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Assessment of Maize Varietal Response to Mineral Fertilizer Application in Two Maize Growing Ecologies in Ghana

Olufisayo Adeyinka Onawumi[1, *], Mensa Bonsu[2], Nana Ewusi-Mensah[2], Olorunfemi Sunday Ojo Akanbi[3], Zafiarisoa Theresa Agathe[4], Jean Christ Noel Langui[4]

[1]Soils and Tree Nutrition Department, Forestry Research Institute of Nigeria, Ibadan, Nigeria

[2]Department of Crop and Soil Sciences, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana

[3]Agronomy and Soil Division, Cocoa Research Institute of Nigeria, Ibadan, Nigeria

[4]Environmental Management Department, Pan African University of Life and Earth Sciences, Ibadan, Nigeria

Email address:

oo1470@gmail.com (Olufisayo Adeyinka Onawumi), akanbioso2008@gmail.com (Olorunfemi Sunday Ojo Akanbi)

[*]Corresponding author

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Abstract: The inadequate yield of maize among smallholder farmers in Ghana has necessitated the implementation of site-specific fertilizer recommendations and the integration of available organic and inorganic fertilizers to achieve increased and sustainable crop production. In an effort to enhance the production capacity of maize in Ghana, a field trial was conducted to assess maize cultivars in the Forest Savannah transition zone at Wenchi and Mampong research stations of the Ministry of Food and Agriculture, Ghana. The Wenchi Municipal is bounded by latitude 7° 301 & 8° 5 N and longitude 2° 15' W & 1° 55' E, while Mampong is bounded by latitude 9° 28' & 7° 4 N and longitude 3° 17' W & 2° 45' E. The nutrients evaluated 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}). The treatment arrangement was an incomplete factorial to limit the number of treatments. Maize varieties, namely Obatanpa quality protein and open-pollinated (QPM, OPV) and Mamaba (QPM Hybrid), were selected for this study. These were laid out in a randomized complete block design with three replications per site-season. The results of the on-farm trials indicated that there were varietal influences on the grain yield, with Obatanpa having a 44% to 82% increase and Mamaba having a 24% to 54% increase over control on Ferric Lixisol. Similarly, on the Chromic Luvisol, Obatanpa and Mamaba recorded grain yield increases of 62% to 75% and 49% to 93% over control, respectively. Mamaba plots with N60P30 +3 t/ha PM recorded a 118% yield increase over control, while Obatanpa had a yield increase of 89% over control. Increasing the level of PM proportionally led to an increased maize yield.

Keywords: Assessment, Fertilizer, Integration, Open – Pollinated, Varietal, Site – Specific

1. Introduction

The importance of maize to global food security and poverty reduction cannot be overestimated. In Africa, it is the most common staple food and is spreading rapidly throughout Asia. Due to the growing demand for animal feed and bioenergy, the demand for maize is increasing and is expected to double by 2050 [15]. It is also an important crop for small holding farmers in Ghana. It is grown in all agro-ecologies in the country. Aside from cassava, it is Ghana's most important staple food. Ghana is one of the major maize producers in Africa south of the Sahara, accounting for about 9% of the total acreage among surveyed countries and 7% of the total acreage in West and Central Africa [2]. In the years 2009 through 2011, maize production in Ghana averaged 1.7 million tons were harvested on around 990,000 hectares. Over time, corn production and acreage increased. Over time, production has increased somewhat faster than the area and thus also the yields (tonnes/ha). Cultivation on marginal soils was possible thanks to the use of mineral fertilizers and manure. Corn can be grown in any soil type, but best yields are generally achieved with corn planted in deep, fertile, well-drained loamy soils [6]. It is very sensitive to droughts of more than two weeks and to excessive water or flooding. However, to achieve good yields, abundant rainfall and large amounts of nutrients, especially nitrogen, phosphorus and potassium, are required. Unfortunately, maize yield (production per hectare) has declined for many African farmers over the last decade despite improvements in agricultural technology [18] Yields are low due to low soil fertility and low fertilizer use. The typical yield of maize grains in the fields of farmers in the savannah area of northern Guinea is estimated at 1.2 t/ha with a national average yield of 1.5 t/ha [13]. With good agronomic practices, improved maize varieties can produce 4 to 6 t of grain/ha. Most maize in developing countries is grown under low-nitrogen conditions due to low nitrogen levels in tropical soils, low nitrogen use efficiency in drought-prone environments, high fertilizer/grain price ratios, and limited availability of fertilizers and low purchasing power of farmers [4, 12, 17].

