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Integrated Application of Mineral Nitrogen and Cattle Manure to Improve Nitrogen Use Efficiency and Grain Yield of Maize

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Abstract Field experiments were conducted at the Plantation Crops Section of Kwame Nkrumah University of Science and Technology in Kumasi, Ghana in 2014 major and minor seasons to study the effect of combining mineral nitrogen at different application times with cattle manure on nitrogen use efficiency and grain yield of maize. The experiments were factorial in randomized complete block design with four replications. The factors were cattle manure at the rates of 0, 2, 4 and 6 tons/ha; and nitrogen application times as follows: 50% N at 2 weeks after planting and 50% at 4 WAP (NT1), 50% N at 2 WAP and 50% at 6 WAP (NT2), 50% N at 2 WAP and 50% at 8 WAP (NT3) and a control (0 kg N/ha). Results showed that NT2 application increased the nitrogen use efficiency in major and minor seasons more than other application times. The nitrogen use efficiency increased with increase in manure rate, but at a diminishing return. Grain yield was also higher at NT2 and also increased with increase in manure rate. Application of mineral nitrogen at NT2 along with 6 tons/ha cattle manure rate was, therefore, considered best combination for increasing yield of maize in the country.

Keywords: *maize, nitrogen, cattle manure, grain yield, nitrogen use efficiency*

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1. Introduction

In Ghana, maize is the most important cereal crop in terms of production and consumption. Farmers grow it as a sole crop or intercropped with cassava for subsistence purposes and also because of the readily available market provided by the urban centers [3]. To meet the needs of farmers, several improved maize varieties of different maturity periods have been developed and released by the Crops Research Institute (CRI) of the Council for Scientific and Industrial Research of Ghana. Among these varieties include Obatanpa, noted for its high grain yield capabilities and improved nutritional status. The variety was first released by CRI in 1992 to help improve the protein nutritional status of large population of low-income families who depend on maize as a major component of their dietary protein intake [2]. It was adopted extensively in Ghana and many other African countries and still by far remained the most popular maize variety in the country [18].

Despite the numerous efforts put into maize research over the years in Ghana, productivity in farmers’ fields has been generally low, averaging 1.6 tons/ha [17]. This low productivity has been attributed mainly to inappropriate nutrient management practices [16]. Nutrient management is an important factor for achieving the potential yield in maize production systems because mineral nutrients are the major contributors to increasing crop production [10]. Finding the best approaches to achieve efficient nutrient management systems is very essential both for economic and environmental reasons.

The application of animal manure to agricultural land has been viewed as an excellent way to supply nutrients and organic matter that can support crop production [6]. Cattle manure supplies nutrients during the course of the cropping season through mineralization, affects soil properties such as cation exchange capacity and pH, as well as root and nutrient interaction [5]. It is, therefore, a safe and effective way of recovering lost plant nutrients. However, only a small fraction of cattle manure nutrients are immediately available for plant use [14]. The use of manure alone has been reported to be inadequate due to unavailability in the required quantities, their relatively low nutrient contents, and slow release of nutrients [13]. Whilst nutrients in mineral fertilizers are immediately available for plant uptake and use, their use in crop production has been associated with increased environmental problems such as soil acidity, pollution of underground water sources and nutrient imbalance. Integrated nutrient management approaches, in which both manure and mineral fertilizers are used, have been widely recommended as the most promising strategy for improving crop yields [4,20]. The objective of this study, therefore, was to determine effects of combining mineral nitrogen at different application times with cattle manure on nitrogen use efficiency and grain yield of maize.

