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Research article

Growth and yield response of maize to integrated nutrient management of chicken manure and inorganic fertilizer in different agroecological zones

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ABSTRACT

The productivity of maize, an essential staple food crop in Africa, is severely constrained by the declining fertility of the soil. The combined use of organic and inorganic fertilizers could ameliorate this challenge in a sustainable way to boost maize productivity. Two field trials were conducted at Ashanti -Mampong and Damongo, in the transitional and Guinea Savannah agro-ecologies of Ghana respectively, to assess the influence of sole and integrated application of chicken manure and NPK fertilizer on the growth and yield of maize. The treatments included two maize varieties; *Abontem* and *Obatanpa,* and five fertilizer rates; 3 t/ha chicken manure (CM), NPK (65:38:38 kg ha^{-1} NPK), ½ CM + ½ NPK and ¾ CM + ¼ NPK and control (no fertilizer). A 2 x 5 factorial randomized complete block design with three replications was used. Significant variations ($p < 0.05$) were revealed between varieties, fertilizer types and their interaction effects for phenological, growth and yield of maize in both locations. The superiority of the integrated application of NPK and chicken manure was also visible in the vegetative parameters such as plant height, number of leaves and shoot dry weight of the maize plants given them the comparative advantage to assimilate more photosynthates for partitioning to the ears and grains. Obatanpa treated with ½ CM + ½ NPK produced the highest yield of 4661.1 kg ha^{-1}, which was 29.6 and 29.9 % higher than the same variety grown on sole NPK and sole chicken manure, respectively at Damongo. Abontem treated with ¾ CM + ¼ NPK recorded a grain yield of 4479.3 kg ha^{-1}, 11.7 % higher than the sole NPK and 10.3 % higher than the sole CM at Damongo. Similarly, Obatanpa grown on the ½ CM + ½ NPK recorded the highest grain yield of 4349.3 kg ha^{-1}at Mampong followed by Abontem treated with the sole NPK (4267.1 kg ha^{-1}). Sole NPK and the combined application of NPK and chicken manure gave comparable responses for vegetative traits while the integrated application proved superior for grain yield of maize across the two agroecologies.

1. Introduction

Maize is an extensively consumed staple crop planted in all agroecologies of Ghana. With a total annual production in excess of 3.07

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million tonnes, maize contributes more than one-fourth of the calories consumed in the country [1]. It is also vital to poultry and livestock, constituting a high proportion of poultry feed ingredients, as well as the base material for industries for manufacturing of starch related items, pharmaceuticals, gums, fabrics and make-ups [2,3].

Due to its importance, maize is cultivated in all the agroecologies in Ghana with a continuously increasing area under production from 464,800 ha in 1990 to 1.60 million ha in 2020 [4]. However, regardless of the expansion of maize cultivation area in Ghana, productivity has not met the increasing demand hence the importation of maize to support the growing poultry industry [5]. This can be attributed to poor grain yield, as the average productivity of maize in Ghana remains low, about 1.9 t/ha in comparison to the world average of 5.6 t ha^{-1}, and much lower than the mean for southern Africa (5.3 t ha^{-1}) [4]. The potential yield is however about 5.5 t ha^{-1} [6].

One of the major constraints of increased maize productivity in Ghana is the poor soil fertility. External inputs, mainly, organic and chemical fertilizers have been applied to increase the yield per unit area of soils in production. Nonetheless, the expected output is not always achieved with the application of chemical fertilizer to degraded lands due to the low organic matter, soil acidity and decreased soil microbial activity [7]. These effects are even more pronounced within the transitional and Guinea Savannah agroecologies of Ghana. The high cost and sometimes scarcity of chemical fertilizer further aggravates the situation by causing low usage by many farmers who cannot afford chemical fertilizers. Organic fertilizers like chicken manure have over the years been used to boost crop productivity including for maize. Chicken manure can be sourced locally hence is readily available, inexpensive and has the added benefit to enhance soil structure compared to inorganic inputs [8]. The recycling of organic materials by soil microbes releases mineral nutrients which enhances the soil's ability to supply nourishment to promote growth and development of plants [9]. Organic manure also helps to maintain plant nutrition by reducing the loss of nutrients beyond the root zone through leaching [10]. Poultry manure application increased soil nitrogen by more than 53 %, and also significantly enhanced exchangeable cations [11]. It is noteworthy that the amount of poultry manure used also influences the quantity of nutrients released as well as the yield of maize [12].

The potential benefits from the application of organic manure are still out of reach of most smallholder farmers because of the large amounts needed to meet crop's nutritional requirements coupled with the high transportation and handling cost which are major impediments [13]. They are therefore rarely utilized in sufficiently large quantities for both smallholder and large-scale maize production. The high cost of mineral fertilizers also hinders the application of sufficient quantities by farmers.

Consequently, integrated soil fertility management, comprising the utilization of locally available organic materials with prudent quantities of inorganic fertilizer is a viable alternative for sustainable growth of small-scale farming [14,15]. The combined use of organic and inorganic fertilizer nutrients results in synergetic effects and enhanced nutrient availability and absorption by crops resulting in increased yields. Yigermal et al. [16] have demonstrated that strategic use of organic and chemical fertilizers led to the actualization of the potential yields on farmers' fields. Even though farmers apply organic and mineral fertilizers independently, the integrated use of both fertilizer sources is now gaining much attention. The potential of integrated soil fertility management in increasing the growth and yield of maize has not been systematically studied in the transitional and Guinea Savannah agroecological zones of Ghana, hence the paucity of information on the recommended doses to apply. Therefore, the objective of this study was to assess the influence of the sole and integrated application of chicken manure and NPK fertilizer on the growth and yield of maize in two agroecological zones in Ghana as components of integrated soil fertility management. The main hypothesis tested here is that the combined use of chicken manure and NPK fertilizer will result in higher growth and yield of maize than sole application of each nutrient source.

2. Materials and methods

2.1. Experimental site

Two field experiments were conducted in 2021. The first was conducted from June to September (rainy season) at Damongo in the Savannah region of Ghana, while the second trial was established at the research fields of Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development, Ashanti - Mampong during the minor rainy season (September to December). Mampong-Ashanti is located within the transitional agroecological zone of Ghana between latitude 0.7°, 0.4° N and longitude 1°, 0.24° W of the equator, 457.5 m above sea level. The area experiences a bimodal rainfall pattern annually, with the main rainy season between March and July and the minor season rains between September and November with a short dry spell in August and an extended dry season from December to March. Average annual rainfall is 1270 mm. The soil is categorized by the FAO/UNESCO legend as chromic Luvisol. The soil is deep, brown sandy-loam, friable, with a small layer of organic matter. The soil is well drained with good moisture-holding capacity [17].

Damongo lies within the Guinea Savannah agroecology of Ghana at latitude 9°50′ N and longitude 1°49′ W at an altitude of 189.1 asl. Rainfall distribution is mono-modal with the growing season between 5 and 6 months thus from May to October after which there is a long dry season till the next season's rains. The average annual rainfall is between 1100 and 1200 mm. The soil at this site is classified as Damongo series (*Ferric luvisol*). Soils are over sandstone with sandy loam texture.