In Ghana, fertilizer use is much higher than previous reports (about half of farmers use fertilizer), although application rate is half the recommended (average 47 kg/ha nitrogen for applicators compared to the recommended 90 kg/ha). Half of non-appliers (mainly in forest areas) stated that they do not apply fertilizers because they do not need them because their soil is fertile [14]. Thirty-six percent of corn farmers (mostly in Northern Savannah Zone) cited lack of money or high cost of fertilizer as primary reasons for non-application. The fertilized plots produced yields that were slightly superior or equivalent to those without fertilizer: only in the northern area of the savannah did the yields of fertilized and unfertilized corn differ significantly. When combined with certified seeds and herbicides, plots with fertilizer produced significantly higher yields (2 tons/ha more) than plots without fertilizer in the northern Savannah area, but plots showed no significant differences in other areas. The seemingly more sensitive yields to fertilizer application in the northern savanna area may be attributed to the lower soil fertility in this area compared to the southern areas [9].

2. Materials and Methods

The study was conducted in the transition zone of the savanna forest (Figure 1) at the Wenchi and Mampong research stations of the Ministry of Food and Agriculture. Wenchi town is defined by the latitude 7° 301 & 8° 5 N and longitude 20 15' W & 1° 55' E, while Mampong passes through the latitude 9° 28' & 7° 4 N and Longitude 30 17' W & 2° 45' E. The savannah forest transition zone was strategically selected for this study as it is an important maize growing area in Ghana.

