

Nutrient / Nitrogen Use Efficiency and maize productivity in the Guinea Savanna Agro-ecological Zone of Ghana

ABSTRACT

In 2014 and 2015 cropping seasons, on-farm research on nutrient / nitrogen use efficiency in maize (*Zea mays*, L.) production was conducted in five districts in the Guinea Savanna Agro-ecological Zone (GSAZ) in the Northern Region of Ghana. The research fields were laid out in a Randomized Complete Block Design with 16 treatments in three replications. The treatments consisted of the control (T₁), eight inorganic fertilizer treatments (T₂, T₃, T₄, T₅, T₁₀, T₁₁, T₁₂, and T₁₃) which were made up of various rates and combinations of the compound fertilizers (15-15-15 NPK and 23-10-05 NPK) and Sulphate of Ammonia fertilizers, six integrated treatments (T₆, T₇, T₈, T₉, T₁₄, and T₁₅) which were made up of combination of the various rates of the inorganic fertilizers and poultry manure, and T₁₆ which involved the application of only Sulphate of Ammonia. The soil analysis indicated that the five locations differed significantly ($P < 0.05$) in terms of pH, organic matter, total N, available P, exchangeable Ca, exchangeable Mg, Exchangeable Cation Exchange Capacity (ECEC), base saturation, and exchangeable acidity. Combined application of poultry manure and inorganic fertilizer recorded significantly higher maize grain yields of 2.15 – 2.76 t/ha. Maize grain yield differed significantly ($P < 0.05$) at the different locations. Nitrogen Use Efficiency (NUE) was significantly ($P < 0.05$) affected by treatments, location, and year. Treatments that involved the combined application of inorganic fertilizers and poultry manure recorded the least NUE values with T₆ recording the lowest figure of 2.14 ± 1.17 . The NUE was significantly lower in 2015 than in 2014. Mognegu significantly recorded the lowest NUE (4.27 ± 0.75) compared with the other locations whilst Kanpong recorded the highest NUE of 19.3 ± 0.68 . Location and year interaction, affected NUE significantly ($P < 0.05$) but location and treatment interaction as well as treatment and year interactions did not affect NUE.

Key words: Nitrogen Use Efficiency, Nutrient Management, Productivity, Northern Region, Ghana, Guinea Savanna Agro-ecological Zone, Maize, Poultry Manure

1.0 INTRODUCTION

Maize (*Zea mays* L.) is the third most important crop after wheat and rice, widely cultivated in tropics, sub-tropics and temperate regions in both irrigated and semiarid conditions. It however, grows best under sub-tropical conditions of 21°C to 28°C and about 600 – 1200 mm of rain [1].

In Ghana, maize is the most important staple and food security crop and it accounts for more

than 50% of total cereal production and the second important commodity crop in the country after cocoa [2]. It is cultivated in all agro-ecological zones of Ghana but grows best in deep and well-drained loamy soils (MoFA, 2005). Of all the major food crops grown in 2011, maize occupied the largest proportion of 24.9% in terms of total area cultivated [2]. Smallholder farmers produce 90% of maize in Ghana [4].

Maize has wider uses than any other cereal [5]. The bulk of maize produced in Ghana is consumed in every household and it is arguably the most important crop for cash and food security because every household in Ghana consumes it. It is estimated that 85% of all maize grown in Ghana is consumed by humans and the remaining 15% is used for the animal feed preparation (mainly poultry) [6]. It contributes about 20% of calories to the Ghanaian diet [7]. In 2000, the per capita consumption of maize in Ghana was estimated at 42.5 kg [8] and in 2011 at 43.8 kg/capita [2]. whilst the national consumption of maize was projected at 943,000 Mt in 2006 [9].

The development and productivity of livestock and poultry sectors in Ghana also depend on the maize value chain since maize is a major component of poultry and livestock feed. The demand for maize for poultry feed is estimated to increase from 73,000 MT in 2010 to 118,100 MT by 2015 [10]. The increasing demand for poultry and poultry products as a source of protein and the concomitant demand for maize as poultry feed ingredient requires corresponding increase in maize production to meet the demand. Northern Region is an important area for cereals, legumes, and livestock production and is considered as one of the breadbasket regions of Ghana [11] but the soil fertility has declined due to annual bushfires, continuous cropping and excessive leaching.

57 Maize is noted to be a heavy nutrient feeder and has been found to respond well to higher
58 fertilizer application, particularly nitrogenous in Northern Ghana [5]. For decades (since 1960s),
59 however, the recommended rate of chemical fertilizer application for maize production in Ghana
60 has been basal application of 250 kg/ha of NPK 15-15-15 compound fertilizer and topdressing
61 with 250 kg/ha of sulphate of ammonia [12, 3]. Even though soil fertility and climatic conditions
62 have since changed in Ghana particularly in the Northern region, the recommended fertilizer
63 rates for maize cultivation has not been revised. Moreover, increasing fertilizer prices and
64 economic considerations have forced farmers to adopt various types and combinations of
65 fertilizers to produce maize in this part of Ghana. Application of low rates of N is noted to
66 negatively affect photosynthesis and transpiration rates thereby reducing crop yields [13].
67 Conversely, excessive application of N may also lead to low nitrogen use efficiency (NUE)
68 which is defined as the efficiency with which applied nitrogen produces additional grain over the
69 control [14], increase production cost, and reduce crop yield [15, 16]. This has been corroborated
70 by [17] who argue that applying higher rates of N to increase crop productivity is not an effective
71 strategy in agricultural ecosystems because that significantly reduces the NUE. Interaction
72 effects of irrigation and nitrogen application on growth, yield, and NUE have been documented
73 by [17] and [18]. [13] have also reported higher water and nitrogen use efficiencies with
74 maximum irrigation confirming them as yield-limiting factors under drier conditions.
75 Unfortunately, no field studies have been conducted in recent years to establish the efficiency of
76 the recommended fertilizer rate and other rates and combinations being adopted by farmers for
77 maize production in Northern Ghana. The objective of the present study was to investigate maize
78 productivity and the NUE of the current recommended fertilizer rate for maize production and

other rates and combinations of inorganic and organic fertilizers being used by farmers in the Guinea Savanna Agro-ecological Zone (GSAZ) of Ghana.

