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Optimal Combination of Organic and Inorganic Fertilizers for Maize Yield in the Forest Savannah Transition Zone of Ghana

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Abstract: Experiments were conducted on Chromic Luvisol (Wenchi) and Ferric Lixisol (Mampong) to evaluate the effect of site-specific inorganic fertilizer rates and its integration with poultry manure on nutrient uptake, biomass and maize yield in the transition zone of Ghana. The experiment consisted of sixteen (16) fertilizer combinations ($N_0P_0K_0$, N_{30}, N_{60}, N_{90}, N_{120}, $N_0P_{10}K_{20}$, $N_{30}P_{10}K_{20}$, $N_{90}P_{10}K_{120}$, $N_{120}P_{10}K_{20}$, $N_{60}P_{10}$, $N_{60}P_0P_0P_0P_{600}$, $N_{60}P_0P_0P_0P_{60}P$ $P_{10}K_{60}$ and $N_{60}P_{10}K_{20}$ PM (2.5 t/ha) two maize genotypes: Obatampa (Open pollinated cultivar) and Mamaba (hybrid maize). Treatments were carried out in a randomized complete block design with three replications. Nutrient intake data were collected at 34 and 54 days after sowing (DAS), in maize at 34 DAS, uptake of N, P and K was significantly increased by N, P and K in fertilization, indicating an increased availability of these nutrients in the soil. All treatments were significantly higher than the control in terms of nutrient intake at 54 DAS. The main season yield of Mamaba maize variety was highest (4950 kg/ha) with $N_{60}P_{10}K_{20}$ PM (2.5 t/ha) compared to other treatments. However, Obatanpa maize cultivar $N_{60}P_{10}K_{20}$ with PM (2.5 t/ha) produced the highest yield compared to other treatments. Maize yields in both Mamaba and Obatanpa were significantly reduced during the short growing season due to low rainfall and planting time. In comparison, the hybrid maize (Mamaba) gave the highest yield in fertilizer than the open pollinator genotype (Obatampa). This indicates that more NPK fertilizer than open pollination is not required to show the potential yield of hybrid corn. Also, the combined application of site-specific fertilizer and organic fertilizer improved the yield of hybrid corn compared to inorganic fertilizer alone.

Keywords: Maize, Genotypes, Fertilizers, Nutrient Uptake, Grain Yield

1. Introduction

Maize is a staple food for many people living in the tropics, but it was an important ingredient in animal feed. Ghana's maize production is largely at a subsistence level; most farmers use little or no soil amendments, despite the poor fertility of some soils. Depletion rates of important soil nutrients in Ghana range from 40 to 60 kg N, P and K ha^{-1} yr-1 [7]. However, approximately 7.2 kg ha^{-1} of fertilizers is used [12]. The amount of fertilizer recommended for growing crops depends on the agro-ecology of the field, soil type and crop history. Similarly, the recommended fertilizer rate for hybrid maize in the forest zone of Ghana on continuously cultivated land is 134 – 56 - 56 kg/ha of N, P_2O_5 and K_2O [1]. The prevailing general recommendation of NPK 90:60:60 kg ha^{-1} (maize) for soils in the semi-deciduous forest zone [8] is huge and beyond the reach of most smallholder farmers. Also, crop varieties and their species were not considered in terms of nutrient requirements.

Several studies have shown that different cultivars of the same crop have different nutrient requirements for their potential yield. Recent developments in agriculture and plant breeding have indicated that high-yielding cultivars may require more nutrients for optimal growth and yield [15]. Although fertilizer recommendations are generally designed to maximize net income per hectare, smallholders around the world often cannot purchase enough fertilizer to apply this amount to their entire farmland [14]. Therefore, they must maximize the net profit from the given purchase value of the fertilizer. Net profit from fertilizer purchases can potentially be maximized by identifying the right combinations of yield, nutrients and application rate [13]. Therefore, strategies must be developed to restore soil fertility, reduce erosion and environmental degradation to increase food production and alleviate chronic hunger [4]. An overall strategy to increase and maintain high yields must include an integrated approach to soil nutrient management and other complementary initiatives. Information on yield potential, applicable yield differences, and limitations to productivity improvement at the field level is still limited. The current and urgent need to achieve maize food security in Ghana has led to research on the ecology of this forest-savanna, particularly in the transition zone of Ghana, commonly referred to as the Ghana Maize Belt. If maize cultivation is to achieve food security, sustainable intensification on the farms of small farmers must be attempted. In addition, there is a need for site-specific fertilization that takes into account soil type and different varieties of a particular crop. A fertilizer site-specific recommendation is a promising alternative to solve the problems of the current general recommendation [16]. This in turn increases the willingness to use inorganic fertilizers and locally available organic materials for productive and sustainable production systems. Therefore, the objective of this study was to evaluate the response of pollinated and hybrid cultivars to different mineral fertilizer formulations and to evaluate yield in the forest-savanna transition zone of Ghana.

2. Materials and Methods

2.1. Study Areas

The study was conducted in the Forest Savanna Transition Zone (Figure 1) at the Wench and Mampong Research Stations of the Ministry of Food and Agriculture. The forest-savanna transition zone was strategically chosen for this study because it is an important maize growing region in Ghana. Wenchi Municipal is bounded by latitude 7°30′ and 8°5′N and longitude 2°15′W and 1°55′W, while Mampong is bounded by latitude 9°28′ and 7°4′N and longitude 3°17′ W and 2°45′ Ok. In 2012, Wench Station was used as an experimental field for growing yams, while Mampong was previously cassava. The zone has a bimodal rainfall pattern, averaging about 1350 mm per year. The average monthly temperature is 25-30 °C throughout the year and there are two heavy rainy seasons; April - June and September -November.