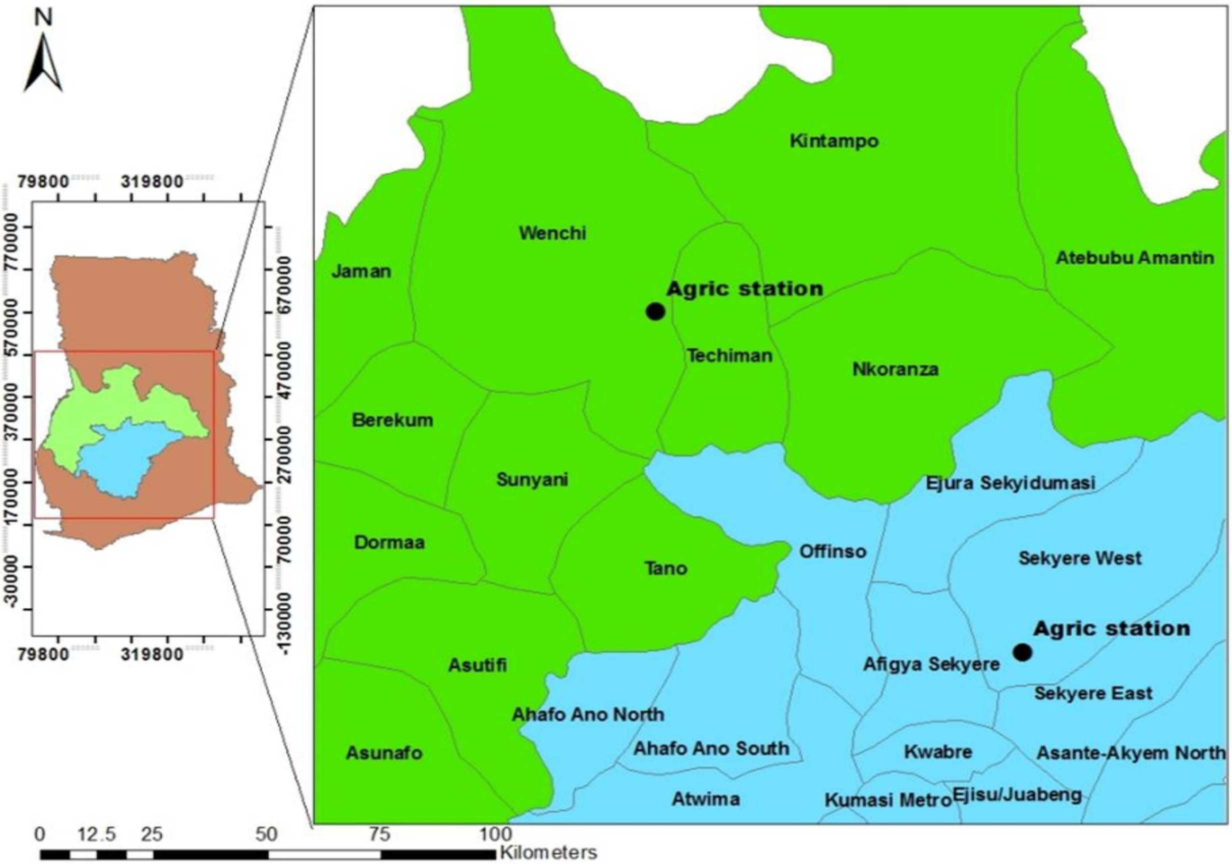

Figure 1. Location of the study area (source; - Ghana Statistical Services, 2002).

Table 1. *On station (omission trial) fertilizer treatments used (Major and Minor season, 2013).*

Experimental activity.	Treatment label	Rate of application (kg/ha)
1	T1	$N_0P_0K_0$ (Control)
2	T2	N_{30}
3	T3	N_{60}
4	T4	N_{90}
5	T5	N_{120}
6	T6	$N_0P_{10}K_{20}$
7	T7	N_{30} P_{10} K_{20}
8	T8	N_{90} P_{10} K_{20}
9	T9	N_{120} P_{10} K_{20}
10	T10	N_{60} P_{10}
11	T11	N_{60} P_{20}
12	T12	N_{60} P_{30}
13	T13	N_{60} P_{10} K_{20}
14	T14	N_{60} P_{10} K_{40}
15	T15	N_{60} P_{10} K_{60}
16	T16	N_{60} P_{10} K_{20} +PM (2.5t/ha)

Field trials (on - farm)

From the omitted sample (at the station), two treatments were selected from sixteen treatments at the station for field-testing with farmers. The list of treatments selected for agricultural trials during the off - and main cropping seasons in 2013 is shown in Table 2 below. It was based on the response curve and fertilizer dosages that ensured optimal grain yield. Six farmers were selected, three each from two locations (Wenchi and Mampong).

Table 2. *Treatments used during the on farm fertilizer trial.*

Location		Rate of application (kg/ha)
Chromic Luvisol	(On-farm- Wenchi) Minor season 2013, major season 2014	1. $N_{60}P_{30}$ 2. $N_{60}P_{10}K_{40}$ 3. N_0 P_0
Ferric Lixisol	(On-farm- Mampong) Minor (2013) and major (2014) cropping seasons	1. $N_{60}P_{10}K_{20}$ 2. $N_{60}P_{10}K_{20}$+PM (2.5t/ha) 3. N_0 P_0

Maize varieties

Obatanpa quality protein and open pollinated (QPM, OPV) and Mamaba (QPM Hybrid) were selected for this study. The two maize varieties were selected because both have been widely adopted by farmers and consumers in Ghana.

2.1. Land Preparation and Sowing

At Wenchi station, the experimental field had been used for yam cultivation in 2012 and Mampong was previously used for cassava. The land was ploughed, harrowed and ridged. Two seeds were planted per hill and later thinned to one. Thinning was done before fertilizer was applied two weeks after planting (WAP). Planting space of 75 cm x 25 cm was used.

2.2. Fertilizer Application

Fifty percent of nitrogen (30, 60, 90, 120 kg N ha^{-1}) and full rate of phosphorus (10, 20, 30 kg P ha^{-1}) and potassium (20, 40, 60 kg K ha^{-1}) were applied two weeks after planting. The remaining urea was applied five weeks after planting. The fertilizer was banded on both sides of the plant and buried.