2.0 MATERIALS AND METHODS

A multi-location on-farm farmer participatory research was conducted in the Northern Region of Ghana in five districts namely Central Gonja, East Gonja, Zabzugu, Tatale, and West Mamprusi in 2014 and 2015 cropping seasons. The specific locations of the study in the districts were Kanpong, Adamupe, Mognegu, Bidribombe, and Buggyakura, respectively. Three hundred and seventy-two farmers comprising of 254 males (68.3%) and 118 females (31.7%) participated in the research from the five locations.

The research fields were laid out in a Randomized Complete Block Design with 16 treatments in three replications at each location. The plot size was 12 m long and 6 m wide, and were separated by 1 m alley with intrablock distance of 2 m. The maize seeds were planted at 80 cm x 40 cm and thinned to two plants per hill to achieve a plant population of about 62,500 plants per hectare. During both years, sixteen treatments (T_1 , ..., T_{16} ,) (Table 2) were applied at each of the five locations. The treatments were selected for the investigation based on the common maize production and fertilizer application practices of farmers in the Northern region and also based on the recommended fertilizer rates for maize production in Ghana.

Chemical analysis of the soil (0-30 cm) was conducted at the start of the experiment at the laboratory of the Soil Research Institute, Kwadaso, Kumasi using chromic acid oxidation method for organic carbon [19], Bray's method for available P [20], neutral ammonium acetate of 1 M with the help of a flame photometer to determine available and exchangeable K [21], Kjeldahl method for total N, exchangeable Ca and Mg were determined by the EDTA titration method [22], and soil pH using a calibrated pH meter of two buffer solutions [20].

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104 **Table 1: Research treatments**

Treatment #	Treatment description per acre*	23-10-05 NPK (kg/ha)	15:15:15 NPK (kg/ha)	Sulphate of ammonia (kg/ha)	3.66% N: 1.32% P: 0.66% K Poultry manure (t/ha)	Nutrient equivalent (kg/ha)			Nutrient equivalent (kg/ha)		
						N	P	K	N	P ₂ O ₅	K ₂ O
T ₁	Control - No fertilization	0	0	0		0	0	0	0	0	0
T ₂	100 kg of 23-10-5 + 50 kg of S/A	250	0	125		84	25	13	84	57	15
T ₃	100 kg of 23-10-5 + 100 kg of S/A	250	0	250		110	25	13	110	57	15
T ₄	100 kg of 15-15-15 + 50 kg of S/A	0	250	125		64	38	38	64	86	45
T ₅	100 kg of 15-15-15 + 100 kg of S/A	0	250	250		90	38	38	90	86	45
T ₆	100 kg of 23-10-5 + 50 kg of S/A + Poultry manure	250	0	125	4.0	230	78	39	230	178	47
T ₇	100 kg of 15-15-15 + 50 kg of S/A + Poultry manure	0	250	125	4.0	210	90	64	210	207	77
T ₈	75 kg of 23-10-5 + 50 kg of S/A + Poultry manure	187.5	0	125	4.0	216	72	36	216	164	43
T ₉	75 kg of 15-15-15 + 50 kg of S/A + Poultry manure	0	187.5	125	4.0	201	81	55	201	185	65
T ₁₀	50 kg of 23-10-5 + 50 kg of S/A	125	0	125		55	13	6	55	29	8
T ₁₁	50 kg of 23-10-5 + 50 kg of 23N-10P-5K	250	0	0		58	25	13	58	57	15
T ₁₂	100 kg of 23-10-5 + 50 kg of 23N-10P-5K	375	0	0		86	38	19	86	86	23
T ₁₃	50 kg of 15-15-15 + 50 kg of S/A		125	125		45	19	19	45	43	23
T ₁₄	50 kg of 23-10-5 + 50 kg of S/A + Poultry manure	125	0	125	4.0	201	65	33	201	150	39
T ₁₅	50 kg of 15-15-15 + 50 kg of S/A + Poultry manure	0	125	125	4.0	201	72	45	201	164	54
T ₁₆	50 kg of S/A only	0	0	125		26	0	0	26	0	0

105 Acre* = 0.4 ha S/A = Sulphate of Ammonia N = Nitrogen P = Phosphorus K = Potassium
106 T₅ is the current recommended fertilizer rate for maize production in Ghana
107
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109 Land preparation was done by ploughing, followed by spraying the field with Sarosate [a.i
110 glyphosate 360 g/l in the form of 480 g/l isopylamine salt of soluble liquid (SL)] to kill any
111 surviving weeds on the field; and alligator 400 EC (a.i. Pendimethaline 400 g/l; EC) as pre-
112 emergence herbicide immediately after planting.