2.2. Experimental Design and Treatments

The evaluated nutrients were N (0, 30, 60, 90 and 120 kg N ha^{-1}), P (0, 10, 20 and 30 kg P ha^{-1}) and K (0, 20, 40 and 60 kg K) ha^{-1}) Liebig's minimum law (Liebig, 1840) was taken into account when choosing the treatment. Treatment management was an imperfect factor in limiting the number of treatment procedures. The experimental design was a randomized complete block design with three replications per site season. Treatment combinations are listed in Table 1. Treatment T1-T5 measures N responses without P and K, T6-T9 measures N responses with minimal background P (10 kg Pha^{-1}) and K (120 kg Kha^{-1}), T10 - T12 measure P response with N alone and T13-T16 measure K response with constant N (60 kg Nha^{-1}) and P (10 kg Ph^{a-1}). The size of each plot was 6 x 4.5 m and the corn sowing spacing was 75 cm x 25 cm.

Table 1. *Treatment label and their rates of application.*

Experimental activity	Treatment label	Rate of application (kg ha^{-1})
1. On-station omission trials (Major and minor season, 2013)	T_1	$N_0P_0K_0$ (Control)
	T_2	N_{30}
	T_3	N_{60}
	T_4	N_{90}
	T_5	N_{120}
	T_6	$N_0P_{10}K_{20}$
	T_7	N_{30} P_{10} K_{20}
	T_8	N_{90} P_{10} K_{20}
	T_9	N_{120} P_{10} K_{20}
	T_{10}	N_{60} P_{10}
	T_{11}	N_{60} P_{20}
	T_{12}	N_{60} P_{30}
	T_{13}	N_{60} P_{10} K_{20}
	T_{14}	N_{60} P_{10} K_{40}
	T_{15}	N_{60} P_{10} K_{60}
	T_{16}	N_{60} P_{10} K_{20} +PM (2.5t/ha)

2.3. Fertilizer Application and Agronomic Data

50 percent of nitrogen (30, 60, 90, 120 kg N ha^{-1}) and full phosphorus (10, 20, 30 kg P ha^{-1}) and potassium (20, 40, 60 kg K ha^{-1}) were applied twice each a week after planting. The remaining urea was applied five weeks after planting by band placement. Plant height and stem circumference were measured with a measuring tape and milk, respectively. Eight maize plants from the first row after the row were randomly selected to measure plant height and girth weekly from 2 WAP to 8 WAP. Cereal yield was determined based on a net plot in all experimental locations. 2.4. Analysis of plant tissue at the end of each harvest period, analyzes of plant tissues (stem and leaves) were performed to determine total N, P, K, Ca and Mg concentrations as described by a study [17].

3. Results and Discussion

3.1. Physical and Chemical Characteristics of Research Sites

Table 2 shows the results of the initial physical and chemical characteristics of the study sites. The low concentrations of soil organic carbon and total nitrogen at both study sites were due to high temperatures that caused rapid organic carbon decomposition with a generally low input of organic material. [15] rated soils with > 20% organic carbon as very high, 10 – 20% as high, 4 –10% as medium, 2 – 4% as low, and < 2 >1.0 as very high, 0.5 – 1.0% the same tall, 0.2 - 0.5% medium, 0.1- 0.2% low and < 0 > 40 very high, 25 - 40 high, 15 - 25 medium, 5-15 low. The low ECEC value recorded may be due to the low pH values of 5.47 and 6.19 for Chromic Luvisol and Ferric Lixisol.

3.2. Poultry Manure Content

Table 3 presents the elemental composition of the poultry manure used in the experiment. The material contained C/N ratio of 12.7%, with a mean N, P and K values of 2.07, 2.04 and 2.31% which is an indication that the material will be good as fertilizer. The decomposition of materials with nitrogen content greater than 2% (or C/N ratio < 25) releases mineral nitrogen [16]. The poultry manure used in this experiment can potentially release nitrogen to increase the low nitrogen content of the soil to improve the growth and corn yield.

Figure 1 shows the monthly rainfall in the off - season and main growing season at the study site in 2013. The amount, intensity and distribution of rainfall in the process of crop production have an important impact on crop growth and yield. Precipitation in mm was measured during the test (Figure 1). The amount of precipitation recorded during the test varied in different months of the year. During the main growing season of 2013, the rainfall in Wenchi and Mapong reached its peak in May (180.1 mm) and June (254.66 mm), respectively. However, during the low season of 2013, rainfall peaked in Mampong (180.1mm) and Wenchi (244.8mm) in October.

