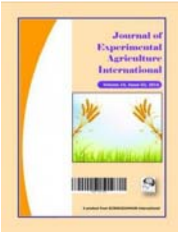

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Nitrogen Use Efficiency and Maize Productivity in the Guinea Savanna Agro-ecological Zone of Ghana

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Authors' contributions

This work was carried out in collaboration between all authors. Author IKB designed the study, wrote the protocol, carried out the field work, managed the literature searches and wrote the first draft of the manuscript. Authors IKB and FKA performed the statistical analyses of the study. All authors monitored the field work, read, and approved the final manuscript.

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ABSTRACT

Blanket fertilizer recommendation for maize (*Zea mays,* L.) production in Ghana was made in the 1960s. Due to changes in soil fertility and for economic reasons, farmers are adopting different fertilizer rates and in various combinations to produce maize. The efficiency of the applications and effect on maize productivity have been rarely investigated. The objective of the study was therefore to investigate maize productivity and the nitrogen use efficiency of the current recommended fertilizer rate for maize production and other rates and combinations of synthetic and organic fertilizers being applied by farmers in the Guinea Savanna Agro-ecological Zone (GSAZ) of Ghana. On-farm research was conducted at five locations during 2014 and 2015 cropping seasons. The fields were laid out in a Randomized Complete Block Design with 16 treatments in three replications. The treatments consisted of the control (T_1), eight synthetic fertilizer treatments alone (T_2, T_3, T_4, T_5, T_{10}, T_{11}, T_{12}, and T_{13}), six integrated treatments (T_6, T_7, T_8, T_9, T_{14}, and T_{15}), and T_{16} which involved the application of only Sulphate of Ammonia as top dressing. The combined application of poultry manure and synthetic fertilizer recorded significantly ($P < 0.05$) higher maize

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grain yields of 2.15 – 2.76 t/ha. Treatments that involved the combined application of synthetic fertilizers and poultry manure recorded the least Nitrogen Use Efficiency (NUE) values with T_6 recording the lowest figure of 2.14±1.17. NUE was lower for synthetic + organic treatments because the total N was much higher for these treatments resulting in increased yields but at a decreasing rate. The NUE was significantly lower in 2015 than in 2014. Kanpong and Mognegu significantly ($P < 0.05$) recorded the highest (19.3±0.68) and lowest (4.27±0.75) NUE, respectively. Optimum maize grain yield can be obtained through the application of integrated nutrient management in the GSAZ of Ghana.

Keywords: Nitrogen use efficiency; nutrient management; productivity; northern region; Ghana; guinea savanna agro-ecological zone; maize; poultry manure.

1. 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 [3]. 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]. The national consumption of maize in Ghana was estimated at 1.96 million MT in 2017/2018 [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. While there is no reliable data for corn used in animal feed, the government of Ghana (GOG) estimates that 15% (270,000 MT) of all corn grown in 2017/2018 in Ghana was used in the animal feed sector (mainly poultry) [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 a 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.

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

2. 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 Bugyakura, respectively. Soils in the locations fall in the Mimi, Kpelesawgu-changnalili, Sambu-pasga soil Associations and are classified by FAO as Planosols, Lixisols, and Pinthosols, respectively as presented in Table 1

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 was 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], Kjedahl 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].

Land preparation was done by ploughing, followed by spraying the field with Sarosate [a.i glyphosate 360 g/l in the form of 480 g/l isopylamine salt of soluble liquid (SL)] to kill any surviving weeds on the field; and alligator 400 EC (a.i. Pendimethaline 400 g/l; EC) as pre-emergence herbicide immediately after planting.

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

Table 1. Classifications of soils at the five research locations

#	District	Location	Soil associations	FAO classification
1.	Tatale Sanguli	Bidribombe	Kpelesawgu-changnalili	Lixisols
2.	Zabzugu	Mognegu	Sambu-pasga	Plinthosols
3.	Central Gonja	Kanpong	Kpelesawgu-changnalili	Lixisols
4.	East Gonja	Adamupe	Sambu-pasga	Plinthosols
5.	West Mamprusi	Bugyakura	Mimi	Planosols

Source: [23]

Table 2. Description of the 16 research treatments and their nutrient equivalents