2.3. Agronomic Parameters

During the omission trial, eight maize plants from the first row after the border row were selected at random after which plant height and girth measurements were taken using a measuring tape at weekly intervals from 2 WAP until 8 WAP.

2.4. Maize Stover and Grain Yield

Grain and Stover yields were determined on net plot area basis in all the experimental sites. In order to determine crop yield, the plants in a 2 m x 2 m delineated area in the central part of each treatment plot were harvested by cutting at the ground level. The cobs from the harvested crop stands were removed from the stalks, weighed and put in brown paper bags. The subsamples were oven dried at 80 °C for 48 hours and weighed. The cobs harvested per plot were shelled, after which the grains were weighed at a moisture content of 13%. Shelling of the maize grains was done manually and weighed. A sample of a hundred grains was randomly taken from each plot, weighed and recorded. The dry weights were then used to determine the grain yield and Stover yield on per hectare basis as:

$$\text{Grain yield (kg/ha)} = \text{TDM (grain)} \times 1111.1$$

Where: TDM = Total dry matter;

$$\text{Stover yield (kg/ha)} = \text{TDM (Stover)} \times 1111.1$$

and 1111.1 = Conversion fctor.

The agronomic measurements that were taken during the experiment included: Plant height, number of cobs per plant, weight of cobs per plot, grain weight per plot and Stover weight.

3. Results

3.1. Effect of Fertilizer Treatments and Cultivars on Some Yield Indices

(a) The response of maize cultivars' grain yield to mineral fertilizers was investigated in this study. The results indicated that there was a significant difference in grain yields between the two cultivars on the Chromic Luvisol during the major season of 2013, as presented in Table 3. The treatments N_{60} P_{10} K_{20} +PM (2.5tha^{-1}) and N_{60} P_{10} K_{20} (Mamaba) resulted in the highest grain yields of 4950 and 4740 kg ha^{-1}, respectively, compared to the control with 2540 kg ha^{-1}. The Obatanpa cultivar yielded 4130 and 4360 kg ha^{-1}, respectively, compared to the control with 2040 kg ha^{-1} (Table 3). However, the grain yield during the minor season did not show a significant difference among the treatments. The yield significantly ($P < 0.05$) declined in the minor cropping season of 2013.

3.2. Effect of Treatments and Cultivar on Grain Yield

Table 4 presents the results of the effect of treatments and cultivar on grain yield during the major cropping season of 2013 on Ferric Lixisol. The yield increase over the control for Mamaba ranged from 1.3 - 246% (1690 − 5780 kg ha) and 33 - 268% (1380-3800 kg ha) for Obatanpa. There was no significant difference in the grain yield for the two cultivars. It is apparent from Table 4 that $N_{60}P_{10}K_{40}$ recorded yield increase of more than 200% and 190% over the control for Mamaba and Obatanpa, respectively. Similarly, $N_{60}P_{30}$ treatment gave 120 and 240% yield increase over the control for Mamaba and Obatanpa, respectively. However, treatments plots with N_{90} P_{10} K_{20} and N_{60} P_{10} K_{20} showed increases over 100% but not consistently for both cultivars. The $N_{60}P_{10}K_{20}$+PM (2.5t/ha) and N60P10K20 treatments gave higher yield responses.

3.3. Effect of Fertilizer Treatments and Cultivar on Hundred Seed Weight of Maize

The effect of fertilizer treatments and cultivar on hundred seed weight of maize is summarized in Table 5. Due to varietal differences, Obatanpa seeds were generally bigger in size compared to Mamaba. The 100 seed weight for Obatanpa ranged between 26.96 g (N_{30}) and 31.21 g (N_{120}), and Mamaba recorded weight range of 20.41g (N_{90}) and 23.11g (N_{60}) for Mamaba during the major season of 2013 (Table 5). Significantly high ($P < 0.05$) values were generally recorded during the major cropping season (2013) compared to the minor season (2013).