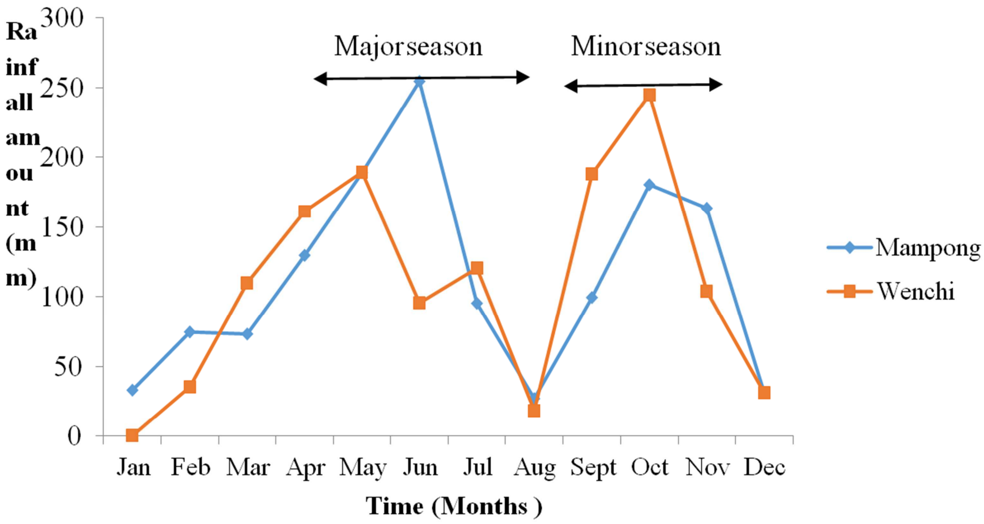

Figure 1. *Monthly rainfall during the minor and major cropping seasons of 2013 at the study locations. (Source: Wenchi and Mampong weather stations).*

Table 2. *Results of the initial soil chemical properties of the study sites.*

Soil parameters	Wenchi (Damongo-Series) Mampong (Bedieseseries)			
	0-15 cm	15-30 cm	0-15 cm	15-30 cm
pH (1:2.5 H_20) Org. C (%)	5.47	5.26	6.19	5.91
Total N (%)	0.55	0.37	0.61	0.54
Exch. Acidity (Al^{3+}+H^+) ($cmol_{(+)}kg^{-1)}$)	0.06	0.04	0.06	0.05
Exchangeable bases ($cmol_{(+)}$ kg)	0.80	0.95	0.19	0.24
Ca^{2+}	2.97	2.40	2.67	2.40
Mg^{2+}	1.34	0.53	2.14	1.60
K	0.22	0.14	0.10	0.12
Na^+	0.06	0.05	0.03	0.04
Available P (mg/kg soil)	7.90	6.22	4.01	1.75
E.C.E.C ($cmol_{(+)}$ kg^{-1})	5.39	4.07	5.13	6.15
Sand	74.72	70.84	75.3	66.34
Silt (%)	18.88	22.36	16.30	29.26
Clay (%)	6.40	6.80	8.40	4.40
Bulk density (g cm^{-3})	1.43	1.45	1.46	1.43
Texture	Sandy loam	Sandy loam	Sandy loam	Sandy loam
Soil type	Chromic Luvisol		Ferric Lixisol	

Table 3. *The elemental composition of the poultry manure used in the experiment.*

Nutrient	Content (%)
Organic carbon	35.14
Total N	2.07
Total P	2.04
Total K	2.31
Total calcium	4.22
Total Magnesium	0.46
C/N Ratio	12.7

3.3. Nutrient Uptake at 34 Days After Sowing

Nitrogen uptake (DAS) 34 days after sowing of Chromic Luvisol and Ferric Lixisol, affected by different treatments are shown in Figure 2 and Figure 3, respectively. The nitrogen uptake of the two maize varieties was affected by the application of nitrogen and phosphorus fertilizers. Nitrogen uptake on Chromic Luvisol ranged from 10.30 to 15.88 kg ha^{-1} for Obatanpa and 14.38 to 40.53 kg ha^{-1} for Mamaba. On the other hand, for Lixisol iron, the nitrogen uptake of Obatanpa ranged from 2.19 to 9.36 kg ha^{-1} and that of Mamaba ranged from 7.62 kg ha^{-1} to 23.53 kg ha^{-1}. Figures 4 and 5 showed the effect of 34 DAS treatment on phosphorus uptake. Phosphorus uptake values ranged from 1.56 to 5.29 kg ha^{-1} for Mamaba and 0.64 to 1.56 kg ha^{-1} for Obatanpaon Chromic Luvisol (Figure 4). However, Mamaba and Obatanpa recorded uptake values for Ferric Lixisol ranging from 0.36 to 1.80 kg ha^{-1} and 0.07 kg ha^{-1} to 1.16 kg ha^{-1} (Figure 5).

At 34 DAS, the effect of cultivar on potassium uptake by plants was highly significant ($p < 0.01$), with Mamaba uptake of Chromic Luvisol (11.70 kg ha^{-1}) higher than Obatanpa (4.94 kg ha^{-1}) (Figure 6). Potassium absorption followed different trends, with the control (Obatanpa) showing the lowest value at 0.85 kg ha^{-1} and the treatment $N_{60}P_{10}$ showing the highest value for ferexol at 4.20 kg ha^{-1} (Figure 7).