2.2. Soil and manure and analyses

Four-month old chicken manure was obtained from a deep litter system of broiler chicken and cured by accumulating under shade for 30 days prior to application. Selected chemical properties of the chicken manure are shown in Table 1. The parameters analysed include soil pH on 1:1 (soil: distilled water) and 1:2 (soil: 0.01 m $CaCl_2$) mixtures and assessed on a pH meter (Veb Pracitron, Dresden, Germany). The Walkey and Black method was used for organic matter determination [18] and total nitrogen ascertained using the micro Kjeldahl method [19]. Available phosphorus was determined colorimetrically after extraction using the Bray method [20][]. Flame emission photometry was utilized for the determination of exchangeable cations [21]. Ca and Mg were assessed with atomic absorption spectrometry after the elimination of ammonium acetate and organic materials at pH 7.0. Results of soil analysis of the experimental sites are presented in Table 2. The climatic conditions of the research locations throughout the crop growth period for the two locations are also presented in Table 3.

2.3. Experimental design and trial management

The field trial was arranged in a 2 x 5 factorial randomized complete block design with three replications. This involved two maize varieties, *Abontem* and *Obatanpa*. Abontem is an extra-early maturing maize variety while Obatanpa is a medium maturing variety. The maize seeds were obtained from the Council for Scientific and Industrial Research Crops Research Institute (CSIR -CRI), Fumesua, Kumasi, Ghana. The maize varieties were planted with five fertilizer regimes: (i) 3 t/ha chicken manure (CM) (sole chicken manure) (ii) NPK (65: 38: 38 kg ha^{-1} NPK) (sole NPK) (iii) ½ CM + ½ NPK (1.5 t/ha +32.5: 19: 19 kg ha^{-1}) (iv) ¾ CM + ¼ NPK (2.25 t/ha chicken manure + 16: 9.5: 9.5 kg ha^{-1} NPK) (v) control (no fertilizer).

The two experimental sites were ploughed, harrowed, levelled, lined and pegged to obtain the desired germination and growth of the crop. The seeds of the two maize varieties were planted on flat land after the plots had been demarcated.

Every experimental unit comprised four rows measuring 3.2 m × 4.8 m with three seeds sown per hill. Thinning was later carried out to obtain two plant stands per hill. Plant spacing was 0.8 m between rows and 0.4 m within rows thus 62,500 plants per hectare. The chicken manure was applied two weeks before the maize seeds were sown whilst the NPK was applied as basal fertilizer after 10 days of sowing maize. Top dressing with sulphate of ammonia was carried out at different rates based on the treatments at 5 weeks after planting.

Weeds were controlled three weeks after planting using the hoe and hand pulling method. Subsequently, weed control was done by hoe and hand pulling every two weeks interval to keep the plots free from weeds during the crop growth period.

Incidence of pests and disease was monitored periodically by frequent visit to the experimental sites to check for diseases such as rust, early leaf spot, and late leaf spot, and pests such as caterpillars, fall armyworm and stem borer. Insecticide Bypel 1 (Pr Gv Bt) Bacillus thuringiensis (16000/N/mg) per knapsack (15 L) was applied four weeks after planting to control army worms.

Harvesting was done manually by cutting the stalk with a cutlass and ear twisted by hand off the stalk when the plants and ears were physiologically mature with drooping ears and senescence of leaves and stalks.

2.4. Plant agronomic traits measured

The stem diameter and height of maize plants were measured on three randomly selected plants per plot with a digital vernier caliper and meter rule, respectively. The number of leaves per plant on three plants in the effective plot area were also counted and recorded. For shoot dry weight determination, three plants were sampled per plot, chopped into pieces, and a sample of 200 g oven dried for 72 h at a temperature of 70^{O}C and the dry weight measured using a sensitive electronic scale. Days to 50 % tasseling were assessed as the number of days from planting to the day when 50 % of the maize plants in the two middle rows in a plot shed their tassels. Days to 50 % silking was taken as the days from sowing to when 50 % of the plants in the effective plot area showed the extrusion of silks. Days to maturity was assessed as the days from planting to when 90 % of plants in the harvestable area per plot formed a black layer at the base of the kernel.

Ear length and diameter were measured on five (5) ears randomly selected per plot using a meter rule and digital vernier caliper after harvest. Dried maize earears were manually shelled per plot and grain weight measured using an electronic weighing scale. The weight of grain per plot was inferred to yield per hectare (kg/ha) after adjusting for 15 % moisture content. The weight of a hundred seeds randomly sampled per plot was taken using a sensitive electronic weighing scale.

2.5. Statistical analysis

All plant attributes assessed were submitted to analysis of variance using the GenStat statistical software version 11 [22] and least significant difference (LSD) applied for mean separation at 5 % probability whenever significant.

$$Y_{ijk} = \mu + Rep_i + Var_j + Fert_k + Var_j \; X \; Fert_k + \varepsilon_{ijk} \tag{1}$$

Where Y_{ijk} is the trait of interest, μ is the overall mean effect, Rep_i is the effect of the ith replicate, Var_j is the effect of the jth variety, $Fert_k$ is the effect of kth fertilizer rate, $Var_j \; X \; Fert_k$ is the variety by fertilizer interaction and ε_{ijk} is the effect due to random error.

Table 1
Chemical properties of chicken manure used for the research.

Property/location		% Nitrogen	% Phosphorus	% Potassium	% organic Carbon
Chicken manure	Damongo	2.45	1.44	2.45	43.50
	Mampong	3.54	0.63	0.86	45.60

Table 2
Chemical properties of the experimental soil at the research sites.

Soil property	Untreated soil sample	
	Mampong	Damongo
pH H_2O (1:2.5)	5.608	5.870
Organic carbon (%)	1.380	0.711
Organic matter (%)	2.380	1.227
Total N%	0.070	0.061
Available P (mg/kg)	6.272	14.407
Available K (mg/kg)	0.281	6.525
Ca ($cmol_c$ Kg-1)	2.960	2.560
Mg ($cmol_c$ kg-1)	1.001	1.060

Table 3
Climatic variables of the research sites.

Mampong				Damongo			
Month	Total Rainfall (mm)	Mean Temperature (^{O}C)	Relative humidity (%)	Month	Total Rainfall (mm)	Mean Temperature (^{O}C)	Relative humidity (%)
September 2021	225.1	31.3	85	July 2021	95.2	30.5	76
October	208.7	27.2	84	August	132.8	29.6	81
November	73.4	28.3	80	September	153.8	29.4	82
December	0.0	29.0	74	October	57.7	32.4	68
Total	507.2				439.5		

3. Results

3.1. *Phenology*

3.1.1. *Days to 50 % tasseling*

Analysis of variance revealed significant difference ($p \leq 0.05$) for the two maize varieties for days to 50 % tasseling in both locations (Table 4). Abontem maize variety was earlier in tasseling than Obatanpa by 10.4 and 9.2 days respectively at Mampong and Damongo. Days to 50 % tasseling was not significantly influenced for all the fertilizer combinations at Damongo, whereas a significant effect was observed for this trait at Mampong. Fertilizer application generally hastened the days to 50 % tasseling by 5–6 days as seen by the significantly early tasseling in sole NPK, sole chicken manure and ½ chicken manure + ½ NPK treatments compared to the control (no fertilizer) at Mampong.

