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Research Article

On-Farm Experimentation with Improved Maize Seed and Soil Amendments in Southern Ghana: Productivity Effects in Small Holder Farms

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Maize production in Ghana is limited by several factors including inadequate use of improved varieties and poor soil fertility management. To contribute to addressing these challenges in maize production, two on-farm experiments were conducted each in the semi deciduous forest and coastal savannah agroecological zones (AEZs) of Ghana during the major and minor cropping seasons of 2017. The study adopted a 3×4 factorial arranged in an RCBD with four replications in the major season. The factors were three maize varieties (Omankwa, Obatanpa, and Ahomatea) and four soil amendments (goat manure at $5\,t{\cdot}ha^{-1}$; inorganic fertilizer (N-P_2O_5-K_2O at 95-37.5–37.5 $kg{\cdot}ha^{-1}$); 50% goat manure ($2.5\,t{\cdot}ha^{-1}$) + 50% inorganic fertilizer (N-P_2O_5-K_2O at 47.5–18.75–18.75 $kg{\cdot}ha^{-1}$); and the control (no soil amendment)).To evaluate the residual implications of these soil amendments in the minor season, each plot used in the major season was further divided into two except for the control plot, resulting in a split plot design with factorial of 3 maize varieties × 7 soil amendments. The results revealed a significant interaction between maize variety and soil amendment in both seasons with the use of sole inorganic fertilizer resulting in significantly higher ($p < 0.05$) grain yields for all varieties in both AEZs in the major cropping season. In the minor season, the combined treatment of 50% goat manure + 50% inorganic fertilizer resulted in higher grain yields for all the varieties in both AEZs with improved maize (Omankwa and Obatanpa) having significantly higher ($p < 0.05$) grain yields (33–40%) than the landrace (Ahomatea). The significantly lower ($p < 0.05$) performance of maize varieties on the residual plots in both AEZs suggests that there were minimal residual effects from the major season. Thus, in continuously cropped fields, the use of inorganic fertilizer + goat manure is required in addition to improved seeds for sustainable maize production.

1. Introduction

Maize (*Zea mays* L) is the most widely grown staple cereal crop for an estimated 50% of the population in sub-Saharan Africa (SSA) and is on more than 33 million hectares of SSA's estimated 200 million hectares of cultivated land [1, 2]. About 67% of the total maize production in the developing world comes from low and lower middle-income countries and provides 50% of their basic calorie needs [1, 3].

In Ghana, maize is the most extensively produced and consumed cereal crop, accounting for more than 50% of total cereal production, and its production has seen an increasing trend since 1965 [4–6]. Maize is therefore considered an important crop for Ghana's agricultural sector and for food security. It is a versatile crop grown in all the agroecological zones of Ghana by predominantly smallholder resource-poor farmers under rain-fed conditions [7, 8]. Sustaining and improving maize productivity would reduce smallholder farmers' food insecurity and poverty.

In spite of the economic importance of maize in Ghana, there is a deficit in its production partly due to the high demand. The deficit in production is attributable to low yields caused by a myriad of challenges including the use of unimproved varieties and declining soil fertility. The average maize yield in Ghana is estimated to be 2.26 Mt·ha^{-1} as against a potential yield of 5.5 Mt·ha^{-1} [7]. This is far lower than yields achieved in similar lowland rain-fed, tropical environments in Thailand (4.5 Mt·ha^{-1}) and southern Mexico (3.2 Mt·ha^{-1}) [4]. Due to the shortfall between production and demand, an average of 78,000 Mt of maize was imported yearly between 2015 and 2018 to augment the shortfall [4]. This shortfall is projected to increase if pragmatic measures are not put in place to address the yield gap.