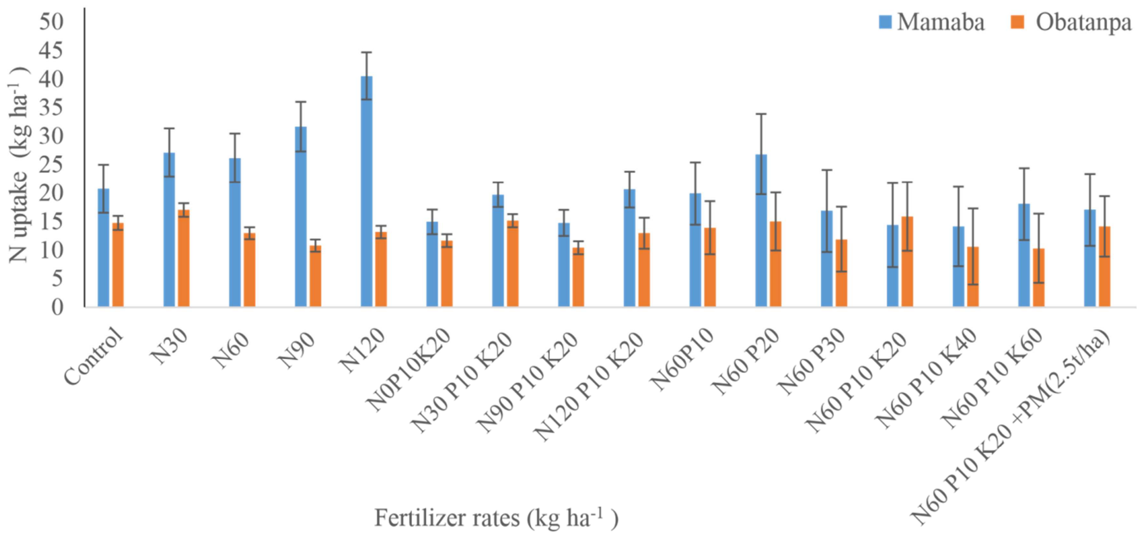

Figure 2. *Effect of treatments on stover N uptake at 34 DAS on a Chromic Luvisol (Major season, 2013).*

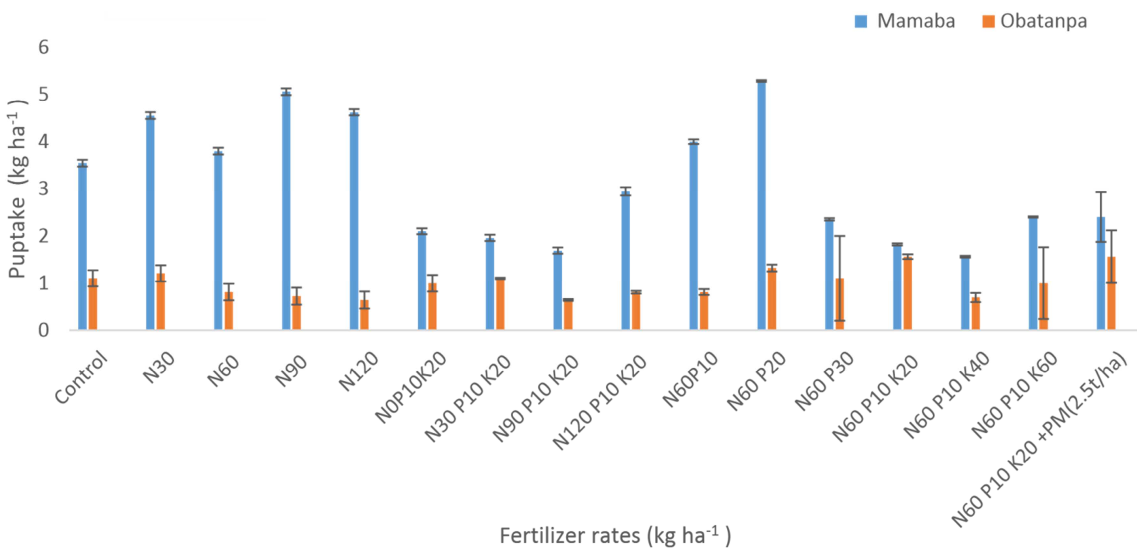

Figure 3. *Effect of treatments on stover N uptake at 34 DAS on a Chromic Luvisol (Major season, 2013).*

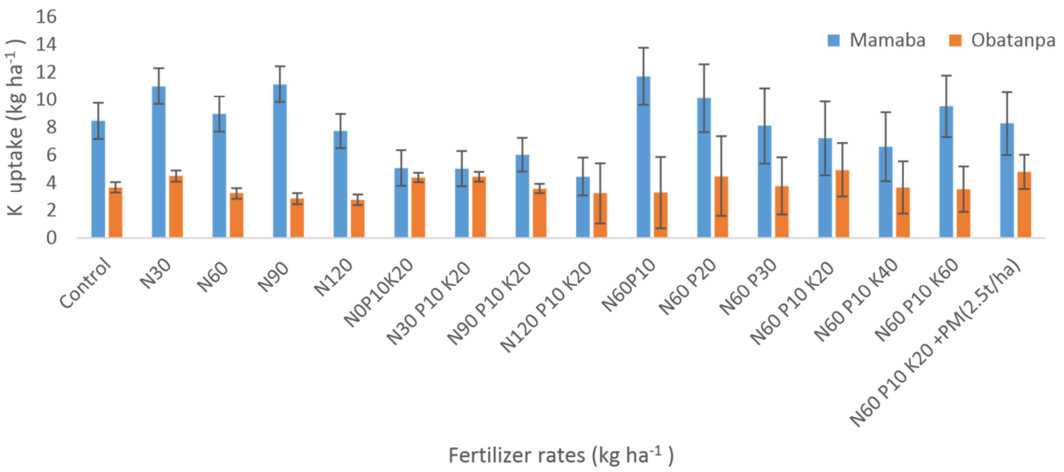

Figure 4. *Effect of treatments on stover K uptake at 34 DAS on a Chromic Luvisol (Major season, 2013).*