3.4. Effect of Fertilizer Treatments and Cultivar on Stover

The effect of fertilizer treatments and cultivar on stover yield during the major and minor cropping seasons (2013) following the application of amendments on Chromic Luvisol and Ferric Lixisol are presented in Tables 6 and 7, respectively. On the Chromic Luvisol (major season), there were significant differences among the treatments. The N60 P_{10} K_{20} + PM (2.5tha^{-1}) treatment on Obatanpa had the highest stover yield (9333 kg ha^{-1}), followed by N120 (8667 kg ha^{-1}) representing 58.5% and 67.6% respectively. The stover yield during the minor season followed a similar pattern as was reported for grain yield. In the Ferric Lixisol, N_{60} P_{10} K_{20} +PM (2.5tha^{-1}) treatment had the highest stover yield with yield increase over the control of 36 and 57% for Mamaba and Obatanpa, respectively, during the major season. All the amendments gave yields that were significantly higher than the control in the minor cropping season. The N_{60} P_{10} K_{20} + PM (2.5tha^{-1}) treatment produced the highest yield (531 kg ha^{-1}) for Obatanpa.

Table 3. *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**	
Treatments	**Grain yield (kg ha^{-1})**			
Control	2040	2540	492	489
N_{30}	3470	3520	826	1099
N_{60}	3720	3890	832	922
N_{90}	3910	4140	990	562
N_{120}	4440	4530	872	1197
$N_0P_{10}K_{20}$	3030	2920	880	1303
N_{30} P_{10} K_{20}	3070	3780	984	1123
N_{90} P_{10} K_{20}	3520	4230	943	1737
N_{120} P_{10} K_{20}	3820	4450	1367	1756
$N_{60}P_{10}$	2780	4040	508	1026
N_{60} P_{20}	3300	4270	483	1327
N_{60} P_{30}	3560	4720	964	1642
N_{60} P_{10} K_{20}	4130	4740	1121	886
N_{60} P_{10} K_{40}	3130	4220	1463	1738
N_{60} P_{10} K_{60}	2900	3180	1170	947
$N_{60}P_{10}K_{20}$ +PM (2.5t/ha)	4360	4950	1316	2148
P values (variety)	0.019*		0.056	
P values (treatment)	0.220		<0.001***	

Table 4. *Effect of treatments and cultivar on maize grain yield on a Ferric Lixisol, Mampong (Major season, 2013).*

Treatment (kg/ha)	Mamaba			Obatanpa		
	Grain yield (kg/ha)	Increase over control (%)	100 seed weight (g)	Grain yield (kg/ha)	Increase over control (%)	100 seed weight (g)
Control	1670	-	22.79	1030	-	23.68
N_{30}	1320	-20.82	21.97	1390	35.47	28.34
N_{60}	2200	31.91	23.11	2100	103.79	27.87
N_{90}	2640	58.31	20.41	2500	143.15	26.96
N_{120}	2860	71.57	27.78	2780	170.46	31.21
$N_0P_{10}K_{20}$	1690	1.32	23.96	1380	33.92	25.99
N_{30} P_{10} K_{20}	1960	17.52	23.29	2760	167.93	24.65
N_{90} P_{10} K_{20}	2680	60.47	21.56	3350	225.07	27.41
N_{120} P_{10} K_{20}	3350	100.72	21.44	3800	268.80	30.81
$N_{60}P_{10}$	2240	34.07	27.10	1610	56.37	26.37
N_{60} P_{20}	2880	72.53	21.59	2070	101.07	21.81
N_{60} P_{30}	3700	121.90	27.75	3580	247.62	34.01
N_{60} P_{10} K_{20}	3160	89.38	19.01	3600	249.76	31.16
N_{60} P_{10} K_{40}	5026	246.55	28.60	3080	199.13	28.61
N_{60} P_{10} K_{60}	3040	82.18	22.17	3120	203.21	26.38
$N_{60}P_{10}K_{20}$+PM (2.5t/ha)	2660	59.63	21.19	3570	247.33	29.14
P values (Variety)	0.58		<0.001	0.58		<0.001
P values (Treatment)	<0.001		0.16	<0.001		0.16
S.E.D (0.05)	233		0.99	233		0.99

Table 5. *Effect of treatments and cultivar on hundred seed weight on a Chromic Luvisol, Wenchi (2013).*