Table 4
Days to 50 % tasseling and silking, and days to maturity of Abontem and Obatanpa as influenced by chicken manure, NPK and their combinations at two locations.

Variety/Treatment	Days to 50 % tasseling		Days to 50 % silking		Days to maturity	
	Damongo	Mampong	Damongo	Mampong	Damongo	Mampong
Variety						
Abontem	47.0_a	46.4_a	51.2_a	52.2_a	98.0_a	98.6_a
Obatanpa	57.4_b	55.6_b	62.4_b	57.2_b	128.0_b	117.2_b
LSD ($P \leq 0.05$)	2.21 *	2.42 *	2.26 *	2.5*	0.87 *	1.82 *
Soil Amendment						
NPK	50.6_a	48.1_a	56.1_a	54.0_{ab}	113.0_a	110.3_a
Chicken manure (CM)	52.0_a	48.1_a	55.8_a	51.6_a	113.0_a	110.3_a
½ CM + ½ NPK	53.8_a	49.6_a	56.5_a	53.0_{ab}	113.0_a	108.8_a
¾ CM + ¼ NPK	50.3_a	54.5_b	55.1_a	57.1_{ab}	113.0_a	109.0_a
Control	54.3_a	54.8_b	60.3_a	57.6_{ab}	113.0_a	101.3_b
Mean	52.2	51.0	56.8	54.7	113.0	107.9
LSD ($P \leq 0.05$)	NS	3.82 *	NS	3.9 *	NS	2.8 *
Variety x fertilizer Interaction	NS	NS	NS	NS	NS	NS
CV (%)	11.6	13.2	11.6	9.3	13.5	9.9

** = significant at $p < 0.01$, * = significant at $p < 0.05$, NS = not significant at $p < 0.05$, CM = chicken manure, LSD = least significant difference, CV = coefficient of variation, means with the same subscript letter are not significantly different.

3.1.2. Days to 50 % silking

The varietal difference for days to 50 % silking was significant ($p \leq 0.05$) at both locations of evaluation, while the effect of the soil amendment was only significant at Mampong (Table 4). Abontem maize variety produced silks earlier than Obatanpa at both locations. The sole chicken manure treated plot was earliest in producing silks at 51.6 days after planting, followed by the ½ chicken manure + ½ N P K treatment, while the control (no soil amendment) plots developed silks later at 57.6 days after planting.

3.1.3. Days to maturity

Days to maturity differed significantly ($p \leq 0.05$) for the two varieties of maize across the two locations. As with the other phenological traits, the Abontem variety was earlier in maturity than Obatanpa (Table 4). Abontem matured at 98 days at Damongo and 98.6 days at Mampong, while that of Obatanpa was 128 days at Damongo and 117.2 days at Mampong.

The effect of soil amendments on maturity was significant ($p \leq 0.05$) at Mampong but not significant at Damongo. The control treatment without fertilizer matured significantly earlier than all the other treatments with fertilizer application, thus 9 days earlier than the sole NPK and sole chicken manure at Mampong.

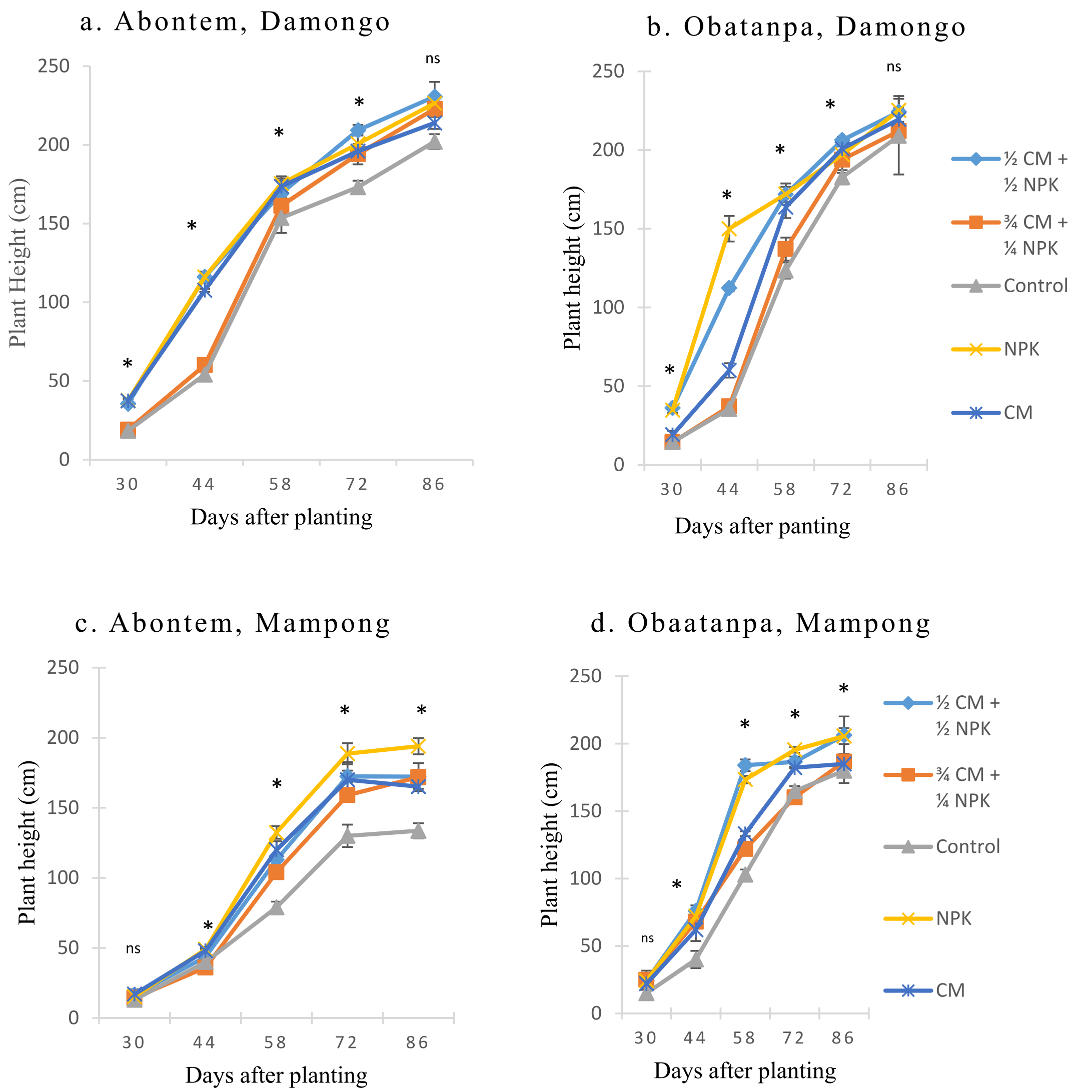

Fig. 1. Plant height of Abontem (a, c) and Obatanpa (b, d) as affected by sole chicken manure, NPK fertilizer and their combinations at two locations (Damongo and Mampong) from 30 to 86 days after planting. The data are represented as mean ± SE, * = significant at 5 % probability level, ns = not significant.