Low soil fertility is among the most important constraints limiting crop productivity in SSA [9, 10]. In smallholder farms, soil fertility decline has been recognised as one of the major biophysical constraints affecting agriculture, particularly nitrogen (N) and phosphorus (P) deficiencies [11]. In Ghana, the soil nutrient depletion rates are estimated at 35 kg·N·ha^{-1}, 4 kg·P·ha^{-1}, and 20 kg·K·ha^{-1} annually [12]. The soil nutrients in the natural resource base are therefore dwindling faster than they are being replaced. Increasing population pressure has resulted in intensification of land use with a number of smallholder farmers practicing continuous cropping with little or no soil amendments, an indication that nutrient depleting cultivation practices are still used extensively. However, in an effort to sustain maize productivity, it is essential to explore alternative soil fertility replenishment strategies such as the use of animal manure which will be more affordable to smallholder farmers. Most rural households in southern Ghana rear sheep and goats as part of their farming systems. Although goat manure is readily available in most smallholders' homesteads, its use as organic manure for crop production has received little research attention in southern Ghana. Manure from these small ruminants can serve as a rich source of nutrients for crop production and for continuous cropping. In [13], it was reported that goat manure significantly increases growth and yield of sweet maize in southeastern Nigeria. However, there is a dearth of information on the effect of goat manure and its combination with inorganic fertilizer on maize production in the coastal savannah (CSZ) and semi deciduous forest (SDFZ) agroecological zones of Ghana. Combined use of manure and inorganic fertilizer is an intervention geared towards reducing cost of inputs and increasing maize production in a sustainable manner.

Apart from declining soil fertility, the use of unimproved varieties and uncertified seeds is among the major constraints influencing maize production in smallholder farms. Most smallholder farmers have resorted to the use of local varieties, and even where they use improved varieties, the seeds have been recycled for several years. These practices could contribute to the low yields that are being recorded [7]. Elsewhere, yield reductions ranging from 45 to 67% have been recorded for local varieties compared to improved open pollinated varieties (OPVs) [14]. The use of soil amendments and improved maize varieties are therefore crucial in achieving increased and sustained maize productivity. The major objective of this paper was to assess the performance of three maize varieties under different soil amendments (goat manure, inorganic fertilizer, and their combination) on smallholder farm environments in two agroecological zones (AEZs) in Ghana.

2. Materials and Methods

2.1. Site Description. The study was conducted as a participatory action research with researcher managed research implemented on farmer fields in three communities each in the coastal savannah zone-CSZ (Awutu Ofaso, Akufful Krodua, and Awutu Bontrase) and semi deciduous forest zone-SDFZ (Okyerekrom, Otareso/Mankrado, and Ahenkorase) agroecological zones (AEZs) of Ghana (Figure 1). The study began with the evaluation of goat manure and inorganic soil amendment options in the major rainy season of 2017 (April to August). Each major season's treatment plot was divided into two for evaluation of the residual effect of the treatments in the minor season of the same year. Farmers were actively involved in this study from land preparation, field layout, planting, weed management, and data collection till harvesting of the maize.

Both AEZs have a bimodal rainfall pattern with the major rainy season starting in April and ending in July with a dry spell in August, while the minor season begins in September and ends in November. The dry season is from mid-December to March. Temperatures are relatively high with a monthly average of between 21°C and 34°C. Annual rainfall ranges from 990 mm to 1650 mm for the forest zone and less than 1000 mm for the coastal savannah. Mean relative humidity ranges from 70% to 81% in the CSZ and 70% to 90% in the SDFZ [15]. The soils at the study areas were mainly Dystric Leptosols and Haplic Lixisols for the coastal savannah zones whereas that of the semi deciduous forest zones were Umbric Leptosols and Cambic Arenosols [16].

2.2. Field Preparation and Experimental Design. The field at each experimental site was cleared and stumped, and a pre-emergence weedicide (glyphosate) was applied at a rate of 1.5 kg·ha^{-1} two weeks before sowing in the major cropping season of 2017. In the minor cropping season of the same year, the old maize stalks from the previous season were slashed after harvesting, and the weedicide (glyphosate) was applied at 1.5 kg·ha^{-1} to the undergrowth weeds before planting. In the major rainy season of 2017 where the effects of the soil amendments were evaluated on maize varieties, a factorial of 3 maize varieties (Omankwa, Obatanpa, and Ahomatea) × 4 soil amendments ((goat manure at 5 t·ha^{-1}, inorganic fertilizer (NPK, 15-15-15, 250 kg·ha^{-1} + Urea, 125 kg·ha^{-1}, thus, 95-37.5-37.5 N-P_2O_5-K_2O kg ha^{-1}), 50% Goat manure (2.5 t·ha^{-1}) and 50% inorganic fertilizer (NPK 15-15–15, 125 kg·ha^{-1} + urea, 62.5 kg·ha^{-1}, thus 47.5–18.75–18.75 N-P_2O_5–K_2O kg ha^{-1}), and the control (no soil amendment)) (Table 1). The experiment was set up in a randomized complete block design (RCBD) with four