Treatment #	Treatment description (kg/ha)	Nutrient equivalent (kg/ha)		
		N	P_2O_5	K_2O
T_1	Control - No fertilization	0	0	0
T_2	250 kg of 23-10-5 + 125 kg of S/A	84	25	13
T_3	250 kg of 23-10-5 + 250 kg of S/A	110	25	13
T_4	250 kg of 15-15-15 + 125 kg of S/A	64	38	38
T_5	250 kg of 15-15-15 + 250 kg of S/A	90	38	38
T_6	250 kg of 23-10-5 + 125 kg of S/A + 4000 kg Poultry manure	230	78	39
T_7	250 kg of 15-15-15 + 125 kg of S/A + 4000 kg Poultry manure	210	90	64
T_8	187.5 kg of 23-10-5 + 125 kg of S/A + 4000 kg Poultry manure	216	72	36
T_9	187.5 kg of 15-15-15 + 125 kg of S/A + 4000 kg Poultry manure	201	81	55
T_{10}	125 kg of 23-10-5 + 125 kg of S/A	55	13	6
T_{11}	125 kg of 23-10-5 + 125 kg of 23N-10P-5K	58	25	13
T_{12}	250 kg of 23-10-5 + 125 kg of 23N-10P-5K	86	38	19
T_{13}	125 kg of 15-15-15 + 125 kg of S/A	45	19	19
T_{14}	125 kg of 23-10-5 + 125 kg of S/A + 4000 kg Poultry manure	201	65	33
T_{15}	125 kg of 15-15-15 + 125 kg of S/A + 4000 kg Poultry manure	201	72	45
T_{16}	125 kg of S/A only	26	0	0

S/A = Sulphate of Ammonia; N= Nitrogen; P = Phosphorus; K = Potassium
Poultry manure composition = 3.66% N: 1.32% P: 0.66% K
T_5 is the current recommended fertilizer rate for maize production in Northern Ghana

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

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

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

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

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

Statistical analysis was done using Minitab v16.2.4.4 statistical package employing a two-sample t-test procedure. Mean grain yield was adjusted for by a number of plants and cobs harvested.

3. RESULTS

3.1 Soil Analysis

Results of the soil analysis at the five locations as presented in Table 3 indicated that the soils at the various sites were largely sandy loam except at Kanpong that falls in the loamy soil characterization. The soils at the locations showed significant ($P< 0.01$) differences in respect of all the soil properties analyzed except for exchangeable K ($P = 0.579$) and exchangeable Na ($P = 0.718$). The pH of the soils ranged from moderately acidic at Adamupe to slightly acidic at Mognegu and neutral at Kanpong, Bugyakura, and Bidribombe [23].

Table 3. Soil characteristics of the five research locations

Location	Soil type	Soil pH	Organic Matter (%)	Total Nitrogen (%)	Available P (ppm)	Exchangeable Bases (cmol/kg)				ECEC	Base Saturation	Exch. Acidity
						K	Ca	Mg	Na			
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**

Means that do not share a letter are significantly different

3.2 Plant Height

Treatments significantly (P = 0.0001) influenced plant height at various growth stages. Beyond 60 DAP, all treatments increased marginally except that of T_{16} which recorded significant increase of 25 cm. Consistently, Treatments T_{16} and T_1 recorded the shortest plant heights throughout the growth period (Table 4).

The difference in plant height between plants of Treatments T_1 and T_{16} were not significant (P > 0.05) at 30 and 60 DAP but otherwise (P < 0.05) at harvest. The poultry manure-treated plots (T_6, T_7, T_8, and T_9,) 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 4. Effect of treatments on plant height from 30 to 110 DAP

Treatments	**Plant height (m)**		
	Days After Planting (DAP)		
	30	**60**	**110**
T_1	0.63 ^{d}	1.37 ^{e}	1.49 ^{d}
T_2	0.78 ^{abcd}	1.78 ^{bc}	1.93 ^{bc}
T_3	0.9 ^{abcd}	1.89 ^{abc}	1.95 ^{ab}
T_4	0.93 ^{abcd}	1.9 ^{abc}	1.94 ^{bc}
T_5	0.88 ^{abcd}	1.91^{abc}	1.98 ^{ab}
T_6	0.95 ^{ab}	2.05 ^{a}	2.10 ^{ab}
T_7	0.99 ^{ab}	2.06 ^{a}	2.12 ^{ab}
T_8	0.96 ^{a}	2.06 ^{a}	2.07 ^{ab}
T_9	0.95 ^{ab}	2.04 ^{ab}	2.15 ^{a}
T_{10}	0.81 ^{abcd}	1.89 ^{abc}	2.02 ^{ab}
T_{11}	0.87 ^{bcd}	1.87 ^{abc}	1.98 ^{ab}
T_{12}	0.83 ^{abcd}	1.83 ^{abc}	1.97 ^{ab}
T_{13}	0.85 ^{bcd}	1.75 ^{cd}	1.95 ^{ab}
T_{14}	0.91 ^{abc}	1.9 ^{abc}	2.00 ^{ab}
T_{15}	0.88 ^{abcd}	1.8 ^{abc}	1.93 ^{bc}
T_{16}	0.71^{cd}	1.49 ^{de}	1.74 ^{c}
P-Value	***0.000***	***0.000***	***0.000***
n	**15**	**15**	**15**
SEM*	**0.04**	**0.06**	**0.04**

