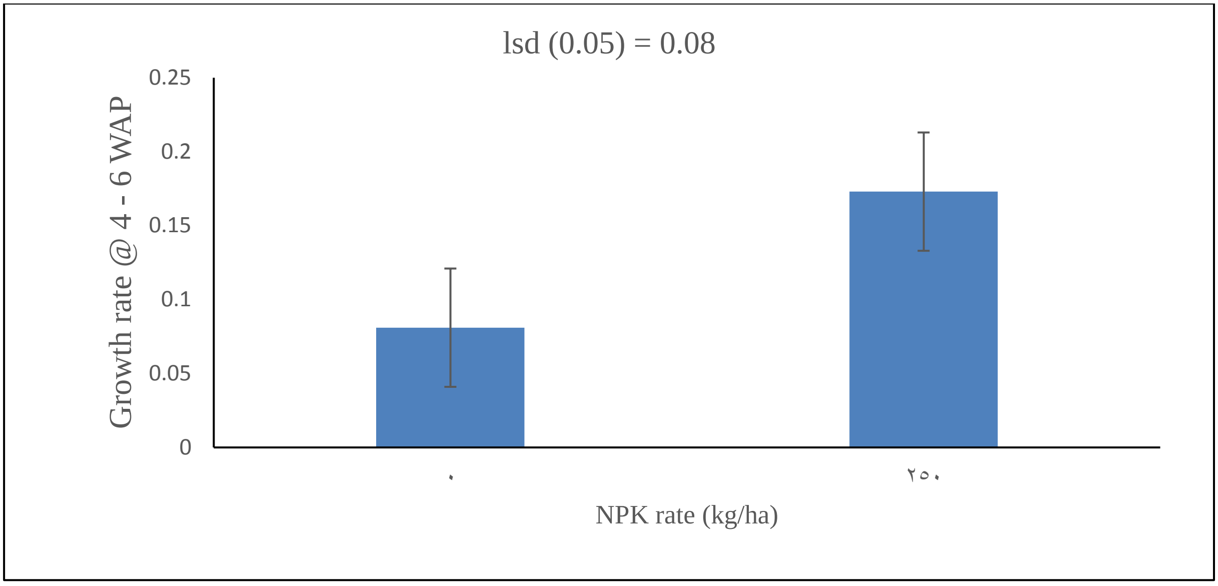

Figure2: Effect of NPK rate on growth rate at 6 WAP of maize. Bars represent SEM

Leaf Area Index (LAI)

At 2 and 8 WAP no significant effect was observed (P > 0.05) by the treatments applied (appendix 24 and 27). At 4 and 6 WAP, LAI was significantly (P < 0.01) affected by the interaction of NPK fertilizer and neem oil application. 250 kg/ha NPK with 10 l/ha neem oil recorded the highest LAI of 5.826 at 6 WAP while 10 l/ha recorded the least leaf area index of 3.971 (Table 3). At 4 WAP, 250 kg/ha NPK+10 l/ha neem oil produced the highest leaf area index 5.617 at 4 WAP while 10 l/ha recorded the least leaf area index of 3.705.

Table 3: Interaction effects of NPK fertilizer by neem oil (NL) on leaf area index at 4 and 6 WAP of maize

LAI at 4 WAP				LAI at 6 WAP			
NPK fertilizer **(kg/ha)**	Neem oil **(l/ha)**			NPK fertilizer **(kg/ha)**	Neem oil **(l/ha)**		
	0	10	20		0	10	20
0	4.42cd	3.97d	4.92bc	0	4.47cd	3.97d	4.92bc
250	5.69a	5.83a	5.24ab	250	5.69a	5.83a	5.24ab
Grand mean	5.02			Grand mean	5.02		
Lsd(0.05)	0.69			Lsd(0.05)	0.61		
Pr value	0.012			Pr value	0.008		

Shoot Biomass

Shoot dry weight was significantly affected (P < 0.05) by the interaction between neem cake and neem oil. All other main effects and interactions did not significantly (P > 0.05) affect shoot dry weight. Application of 400 kg/ha neem cake with 10 l/ha neem oil yielded maximum dry weight of 16711 kg/ha while the least shoot dry weight of 10498 kg/ha was obtained from the control (Table 4).