Treatment (kg/ha)	Mamaba			Obatanpa		
	Grain yield (kg/ha)	Increase over control (%)	100 seed weight (g)	Grain yield (kg/ha)	Increase over control (%)	100 seed weight (g)
Control	1670	-	22.79	1030	-	23.68
N_{30}	1320	-20.82	21.97	1390	35.47	28.34
N_{60}	2200	31.91	23.11	2100	103.79	27.87
N_{90}	2640	58.31	20.41	2500	143.15	26.96
N_{120}	2860	71.57	27.78	2780	170.46	31.21
$N_0P_{10}K_{20}$	1690	1.32	23.96	1380	33.92	25.99
N_{30} P_{10} K_{20}	1960	17.52	23.29	2760	167.93	24.65
N_{90} P_{10} K_{20}	2680	60.47	21.56	3350	225.07	27.41
N_{120} P_{10} K_{20}	3350	100.72	21.44	3800	268.80	30.81
$N_{60}P_{10}$	2240	34.07	27.10	1610	56.37	26.37
N_{60} P_{20}	2880	72.53	21.59	2070	101.07	21.81
N_{60} P_{30}	3700	121.90	27.75	3580	247.62	34.01
N_{60} P_{10} K_{20}	3160	89.38	19.01	3600	249.76	31.16
N_{60} P_{10} K_{40}	5026	246.55	28.60	3080	199.13	28.61
N_{60} P_{10} K_{60}	3040	82.18	22.17	3120	203.21	26.38
$N_{60}P_{10}K_{20}$+PM (2.5t/ha)	2660	59.63	21.19	3570	247.33	29.14
P values (Variety)	0.58		<0.001	0.58		<0.001
P values (Treatment)	<0.001		0.16	<0.001		0.16
S.E.D (0.05)	233		0.99	233		0.99

Table 6. *Effect of treatments and cultivar on stover yield on a Chromic Luvisol, Wenchi (2013).*

Maize variety	Mamaba	Obatanpa	Obatanpa	Mamaba
Cropping season	Major season		Minor season	
Treatment (kg/ha)	Stover weight (kg/ha)			
Control	5074	5259	406	395
N_{30}	5185	7259	401	479
N_{60}	4444	6037	482	353
N_{90}	4481	8815	313	401
N_{120}	5259	8667	1284	629
$N_0P_{10}K_{20}$	4296	7296	407	549
N_{30}+$P_{10}K_{20}$	5259	6926	382	396
$N_{90}P_{10}K_{20}$	4963	6926	436	496
$N_{120}P_{10}K_{20}$	5222	8333	371	561
$N_{60}P_{10}$	4407	5000	380	326
$N_{60}P_{20}$	4111	5481	475	633
$N_{60}P_{30}$	5222	6222	320	454
$N_{60}P_{10}K_{20}$	5259	7074	490	548
$N_{60}P_{10}K_{40}$	5481	5519	356	435

Maize variety	Mamaba	Obatanpa	Obatanpa	Mamaba
Cropping season	Major season		Minor season	
Treatment (kg/ha)	Stover weight (kg/ha)			
$N_{60}P_{10}K_{60}$	5074	5481	428	531
$N_{60}P_{10}K_{20}$+PM (2.5t/ha)	5704	9333	499	440
S.E.D (0.05)	341		231	
P values (variety)	<0.001		0.133	
P values (treatment)	0.195		0.841	

Table 7. *Effect of treatments and cultivar on stover yield (kg/ha) in a Ferric Lixisol, Mampong (2013).*