3.2. Vegetative growth

3.2.1. Plant height (cm)

Variety, fertilizer type and variety by fertilizer interaction effects significantly influenced ($P < 0.05$) the height of the maize plants across the sampling periods at both locations, except for 86 days after planting (DAP) at Damongo and 30 DAP at Mampong (Fig. 1). Plant height of Abontem and Obatanpa in both control and amended plots showed a progressive increase throughout the sampling periods from 30 DAP to 86 DAP at both locations. Taller plants were observed for both Abontem and Obatanpa in the amended plots than those grown on the control plots. Abontem treated with ½ CM + ½ NPK produced the tallest plants of 209.3 cm at 72 DAP at Damongo, followed by sole NPK with 200.7 cm. Plant height for the sole Chicken manure and ¾ CM + ¼ NPK were 195.9 cm and 194.1 cm, respectively at Damongo. At Mampong, Obatanpa grown on the sole NPK was the tallest with a height of 195.4 cm at 72 DAP,

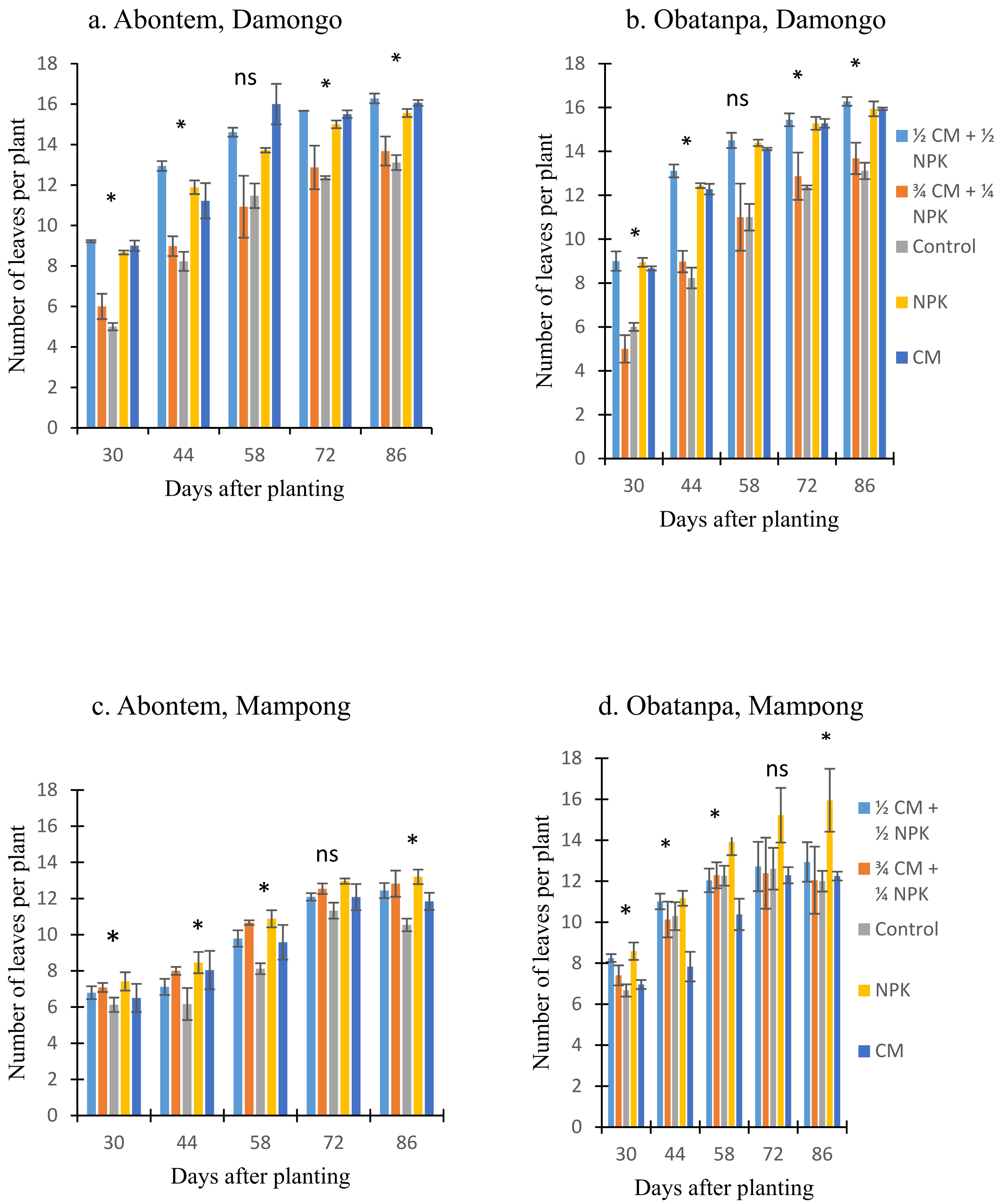

Fig. 2. Number of leaves per plant of Abontem (a, c) and Obatanpa (b, d) as affected by sole chicken manure, NPK fertilizer and their combinations at two locations (Damongo and Mampong) from 30 to 86 days after planting. The data are represented as mean ± SE, * = significant at 5 % probability level, ns = not significant.

followed by ½ NPK + ½ CM with 186.5 cm and sole Chicken manure with 182 cm.

3.2.2. Number of leaves per plant

Significant differences ($p < 0.05$) were observed for number of leaves of the maize plants with the fertilizer throughout the sampling periods at Damongo except for 58 DAP where this effect was not significant (Fig. 2). Conversely, the effect of variety and variety by fertilizer interaction was not statistically significant for this trait at Damongo. For Mampong, the influence of variety, fertilizer type and variety by fertilizer interaction significantly affected the leaves of the maize plants across the sampling periods except at 72 DAP (Fig. 2). Leaf number under the different fertilizer treatments generally increased from 30 DAP to a peak at 58 DAP. Abontem and Obatanpa cultivated on the control treatment (no fertilizer) gave the minimum number of leaves at both locations. The highest number of leaves per plant of 16 was observed for both Abontem and Obatanpa treated with ½ CM + ½ NPK, sole NPK and sole CM at 86 DAP at Damongo while Obatanpa grown on the sole NPK plot had a highest of 16 leaves at Mampong followed by ½ CM + ½ NPK with 13 leaves per plant.