113 Poultry manure was evenly spread on treatment respective plots and thoroughly incorporated into
114 the soil with a hoe, seven days before planting. Three seeds were planted per hill using a dibbler.
115 Seedlings were thinned to two plants per hill before fertilizer application. In both years, planting
116 was done under rain-fed conditions. Manual weeding was done before top dressing (2nd fertilizer
117 application) when weeds appeared. This helped to loosen the soil and to earthen up around the
118 base of the plants. Weeds that appeared subsequently were hand-picked as and when necessary.
119 Compound fertilizers were applied within the first two weeks after planting depending on the
120 available soil moisture. Application of sulphate of ammonia as topdressing was done 4 weeks
121 after planting.

122 Plant heights were measured at 30 and 60 DAP from the ground level to the tip of the plant and
123 at harvest from the ground level to the point of the flag leaf using a graduated wooden meter bar.
124 Ten plants from the central rows in each plot were randomly selected and measured. Yield data
125 was collected from the five (5) central rows of each plot at physiological maturity. Number of
126 crops harvested from the 5 central rows were counted and recorded.

127 The Harvest Index (HI) was calculated by dividing grain yield (Economic yield) by the total
128 biological yield.

129 The NUE was calculated using the formula described by [14] as follows:

$$\text{NUE} = \frac{Y_N - Y_0}{N} \times 100$$

131

132 Where Y_N is the grain yields (kg/ha) with applied nitrogen, Y_0 is the yield obtained without
 133 nitrogen application (the averaged control yield), and N is the amount of nitrogen applied (kg/ha)
 134 in the particular treatment. NUE is, therefore, the increase in grain yield per kilogram nitrogen
 135 applied.

136 Statistical analysis was done using Minitab v16.2.4.4 statistical package employing a two-sample
 137 t-test procedure. Mean grain yield was adjusted for by number of plants harvested, number of
 138 cobs harvested, cob diameter, cob length, and plant height at harvest.

139 3.1 **RESULTS**

140 3.2 **Soil analysis**

141 Results of the soil analysis at the five locations as presented in Table 2 indicated that the soils at
 142 the various sites are largely sandy loam except at Kanpong that falls in the loamy soil
 143 characterization. The soils at the locations showed significant ($P < 0.01$) differences in respect of
 144 all the soil properties analyzed except for exchangeable K ($P = 0.579$) and exchangeable Na ($P =$
 145 0.718). The pH of the soils ranged from moderately acidic at Adamupe to slightly acidic at
 146 Mognegu and neutral at Kanpong, Bugyakura, and Bidribombe [23].

147 **Table 2: Soil characteristics of research locations**

Location	Soil type	Soil pH	Organic Matter (%)	Total Nitrogen (%)	Available P (ppm)	Exchangeable Bases (cmol/kg)					Base Saturation	Exch. Acidity
						K	Ca	Mg	Na	ECEC		
Bidribombe	Sandy loam	6.55 ^b	1.69 ^{ab}	0.09 ^b	4.73 ^b	0.15 ^a	4.11 ^a	1.69 ^a	0.10 ^a	6.15 ^b	98.30 ^a	0.10 ^d
Mognegu	Sandy loam	6.38 ^c	1.84 ^a	0.10 ^a	5.53 ^b	0.21 ^a	4.47 ^a	1.95 ^a	0.11 ^a	6.92 ^a	97.24 ^b	0.19 ^a
Kanpong	Loam	6.73 ^a	1.15 ^c	0.07 ^c	4.81 ^b	0.20 ^a	2.97 ^b	1.27 ^b	0.13 ^a	4.69 ^c	97.16 ^b	0.13 ^c
Adamupe	Sandy loam	5.94 ^d	1.64 ^b	0.08 ^b	6.69 ^a	0.20 ^a	2.31 ^c	1.69 ^a	0.12 ^a	4.48 ^c	96.27 ^c	0.16 ^b
Bugyakura	Sandy loam	6.56 ^b	1.14 ^c	0.07 ^c	3.23 ^c	0.13 ^a	3.45 ^b	1.06 ^b	0.07 ^a	4.88 ^c	96.17 ^c	0.17 ^{ab}
P- Value	-	0.000	0.000	0.000	0.000	0.579	0.000	0.000	0.718	0.000	0.000	0.000

148
149 Means that do not share a letter are significantly different

150 **RESULTS**

151 **3.3 Plant height**

152 Treatments significantly (P = 0.0001) influenced plant height at various growth stages. Beyond 60 DAP, all treatments increased
153 marginally except that of T16 which recorded significant increase of 25 cm. Consistently, Treatments T₁₆ and T₁ recorded the shortest
154 plant heights throughout the growth period (Table 3).

The difference in plant height between plants of Treatments T₁ and T₁₆ were not significant ($P > 0.05$) at 30 and 60 DAP but otherwise ($P < 0.05$) at harvest. The poultry manure-treated plots (T₆, T₇, T₈, and T₉,) supported tallest plant heights during the growth period. The differences in plant heights between the poultry manure treatments at all the growth stages were not significant ($P > 0.05$).