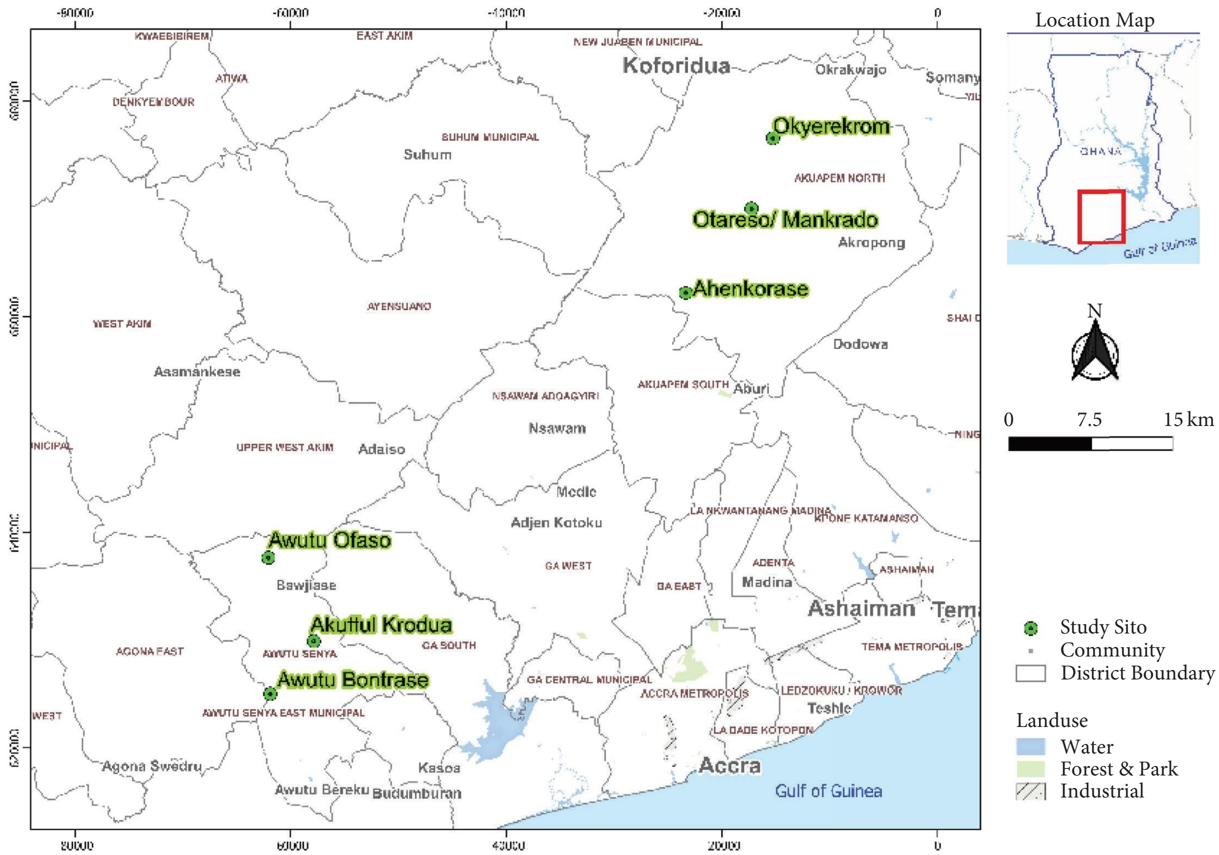


Figure 1: A section of the map of Ghana showing the study areas and the experimental sites in the coastal savannah and semi deciduous forest agroecological zones of Ghana.

Table 1: Soil amendments and rates used in the major cropping season 2017.

Soil amendments	Rates of application	Treatment names
(1) N-P_2O_5-K_2O: 95-37.5–37.5	250 kg·ha^{-1} NPK 15-15–15 + 125 kg·ha^{-1} urea	Fertilizer
(2) Goat manure (GM)	5.0 t·ha^{-1}GM	Manure
(3) 50% GM + 50% N-P_2O_5-K_2O, (47.5–18.75–18.75)	2.5 t·ha^{-1}GM + 125 kg·ha^{-1} NPK 15-15–15 + 62.5 kg·ha^{-1} urea	Fert + manure
(4) Control (no amendment)	None	Control

replications at each experimental site. In the minor season of 2017 when the residual effects of these soil amendments were evaluated, each treatment used in the major season except for the control was further divided into two resulting in a 3 (maize varieties) × 7 (soil amendments) factorial arranged in a split plot design with four replications. In the minor season, the soil amendments for the major season were either repeated on the subplots or were left out for the plants to rely on the residual nutrients from the major season (Table 2).

