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Yield and Nitrogen Use Efficiency of Maize (*Zea mays* L.) Following the Application of Various Nitrogen Sources under Rainfed Conditions in the Bono Region of Ghana

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ABSTRACT

Background: Poor soil fertility management in Ghana has necessitated the need to investigate the appropriate source of nitrogen which enhances nitrogen use efficiency and improves maize productivity under rainfed condition.

Methods: The experiment consisted of five treatments; control (no fertilizer), NPK 15-15-15 (90 kg N ha^{-1}), urea (90 kg N ha^{-1}), poultry manure (4.2 tons ha^{-1}) and combination of NPK 15-15-15 and poultry manure (½NPK 15-15-15 + ½ poultry manure). Randomized complete block design was the experimental design used for the experiment with three replications.

Result: The greatest grain yield (5,551 kg ha^{-1}) and biomass yield (14,296 kg ha^{-1}) for the major rainy season were recorded by the combined application of NPK 15-15-15 and Poultry manure treatment, while the highest grain yield (3,507 kg ha^{-1}) and biomass yield (7,976 kg ha^{-1}) was recorded by NPK 15-15-15 treatment during the minor rainy season.

Key words: Fertilizers, Maize productivity, Nitrogen sources, Nitrogen use efficiency, Rainfed.

INTRODUCTION

Maize (*Zea mays* L.) accounts for more than 50% of the total cereal production, making it an essential cereal crop in Africa (Partey *et al*. 2018). After wheat and rice, maize is the third most valuable crop (Ofori and Kyei-Baffour, 2006). Ragasa *et al*. (2013) reported that production of maize in Sub-Sahara Africa is mainly for food consumption making it an important crop for food security. In Ghana, maize cultivation is mainly done under rainfed conditions in almost all the agro-ecological zones by smallholder farmers (Ofori and Kyei-Baffour 2006). The average yield of maize is estimated to be 1.9 t ha^{-1} (FAO, 2015). According to Rockström *et al*. (2010), rainfed maize cultivation contribute to 75% of agriculture in areas where the crop is the main source of food and livelihood for the people.

Ofori and Kyei-Baffour (2006) stated that the difference in maize yield is as a result of environmental conditions under which it is grown, the genetic composition of the hybrid and the degree of pest infestation. However, soil nutrient depletion through poor soil fertility management accounts for poor yield of crops such as maize (Ojobor *et al*. 2021). In addition, yield of maize is affected by deficient recharge of essential nutrients including nitrogen and phosphorus (FAO, 2007). Nutrient uptake in plants are hindered by improper soil fertility management resulting in lower nitrogen use efficiency (NUE) in crops. Therefore, utilization of organic and inorganic fertilizers has been detected to have the ability to better growth and yield of maize (Kalyanasundaram and Augustine, 2021; Almaz *et al*. 2017) which brings about an improvement in the nutrient level of the soil and high amount of residues that can be incorporated into the soil to enhance its fertility (Campbell *et al*. 2001). Although the use of nitrogen is increasing worldwide, NUE for maize is about 30% in agricultural production (Cassman *et al*. 2002). According to Fageria *et al*. (2015), enhancing NUE is an essential way for not only contributing to increment in crop yield but also help to reduce crop production cost and environmental pollution. Therefore, this research aimed at determining the responsiveness of maize yield and nitrogen use efficiency to different nitrogen sources.

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MATERIALS AND METHODS

The experiment was conducted during the major and minor rainy seasons of 2019 at the Demonstration Farm of the School of Agriculture and Technology, UENR, Dormaa-Ahenkro Campus from April to December 2019. The trial was laid out in a randomized complete block design with five treatments replicated three times. The treatments were NPK 15-15-15, Urea, Poultry manure, ½ NPK 15-15-15 + ½ Poultry manure (NPKM) and Control (No fertilizer). The soil initial physical and chemical analyses were carried out following standard procedures as described by Motsara and Roy (2008) (Table 1). Samzal Sima (maize variety) was sourced from Savannah Agricultural Institute, Tamale. Sowing of seeds for the major and minor rainy seasons was carried out on 4th April and 4th September 2019 respectively at a spacing of 75cm between rows and 25cm within rows at a rate of one seed per stand. The recommended rates of applications per hectare in Ghana is 90:60:60 kg $N:P_2O_5:K_2O$ (Tetteh *et al*. 2008). The poultry manure was applied two weeks before planting. The application of the inorganic fertilizers was done using the split method. The first (60 kg N ha^{-1}) and second application (30 kg N ha^{-1}) were done two and six weeks after sowing as side placement respectively. The application rates of the treatments used were NPK 15-15-15 at (90:60:60 kg ha^{-1} N:P:K), Urea (90 kg ha^{-1}) Poultry manure (4.2 ton ha^{-1}) and combination of ½ NPK 15-15-15 and ½ poultry manure. During the cropping season, pesticide (Deviance) with the active ingredient emamectin benzoate was used to control fall army worm. The nitrogen concentration was determined using the Carbon Nitrogen Sulphur analyzer machine. Phosphorus and potassium were obtained using the wet digestion method (Mehlich, 1984). The procedure involved in developing the P colour was the use of paranitrophenol and ammonia (Bray and Kurtz, 1945) and read using spectrophotometer. The N, P and K uptakes were estimated by multiplying the biomass weight by the corresponding N, P and K total concentration.