2. Materials and Methods

2.1. Study Area Description

The study was conducted at the Plantation Crops Section of the Department of Crop and Soil Sciences, Kwame Nkrumah University of Science and Technology, Kumasi. The area is located within the semi-deciduous forest zone of Ghana. The soils of the area were classified by Adu [1] as Asuansi series or Orthi-Ferric Acrisol. The area is characterized by marked wet and dry season with a bimodal rainfall pattern which makes two crop growing seasons possible. The major season extends from April to July and is characterized by heavy rainfalls. This is interrupted by a dry period of about four weeks in August. The minor season follows from September to November with usually less rainfall. The rainfall data for the periods of the two experiments is presented in Figure 1. The maximum and minimum temperatures and relative humidity of the experimental site during the crop grown periods were respectively, 30.35°C, 22.19°C and 76.36% in the major season; and 31.0°C, 21.94°C and 74.67% in the minor season. Rainfall, temperature and relative humidity data for the crop grown periods were obtained from the Ghana Meteorology Agency's satellite weather station located at the university farm about 300 meters away from the experiment site.

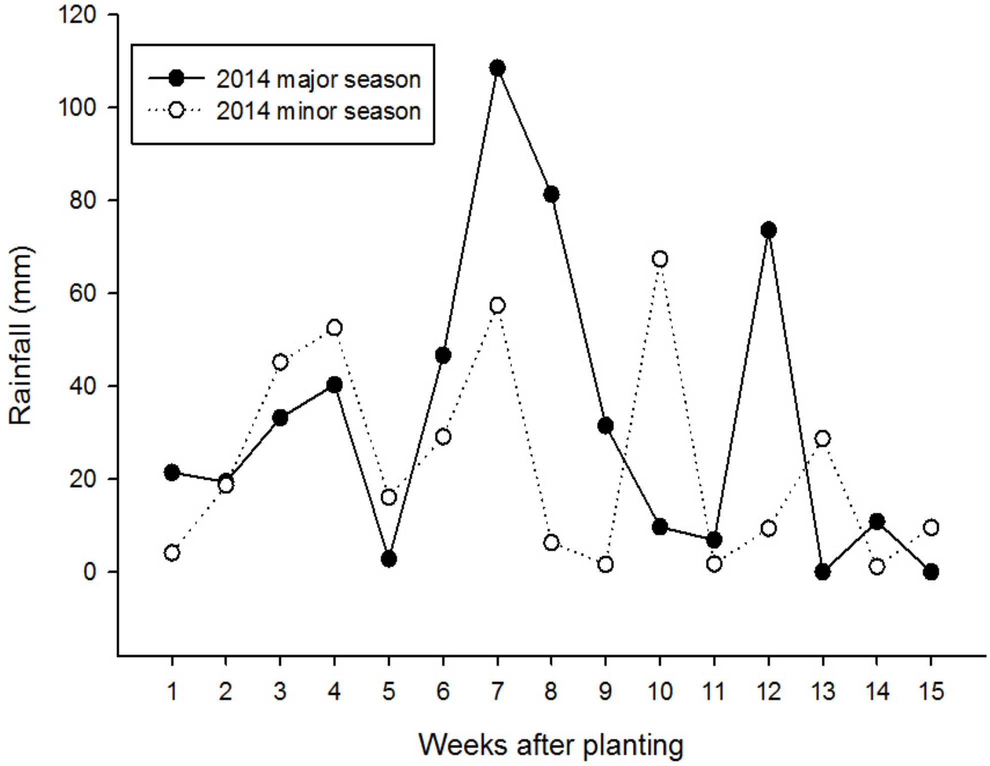

Figure 1. Rainfall received from sowing to harvest during each cropping season within the experimental site

2.2. Field Experiments

Field experiments were carried out in 2014 major and minor seasons. The experiments were factorial in randomized complete block design with four replications. The treatment details of the experiments are shown in Table 1. Obatanpa, an intermediate quality protein maize variety was used as the test crop. During planting, four seeds were sown in each planting hole and seedlings were later thinned to two per stand at 12 days after planting. The planting distance was 80 x 40 cm, between rows and stands respectively, giving a plant density of 62,500 plants/ha.