The improved maize varieties used in the study were obtained from the Council for Scientific and Industrial Research (CSIR)–Crops Research Institute (CRI), Ghana, and the local variety was obtained from the study areas (Table 3). Maize was sown using a planting distance of 0.80 m × 0.40 m with each plot size measuring 6.4 m × 5.6 m in the major season and plot size of 3.2 m × 5.6 m in the minor season. Three seeds were sown per hill and later thinned to two plants per hill 14 days after germination, resulting in a total plant population of 62,500 plants per hectare. Planting was conducted between 20th–25th April and 12th–16th September during the major and minor seasons of 2017, respectively, in both AEZs. The organic manure amendment (goat manure) was by basal application (spot placement) a week before sowing. The inorganic fertilizer (NPK) was applied as a side dressing at 2 weeks after sowing (WAS) followed by urea at 4 WAS. After application, the soil was turned lightly to incorporate the fertilizer to avoid exposure to direct sunlight and surface runoff. Weeds were controlled with a post-emergence herbicide for maize, i.e., nicosulfuron 40 (Nicoking) at a rate of 1.5 L·ha^{-1} at 4 and 8 WAS.

2.3. Data Collection and Analysis. Conventional rain gauges were installed in all the experimental sites to record the amount of rainfall on the farm throughout the study period. Mean temperatures of the study areas were sourced from the Ghana Meteorological Agency.

Table 2: Soil amendments and rates used in the minor cropping season 2017.

Soil amendments	Treatment names	Treatment codes
(1) N-P_2O_5-K_2O: 95-37.5–37.5 (sole inorganic fertilizer)	Fertilizer	F
(2) Goat manure (GM)	Manure	GM
(3) 50% GM + 50% N-P_2O_5–K_2O: 47.5-18.75–18.75 (fertilizer + manure)	Fert + manure	F + GM
(4) Residual nutrient sole fertilizer	Res fertilizer	RNSF
(5) Residual nutrient goat manure	Res manure	RNGM
(6) Residual nutrient fertilizer + goat manure	Res fert + manure	RNF + GM
(7) Control (no amendment)	Control	C

Table 3: Attributes of maize varieties used in the study.

Variety	Year of release	Attributes
(1) Omankwa	2010	Early maturing; drought tolerant; striga tolerant; quality protein maize (QPM); open pollinated variety (OPV)
(2) Obatanpa	1992	Intermediate maturing; quality protein maize; tolerance to pests and diseases (blight, rust, streak, and stem borer); OPV
(3) Ahomatea (local variety)	Unknown	Late maturing; OPV

2.3.1. Soil. Composite soil samples were collected from 0 to 15 cm and 15–30 cm depth on treatment plots with auger at all experimental sites in the AEZs before the study in the major season of 2017. The composite soil samples were sent to the CSIR-Soil Research Institute's laboratory for analysis. Soils were air-dried and passed through 2 mm sieve to remove large particles, debris, and stones. The soils were analyzed for physical properties mainly particle size analysis (i.e., percent sand, silt, and clay) using the pipette method [17]. Chemical properties of the soils such as pH, total nitrogen, available phosphorus (P), organic carbon/matter, and exchangeable cations (K, Na, Ca, and Mg) were ascertained. In addition, total acidity, total exchangeable bases, effective cation exchange capacity (ECEC), and percent base saturation were also determined. Soil reaction (pH) was measured in 1 : 2.5 soil: water suspension. Total nitrogen in the samples was determined by the modified Kjeldahl method [18]. Available phosphorus content in the soils was extracted by Bray's P1 solution and measured with a spectrophotometer [19]. Organic carbon was determined by the wet oxidation method of [20]. Exchangeable bases were extracted with 1.0 M ammonium acetate solution at pH 7.0. Sodium and potassium contents in the extract were determined by using flame photometry, while calcium and magnesium were determined by titration. The determination of exchangeable acidity was done using the method of [21].

2.3.2. Organic Manure (Goat Manure). Goat manure for the study was obtained from the CSIR-Animal Research Institute farms, Accra-Ghana, and composted for four months to ensure ample decomposition before application. The nutrient content of the goat manure was analyzed by sampling ten handfuls (about 2.0 kg) of the manure from each compost pit, which was then bulked to form a single composite sample. The composite sample was air-dried, thoroughly mixed, and ground to pass through a 2 mm sieve. Subsamples were then collected for chemical analysis [22] prior to application on the field.