Table 1: Physical and chemical properties of the soil.

Physical properties	Composition (%)
Sand	78.00
Silt	14.00
Clay	8.00
Texture	Sandy loam
Chemical properties	**Analytical level**
pH (1:2.5)	7.46
Nitrogen (%)	0.38
Organic carbon (%)	2.50
Organic matter (%)	4.31
Phosphorus (mgP kg^{-1})	0.12
Exchangeable cations (cmol kg^{-1})	
Calcium	5.8
Magnesium	1.8
Sodium	0.05
Potassium	0.24
Ex. acidity	0.10
Cation exchange capacity	17.35

Data were collected on the yield and yield components (ear length, ear diameter, kernel number, 1000 grain weight, grain yield), harvest index, biomass, NUE and nutrients uptake. NUE, Partial factor productivity, Agronomic efficiency nitrogen, Recovery efficiency nitrogen and Nitrogen harvest index were obtained using the formulae described by Dobermann (2007). Data collected were subjected toanalysis of variance using the GenStat Statistical package (Version 11.1). Mean separation was carried out using the least significant difference at p=0.05.

RESULTS AND DISCUSSION

Yield and yield components

All the yield and yield components, except 1000-grain weight in the major rainy season and grain yields during the minor rainy season, were not significantly affected (*P>0.05*) by

Table 2: Effect of different nitrogen sources on the yield component and biomass.

Treatment	Grain yield (kg/ha)	Biomass (kg/ha)	1000 grain weight (kg)	Ear diameter (cm)	Ear length (cm)	Kernel number	Harvest index
				Major rainy season 2019			
NPK 15-15-15	5270a±225	14140a±2024	410ab±10	17a±1.3	16.7a±2.1	500a±18.3	0.377a±0.04
Urea	5007a±667	14225a±3769	330c±10	16.4a±1.2	16.2a±0.9	516a±49.1	0.360a±0.05
Poultry manure	4692a±895	14285a±4420	440a±20	17.7a±0.2	16.3a±0.3	522.7a±40.3	0.343a±0.08
NPKM	5551a±1225	14296a±2686	430a±10	18a±0.8	16.5a±2	551.3a±30.0	0.387a±0.01
Control	5302a±392	13063a±2889	393b±11.6	16.3a±1.3	14.1a±2.3	477.3a±30.3	0.422a±0.11
CV (%)	14.7	13.3	3.1	6.3	10.2	6.7	15.1
LSD (5%)	1426.4	3516.8	23.57	2.04	3.06	64.53	0.12
				Minor rainy season 2019			
NPK 15-15-15	3507a±384	7976a±1816	265a±5.0	15.2a±0.5	16a±0.6	563a±61	0.449a±0.07
Urea	3401a±343	7792a±489	258a±12.5	15.1a±0.6	16.1a±1.1	564a±73.6	0.438a±0.06
Poultry manure	3375a±252	6783a±66.8	275a±5.6	15.4a±0.5	16.3a±0.6	558a±37.7	0.498a±0.04
NPKM	3498a±161	7755a±735	275a±14.6	15.4a0.8	16a±1.2	543a±48.7	0.453a±0.04
Control	2838b±251	6276a±1079	276a±2.7	14.7a0.4	16.6a±0.8	573a±66.8	0.457a±0.04
CV (%)	5.94	13.22	2.74	3.31	3.01	9.90	11.90
LSD (5%)	371.42	1821.2	13.95	0.93	0.92	104.44	0.13

Means (±SD) in the same column followed by the similar letter (s) are not significantly different at *p = 0.05.*

fertilizer application for both seasons (Table 2). The greater grain yield (5551 kg ha^{-1}) and biomass yield (14296 kg ha^{-1}) were produced by the NPKM treatment during the major season. This confirms the observation that the integrated use of organic and inorganic fertilizers improves soil fertility and also enhance maize yield as likened to the sole application of organic or inorganic fertilizer (Mahmood *et al.* 2017).