Soil samples were collected prior to planting to assess the initial mineral, physical and chemical properties of the experimental fields. The soil analysis data is presented in Table 2. Cattle manure was also analyzed prior to application. The moisture content of the manure was 70%. Total organic carbon and nitrogen contents were respectively, 35.68% and 1.12% with a C/N ratio of 32:1. Calcium, magnesium, available phosphorus and potassium contents were 0.81%, 0.44%, 0.18%, and 2.15% respectively.

Table 1. Levels of the two factors used in the experiments in the two seasons

No.	Mineral nitrogen application time	Cattle manure rate (tons/ha)
1.	0 N	0
2.	50% N at 2 WAP and 50% at 4 WAP (NT1)	2
3.	50% N at 2 WAP and 50% at 6 WAP (NT2)	4
4.	50% N at 2 WAP and 50% at 8 WAP (NT3)	6

Table 2. Mineral, physical and chemical properties of field experiment soils at 0-15 cm prior to application of amendments.

Soil property	2014 major season	2014 minor season
pH	6.15	5.92
Organic carbon (%)	1.40	1.59
Total N (%)	0.08	0.10
Available P (mg/kg soil)	6.09	5.92
Exchangeable bases (cmol/kg soil)		
K^+	0.12	0.17
Na^+	0.05	0.09
Mg^{2+}	1.68	2.12
Ca^{2+}	2.24	3.36
Exchangeable acidity (cmol/kg soil)		
Al^{3+}	0.76	0.52
H^+	1.68	1.30
ECEC (cmol/kg soil)	6.51	7.06
Soil particle size (%)		
Sand	84.80	77.32
Silt	8.56	13.63
Clay	6.64	9.05
Bulk density (g/cm^3)	1.45	1.40
Textural class	Loamy fine sand	

2.3. Manure and Inorganic Fertilizer Application

Cattle manure was applied two weeks prior to planting. The semi-decomposed manure was broadcasted in the plots and incorporated immediately by turning the soil lightly. Ammonium sulphate (21% N), Triple superphosphate (46% P) and Muriate of potash (60% K) were used as the sources of nitrogen, phosphorus and potassium, respectively. Nitrogen at the rate of 90 kg/ha was applied in two splits to all nitrogen treatments. With the exception of the control plots, all other plots received 50% N at 2 WAP. The remaining nitrogen was applied at 4, 6 and 8 WAP for NT1, NT2 and NT3 application times, respectively. Phosphorus and potassium were each applied in full at the rate of 60 kg/ha at 2 WAP along with the basal nitrogen. Fertilizer rates used in this study followed the recommendations by Morris *et al*. [12] reported by Ragasa *et al*. [18] for lands in the forest and transitional zones of Ghana under continuous cultivation.

2.4. Nitrogen Use Efficiency

Nitrogen use efficiency was estimated as kg grain produced per kg nitrogen applied. It was calculated using the formula below [19].

$$NUE = \frac{\left[\begin{array}{l} Grain\ yield\left(fertilized\ plot\right) \\ -Grain\ yield\left(control\right) \end{array}\right]}{Rate\ of\ \ N\ Applied}.$$

2.5. Grain Yield

For grain yield determination, maize ears were harvested from the three inner rows of each plot, covering an area of 6.72 m^2. After harvesting, ears were dehusked and oven dried to a constant weight. The ears were then shelled and the grain weights were recorded.

2.6. Data Analysis

All data were subjected to Analysis of Variance (ANOVA) using the GenStat statistical package [9]. The means were separated using the Least Significant Difference (LSD) at 5% level of probability.

3. Results

3.1. Nitrogen Use Efficiency

At sole nitrogen applications, nitrogen use efficiency was significantly higher at NT2 than at other application times. Nitrogen use efficiency increased at all nitrogen application times when the nitrogen was applied along with cattle manure. The increment was higher as manure rate increased, but at a diminishing return (Table 3). In the major season, manure effect on NUE was significant in all manure treatments. In the minor season, the effects were significant in the 4 and 6 tons/ha manure treatments, the effect at 2 tons/ha manure treatment was not significantly different (P > 0.05) from no manure application at all N application times. Among the N application times, NUE was greater at NT2 in both seasons.