Values are least square means ± SEM
Means that do not share a letter are significantly different
** SEM = Standard Error of the Means*

3.3 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 6). 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. Differences among the poultry manure treatments were generally not significant (P > 0.05) except for the 2014 and 2015 pooled data where T_6, and T_8, differed significantly (P<0.05) from T_{15} and in 2015 where T_6 again differed from T_{15}. The mean grain yields for 2014 were generally lower than 2015 even though rainfall in 2015 was less.

There was significant (P < 0.0001) differences in grain yields among locations in 2014 and 2015 (Table 5). The pooled data of 2014 and 2015 did not, however, show significant differences among Mognegu, Adamupe, and Kanpong locations. Similarly, grain yields at Bidribombe, Kanpong, and Bugyakura were statistically similar. Grain yield obtained from Mognegu location was, however, significantly different from Bugyakura and Bidribombe locations.

3.4 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 diffferent (Fig. 1).

3.5 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.

The greatest and the least NUEs were recorded by T_{13} and T_6, respectively (Table 7).

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

3.6 Interaction Effects on Nitrogen Use Efficiency (NUE)

Location and treatments interaction as well as treatments and year interaction did not significantly (P = 0.506 and P = 0.849, respectively) affect the NUE. Location and year interaction, however, affected NUE significantly (P = 0.001) (Table 8).

Table 1. Comparative maize grain yield performances at the five locations in 2014 and 2015

Location	Grain yield (kg/ha)						% change in grain yield (kg/ha)
	2014 & 2015	**SEM***	**2014**	**SEM**	**2015**	**SEM**	
Bidribombe	1987.70[c]	54.10	1802.87 [d]	± 69.28	2172.53 [bc]	± 73.11	20.50
Mognegu	2336.78[a]	52.11	2628.21[a]	± 66.66	2045.35 [cd]	± 67.61	-22.18
Kanpong	2162.06[abc]	42.78	2183.17 [bc]	± 58.46	2140.94 [bc]	± 61.93	-1.93
Adamupe	2223.84[ab]	48.07	2229.68 [bc]	± 62.88	2218.00 [bc]	± 61.79	- 0.52
Bugyakura	2084.78[bc]	47.82	1787.89 [d]	± 59.43	2381.67 [ab]	± 66.66	33.21
P-value	***0.000***		***0.000***		***0.000***		
n	***96***		***48***		***48***		

*The values represent the least square means; Means that do not share a letter within 2014 & 2015 column and within the 2014 and 2015 columns are significantly (P < 0.0001) different; * SEM = Standard Error of the Means; Mean grain yield was adjusted for by number of plants and cobs harvested*