2.4. Phenology, Growth, and Yield Records

2.4.1. Phenology Records. Data were recorded at all the experimental sites. The number of days to 50% emergence was recorded as the number of days 50% of the seedlings emerged on the plots. Days to 50% anthesis was recorded as the number of days when 50% of the plants had tasseled and days to 50% silking, as the number of days from planting to when 50% of the plants had emerged silks. The anthesis-silking interval (ASI) was then determined as the difference between days to 50% silking and 50% anthesis. The number of days to physiological maturity was counted as the number of days maize grains showed a black layer at the tip or base of the kernel. This black layer signifies that the kernel had reached physiological maturity.

2.4.2. Growth Measurements. The growth data collected during the field experiment were the plant height, stem girth, number of leaves, and leaf area, and then the leaf area index was calculated. Growth data were collected at 2- week intervals starting from 5 weeks after sowing (WAS) to 11 WAS. Ten maize plants were randomly selected from the middle rows of each treatment plot and tagged for growth measurements at 4 WAS. The selection of plants was from the six middle rows.

(1) Plant Height. Plant height was measured as the distance from the base of the stem at the soil level to the point of attachment of the uppermost leaf using a graduated pole. The mean from the ten plants was then determined to obtain the mean height per plant in each plot.

(2) Leaf Area. Leaf area was also determined using destructive analysis. Two plants were randomly selected from the 2^{nd} and 7^{th} inner rows on each plot at 5, 7, 9, and 11 WAS for determination. The length and the widest part of each green leaf and leaves with more than 50% of lamina being green from each plant were then taken with a tape measure. The product of the length and maximum leaf width of each

leaf was multiplied by a constant (0.75) to give the area for each leaf [23]. The total leaf area per plant was obtained by summing up the leaf area of each plant, and then the mean leaf area per plant was then determined for each treatment.

2.4.3. Yield Parameters. Harvesting was carried out when all the plants in the plots were dried with the cob husk turning light brown straw colored. Plants were sampled from an area of 1 m × 1 m within the inner rows (4^{th} and 5^{th} rows). Plants were harvested by cutting at the ground level and weighed. The plants were then separated into ears (cob + grains) and stovers (stem + leaves).

(1) Mean Number of Cobs per Plant. This was obtained by dividing the total number of cobs by the number of plants in the harvested area.

(2) Mean Cob Length. The length of five dehusked maize cobs per plot was taken with a measuring tape, and the mean value was determined.

(3) Mean Cob Diameter. This was calculated from the cob girth which was obtained from measuring the circumference of five cobs per plot with the use of a measuring tape, and the values were recorded, averaged, and converted with a formula $d = C/\pi$ to obtain the diameter, where C is the circumference and d is the diameter.

(4) Mean Weight per Cob. The total weight of five cobs from each plot was taken and was divided by the number of cobs to determine the mean weight per cob.

(5) Mean Number of Kernel Rows per Cob. The number of rows per cob for five cobs from each plot was counted, and the mean number was determined.

(6) Mean Number of Kernels per Row. This was the number of grains counted in a row (for five cobs), and the mean number was determined.

(7) Mean Number of Kernels per Cob. The total number of grains on five cobs from each plot was counted, and then they had been dried and shelled, and it was divided by the number of cobs to determine the mean number of kernels per cob.

(8) 1000 Grain Weight. One thousand grains were counted from each plot and weighed.

(9) Grain Yields. Grain yields were also estimated from grains from the shelled cobs from the harvested area on each plot at grain moisture content of 14% using a grain moisture meter (John Deere Moisture Chek Plus, Deere and company, USA), and weights were recorded. Grain yield is the weight of the grain expressed in kilogram per hectare (kg ha^{-1}).

All weights were recorded using an electronic scale (Electronic Portable scale, Constant Company, China).

2.5. Data Analysis. The data collected were subjected to analysis of variance (ANOVA) using the GenStat statistical package 12th edition (GenStat, 2009). This was to establish single and interactive factor effects on the phenology, growth, and yield of maize in the two locations. Data were later combined across the locations and analyzed for measured parameters in both seasons. Treatment means were separated using Tukey's honest significance test at 5% level of probability. The standard error of the difference (SED) was used for the error bars in the graphs. Line graphs were constructed using Microsoft Office Excel 2013.