Table 3. Effect of time of mineral nitrogen application and cattle manure rate on nitrogen use efficiency of maize in the 2014 major and minor seasons

Manure rate (tons/ha)	2014 major season			2014 minor season		
	NT1	NT2	NT3	NT1	NT2	NT3
	NUE (kg grain/ kg N applied)					
0	14.70	16.50	12.15	10.84	12.16	11.26
2	18.42	18.44	14.11	11.59	12.17	11.41
4	19.02	20.71	15.03	12.06	12.64	11.83
6	19.06	20.93	16.03	12.65	12.89	11.85
LSD (0.05)	1.77			0.87		
CV (%)	6.1			4.3		

Contrast comparisons in the major season showed that nitrogen use efficiency at NT1, NT2 and NT3 application times combined with manure treatments were significantly higher (P < 0.01) than NT1, NT2 and NT3 without manure (Table 4). Nitrogen use efficiency from NT2 application time combined with manure treatments was also significantly higher (P < 0.05) than from NT1 combined with manure and NT3 combined with manure treatments. In the minor season, contrast comparisons showed NUE to be significantly higher at NT1 with manure treatments than at NT1 without manure; however, NT2 and NT3 application times with manure were not significantly different (P > 0.05) from without manure.

Table 4. Nitrogen use efficiency differences among nitrogen application times with manure and without manure from contrast comparisons.

Contrasts	2014 major season	F pr.	2014 minor season	F pr.
	NUE (kg grain/ kg N applied)			
NT1 with manure vs. NT1 without manure	9.4	<.001	5.0	<.001
NT2 with manure vs. NT2 without manure	7.6	0.001	1.2	0.267
NT3 with manure vs. NT3 without manure	8.7	<.001	1.3	0.217
NT2 with manure vs. NT1 with manure	3.5	0.025	1.39	0.069
NT1 with manure vs. NT3 with manure	11.4	<.001	1.21	0.110
NT2 with manure vs. NT3 with manure	14.9	<.001	2.60	0.002

3.2. Grain Yield

Grain yield in the major season was greater at NT2 application time in all the manure rates (Figure 2A). In the minor season, grain yield was greater at NT2 application time in all the manure rates except in the 4 tons/ha rate where NT1 application was highest (Figure 2B). In the major season, grain yield at NT1 application time combined with 6 tons/ha manure treatment was 1.18 tons/ha significantly higher (P < 0.05) than at NT1 without manure; NT2 application time with 6 tons/ha manure treatment was 1.14 tons/ha significantly higher than at NT2 without manure. In the minor season, grain yield at NT1 with 6 tons/ha manure treatment was 1.06 tons/ha significantly higher than NT1 without manure, NT2 with 6 tons/ha manure treatment was 1.12 tons/ha significantly higher than NT2 without manure. At NT3 application, increase in grain yield obtained due to addition of manure was not significantly different (P > 0.05) from sole mineral nitrogen application in both seasons.