The yield of all treatments were significantly higher than the yield of the control during the minor season (Table 2). However, there was a reduction of yields in the minor rainy season as compared to the major season. This reduction might be due to variations in climatic conditions such as rainfall. In line with this, reduction of 40% to 60% yields of maize in the dry season compared to yields in the rainy season due to low rainfall was reported by Sogbedji *et al*. (2006). However, the greatest grain yield (3507 kg ha^{-1}) was recorded by the NPK 15-15-15 treatment whilst the lowest grain (2838 kg ha^{-1}) yield was recorded by the control. This could be attributed to the presence of the inorganic nutrients which is readily available and accessible to plants for growth and development. In a similar study by Arije *et al*. (2018), the highest yield of maize was recorded by the NPK 15-15-15 treatment and the lowest maize yield was recorded by the control.

Nitrogen use efficiency

Better yield of crops and a reduction in plant nutrient loss can be greatly achieved in crop production when there is an improvement in plant nitrogen use efficiency (Cassman *et al*. 2002). From the results, Partial Factor Productivity was higher in the NPKM treatment (61.68 kg ha^{-1}) and NPK 15-15-15 treatment (38.96 kg ha^{-1}) for major and minor rainy seasons respectively (Table 3). This resulted from the high performance of the two treatments with regards to grain yields. Except for NPKM which recorded a positive agronomic efficiency nitrogen (AE_N) (2.8 kg ha^{-1}**)**, all the other treatments recorded negative mean values for AE_N during the major rainy season. This was as a result of the higher performance of the control plot than the fertilized plots with respect to grain yield. The plot treated with urea recorded the highest recovery efficiency nitrogen (1.62 and 1.08 kg ha^{-1}) for the major and minor seasons respectively.

The performance of urea is a reflection of the results for plant nitrogen uptake where it had the highest nitrogen uptake for both seasons. However, it can be said that urea recovered more nitrogen than the other treatments. Barbieri *et al*. (2008) stated that one beneficial way of improving NUE of maize is the increase its recovery efficiency. Nitrogen harvest index shows the efficiency of plants to utilize the accumulated nitrogen in the grains (Fageria, 2014). For the major season, the control treatment recorded the highest nitrogen harvest index (0.179) but it did not differ significantly from the fertilized treatments. The fertilized treatments did not significantly ($P>0.05$) affect nitrogen harvest index. This could be due to the partitioning of the total nitrogen to the vegetative parts of the crop. However, significant differences were recorded during the minor season. Similar results were recorded by Belete *et al*. (2018) on nitrogen fertilizers on different varieties of bread wheat.

Nutrients uptake

The most limiting nutrient to maize yield is nitrogen (Stevens *et al*. 2005), however, inorganic sources of nitrogen are readily available for plant use but organic sources of nitrogen such as manure has to undergo a mineralization procedure which is controlled by soil microbes, moisture level and quantity of nitrogen and carbon in the manure **(**Nyiranneza *et al*. 2009). From the results, it was observed that urea treatment absorbed more plant nitrogen as compared to the

Table 3: Effects of different nitrogen sources on partial factor productivity (PFP), agronomic efficiency nitrogen (AE_N), recovery efficiency nitrogen (RE_N) and Nitrogen harvest index (NHI).

Treatment	PFP (kg ha^{-1})	AEN (kg ha^{-1})	RE_N (kg ha^{-1})	NHI
		Major rainy season 2019		
NPK 15-15-15	58.55a±2.5	-0.36a±6.8	1.01a±1.5	0.156a±0.03
Urea	55.63a±7.4	-3.28a±11.1	1.62a±1.8	0.135a±0.03
Poultry manure	52.14a±10.0	-6.77a±9.0	1.25a±1.0	0.127a±0.03
NPKM	61.68a±13.6	2.8a±18.0	0.78a±0.9	0.157a±0.00
Control	-	-	-	0.179a±0.03
CV (%)	14.72	-439.03	108.34	13.0
LSD (5%)	16.76	16.76	2.53	0.04
		Minor rainy season 2019		
NPK 15-15-15	38.96a±4.3	7.43a±1.7	1.05a±0.7	0.193ab±0.03
Urea	37.79a±3.8	6.26a±1.0	1.08a±0.5	0.188b±0.03
Poultry manure	37.50a±2.8	5.97a±3.0	0.28a±0.2	0.251ab±0.03
NPKM	38.87a±1.8	7.34a±2.5	0.97a±0.3	0.208ab±0.01
Control	-	-	-	0.247ab±0.01
CV (%)	6.60	37.41	34.94	8.61
LSD (5%)	5.05	5.05	0.59	0.04