Table 3: Effect of treatments on plant height

Treatments	Plant height (m)		
	Days After Planting (DAP)		
	30	60	110
T ₁	0.63	1.37	1.49
T ₂	0.78	1.78	1.93
T ₃	0.9	1.89	1.95
T ₄	0.93	1.9	1.94
T ₅	0.88	1.91	1.98
T ₆	0.95	2.05	2.10
T ₇	0.99	2.06	2.12
T ₈	0.96	2.06	2.07
T ₉	0.95	2.04	2.15
T ₁₀	0.81	1.89	2.02
T ₁₁	0.87	1.87	1.98
T ₁₂	0.83	1.83	1.97
T ₁₃	0.85	1.75	1.95
T ₁₄	0.91	1.9	2.00
T ₁₅	0.88	1.8	1.93
T ₁₆	0.71	1.49	1.74
<i>P-Value</i>	<i>0.000</i>	<i>0.000</i>	<i>0.000</i>
n	15	15	15
SEM	0.04	0.06	0.04

Values are least square means $\pm$ SEM

3.4 Grain yield

All the treatments that included poultry manure (T_6 , T_7 , T_8 , T_9 , T_{14} , and T_{15}) produced significantly ($P < 0.0001$) higher grain yield than the rest of the treatments without poultry manure (Table 4). The pooled results indicated that T_6 produced the highest grain yield (2591.85 kg/ha) whilst T_{10} recorded the least grain yield of 1887.87 kg/ha. Treatment difference among the poultry manure treatments were not significant ($P > 0.05$).

[T6 and T7 application differ from T15 and T16](#)

3.5 Harvest Index (H. I.)

Treatments significantly ($P < 0.0001$) affected H. I. with poultry manure treatments recording significantly ($P < 0.0001$) greater H. I. compared to the other treatments, but the integrated treatment effects were not statistically different from each other. The performance of T_1 and T_{16} were not statistically different (Figure 1).

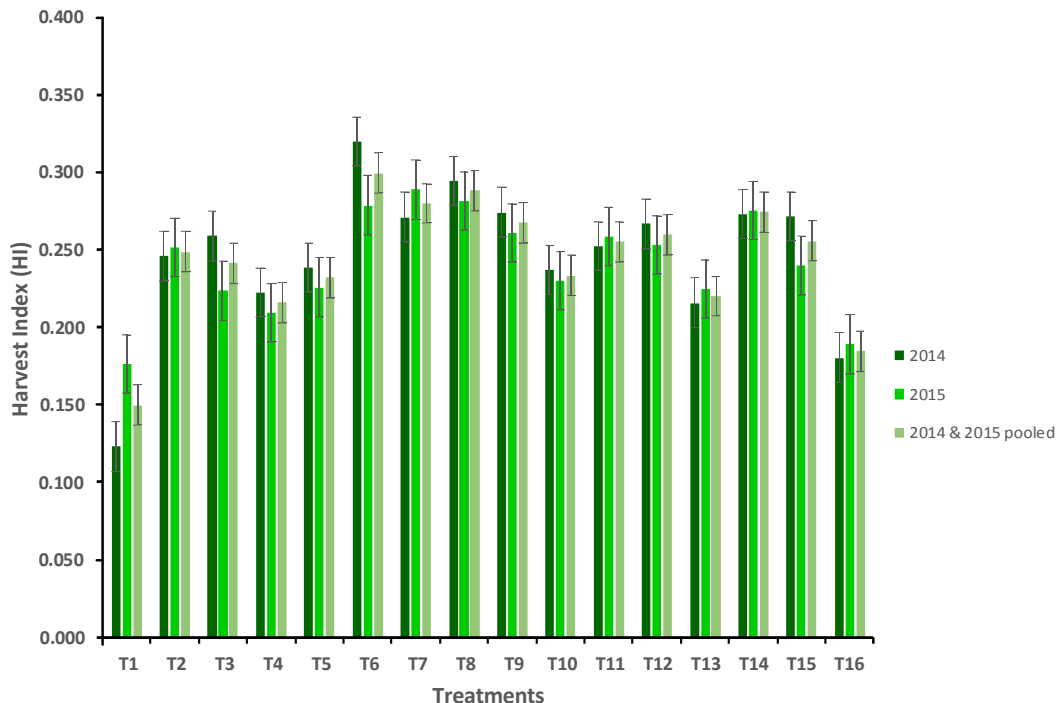


Figure 1: Effect of treatment on Harvest Index (H. I.)