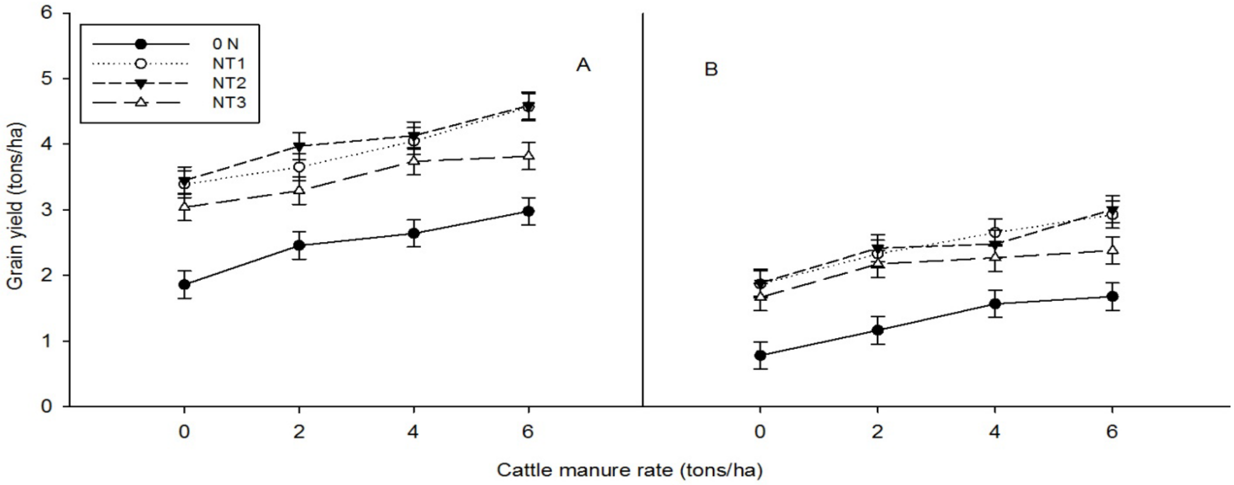

Figure 2. Effect of time of nitrogen application and cattle manure on grain yield of maize in A: 2014 major and B: 2014 minor seasons. Bars on graph represent standard errors

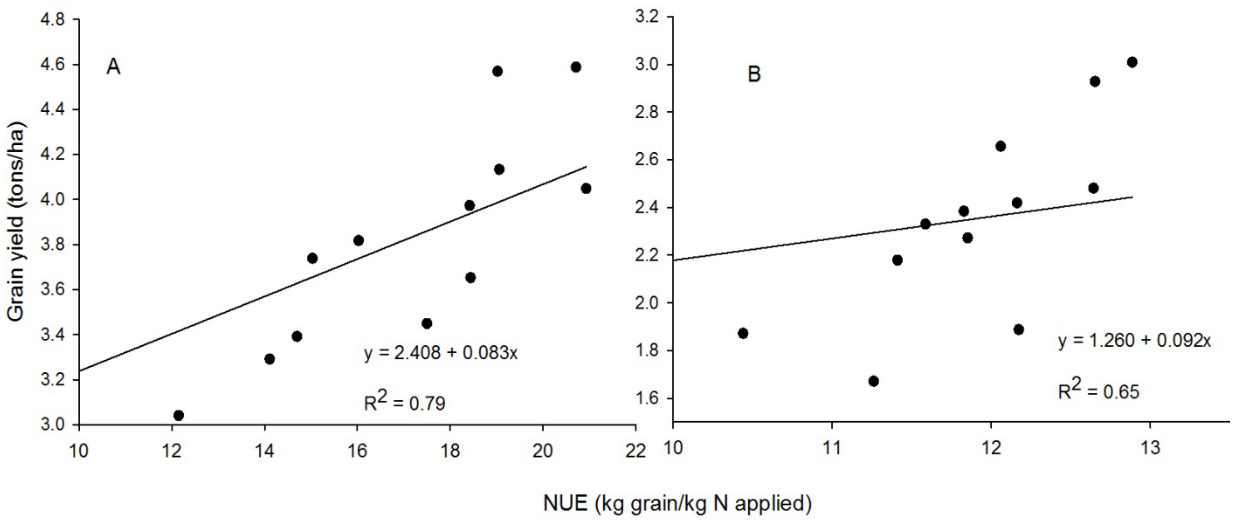

Figure 3. Relationship between maize grain yield and nitrogen use efficiency in A: 2014 major and B: 2014 minor seasons

Significant positive relationship, indicated by R squares of 0.79 and 0.65 was found between nitrogen use efficiency and grain yield of maize in the major and minor seasons, respectively (Figure 3).