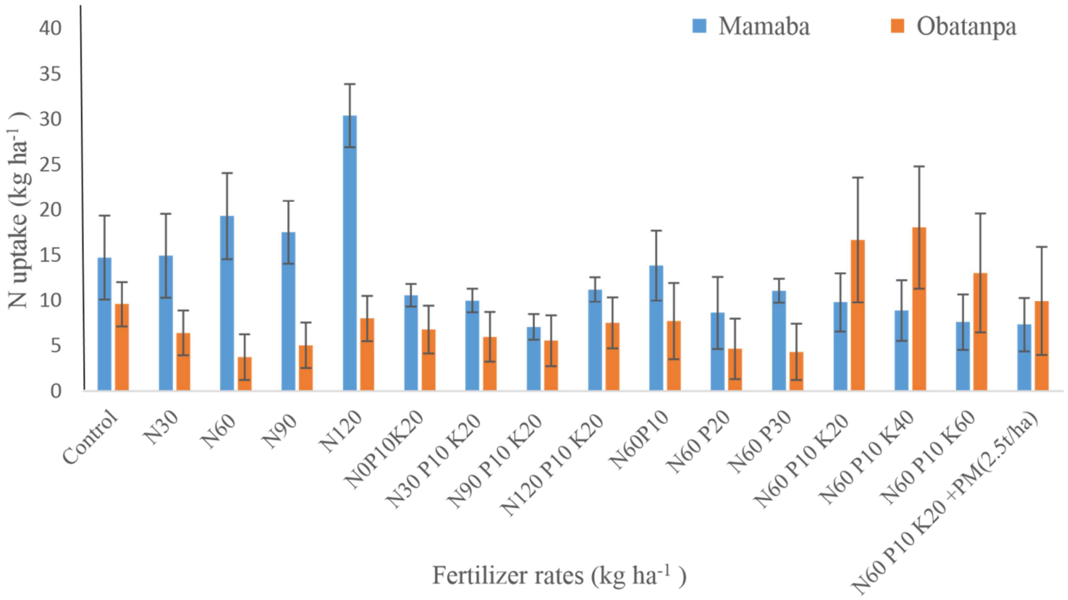

Figure 5. *Effect of treatments on stover N uptake at 34 DAS on a Ferric Lixisol (Major season, 2013).*

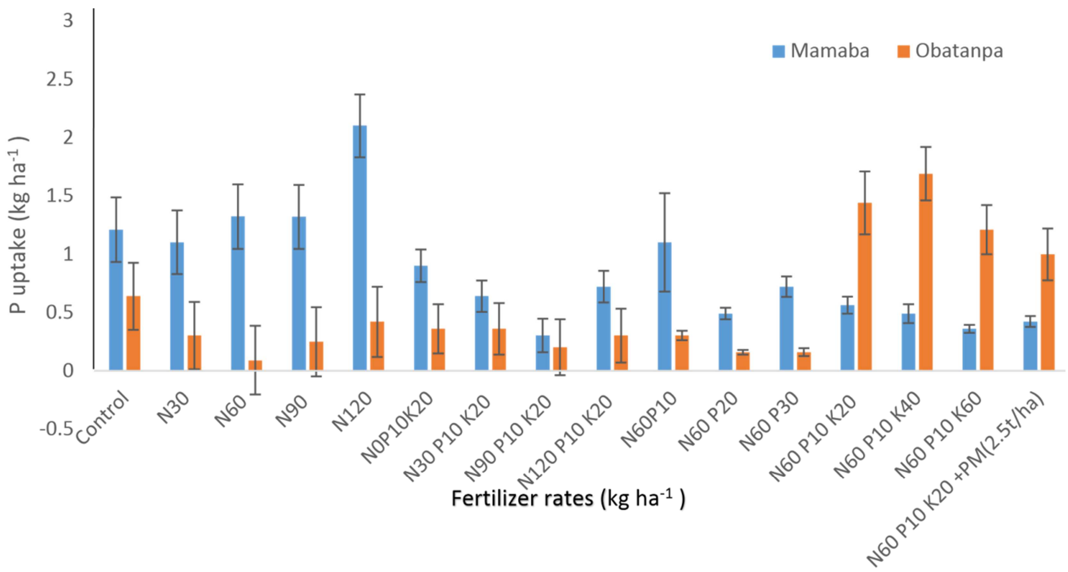

Figure 6. *Effect of treatments on stover P uptake at 34 DAS on a Ferric Lixisol (Major season, 2013).*

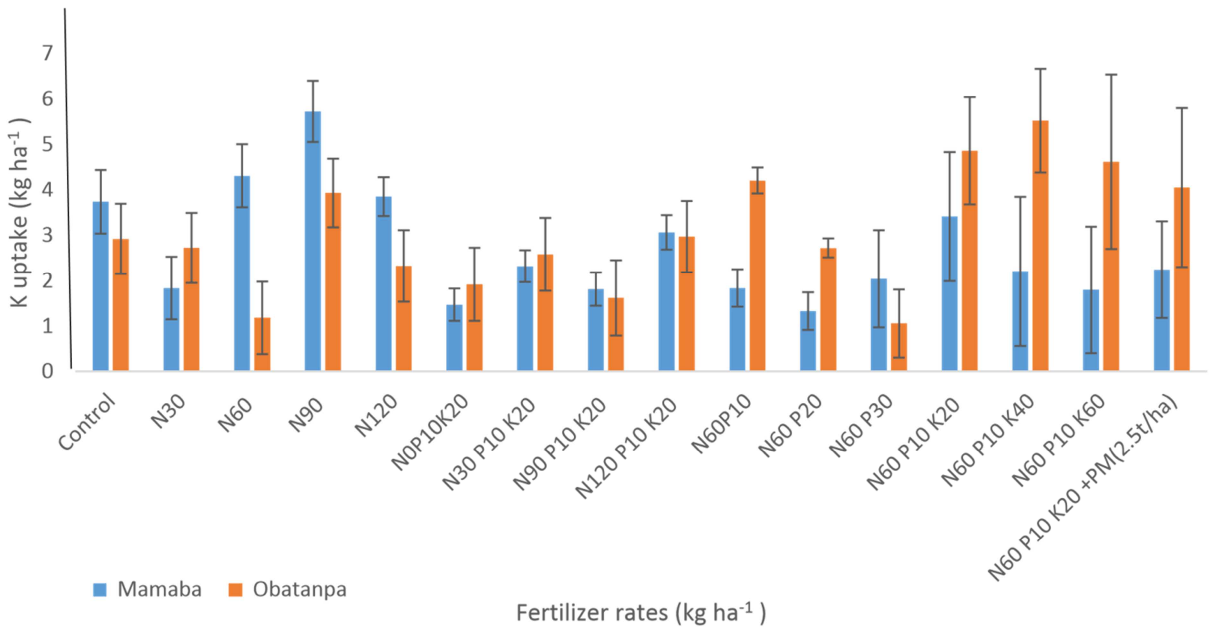

Figure 7. *Effect of treatments on stover K uptake at 34 DAS on a Ferric Lixisol (Major season, 2013).*