Values represent least square means

Bars represent standard error of the means

179 **Table 4: Effect of Treatments on grain yield**

Treatment	Grain Yield (kg/ha)						% variation in grain yield (kg/ha)
	2014 & 2015 pooled	SEM*	2014	SEM	2015	SEM	
T ₁	2117.78 ^{bc}	± 91.59	1693 ^{de}	± 137.74	1967 ^{cdef}	± 136.73	16.18
T ₂	2002.71 ^c	± 68.74	1981 ^{cde}	± 111.42	2020 ^{def}	± 99.31	1.97
T ₃	2144.44 ^{bc}	± 68.89	2043 ^{bcde}	± 107.15	2186 ^{bcdef}	± 100.43	7.00
T ₄	1953.89 ^c	± 68.64	1866 ^{cde}	± 105.04	1965 ^{ef}	± 99.99	5.31
T ₅	1990.51 ^c	± 68.55	2041 ^{bcde}	± 105.74	1961 ^{ef}	± 99.73	-3.92
T ₆	2591.85 ^a	± 71.58	2668 ^a	± 107.85	2766 ^a	± 104.37	3.67
T ₇	2443.70 ^{ab}	± 72.40	2543 ^{ab}	± 109.65	2512 ^{abcd}	± 108.04	-1.22
T ₈	2559.34 ^a	± 71.85	2650 ^a	± 110.95	2656 ^{ab}	± 106.57	0.23
T ₉	2412.63 ^{ab}	± 71.30	2533 ^{ab}	± 107.32	2526 ^{abc}	± 104.67	-0.28
T ₁₀	1887.87 ^c	± 69.11	1875 ^{cde}	± 107.14	1947 ^{ef}	± 99.79	3.84
T ₁₁	1924.80 ^c	± 68.70	1825 ^{de}	± 104.76	1986 ^{ef}	± 99.54	8.82
T ₁₂	2147.24 ^{bc}	± 68.80	2225 ^{abcd}	± 106.20	2132 ^{cdef}	± 99.90	4.18
T ₁₃	1927.35 ^c	± 68.62	1893 ^{cde}	± 106.93	1839 ^f	± 100.39	-2.85
T ₁₄	2366.71 ^{ab}	± 69.70	2357 ^{abc}	± 106.48	2422 ^{abcde}	± 101.08	2.78
T ₁₅	2153.84 ^{bc}	± 68.92	2187 ^{abcde}	± 107.50	2224 ^{bcdef}	± 100.65	1.69
T ₁₆	1919.86 ^c	± 72.22	1660 ^e	± 114.18	1941 ^{cdef}	± 119.50	16.93
<i>P-value</i>	<i>0.000</i>		<i>0.000</i>		<i>0.000</i>		
<i>n</i>	<i>30</i>		<i>15</i>		<i>15</i>		

180 Values are least square means.

181 Means that do not share a letter within a column are significantly different

182 * SEM = Standard Error of the Means

183 Mean grain yield was adjusted for by number of plants harvested, number of cobs harvested, cob diameter, cob length, and plant height at harvest

3.6 Nitrogen Use Efficiency (NUE)

Kanpong recorded the highest NUE of 19.3 kg. This was statistically similar to Bidribombe (18.75 kg) and Adamupe (18.41 kg) values but significantly ($P < 0.0001$) higher than at Bugyakura (15.32 kg) and Mognegu (4.27 kg), which recorded the least efficiency.

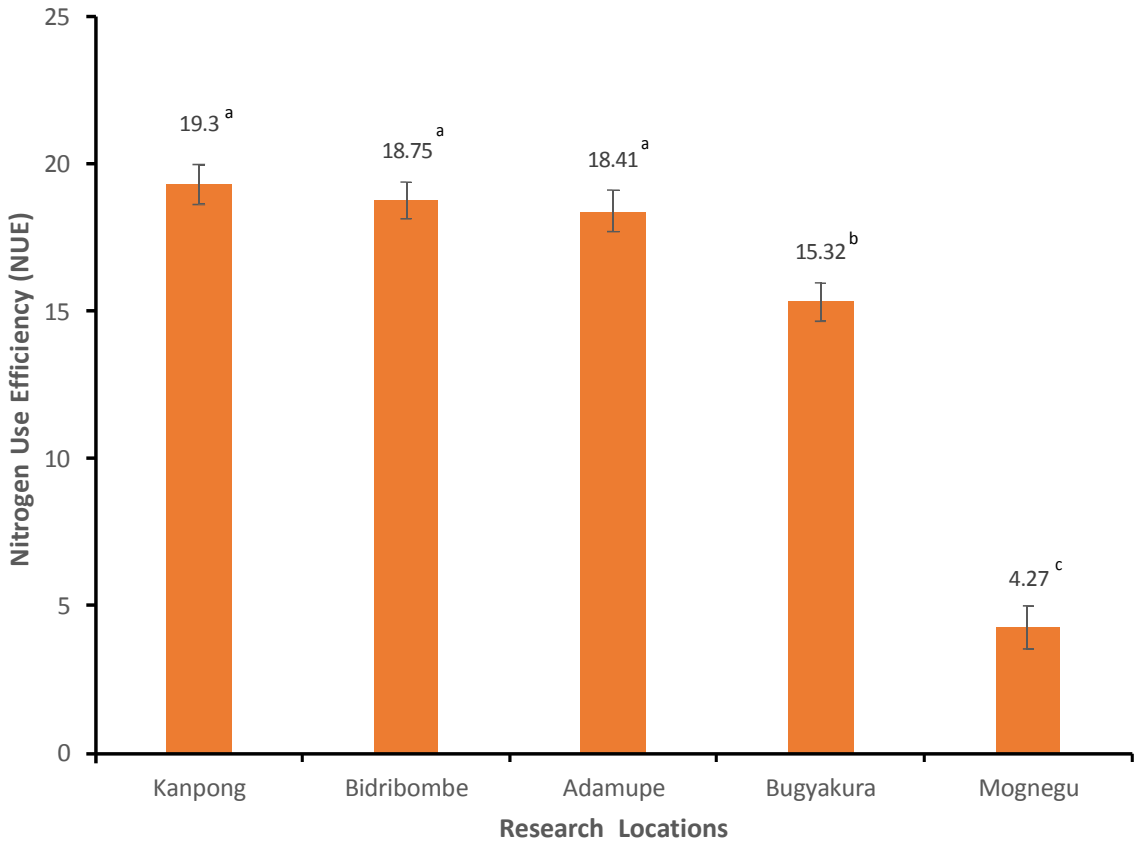


Figure 2: Nitrogen Use Efficiency at various locations

Values are least square means

Bars represent standard error of the means

Means that do not share a letter are significantly different

Table 5: NUE of various treatments

Treatment	NUE	SEM*
T₂	18.57 ^{cd}	± 1.11
T₃	14.71 ^d	± 1.10
T₄	22.62 ^{bc}	± 1.12
T₅	17.58 ^{cd}	± 1.11
T₆	2.14 ^f	± 1.17
T₇	3.43 ^{ef}	± 1.16
T₈	2.79 ^{ef}	± 1.17
T₉	4.71 ^{ef}	± 1.14
T₁₀	25.41 ^{ab}	± 1.12
T₁₁	26.05 ^{ab}	± 1.11
T₁₂	18.52 ^{cd}	± 1.10
T₁₃	30.38 ^a	± 1.12
T₁₄	5.74 ^{ef}	± 1.12
T₁₅	7.97 ^e	± 1.10
T₁₆	27.50 ^{ab}	± 1.24
<i>P</i>-value	0.000	
<i>N</i>	30	