Means (±SD) in the same column followed by the similar letter (s) are not significantly different at $p = 0.05$.

Table 4: Effects of fertilizer treatments on plant nitrogen uptake (NUPT), phosphorus uptake (PUPT) and potassium uptake (KUPT).

Treatments	NUPT (kg ha^{-1})	PUPT (kg ha^{-1})	KUPT (kg ha^{-1})
		Major rainy season 2019	
NPK 15-15-15	507.8a±106.3	275.8a±63.6	585.8a±169.4
Urea	562a±227	246.5a±5.9	909a±390
Poultry manure	529.5a±162.2	327.3a±128.8	918a±416
NPKM	487.2a±124.3	292.5a±65.8	916.4a±149.9
Control	416.6a±73.0	286.6a±17.3	729.8a±80.1
CV (%)	20.63	20.70	33.5
LSD (5%)	194.48	111.2	511.3
P- value (%)	0.54	0.60	0.50
		Minor rainy season 2019	
NPK 15-15-15	266.5a±53.4	130.9a±97.3	977a±551
Urea	269.2a±31.8	100.3a±37.4	768a±240
Poultry manure	196.9ab±9.6	127.7a±57.0	923.5a±71.9
NPKM	259.2a±12.1	87.4a±10.3	768a±383
Control	171.8b±19.2	88.2a±55.1	696a±399
CV (%)	12.14	50.60	42.60
LSD (5%)	53.18	101.83	712.1
P- value (%)	0.01	0.77	0.74

Means (±SD) in the same column followed by the similar letter (s) are not significantly different at $p = 0.05$.

other treatment during both seasons. This is a characteristic of urea being an inorganic fertilizer which is readily available for plant use. Gutser *et al*. (2005) reported that higher plant nitrogen uptake by inorganic fertilizers than organic fertilizers could be as a result of the slow release of plant nutrients by organic fertilizers due to their higher C/N ratio because C/N ratio plays an important role in mineralization and nutrientrelease during decomposition.

Our results differ with the findings of Songo (2017) who observed higher nitrogen uptake by the combination of manure and mineral fertilizer. Similar results were recorded by Chikowo *et al*. (2004). Statistically, observing the results for both seasons, nitrogen uptakes were higher in the inorganic treatments than the organic treatment (Table 4). This could be attributed to the fast release of nitrogen to plants by inorganic amendments than organic amendments. The N and P uptake in the major season was higher for all the treatments as compared to the minor season. Moreover, poultry manure recorded the highest phosphorus (327.3 kg ha^{-1}) and potassium (918 kg ha^{-1}) uptake while urea and NPK 15-15-15 recorded the lowest phosphorus (246.5 kg ha^{-1}) and potassium (585.8 kg ha^{-1}) uptake respectively for the major season. This could be attributed to the influence of poultry manure through its decomposition, microbial activities and chemical properties of the soil (Ylivainio *et al*. 2008). The performance of the poultry manure is in line with the findings of Pinto *et al*. (2012) who stated that there is a high concentration of phosphorus and potassium in manure obtain from poultry production. Also, poultry manure enhances the chemical and physical properties of the soil, hence increasing the concentration and uptake of plant nutrients. However, this is dependent on the quantity of manure applied (Hou *et al*. 2012).

CONCLUSION

Significant (*P>0.05*) differences were not recorded among the treatment means except for 1000 grain weight for the major rainy season and grain yield, nitrogen uptake and nitrogen harvest index for the minor rainy season. Combined application of NPK 15-15-15 and poultry manure produced higher results with respect to grain yield, yield component, partial factor productivity and agronomic efficiency nitrogen, than the other treatments. Application of urea resulted in higher nitrogen uptake and poultry manure recorded the highest phosphorus and potassium uptake by the plant. Further research should be conducted at the experimental site for long term. This will enable the researcher to know the actual effects of the fertilizer treatments on the crop.

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