3.4. N, P and K Uptake at 54 Days After Sowing DAS

The effects of different treatments of Chromic-Luvisol and Eisen - Lixisol on N uptake at 54 DAS are shown in Figures 8 and 9, respectively. The nitrogen uptake of the two maize varieties was affected by the application of nitrogen and phosphorus fertilizers. Nitrogen uptake on Chromic Luvisol ranged from 26.78 to 40.70 kg ha^{-1} for Obatanpa and 24.05 to 75.95 kg ha^{-1} for Mamaba. On the other hand, for Lixisol iron, the nitrogen uptake of Obatanpa ranged from 23.04 to 97.16 kg ha^{-1} and that of Mamaba ranged from 9.55 kg ha^{-1} to 37.92 kg ha^{-1}. Figures 10 and 11 showed the effect of 54 DAS treatment on phosphorus uptake. Phosphorus uptake values ranged from 3.64 to 9.77 kg ha^{-1} for Mamaba and 5.58 to 8.61 kg ha^{-1} for Obatanpaon Chromic Luvisol (Figure 10). However, Mamaba and Obatanpa recorded uptake values for Ferric Lixisol ranging from 1.13 to 6.14 kg ha^{-1} and 2.34 kg ha^{-1} to 8.91 kg ha^{-1} (Figure 11) respectively.

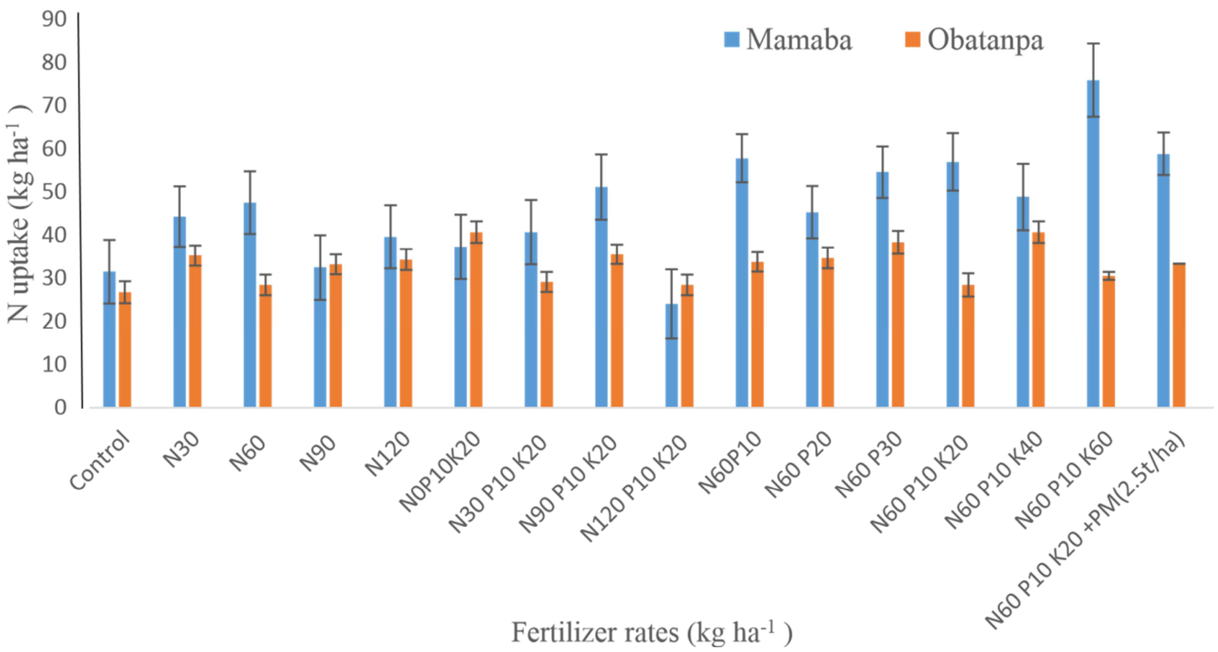

Figure 8. *Effect of treatments on stover N uptake at 54 DAS on a Chromic Luvisol (Major season, 2013).*