Means that do not share a letter are significantly different

* SEM = Standard Error of the Means

The greatest and the least NUEs were recorded by T₁₃ and T₆, respectively (Table 5).

Generally, integrated nutrient treatments recorded lower NUE. The NUE was significantly ($P < 0.0001$) lower in 2015 than in 2014 (Figure 3).

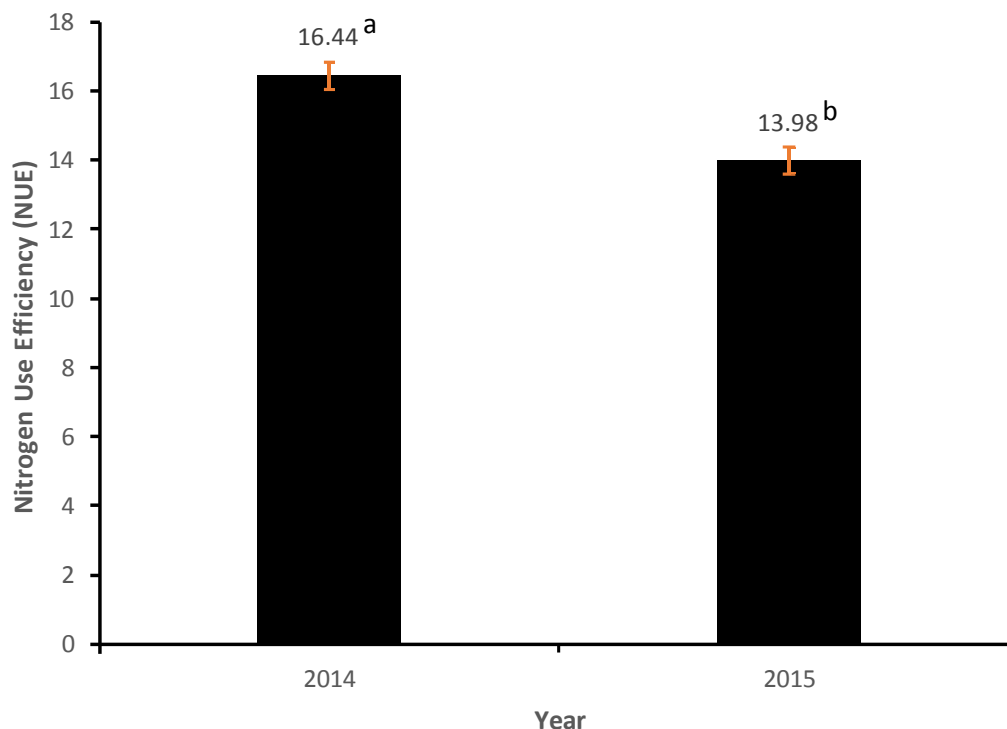


Figure 3: Nitrogen Use Efficiency (NUE) in 2014 and 2015

Values are least square means

Bars represent standard error of the means

Means that do not share a letter are significantly different

3.7 Interaction Effects on Nitrogen Use Efficiency (NUE)

Community and treatments interaction as well as treatments and year interaction did not significantly ($P = 0.506$ and $P = 0.849$, respectively) affect the NUE. Community and year interaction, however, affected NUE significantly ($P = 0.001$) (Table 6).

Table 6: Location and year interaction effect on Nitrogen Use Efficiency at the different research locations

Location	Year				% Decline in NUE
	2014	SEM*	2015	SEM	
Bidribombe	18.85 ^a	± 0.90	18.64 ^a	± 0.90	1.11
Mognegu	7.95 ^c	± 1.04	0.59 ^d	± 0.94	92.58
Kanpong	20.09 ^a	± 0.92	18.51 ^a	± 0.95	7.86
Adamupe	18.70 ^a	± 0.93	18.12 ^{ab}	± 0.94	3.10
Bugyakura	16.61 ^{ab}	± 0.91	14.02 ^b	± 0.96	15.59
<i>P- value</i>	0.001		0.001		-
<i>n</i>	48				

Values are least square means.

Means that do not share a letter are significantly different

* SEM = Standard Error of the Means

The NUE at Mognegu was significantly ($P = 0.001$) the lowest in 2014 and 2015 and recorded highest decline of 92.58% from 2014 to 2015.

4.1 DISCUSSION

4.2 Soil Analysis

Analysis of the soils at the various locations indicated that the soils vary significantly from one another in their soil properties. This means that application of the same nutrient management practices at all the locations will not yield the same results. Fertilizer recommendation and nutrient management practices should, therefore, be location specific. The sandy nature of the soils with low organic matter content at the locations means that the soils would generally be susceptible to leaching and nutrient loss without proper soil management practices.