Maize variety	Obatanpa	Mamaba	Mamaba	Obatanpa
Cropping season	Major season		Minor season	
Treatment (kg/ha)				
Control	7,833	7,019	283	237
N_{30}	8,019	4981	331	330
N_{60}	9,459	7,870	401	463
N_{90}	7,722	8,241	352	343
N_{120}	9,722	6,093	308	311
$N_0P_{10}K_{20}$	5,759	3,685	335	287
$N_{30}P_{10}K_{20}$	9,944	5,981	281	403
$N_{90}P_{10}K_{20}$	11,759	7,759	278	320
$N_{120}P_{10}K_{20}$	9,944	6,611	300	322
$N_{60}P_{10}$	10,463	6,241	404	406
$N_{60}P_{20}$	9,241	6,685	328	418
$N_{60}P_{30}$	10,648	9,315	411	329
$N_{60}P_{10}K_{20}$	11,389	8,019	302	454
$N_{60}P_{10}K_{40}$	11,278	8,870	361	398
$N_{60}P_{10}K_{60}$	10,315	8,907	323	361
$N_{60}P_{10}K_{20}$+ PM (2.5t/ha)	12,315	9,648	403	531
SED	2182.4		73.18	
P values (variety)	<0.001		0.083	
P values (treatment)	0.032		0.024	

4. Discussion

According to [1] the growth and yield of a crop is determined by the interaction between its genetic makeup and the environment. The variation in maize grain yield observed in this study, as affected by cultivars and the chromic luvisol and ferric Lixisol treatments, was attributed to differences in soil properties at the two study sites. All treatments were found to be significantly better than the control. 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 main harvest season at both study sites can be attributed to readily available nutrients that the plant could use for growth. Results showed a significant increase in maize grain yield in response to an increased application of 30 kg ha^{-1} with no P or K application across seasons and trial sites. The study showed that N was more limiting than P or K for corn yield. However, the addition of P slightly increased yield over the amended plot $N_{60}P_{30}$, indicating the ability of P to increase grain yield. This observation agrees with the earlier results of [5, 7, 15]. Differences in phosphorus uptake and utilization, as well as adaptability to different soil types, were observed among maize varieties, indicating differences in phosphorus requirements. Conversely, there were no significant differences in grain yield between $N_{60}P_{30}$, $N_{60}P_{10}K_{20}$ and $N_{60}P_{10}K_{40}$. Grain yield was in the order $N_{60}P_{30}$, > $N_{60}P_{10}K_{20}$> $N_{60}P_{10}K_{40}$. The amount of rainfall during the season could also account for the high yield obtained for all treatments compared to other seasons. Low rainfall during the planting season and season is a likely cause of low off-season production. This is consistent with the research done by [19, 20]. The addition of poultry manure had a significant effect on maize grain yield and supported the use of integrated plant nutrition as a best practice to sustain increased crop production in West Africa. This is in agreement with the result of [3]. The increase in grain yield could be due to the synergistic effects of NPK and poultry manure. This observation is consistent with the findings of [16] that, the use of integrated plant nutrition is the best practice for sustaining increased crop production. The interactions confirmed that the combined application of organic and inorganic fertilizers is more effective than the use of one of them alone [8, 10]. For Ferric Lixisol, the increase in maize grain yield over the control $N_{60}P_{30}$ treatment for Obatanpa and Mamaba was essentially comparable to the $N_{60}P_{10}K_{40}$ treatment. The difference in grain yield of the two cultivars is attributed to the difference in days to completion of the life cycle and the genetic make-up of these cultivars [10]. The study also showed that $N_{60}P_{30}$ was more productive in increasing Stover yields than using only N120 or $N_0P_{10}K_{20}$. A pooled analysis of data from two seasons showed that all treatments were significantly better than the control. Nitrogen uptake and grain yield were well correlated with Stover yield, indicating the significant role of nitrogen in the final Stover yield of the crop [11, 19, 20]. The differences in Stover yield resulting from the two soil types can be attributed to nutrient losses by leaching due to the undulating topography of the ferric lixisol.

5. Conclusion

The inadequate yield of maize among smallholder farmers in Ghana has necessitated the implementation of site-specific fertilizer recommendations and the integration of available organic and inorganic fertilizers to achieve increased and sustainable crop production. However, the results of the on-farm trials indicated that there were varietal influences on the grain yield. Integrated application of mineral fertilizers with poultry manure (N60P30 +3 t/ha PM) produced a 118% yield increase over control and therefore recommended. Increasing the level of PM proportionally led to an increased maize yield.

Acknowledgments

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Conflicts of Interest

The authors declare no conflicts of interest.

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