Table 4: Interaction of neem cake (NC) by neem oil (NL) on shoot biomass of maize

Shoot biomass			
Neem cake **(kg/ha)**	Neem oil **(l/ha)**		
	0	10	20
0	10498c	12267bc	15644ab
200	14578abc	15289ab	12800abc
400	16533ab	16711a	14400abc
Grand mean	14301		
Lsd (0.05)	3763.2		
Pr value	0.042		

Potassium Uptake in grain

K uptake in grain was significantly ($P < 0.05$) affected by the interaction of NPK and neem. All other main effects and interactions did not significantly ($P > 0.05$) affect K uptake in grain.

250 kg/ha NPK with 400 kg/ha neem cake recorded the highest P uptake of 133 kg/ha while the control supported the minimum P uptake of 44.5 kg/ha. Percentage increase for K uptake was 34% (from 99 kg/ha to 133 kg/ha) for NPK at 250 kg/ha combined with neem cake at 400 kg/ha) compared to the recommended NPK rate (Table 5).

Table 5: Effect of neem cake (NC) by NPK fertilizer application on K -uptake in grain of maize

K Uptake in grain			
NPK **(kg/ha)**	Neem cake **(kg/ha)**		
	0	200	400
0	44.8c	51.5c	68.7c
250	99b	117.6ab	133a
Grand mean	85.8		
Lsd (0.05)	25.46		
Pr value	0.043		

Economic yield

The results showed combining 250 kg NPK/ha with 400 kg/ha neem cake increased economic yield astronomically by 61% (from 4736 kg/ha to 7637 kg/ha) compared to the recommended NPK rate (Table 6). Even though there was no significant difference amongst the treatments.

Application of 250 kg/ha NPK with 400 kg/ha NC gave the highest economic yield of 7637 kg/ha, while the control had the least biological yield of 12,163 kg/ha (Table 6).

Table 6: Effect of NPK fertilizer by Neem cake (NC) by Neem oil (NL) on economic yield of maize

Economic yield				
NPK fertilizer **(kg/ha)**	Neem cake **(kg/ha)**	Neem oil **(l/ha)**		
		0	10	20
0	0	2012ef	1596f	4441bcdef
	200	2756ef	3630def	2428ef
	400	4192cdef	4046cdef	3655def
250	0	4736abcde	5945abcd	6276abcd
	200	6180abcd	6940abc	5724abcd
	400	7637a	7182ab	6066abcd
Grand mean		4747		
Lsd (0.05)		2538.6		

Biological Yield

Biological yield was significantly ($P < 0.05$) effected by the interaction of neem cake rate with NPK fertilizer rate application. All other interactions and main effects did not statistically ($P > 0.05$) affect biological yield.

Application of 250 kg/ha NPK with 400 kg/ha NC gave the highest biological yield of 26,873 kg/ha, while the control had the least biological yield of 12,163 kg/ha (Table 7).

Table 7: Interaction effect of neem cake by neem oil application on biological yield of maize.

Biological yield			
NPK **(kg/ha)**	Neem cake **(kg/ha)**		
	0	200	400
0	12165c	13368c	15816c
250	21771b	24296ab	26873a
Grand mean	19048		
Lsd (0.05)	5398.5		
Pr value	0.032		