The pH of the soils at all the locations ranging between 5.94 and 6.73 indicates that the soils are mildly acidic, which can support cultivation of many crops. This is because plants generally prefer soils that have pH close to either side of neutrality as most nutrients are available in the

pH range of 5.5 – 6.5 [20]. The pH range recorded will also promote soil microbial population and activity. The relatively low soil pH of the soils at Adamupe (5.94) and Mognegu (6.38) as compared to the pH levels at Kanpong, Bugyakura, and Bidribombe could be attributed to leaching of bases and continuous application of sulphate of ammonia at the two sites in previous cropping seasons. According to [24], application of ammonium sulphate fertilizer tends to leave a slight acidic residue after the cropping season in most of the soils in the Guinea Savannah Agro ecological Zone (GSAZ). The soil pH and organic matter content of the soils at the research locations are within the ranges reported by [25]. The percent total N content (0.07 – 0.10) of the soils at the locations being higher than the reported range (0.02-0.05) for soils in the Northern region could be attributable to favourable pH recorded at the sites which promotes microbial activities and ensures nutrient availability. Even though the Exchangeable Cation Exchange Capacity (ECEC) at the different locations showed significant differences, the levels were low. The low levels is attributable to the low clay and organic matter content of the soils. This means that the soils can retain less cations. The low levels was, however, not expected to pose any aluminum toxicity or soil acidity problem because the exchangeable acidity levels were also low. Generally, Mognegu recorded the highest values in most of the soil properties analysed (organic matter, N, K, Mg, and ECEC) and second to Adamupe in the case of P. It can, therefore, be concluded that Mognegu was the most fertile site which was expected to support improved crop growth and yield than the other sites *ceteris paribus*.

4.3 Plant height

Plant height is an indicator of vegetative growth. The consistently higher than 175 cm maize plant height recorded by all the treatments except for T₁ and T₁₆ across the five (5) locations means that the various treatments provided the right nutrients to stimulate good vegetative

growth. Conversely, the shorter plants recorded by T₁ and T₁₆ is an indication that both failed to supply adequate plant nutrients for good plant growth. This means that even though the soils at the locations had higher total N content (0.07 – 0.10) than the reported range (0.02-0.05) for soils in the Northern region, the levels were still not enough to promote good vegetative growth. In 2005, [3] recorded average (potential) plant height of 175 cm for Obatanpa maize variety from across 8-10 trial stations. This suggests that given proper nutrition, Obatanpa can grow taller than 175 cm.

The significantly taller maize plants recorded by the integrated (poultry manure and inorganic fertilizers) plots (T₆, T₇, T₈, T₉, T₁₄, and T₁₅) irrespective of the levels and types of inorganic fertilizers applied, means that the poultry manure helped the plant to make efficient use of the nutrients supplied by the inorganic fertilizers. The findings agree with [26] who reported significant increases in the growth parameters of chili crop (*Capsicum annum* L.), and [27] who also reported significant increase in agronomical attributes of *Solanum melongena* L. with the application of integrated nutrients. The fact that the integrated plots did not significantly differ from one another is a demonstration that once poultry manure is applied to maize at a rate of 4 t/ha, application of the recommended compound fertilizer rate of 250 kg/ha NPK can be reduced to 187.5 kg/ha and still achieve optimum maize plant height.

The consistently shorter and slender plants produced by the control (T₁) confirms the fact that plant nutrients are necessary for plant growth [28, 29] and that insufficient plant nutrients are responsible for limiting crop growth [27]. The results, undoubtedly, confirm the need for maize fertilization in the Northern region of Ghana. This is further confirmed by the fact that T₁₆ plants which received only topdressing with 125 kg/ha of sulphate of ammonia at 4-6 weeks after planting recorded significantly taller plants after the application of the ammonia.

4.4 Grain yield

Generally, the maize grain yields was influenced significantly by the various treatments of the inorganic and organic fertilization. The consistently lower grain yields recorded by T₁ (control – no fertilization) and T₁₆ (application of 125 kg of Sulphate of Ammonia only) is attributed to inadequate nutrition. Nutrient deficiencies have been reported to cause changes in physiological and biochemical processes that result in growth retardation, delayed development as well as qualitative and quantitative yield reduction [30]. This was observed in the field as the T₁ plants looked stunted with yellowish coloration, an indication of nitrogen deficiency. Nitrogen is important for the synthesis of protein and nucleic acid and an essential constituent of other compounds needed for plant growth processes such as chlorophyll and many enzymatic processes [31]. It affects growth negatively when it is sub-optimal [32]. Even though T₁₆ appeared better than T₁, both effects were statistically similar. This demonstrates that application of 125 kg/ha of S/A to maize at the latter growth stage was inadequate and uneconomical. It further implies that adequate and timely application of nutrients is critical to ensure good plant growth and yield and that delayed application could cause nutrient deficiencies and irreversible damage. The result is consistent with CSIR-SARI (1996) and [24] who reported that maize grain yields in the GSAZ of Ghana are low and uneconomical when cultivated without fertilizers.