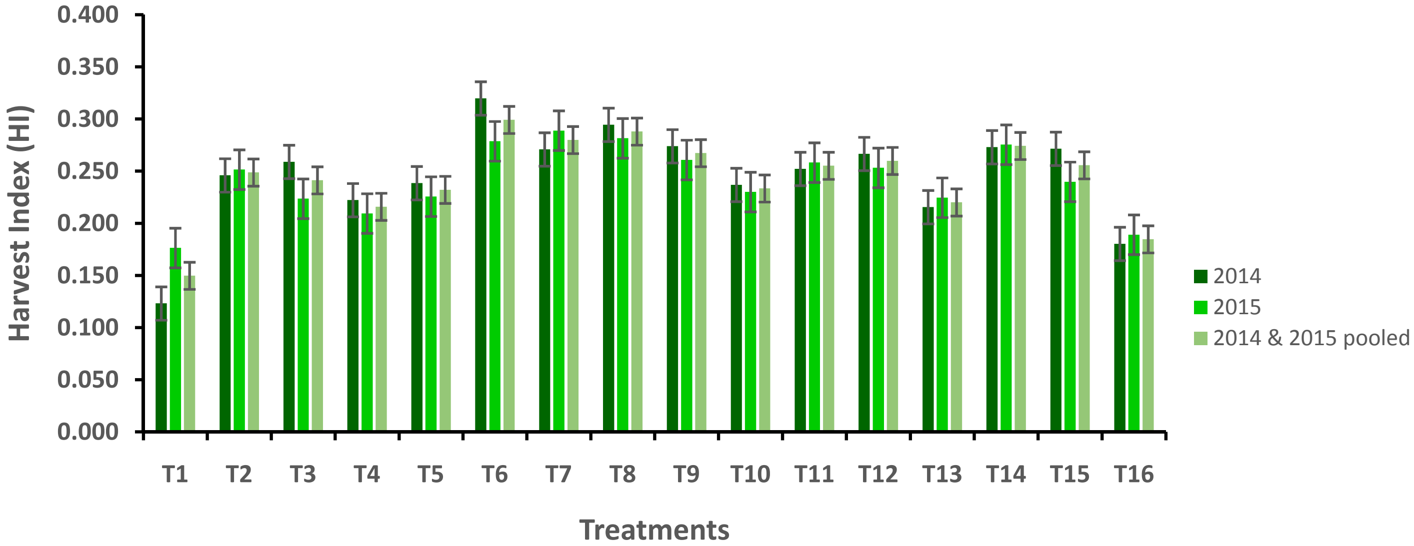

Fig. 1. Effect of treatment on Harvest Index (H. I.) of maize during 2014 and 2015 cropping seasons
Values represent least square means; Bars represent standard error of the means

Table 2. Effect of treatments on grain yield during 2014 and 2015 cropping seasons

Treatment	**Grain Yield (kg/ha)**						
	2014 & 2015 pooled	**SEM***	**2014**	**SEM**	**2015**	**SEM**	**% change in grain yield (kg/ha) from 2014 to 2015**
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
P-value	***0.000***		***0.000***		***0.000***		
n	***30***		***15***		***15***		

*Values are least square means; Means that do not share a letter within a column are significantly different; * SEM = Standard Error of the Means*
Mean grain yield was adjusted for by number of plants and number of cobs harvested