6.Discussion

At 4 and 6 WAP the interaction between 250 kg/ha NPK and 10 l/ha neem oil showed a significant increase on LAI (Table 3). Higher LAI was observed with 250 kg/ha NPK with 10 L/ha neem oil. This was probably due to the longer availability of N as influenced by neem nitrification inhibition, in the soil for absorption by the maize plant. This confirmed the findings of [32] and [33] which reported application of neem considerably affected okra development and yield. The use of neem product has also been shown to considerably boost wheat dry matter yield [34]. Combined use of organic manure with the recommended dose of NPK positively correlate with yield in comparison with control [35]. 400 kg/ha Neem cake with 10 l/ha neem oil gave the highest dry matter weight (Table 4) affirmed the role of neem as nitrification inhibitor, which detains nutrients necessary for all plant growth in the soil for absorption and helps to increase the dry matter yield of plants [36]. Neem cake, according to [35] and [29], not only adds organic matter to the soil but also prevents nitrogen from escaping from the soil, acting as a biofertilizer for the plant's efficient growth and development. K uptake at Nyankpala was significantly influence by neem cake with NPK application (Table 5). The results showed combining 250 kg NPK/ha with 400 kg/ha neem cake increased K uptake by 34% (from 99 kg/ha to 133 kg/ha) compared to the recommended NPK rate. Our studies revealed that application of neem cake at 400 kg/ha neem cake with 250 kg/ha NPK fertilizer enhanced K uptake in grain. This could be due to neem effect of enhancing the physicochemical qualities of the soil and theteby retaining the essential nutrient and enhancing K uptake. According to [37], neem cake not only provides organic amendment to the soil but also minimizes nutrient loss in the soil, giving the necessary nutrient and also acting as a biofertilizer for the plant's efficient growth and development and improving K uptake. Similar findings were by [35] who reported maize uptake of K was increased by applying 75% of the prescribed fertiliser dose and 2.7 t/ha vermicompost. Studies by [38] stated organic manures such as FYM and Vermicompost not only help to sustain soil productivity by enhancing the physicochemical qualities of the soil, but also aid to improve the efficacy of chemical fertilisers that are applied. [39] found treatments that received vermicompost or FYM in combination with chemical fertilisers had higher nutrient uptake levels than the control. [40] found that combining inorganic and organic fertilizers resulted in increased nutrient uptake in maize. It was equally observed that beyond the 10 liters/ha threshold K Uptake in grain dropped. This finding conforms to [40] who showed dose-dependent nitrification inhibition action of neem oil.The highest economic yield of 7637 kg/ha was recorded at 250 kg/ha NPK with 400 kg/ha neem cake (7471 kg/ha) (Table 6). This observation could be attributed to improved nutrient availability and uptake, which might have resulted in a balanced C/N ratio of plant and boosted plant metabolism. Incorporating neem seed cake into the soil has the potential to slow down nitrification, increase soil nutrient content and eventually increase crop yield, resulting in higher economic yield. According to [1], the application of neem cake (0.57 t/ha), urea (130.5 kg/ha), zinc (5 kg/ha), and boron (0.5 kg/ha) was shown to be more productive and may be used by farmers to gain the most yield and financial returns from their maize crop. The maximum yield of green gram was achieved by [41] using an NPK rate of 20:40:00 kg/ha together with 1 t/ha neem cake. He attributed the higher yield to the positive effects of the treatment's higher growth parameters, the large amount of stored photosynthetic energy that was transferred into different yield attributes, the ongoing mineralization process, and the availability of nutrients in accordance with the plant growth's later stages.

Application of 400 kg/ha neem cake with 10 l/ha neem oil significantly increased biological yield as compared with control (Table 12). The addition of neem cake to soil could have reduced nitrogen loss, which resulted in increased absorption, cell growth, elongation, and cell division, resulting in increased biological yield. [1] showed in maize that application of Neem cake with 130.5 kg/ha Urea recorded maximum plant height, plant dry weight, crop growth rate, number of cobs per plant, length of cob, diameter of cob, number of grains per cob, grain yield and straw yield as compared to other treatments. [43] reported increased biomass, cob length, number of grains per cob and Grain yield in treatment of N: P: K, with 100% Neem cake as compared to control. [44] reported highest plant dry weight with 5 t/ha neem cake and inorganic fertilizer in spinach production. [45] revealed organic manures like FYM and Vermicompost not only help to maintain soil productivity by improving the soil physicochemical properties, but also served to improve the efficacy of chemical fertilizers and raise yield.

7.Conclusion

The study showed that the soils amended with 400kg/ha Neem cake + 250kg/ha NPK increased the maize K uptake, maize grain yield and biological yield. It was also observed on neem oil that 10liters/ha with 250 kg/ha NPK application outperformed the 20 liter/ha combinations. The neem oil was observed to be dose-dependent effective. Appropriate combinations of both organic amendments and inorganic fertilizer improved maize K uptake and maize grain yield compared to sole application of either of them. Coupled with the results obtained, it can be inferred a threshold of 10 liters/ha is good whereas the 20liters/ha showed a drop in yield and yield parameters.

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8.Disclosure of conflict of interest

The authors state no conflict of interest

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