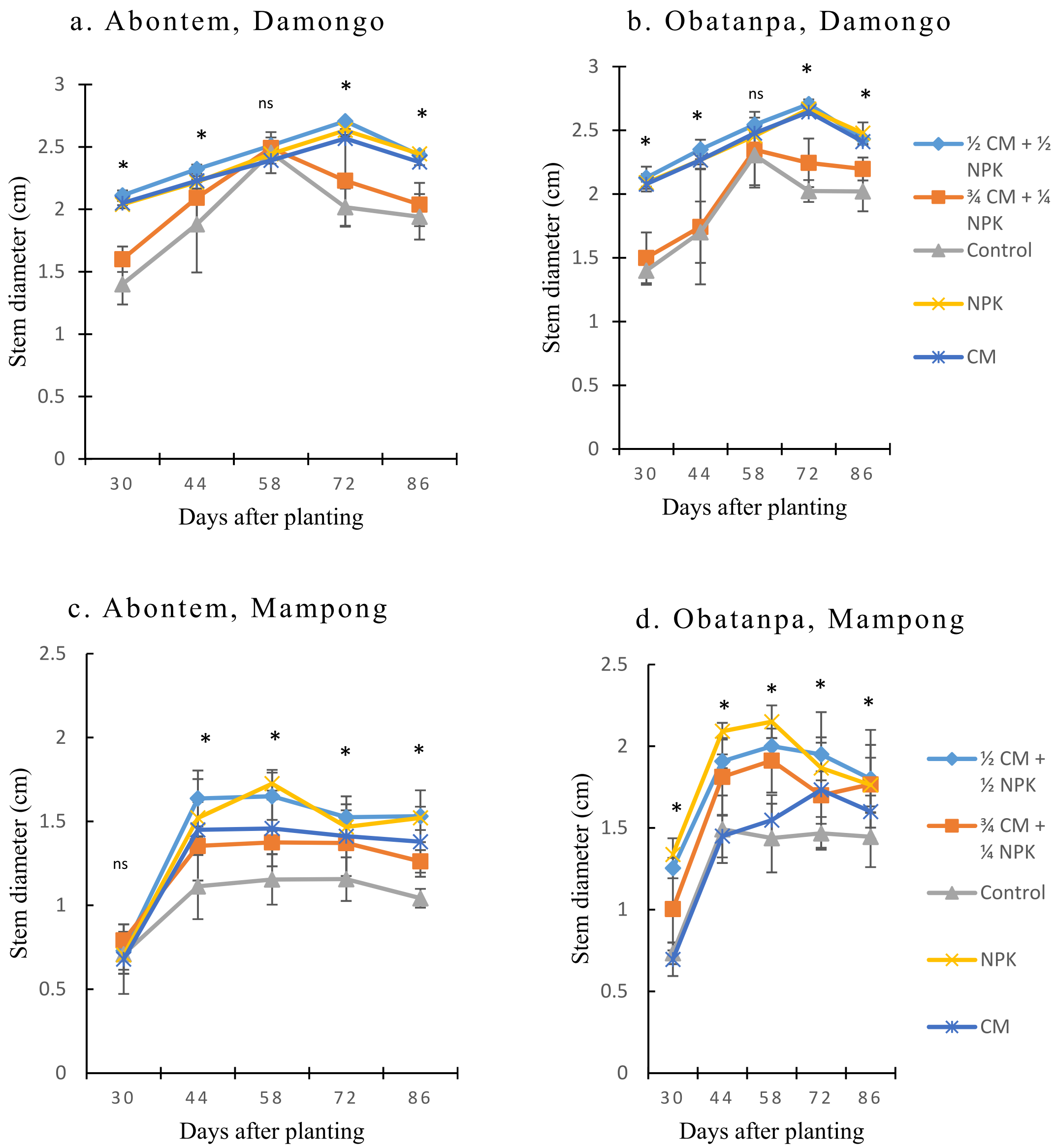

Fig. 3. Stem diameter of Abontem (a, c) and Obatanpa (b, d) as affected by sole chicken manure, NPK fertilizer and their combinations at two locations (Damongo and Mampong) from 30 to 86 days after planting. The data are represented as mean ± SE, * = significant at 5 % probability level, ns = not significant.

3.2.3. Stem diameter

The diameter of maize stems varied significantly with the fertilizer types across the sampling periods except for 58 DAP where the effect was not significant, while the varietal and variety by fertilizer interaction effects on this trait were not statistically significant ($P < 0.05$) at Damongo (Fig. 3). The varietal effect on the stem diameter of the maize plants was significant across the five sampling periods at Mampong, while the effect of fertilizer rate was significant at 30 DAP, 44 DAP and 58 DAP. The interaction effect did not significantly affect this trait at Mampong. Abontem and Obatanpa grown on ½ CM + ½ NPK, sole NPK and sole chicken manure reached the highest stem diameter at 72 DAP, while the highest diameter for ¾ CM + ¼ NPK and the control was attained at 58 DAP after which there was a decline in stem diameter at Damongo (Fig. 3). The highest stem diameter of 2.7 cm was obtained by both Abontem and Obatanpa grown on the ½ CM + ½ NPK treatment, followed by the sole NPK, then the sole poultry manure while the ¾ CM + ¼ NPK and the control lagged behind for this trait at Damongo. The progression of stem diameter was similar at both locations. The highest stem diameter for both varieties was obtained under the sole NPK regime at 58 DAP at Mampong, followed by the ½ CM + ½ NPK. The control treatment recorded the smallest stem diameter across the two locations.