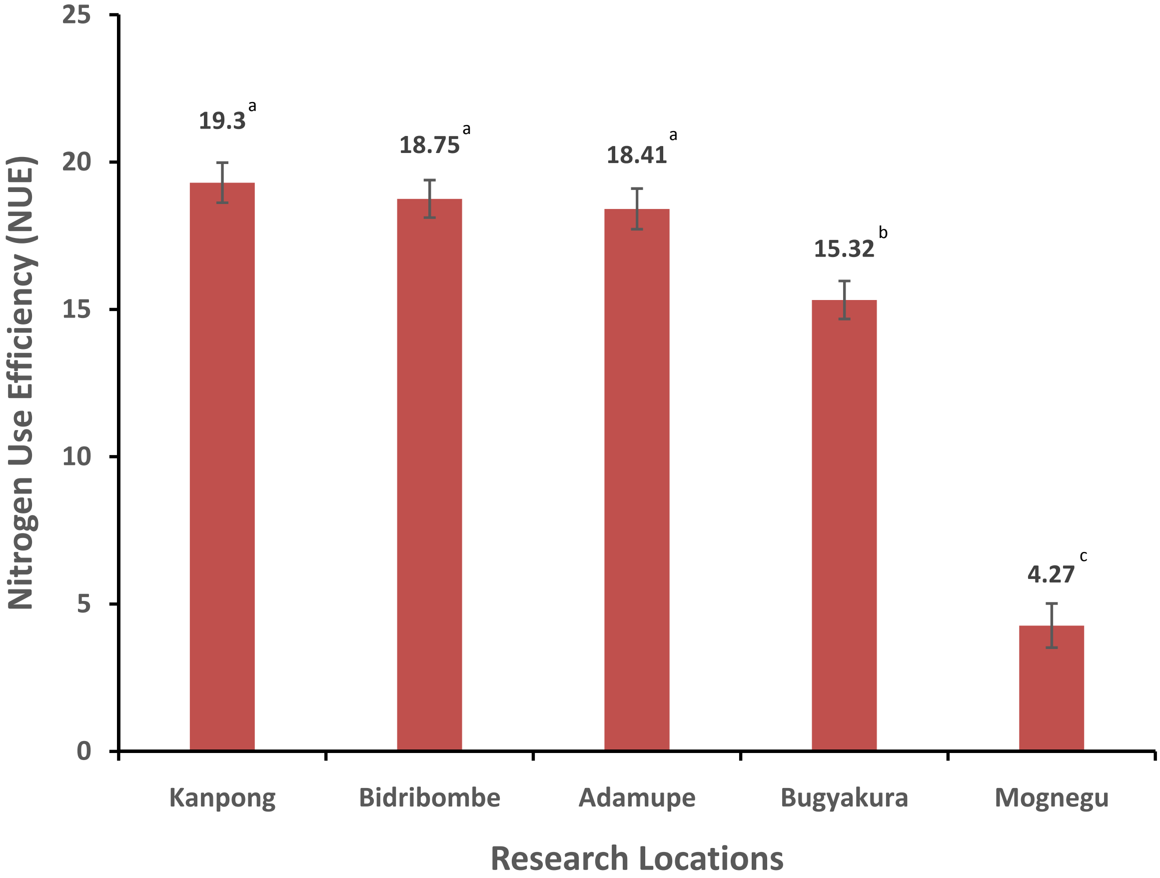

Fig. 2. Nitrogen use efficiency at five locations
Values are least square means
Bars represent standard error of the means
Means that do not share a letter are significantly different

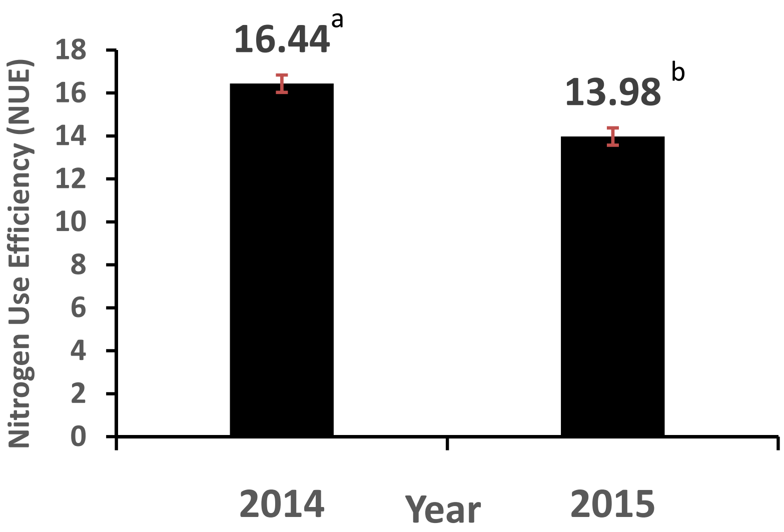

Fig. 3. Comparison of Nitrogen Use Efficiency (NUE) in 2014 and 2015
Values are least square means
Bars represent standard error of the means
Means that do not share a letter are significantly different

Table 7. Nitrogen use efficiency of 15 treatments compared with the control

Treatment	NUE	SEM*
T_2	18.57 [cd]	± 1.11
T_3	14.71 [d]	± 1.10
T_4	22.62 [bc]	± 1.12
T_5	17.58 [cd]	± 1.11
T_6	2.14 [f]	± 1.17
T_7	3.43 [ef]	± 1.16
T_8	2.79 [ef]	± 1.17
T_9	4.71 [ef]	± 1.14
T_{10}	25.41 [ab]	± 1.12
T_{11}	26.05 [ab]	± 1.11
T_{12}	18.52 [cd]	± 1.10
T_{13}	30.38 [a]	± 1.12
T_{14}	5.74 [ef]	± 1.12
T_{15}	7.97 [e]	± 1.10
T_{16}	27.50 [ab]	± 1.24
P- value	**0.000**	
n	**30**	

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. DISCUSSION

4.1 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 are attributable to the low clay and organic matter content of the soils. This means that the soils can retain less cations. The low levels were, however, not expected to pose any aluminum toxicity or soil acidity problem because the exchangeable acidity levels were also low.

Table 8. Location and year interaction effect on nitrogen use efficiency at the five research locations

Location	Year				% change in NUE from 2014 to 2015
	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
P- value	***0.001***		***0.001***		**-**
n	**48**				

Values are least square means.
*Means that do not share a letter are significantly different; * SEM = Standard Error of the Means*

Generally, Mognegu recorded the highest values in most of the soil properties analyzed (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*.