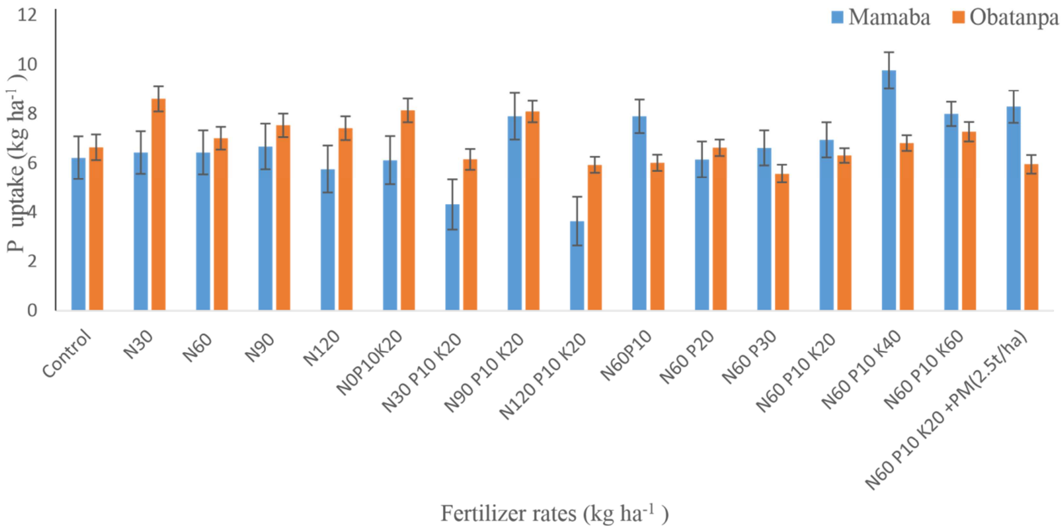

Figure 9. *Effect of treatments on stover P uptake at 54 DAS on a Chromic Luvisol (Major season, 2013).*

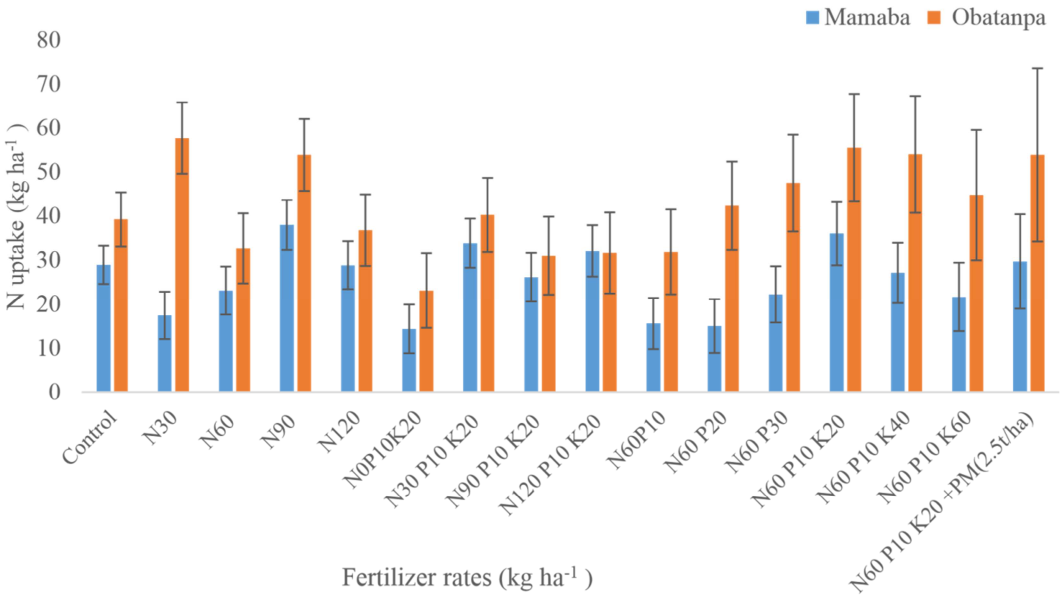

Figure 10. *Effect of treatments on stover N uptake at 54 DAS on a Ferric Lixisol (Major season, 2013).*

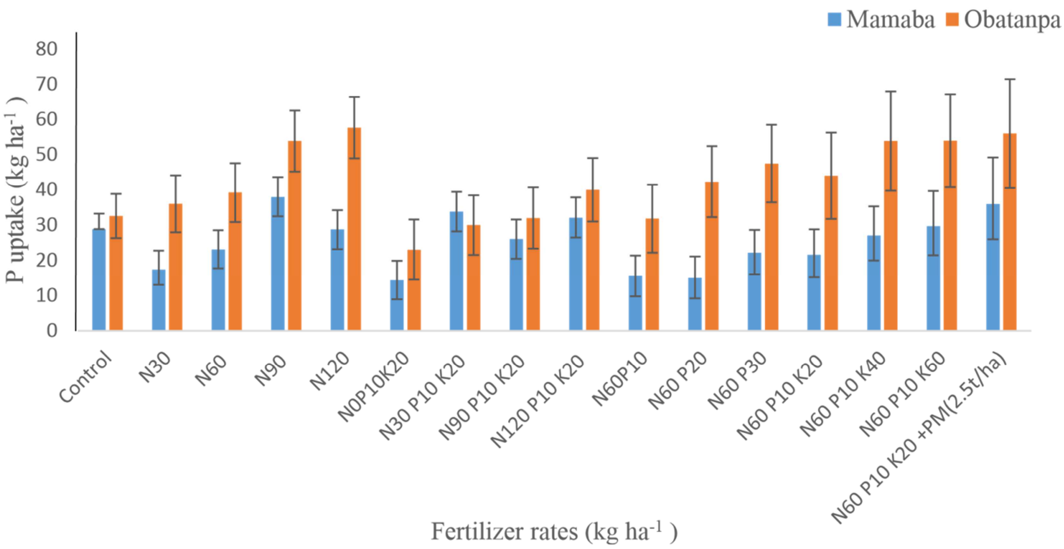

Figure 11. *Effect of treatments on stover P uptake at 54 DAS on a Ferric Lixisol (Major season, 2013).*