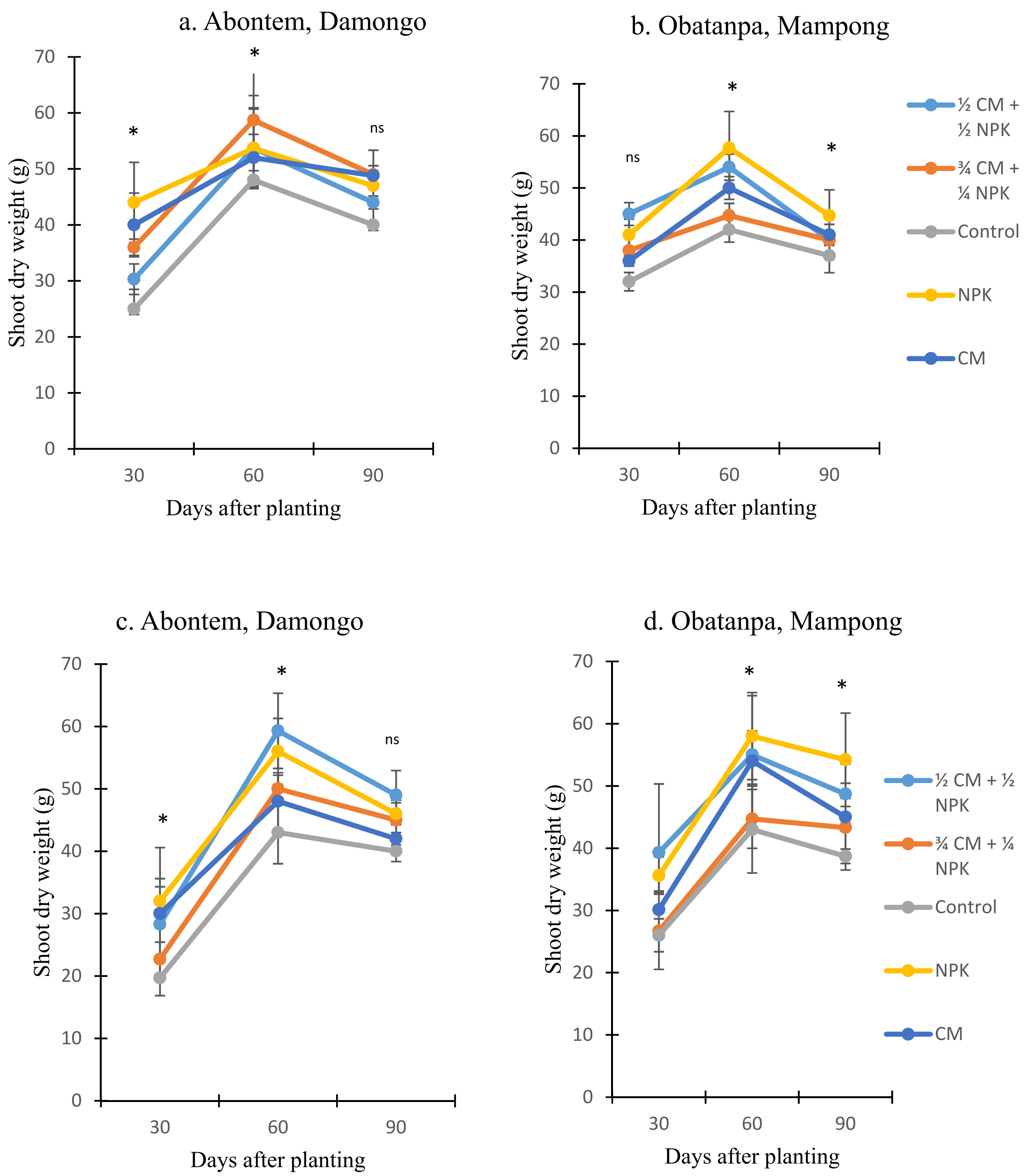

Fig. 4. Shoot dry weight of Abontem (a, c) and Obatanpa (b, d) as influenced by sole chicken manure, NPK fertilizer and their combinations at two locations (Damongo and Mampong) from 30 to 86 days after planting. The data are represented as mean ± SE, * = significant at 5 % probability level, ns = not significant.

3.2.4. Shoot dry weight

Except for the interaction effect of variety and fertilizer that significantly influenced shoot dry weight ($P < 0.05$) at 30 DAP, the difference observed among the variety and fertilizer rates was not significant at Damongo (Fig. 4). The fertilizer type effect on shoot dry weight at Mampong was significant at 90 DAP, whereas the variety and variety by fertilizer interaction effects were significant only at 60 DAP. Shoot dry weight of the two maize varieties generally increased from 30 DAP with a peak at 60 DAP, after which there was a gradual decline at 90 DAP (Fig. 4). Abontem grown on ¾ CM + ¼ NPK recorded the highest shoot dry weight of 58.7 at Damongo followed by both sole NPK and ½ CM + ½ NPK with 53.7g. In the case of Obatanpa, the sole NPK treatment recorded the highest shoot dry weight of 57.7g, followed by the ½ CM + ½ NPK and then the sole chicken manure. At Mampong, Abontem on ½ CM + ½ NPK had the highest shoot dry weight, followed by sole NPK, then ½ CM + ½ NPK. The shoot dry weight of Obatanpa at Mampong followed the same trend observed at Damongo.

3.3. Yield and yield components

3.3.1. Ear length (cm)

The variation observed among the varieties, fertilizer rates and variety by fertilizer interaction for ear length was significant ($p < 0.05$) at both locations (Table 5). Abontem consistently produced higher mean ear length than Obatanpa at both locations of evaluation. ½ CM + ½ NPK treatment produced the longest ears of both Abontem and Obatanpa at Damongo, followed by sole chicken manure for Obatanpa. Abontem on ½ CM + ½ NPK had the same ear length of 27.7 cm as the sole NPK at Damongo. Obatanpa grown on ½ CM + ½ NPK recorded the highest ear length of 29 cm at Mampong. This was closely followed by Abontem grown on sole NKP and ½ CM + ½ NPK. The control consistently produced the shortest ears.

3.3.2. Ear diameter (cm)

The ear diameter of the maize varieties did not vary significantly at Damongo and Mampong even though Obatanpa had bigger ears than Abontem (Table 6). The fertilizer types differed significantly ($P < 0.05$) for this trait at both locations, while the variety by fertilizer interaction was significant only at Damongo. The biggest ears of 6.27 cm were observed from Obatanpa grown on the sole NKP treatment at Damongo, followed by Abontem treated with ¾ CM + ¼ NPK. Abontem grown on ¾ CM + ¼ NPK produced the highest ear diameter of 4.47 cm at Mampong, followed by Obatanpa on the sole NPK treatment. The control treatment produced the smallest ears of both varieties at the two locations of evaluation.

3.3.3. Hundred seed weight (g)

Fertilizer types and variety by fertilizer interaction effect highly influenced ($P < 0.01$) hundred seed weight at the two locations, while the varietal effect was only significant at Damongo (Table 7). Obatanpa and Abontem treated with ½ CM + ½ NPK produced the highest hundred seed weight of 46.3 and 43.0 g respectively at Damongo, followed by the sole NPK for both varieties. The highest hundred seed weight of 37.7 g at Mampong was obtained from Obatanpa grown on sole NKP, followed by Abontem treated with ¾ CM + ¼ NPK. The control treatment (no fertilizer) consistently produced the lowest hundred seed weight of both varieties in the two seasons of evaluation.

3.3.4. Grain yield

Maize yield varied significantly ($P < 0.05$) for the fertilizer types and variety by fertilizer interaction at both locations, while the variety effect was statistically significant only at Damongo (Table 8). Obatanpa treated with ½ CM + ½ NPK gave the highest yield of 4661.1 kg ha^{-1}, which was 29.6 and 29.9 % higher than the same variety grown on sole NPK and sole poultry manure, respectively at Damongo. Abontem treated with ¾ CM + ¼ NPK recorded a yield of 4479.3 kg ha^{-1}, which was 11.7 % higher than the sole NPK and 10.3 % higher than the sole poultry manure also at Damongo. Similarly, Obatanpa grown on the ½ CM + ½ NPK gave the highest yield of 4349.3 kgha^{-1} at Mampong followed by Abontem treated with the sole NPK (4267.1 kg ha^{-1}). Grain yield of Abontem grown on the

Table 5
Ear length of Abontem and Obatanpa under sole chicken manure, NPK fertilizer and their combinations at two locations.