4.2 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 T_1 and T_{16} 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 T_1 and T_{16} 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 synthetic fertilizers) plots (T_6, T_7, T_8, T_9, T_{14}, and T_{15}) irrespective of the levels and types of synthetic fertilizers applied, means that the poultry manure helped the plant to make efficient use of the nutrients supplied by the synthetic fertilizers. The better growth of the integrated nutrient treated plants could also be attributed to the higher total N for those treatments. The findings agree with [26] who observed positive effect of integrated nutrient management on maize leaf area and plant height, and [27] who also recorded significant increases in maize plant height, leaf number, and Leaf Area Index with combination of farm yard manure (FYM) and mineral fertilizer under irrigation. 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 (T_1) confirms the fact that plant nutrients are necessary for plant growth [28,29] and that insufficient plant nutrients are responsible for limiting crop growth. The results, undoubtedly, confirms the need for maize fertilization in the Northern region of Ghana. This is further confirmed by the fact that T_{16} 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.

4.3 Grain Yield

Generally, the maize grain yields were influenced significantly by the various treatments of the synthetic and organic fertilization. The consistently lower grain yields recorded by T_1 (control – no fertilization) and T_{16} (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 T_1 plants looked stunted with yellowish coloration. 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 T_{16} appeared better than T_1, both effects were statistically similar implying that application of 125 kg/ha of S/A to maize at the latter growth stage was inadequate and uneconomical. It further demonstrates that adequate and timely application of nutrients is critical to ensure good plant growth and yield and that delayed application could not reverse damage caused by nutrient deficiencies. The result is consistent with [5] 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 (T_2) as compared to the same rate of 15-15-15 NPK plus the sulphate of ammonia (T_4) 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 for production of photosynthates in the maize plants. The improved yields obtained from T_6 and T_7 as compared to the synthetic fertilizer alone in T_2 and T_4, could also be due to the poultry manure that enhanced soil available nitrogen, phosphorus, and potassium as was observed by [33]. The trend is a demonstration that application of the synthetic fertilizers alone failed to meet the nutrient requirements of the maize plants. Besides supplying macro and other micronutrients, organic sources are also noted to make available the unavailable sources of elemental nitrogen, bound phosphates, micronutrients and decomposed plant residues to aid absorption of nutrients by the plants [34,35] and ensuring proper functioning of the plant metabolism [27] for improved crop growth, stover yield, and general crop performance. The significantly improved grain yields recorded for treatments that included poultry manure (T_6, T_7, T_8, T_9, T_{14}, and T_{15}) confirms the observation by [28,36,37] that increased application of organic and synthetic fertilizers in developing countries could enhance the environment and increase crop yields. The results also agree with the view expressed by [38] that unless farmers in the GSAZ of Ghana ameliorated their soils, maize production was not profitable and sustainable. The ability of poultry manure to improve the soil physical conditions by acting as a binding agent might have helped to improve water retention, aeration, and nutrient availability and thus contributing to better performance in 2015 even when total rainfall was low. Elsewhere, other researchers [39,40,41,42] demonstrated that various soil amendments improved yields and productivity of various crops under water-stressed conditions. The improved mean grain yields in 2015 over 2014 could be attributed to the residual effects of the various treatments. The non-burning of crop residue on the fields could have also contributed to organic matter build up and hence the general improved yields recorded in 2015 even though rainfall was lower.

The yield differences observed among the locations could be attributed to the differences in soil chemical properties and the different rainfall amounts (not shown) recorded at the different locations. The high grain yield obtained at Mognegu location in 2014 and when data was pooled together could be explained by the high initial organic matter and total N content of the soil which might have significantly contributed to meeting the nutrient requirements of the plants for optimum growth and yield.

4.4 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 which had higher initial total N and organic matter. This probably means that the total applied N was near the optimum requirements by the plant.

NUE was lower for synthetic + organic treatments because the total N was much higher for these treatments. Consequently, the integrated treatments increased maize grain yields but at a decreasing rate as the total N increased.

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 a reduction in morpho-physiological and biochemical attributes of maize when maize experienced drought conditions at tasseling stage. The findings are 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 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. CONCLUSION

Application of synthetic fertilizers and poultry manure improved plant growth and maize grain yield in the Guinea Savannah Agro-ecological

Zone of Ghana. Nitrogen Use Efficiency (NUE) of maize was lower with the combined application of synthetic fertilizers and poultry manure because the total N was much higher for these treatments resulting in increased yields but at a decreasing rate. The lower NUE could be an underestimation because of residual effects of the application on future crops. Lower levels suggest changes in management could increase crop response or reduce input costs.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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