4. Discussion

Nitrogen use efficiency has been greater at NT2 application time in both seasons (Table 3) due to the fact that plants in these plots recovered more nitrogen from the applied N fertilizer than at other N application times. This was because half of the nitrogen at this application time was applied a week prior to onset of tasseling (6 WAP), a stage which in maize is regarded as active nitrogen uptake period [7].

Nitrogen use efficiency was higher when mineral nitrogen was applied along with cattle manure than in the nitrogen alone treatments. This could be as a result of the manure improving soil properties, thus, limiting nitrogen losses and increase concentration and uptake of nitrogen. According to Erisman *et al*. [8], under high N application, only 5–15% of the applied N is transformed into grain yield and the remaining N is lost as gaseous emissions or leached from the soil. Obtaining NUE values of 20.93 kg grain per kg N applied at NT2 combined with 6 tons/ha manure treatment in the major season (Table 3) showed that NUE of maize can be improved by applying the N fertilizer along with cattle manure. A decrease in NUE when organic and inorganic sources of nitrogen were combined due to increased nitrogen immobilization was reported in some previous studies [21]. However, the immobilization of N associated with application of organic nitrogen sources was temporal and less severe in manure when it goes through a decomposition phase prior to planting [11]. Manure effect also significantly reduced NUE differences that existed among N application times when no manure was applied.

Results of the study showed that differences in times of nitrogen applications had significantly affected maize grain yield, with NT2 application time producing highest yields (Figure 2). Grain yield been higher at NT2 application time could be as a result of the higher NUE that occurred at this application time (Table 3) because strong positive relationships were found between grain yield and NUE (Figure 3). Worku *et al*. [22] also reported a positive relationship between maize grain yield and nitrogen use efficiency.

Grain yields were also higher in the nitrogen and manure combined treatments than in the nitrogen alone and manure alone treatments. Highest grain yields from sole mineral nitrogen treatments of 3.45 tons/ha and 1.89 tons/ha were obtained at NT2 application in the major and minor seasons respectively. At sole manure treatments, highest grain yield of 2.98 and 1.68 tons/ha were obtained in the 6 tons/ha manure treatment in the major and minor seasons, respectively. The combined effect of mineral N and cattle manure produced highest grain yields of 4.59 and 3.01 tons/ha at NT2 application time with 6 tons/ha manure treatment in the major and minor seasons, respectively. These results compared very well to the 1.96 tons/ha and 3.44 tons/ha grain yields at 3 and 6 tons/ha cattle manure rates, and 4.28 tons/ha at 6 tons/ha cattle manure plus the recommended N rate reported by Ncube *et al*. [15] in Zimbabwe.

Application of the recommended N rate alone in this study has produced an average grain yield of 3.29 tons/ha which was 28.5% lower than the potential yield of 4.6 tons/ha for the maize variety used. In contrast, average grain yield in the mineral nitrogen combined with 4 tons/ha manure treatment was 3.97 tons/ha which was 13.6% lower than the potential yield. In the N combined with 6 tons/ha manure treatment, average grain yield obtained was 4.33 tons/ha which was only 6% lower than the potential yield. Combining mineral nitrogen with cattle manure also significantly reduced grain yield differences that existed among N application times when no manure was applied. This suggests that integrated application of mineral nitrogen with cattle manure can reduce maize yield decreases associated with late nitrogen application. Higher maize yields from combined application of manure and inorganic nitrogen than from sole inorganic nitrogen and sole manure applications was also reported by Mugwe *et al*. [13] in Kenya and Ayoola and Makinde [4] in Nigeria.

5. Conclusion

From the results obtained, it can be concluded that application of mineral nitrogen at any of the times used in this study along with cattle manure increased the nitrogen use efficiency and grain yield of maize than sole mineral nitrogen application, however, the highest increments were obtained when the mineral nitrogen was applied at NT2 (50% N at 2 WAP and 50% at 6 WAP) in combination with 6 tons/ha cattle manure rate.

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