Fertilizer Types	Ear length (cm)					
	Damongo			Mampong		
	Abontem	Obatanpa	mean	Abontem	Obatanpa	mean
½ CM + ½ NPK	27.7$_{bc}$	28.8$_{c}$	28.2	27.6 $_{bc}$	29.0$_{c}$	28.3
¾ CM + ¼ NPK	25.9$_{bc}$	18.0$_{a}$	22.0	26.1 $_{bc}$	16.2$_{a}$	21.1
NPK	27.7$_{bc}$	26.2$_{bc}$	26.9	27.6 $_{bc}$	26.2 $_{bc}$	25.5
Chicken Manure (CM)	25.0$_{b}$	27.4$_{bc}$	26.2	25.4$_{b}$	27.4$_{bc}$	26.4
Control	24.8$_{b}$	16.2$_{a}$	20.5	24.8$_{b}$	16.1$_{a}$	21.9
Average	26.2	23.3	24.8	26.3	23.0	24.6
LSD (0.05) Variety		1.62 **			1.6 **	
LSD (0.05) fertilizer		2.56 **			2.5 **	
LSD (0.05) Var* fert		3.63 **			3.5 **	
CV (%)		8.5			8.3	

** = significant at $p < 0.01$, CM = chicken manure, LSD = least significant difference, CV = coefficient of variation.

Table 6
Ear diameter of Abontem and Obatanpa as influenced by sole chicken manure, NPK fertilizer and their combinations at two locations.

Fertilizer rates	Ear diameter (cm)					
	Damongo			Mampong		
	Abontem	Obatanpa	Mean	Abontem	Obatanpa	mean
½ CM + ½ NPK	4.70_{b}	4.53_{b}	4.62	4.37_{a}	4.17_{a}	4.22
¾ CM + ¼ NPK	4.80_{b}	4.15_{b}	4.47	4.47_{a}	4.37_{a}	4.42
NPK	4.72_{b}	6.27_{c}	5.49	4.13_{a}	4.43_{a}	4.23
Chicken Manure (CM)	4.59_{b}	4.67_{b}	4.63	4.03_{a}	4.00_{a}	3.78
Control	2.77_{a}	2.50_{a}	2.63	3.57_{a}	4.07_{a}	4.15
Mean	4.32	4.42	4.37	4.11	4.20	4.16
LSD (0.05) Variety		NS			NS	
LSD (0.05) fertilizer		0.66 **			0.31 *	
LSD (0.05) Var x fert		0.93 *			NS	
CV (%)		12.5			6.2	

** = significant at $p < 0.01$, * = significant at $p < 0.05$, NS = not significant at $p < 0.05$, CM = chicken manure, LSD = least significant difference, CV = coefficient of variation, means with the same subscript letters are not significantly different.

Table 7
Hundred seed weight of Abontem and Obatanpa as affected by sole chicken manure, NPK fertilizer and their combinations at two locations.

Fertilizer types	Hundred seed weight (g)					
	Damongo			Mampong		
	Abontem	Obatanpa	Mean	Abontem	Obatanpa	Mean
½ CM + ½ NPK	43.0_{ef}	46.3_{f}	44.7	32.0_{bc}	31.7_{bc}	31.8
¾ CM + ¼ NPK	35.0_{bcd}	37.7_{cde}	36.3	34.7_{d}	31.7_{bc}	33.2
NPK	41.7_{ef}	41.3_{def}	41.5	30.3_{b}	37.7_{d}	34.0
Chicken manure (CM)	29.7_{ab}	32.3_{abc}	31.0	29.7_{b}	33.3_{cd}	31.5
Control	29.0_{ab}	28.0_{a}	28.5	26.3_{a}	24.3_{a}	25.3
Mean	35.7	38.3	37.0	30.6	31.7	31.2
LSD (0.05) Variety		NS			1.0 *	
LSD (0.05) fertilizer		4.60 **			1.7 **	
LSD (0.05) Var x fert		6.50 **			2.3 **	
CV (%)		10.4			4.4	

** = significant at $p < 0.01$, * = significant at $p < 0.05$, NS = not significant at $p < 0.05$, CM = chicken manure, LSD = least significant difference, CV = coefficient of variation, means with the same subscript letters are not significantly different.

Table 8
Grain yield of Abontem and Obatanpa as affected by sole NPK fertilizer, chicken manure and their combinations at two locations.

Fertilizer types	Grain yield (kg ha^{-1})					
	Damongo			Mampong		
	Abontem	Obatanpa	Mean	Abontem	Obatanpa	Mean
½ CM + ½ NPK	4089.2_{bc}	4661.1_{a}	4375.2	2786.7_{abc}	4349.3_{d}	3568.0
¾ CM + ¼ NPK	4479.3_{c}	3109.3_{a}	3294.3	3239.2_{c}	3203.2_{c}	3221.2
NPK	4010.5_{bc}	3594.9_{b}	3802.7	4267.1_{d}	4167.1_{d}	4217.1
Chicken manure (CM)	4062.6_{bc}	3568.3_{b}	3815.5	4129.1_{d}	2481.4_{ab}	3305.3
Control	3255.8_{b}	2031.4_{a}	2643.6	2839.8_{bc}	2109.1_{a}	2474.5
Mean	3979.5	3193.0	3586.2	3452.4	3262.0	3357.2
LSD (0.05) Variety		388.1 **			NS	
LSD (0.05) fertilizer		613.6 **			509.5 **	
LSD (0.05) Variety x fertilizer		867.7 **			720.6 **	
CV (%)		14.1			12.6	

** = significant at $p < 0.01$, * = significant at $p < 0.05$, NS = not significant at $p < 0.05$, CM = chicken manure, LSD = least significant difference, CV = coefficient of variation, means with the same subscript letters are not significantly different.

sole chicken manure and sole NPK were comparable at both locations.

4. Discussions

The results generally showed that Abontem was precocious for all the phenological traits including tasseling, silking and maturity compared to Obatanpa. This is mainly because the two varieties belong to different maturity groups, with Abontem being an extra-early maturing and Obatanpa an intermediate maturing variety [23]. Fertilizer application might have encouraged early establishment, rapid growth and development of the crops thereby shortening the vegetative growth phase. With the rapid formation of the source, the delayed maturity period observed in all the fertilizer treatments could be as a result of increased reproductive growth period of maize due to the availability of nutrients making enough assimilates available to be transferred to the sink at a later stage of the crop growth. Corroborating the present results, Khalid [24] and Bekele et al. [25] also observed significantly early tasseling and silking of maize with the integrated use of animal droppings and NPK. Kumar et al. [26] reported delayed maturity of maize with the application of NPK and farm yard manure in comparison with the control, in agreement with the results of this present investigation. Similarly, Khalid [24] and Bekele et al. [25] found the utilization of sole chemical fertilizer, organic manure and the combination to prolong the maturity of maize plants.