Crop growth and development depend on the effectiveness of crop uptake, transport and distribution of nutrients to facilitate dry matter accumulation [11]. Nutrient uptake by maize plants and their subsequent distribution to different parts is mainly influenced by factors such as soil inherent fertility, application of inorganic and organic fertilizers, plant growth stage, and prevailing environmental conditions [2] Therefore, understanding plant nutrient uptake and distribution is important for understanding a plant's diet. In this study, the distribution of nitrogen, phosphorus and potassium uptake in maize biomass was assessed in the context of changes in soil fertility. At 34 DAS, nitrogen uptake increased after addition of 30 kg N ha^{-1} on Ferric Lixisol and Chromic Luvisol, and Obatanpa had higher N, P and K uptake than Mamaba. Studies on nitrogen uptake further supported the superiority of combined application of N and P over application of sole of either of them [10]. In this study, N, P and K uptake significantly increased with N, P and K fertilization (Figures 2 - 11), showing increased availability of these nutrients in the soil. Application of NPK fertilizer showed maximum nitrogen uptake followed by application of sole use of each. The overall N uptake following the various treatments application showed that combined use of NPK fertilizer was better utilized by the two maize varieties. The Chromic Luvisol (Wenchi) had relatively lower SOC (0.4 - 0.61%), a range considered low according to [17]. The very low soil available P obtained at the sites is illustrative of P insufficiency that is endemic in many farms in SSA [5]. Continuous cropping without commensurate nutrient replenishment is reported to contribute to low P content of many soils [19, 5, 9]. The higher amount of rainfall at Wenchi during the major season led to higher biomass production. The major influencing factors for grain yield were cultivars, climate (seasonal) and the edaphic environment as affected by soil type and soil fertility amendments. During the major season of 2013, the results of this study indicated that grain yields of the two cultivars were significantly different on the Chromic Luvisol (Table 4). The treatments ($N_{60}P_{10}K_{20}$+PM and $N_{60}P_{10}K_{20}$) produce the most grain, with 4950 and 4740 kg/ha respectively. This was compared to the control, which only produced 2540 kg/ha. The Obatanpa cultivar also had good results, producing 4130 and 4360 kg/ha. However, during the minor season, the grain yield was not significantly different among the different treatments. In 2013, thegrain yield decreased during the minor cropping season.

Table 4. *Effect of treatment and cultivar on grain yield on a Chromic Luvisol, Wenchi (2013).*

Maize variety	Obatanpa	Mamaba	Mamaba	Obatanpa
Cropping season	**Major season Minor season**			
Treatment	**Grain yield (kg ha^{-1})**			
Control	2040	2540	832	826
N30	3470	3520	1396	1857
N60	3720	3890	1406	1558
N90	3910	4140	1673	950
N120	4440	4530	1474	2023
N0P10K20	3030	2920	1487	2202
N30 P10 K20	3070	3780	1663	1898
N90 P10 K20	3520	4230	1594	2936
N120 P10 K20	3820	4450	2310	2968
N60P10	2780	4040	859	1734
N60 P20	3300	4270	816	2243
N60 P30	3560	4720	1629	2775
N60 P10 K20	4130	4740	1895	1497
N60 P10 K40	3130	4220	2473	2937
N_{60} P_{10} K_{60}	2900	3180	1977	1600
$N_{60}P_{10}K_{20}$ +PM (2.5t/ha)	4360	4950	2224	3630
S.E.D (Treatment)	234		86	
Effects			F- probability	
Variety	0.220		0.056	
Treatment	0.019*		<0.001**	
Variety* Treatment	0.089		0.03*	

NS = Non-significant; *, ** = Significant at 0.05 and 0.01, respectively.

The differences in the maize grain yield as influenced by cultivars and treatments on Chromic Luvisol and Ferric Lixisol were due to variation in soil properties across the two study sites. The high grain yield recorded by $N_{60}P_{10}K_{40}$, $N_{60}P_{10}K_{20}$ PM (2.5tha^{-1}) and $N_{60}P_{30}$ during the major cropping season on both study sites could be attributed to the readily available nutrients which could be utilized by the plant for growth. There was a significant increase in the maize grain yield in response to the increased application of 30 kg ha^{-1} with no P or K applied across the seasons (Table 4). Conversely, there were no significance differences in grain yield between $N_{60}P_{30}$, $N_{60}P_{10}K_{20}$, and $N_{60}P_{10}K_{40}$. From the data in Table 3 (major season), it was apparent that there was significant difference between $N_{60}P_{10}K_{20}$ and $N_{60}P_{10}K_{20}$ PM (2.5tha^{-1}). Low yield in the minor season could be attributed to low rainfall received during the period and time of planting. The addition of poultry manure had a significant effect on maize grain yield. The application of FYM with mineral fertilizer produces a higher grain yield of maize [3]. This agrees with the findings of this study and supported the use of integrated plant nutrition as the best practice for sustaining increased crop production in West Africa as also reported by [18]. Maize grain yields were significantly affected by combined manure and fertilizer application [6]. The increase in grain yield could be due to synergistic effects of NPK and poultry manure ($N_{60}P_{10}K_{20}$ PM (2.5tha^{-1})).

4. Conclusions

All the treatments were significantly greater than the control during the 54 DAS in respect of nutrient uptake. During the major season, Mamaba maize cultivar had the highest yield (4950 kg/ha) under $N_{60}P_{10}K_{20}$ PM (2.5 t/ha) than other treatments. However, Obatanpa maize cultivar gave the highest yield under $N_{60}P_{10}K_{20}$ PM (2.5 t/ha) compared to other treatments. Combined application of SSFR and organic fertilizers improved nutrient uptake, biomass and maize yield of the two maize varieties.

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Conflicts of Interest

The authors declare no conflicts of interest.

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