The consistently higher grain yields recorded by the application 250 kg/ha 23-10-05-NPK and 125 kg/ha Sulphate of Ammonia (T₂) as compared to the same rate of 15-15-15 NPK plus the sulphate of ammonia (T₄) can partly be explained by the higher levels of N in 23-10-05 NPK than 15-15-15 NPK that resulted in greener coloration and chlorophyll development in the maize crops and therefore higher production of assimilates which eventually resulted in higher grain and biomass yield. Addition of 4 t/ha of poultry manure to the inorganic rates in T₆ and T₇,

307 respectively further improved the grain yields and the trend was similar with T₆ performing better
308 than T₇. The trend is a demonstration that application of the inorganic fertilizers alone failed to
309 meet the nutrient requirements of the maize plants. The improved yields obtained from T₆ and T₇
310 as compared to the chemical fertilizer alone rates in T₂ and T₄, respectively, could also be due to
311 the poultry manure that enhanced soil available nitrogen, phosphorus, and potassium as was
312 observed by [33]. Besides the high N contributed by 23-10-05 and the poultry manure, the
313 presence of Zn in 23-10-05 and Fe and Zn in the poultry manure may have played
314 complementary role in ensuring proper functioning of the plant metabolism [27]. Zn is
315 considered one of the most deficient micronutrient in the soil but maize is noted to be sensitive to
316 Zn deficiency [20]. Besides supplying N, P, and K and other micronutrients, organic sources are
317 also noted to make available the unavailable sources of elemental nitrogen, bound phosphates,
318 micronutrients and decomposed plant residues to aid absorption of nutrients by the plants [34,
319 35].

320 The significantly improved grain yields recorded by treatments that included poultry manure (T₆,
321 T₇, T₈, T₉, T₁₄, and T₁₅) confirms the observation by [28], [36] and [37] that increased
322 application of organic and inorganic fertilizers in developing countries could enhance the
323 environment and increase crop yields. The results also agrees with the view expressed by [38]
324 that unless farmers in the GSAZ of Ghana ameliorated their soils, maize production was not
325 profitable and sustainable. The improved yields of the integrated poultry manure and inorganic
326 fertilizer fields can be attributed to the additional and balanced plant nutrients supplied and
327 ameliorating effects of the poultry manure which helped to increase number of cobs per plant.
328 The poultry manure supplied additional macro and micro nutrients which improved crop growth,
329 stover yield, and general crop performance. The poultry manure also assisted in improving the

soil physical conditions by acting as a binding agent that helped in binding the soil particles and improving in water retention, aeration, and nutrient availability. This contributed to better performance even in 2015 when total rainfall was low. Elsewhere, other researchers [39, 40, 41, and 42] who demonstrated with various soil amendments observed improved yields and productivity of various crops under water-stressed conditions.

The grain yield recorded by all the treatments, however, fell below the 4.6 t/ha average (potential) grain yield of Obatanpa reported by [3]. The yield variations could be attributed to differences in soil fertility, climatic conditions, and other environmental factors. This further confirms that with the gradual depletion of soil nutrients and the changing climate over the years, the recommended fertilizer rate of 90-38-38 kg/ha NPK is no longer tenable as even the higher rates above this rate failed to achieve the potential grain yield.

4.5 Nitrogen Use Efficiency

The Nitrogen Use Efficiency (NUE) varied significantly at the different locations because the inherent Nitrogen levels of the soils differed from each other. The soils with lower fertility recorded the highest NUE indicating that better responses are obtained from application of Nitrogen when the soil is poor in fertility. The higher NUE recorded at Kanpong means that application of N at Kanpong was more efficient than at all the other locations and the high responsive yields to N use at the location can be attributed to the lower soil fertility status as compared to the more fertile locations particularly Mognegu. Likewise, the significantly low NUE recorded at Mognegu is attributed to the higher initial total N and organic matter status in the soil.

The general decline in NUE from 2014 to 2015 is attributable to the residual effect of the treatments applied in 2014 which might have further improved the N content of the soil thereby

reducing the efficiency of the N applied in 2015. Again, the general low rainfall recorded in 2015 might have affected N uptake from soil and the ability of the crop to make efficient use of all the applied N for growth and production of crop harvests. This agrees with [43] who reported reduction in morpho-physiological and biochemical attributes of maize when maize experienced drought conditions at tasseling stage. The findings is also in line with [13] who recorded higher nitrogen use efficiencies with maximum irrigation.

Failure of treatments and location interaction as well as treatments and year interaction to significantly influence NUE means that irrespective of the location or the year of application, a particular treatment will produce the same efficiency *ceteris paribus*. However, the significance of location and year interaction effect on NUE is explained by the differences in the amount of reduction in rainfall at the various locations and the growth stage of the crop during which the water deficit occurred. According to [44] and [43] the negative effect of water deficit on maize production is more pronounced during reproductive stages.

5.0 CONCLUSION

The integrated treatments (T₆, T₇, T₈, T₉, T₁₄, and T₁₅) performed better in respect of plant growth, grain yield, and harvest index than treatments that involved application of only inorganic fertilizers. Even halving the quantities of the current recommended fertilizer rates and combining with 4 t/ha of poultry manure (T₁₅) yielded better results. The 23-10-05 NPK compound fertilizers resulted in superior yields and general performance than 15-15-15 NPK fertilizer in all combinations.

Nitrogen Use Efficiency (NUE) decreased with continuous application of fertilizers and manures and increased soil fertility. Fertilizer application should therefore take into consideration inherent

fertility of the soil. The results of the research underscore the need to promote integration of inorganic and organic fertilizers to promote maize production in the GSAZ of Ghana. It also emphasizes the need for the government to introduce interventions such as fertilizer subsidy programmes that make both organic and inorganic fertilizers available to smallholder maize farmers at affordable rates. Fertilizer subsidy programmes should therefore not be limited to inorganic fertilizers to promote integrated nutrient management.

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