Priya et al. [27] recorded significant effect of the combined use of NPK and farmyard manure on the height of maize plants with the tallest plants emanating from the integrated application of NPK and farmyard manure treatment, as also found in this study for Abontem at Damongo.

In agreement with the present findings, Adekiya et al. [12] also reported comparable number of leaves of maize plants with the application of sole chicken manure, inorganic fertilizer and their combination. This could be because the chicken manure contains not only NPK but also other plant nutrients and improves the overall soil condition that can increase nutrient uptake compared to mineral fertilizers alone thereby boosting the vegetative growth of the plants. The taller plants with high number of leaves observed in this study for the fertilizer treatments has implications on the yield components as these plants may be able to intercept more solar radiation and therefore produce more photosynthates for partitioning to the ear and grains.

Stem diameter of the maize plants from the sole NPK and ½ CM + ½ NPK were comparable in the present study even though it was slightly higher with ½ CM + ½ NPK at Damongo and vice versa at Mampong. Afe et al. [28] also found the sole NPK and the combined NPK and organic manure to have similar effects on the stem diameter of maize plants as observed in the significantly higher shoot dry weight observed in the NPK amended plots might be due to higher solubility and speedy release of nitrogen besides providing favorable rhizosphere for maize to utilize higher amount of nutrients. The increased shoot dry weight in the integrated chicken manure and NPK treatments could be ascribed to the continuous steady release of nutrients which might have enabled the leaf area duration to extend, thereby enabling photosynthesis to continue to occur for a longer period allowing more dry matter accumulation in the plant [29].This phenomenon was also observed in this study as shown by the prolonged maturity period of the NKP and combined treatments. Mahesh et al. [30] also found higher shoot dry weight of maize following the integrated use of NPK and farmyard manure and indicated further that the organic matter served as an energy source for the soil microorganisms, which converts inorganic nutrients in the soil or applied in the form of fertilizers to readily available form for utilization by the plants.

The slow release of nutrients from chicken manure may have complemented the application of NPK in improving nutrient availability and use from the two sources to promote the yield components of maize as observed in the present study. Earlier studies by Laekemariam and Gidago [31] also reported the highest ear length for the combined use of poultry droppings and chemical fertilizer than the full dose of each applied independently. The current findings that the integrated application of organic manure and inorganic fertilizer results in improved grain weight in comparison with the sole application of each is consistent with the observations of Rizwan et al. [32] and Admas et al. [33].The integrated use of NPK and chicken manure as ½ CM + ½ NPK and ¾ CM + ¼ NPK recorded the highest grain yield of both varieties at Damongo, and Obatanpa at Mampong, while the sole NPK produced the highest yield of Abontem at Mampong in this study. This is consistent with the observation of Endris and Dawid [34] who also recorded higher yields of maize with the application of 50 % NPK + 50 % compost at one location and higher yield response from the full dose of NPK in another. Furthermore, Pandey and Awasthi [35] also found the utilization of farmyard manure alongside mineral fertilizers gave rise to improved maize yield over the full dose of NPK. Earlier studies by Essilfie et al. [36] in the transition zone of Ghana observed comparable grain yield response of obatanpa and omankwa maize varieties to the application of sole NPK and integrated use of 50 % NPK and 50 % chicken manure. The current study however covered two important agroecologies for maize production that share a similar constraint of low grain yield as a result of inherent poor soils. The current findings of higher grain yield of obatanpa (intermediate) and Abontem (extra-early maturing) maize varieties with the combined application of mineral fertilizer and chicken manure in the Guinea Savanna and transitional agroecological zones has significant implication for maize production in Ghana. The higher yield performance may be ascribed to enhanced efficiency in nutrient use resulting from the combination of chicken manure with NPK fertilizer [37,38]. Additionally, Adekiya et al. [12] asserted that the incorporation of NPK with chicken manure enhanced the nutrient mineralization in the manure due to the readiness of nutrients thereby resulting in improved development and yield of maize. Additionally, the chicken manure may have played a role in preventing the leaching of nitrogen from the chemical fertilizer by enhancing the structure of the soil and anchoring mineral nutrients [10]. In comparison with different organic manure sources applied in agriculture, chicken manure was densest for nutrient composition [39]. Sharply and Smith [40], noted that chicken manure comprises all the elementary nutrients essential for promoting the growth and productivity of crops and also enhances the accessibility of some minerals in the soil. Zhang et al. [41] found improved root growth of maize and increased grain yield as the crop extracted soil water more efficiently with the application of poultry droppings. All these many benefits of poultry manure in conditioning the soil in addition to the readily accessibility of nutrients from the mineral fertilizer accounts for the complementarity and synergetic effects of the duo in improving maize growth and yield.

The higher grain yield of maize in this study for the combined NPK and chicken manure treatments was not surprising in that the combined treatments gave superior plants in terms of vegetative growth, which translated to longer ear length and the higher yield. The rapid development of the source also gave more time for the reproductive phase as shown in the extended maturity period of the fertilizer treated plots. This allowed more time for photosynthesis and partitioning of dry matter to the ears and grain. This could have contributed to the general higher yield obtained in the fertilized treatments, while the synergistic role of chicken manure and NPK accounted particularly for the higher yield in the integrated treatment. The superiority of the integrated application of NPK and chicken manure was also visible in the vegetative parameters such as plant height, number of leaves and shoot dry weight of the maize plants given them the comparative advantage to assimilate more photosynthates for partitioning to the ears and grains. This high vegetative growth translated to yield components such ear length and diameter and ultimately the higher yield of the integrated NPK and chicken manure treatment.

This study assessed the response of extra-early and intermediate maturing maize varieties to integrated nutrient management in two agroecologies and found that neither organic nor inorganic fertilizer alone could be panacea to address low soil fertility to boost maize productivity but rather a combination of the two nutrient sources to take advantage of the synergistic effects. Further studies are recommended to confirm the results in the same and different agroecologies.

5. Conclusion

This study examined the effects of integrated application of chicken manure and mineral fertilizer on the growth and yield of maize. The study concludes that the response of the maize plants for vegetative traits was comparable with the application of full dose NPK and the combined utilization of NPK and chicken manure. For the grain yield of maize, the combined application of chicken manure and NPK proved superior to the sole application of each nutrient source. Integrated use of chicken manure and NPK (½ chicken manure + ½ NPK) is hence recommended for sustainable improvement of maize growth and yield in the study areas. Future studies are suggested to investigate the influence of integrated nutrient management on soil physical, chemical and microbial properties in the transitional and guinea savanna agroecologies.

Data availability

Data will be made available on request to the corresponding author.

CRediT authorship contribution statement

Margaret Esi Essilfie: Writing – review & editing, Supervision, Resources, Methodology, Conceptualization. **Kwabena Darkwa:** Writing – original draft, Visualization, Validation, Methodology, Formal analysis, Data curation. **Veronica Asamoah:** Writing – review & editing, Methodology, Investigation, Funding acquisition, Data curation.

Declaration of competing interest

The authors declare that they have no known competing interests that could have influenced the work reported in this paper.

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