3. Results

3.1. Properties of Soil and the Manure Used. The soils in the CSZ and SDFZ were loamy sand and sandy loam, respectively, in texture. Also, the soils were generally acidic, with low amounts of the major nutrients such as N, P, K, and Ca as well as organic matter. The pH values of the soils were higher in the CSZ (6.62–6.64) than the SDFZ (5.91–6.18), whereas soils in the SDFZ had relatively higher levels of soil nutrients than the CSZ (Table 4).

3.2. Effect of Variety and Soil Amendments on Growth of Maize. Significant differences ($p < 0.05$) were observed in plant height and leaf area for the three varieties at 5, 7, 9, and 11 WAS in both seasons and AEZs. Soil amendments also significantly influenced the plant height and leaf area of the three varieties at 5, 7, 9, and 11 WAS in both seasons and AEZs. Ahomatea was the tallest followed by Obatanpa and Omankwa with rapid growth from 5 to 7 WAS, then a steady growth from 7 to 9 WAS, and then a very marginal increase in height between 9 and 11 WAS irrespective of the soil amendments, in both seasons and AEZs (Figures 2(a) and 2(b)). The plant height of all the maize varieties on the soil amendments followed the trend of Fertilizer > Fertilizer + Manure > Manure > Control in both AEZs during the major season (Figure 2(a)). In the minor season when the residual effect was introduced, soil amendment effects on plant height followed the general trend of Fertilizer + Manure > Fertilizer > Manure > Residual Manure > Residual Fertilizer + Manure > Residual Fertilizer > Control in both AEZs (Figure 2(b)).

Obatanpa had a significantly ($p < 0.05$) higher leaf area than Omankwa and Ahomatea whose leaf areas were not significantly different in both locations and seasons (Figures 3(a) and 3(b)). Generally, the soil amendments influenced the leaf area and followed the trend: Fertilizer > Fertilizer + Manure > Manure > Control across maize varieties and locations in the major season (Figure 3(a)). In the minor season when the residual effect was introduced, the influence of the amendments on the leaf area followed the trend: Fertilizer + Manure > Fertilizer > Manure > Residual manure = Residual Fertilizer + manure > Residual Fertilizer = Control across varieties and locations (Figure 3(b)).

Table 4: Chemical and physical properties of soil at 0–15 cm and 15–30 cm soil depths of the coastal savannah and semi deciduous forest zones of Ghana used for the study.

Soil properties	Agroecological zone			
	Coastal savannah (CSZ)		Semi deciduous forest zone (SDFZ)	
	0–15 cm	15–30 cm	0–15 cm	15–30 cm
Chemical properties				
pH (H_2O) (1 : 2.5)	6.64	6.62	6.18	5.19
Total *N* (%)	0.07	0.04	0.10	0.07
Av. P (mg/kg)	19.76	15.81	21.39	19.45
Av. K (mg/kg)	21.77	13.95	27.91	23.15
Organic M (%)	1.35	0.85	2.06	1.48
Ex. Ca ($Cmol_c\ kg^{-1}$)	3.73	3.27	4.40	3.80
Ex. Mg ($Cmol_c\ kg^{-1}$)	1.87	2.33	2.13	2.47
Ex. K ($Cmol_c\ kg^{-1}$)	0.19	0.15	0.19	0.20
Ex. Na ($Cmol_c\ kg^{-1}$)	0.51	0.46	0.45	0.55
Ex. Acidity (Cmol (+) kg^{-1}	0.13	0.15	0.12	0.14
ECEC ($Al^{3+} + H^+$).($Cmol_c$ (+) kg^{-1})	6.43	6.36	7.29	7.16
Base saturation (%)	97.98	97.64	98.35	98.04
Physical characteristics				
Sand%	78.67		76.33	
Silt%	16.00		17.00	
Clay%	5.33		6.67	
Textural class	Loamy sand		Sandy loam	

Table 5: Chemical properties of goat manure used for the study.

Parameters	Composition/amount
pH in (H_2O) (1 : 2.5)	8.4
Organic carbon %	22.5
Total nitrogen (% N)	1.87
Total phosphorus (P %)	1.51
Total potassium (K %)	0.62
Total magnesium (Mg %)	0.53
C : N ratio	12.03
Iron (Fe %)	0.68
Zinc (Zn %)	0.0013
Copper (Cu %)	0.0068
Manganese (Mn %)	0.0301
Sodium (Na %)	0.0003

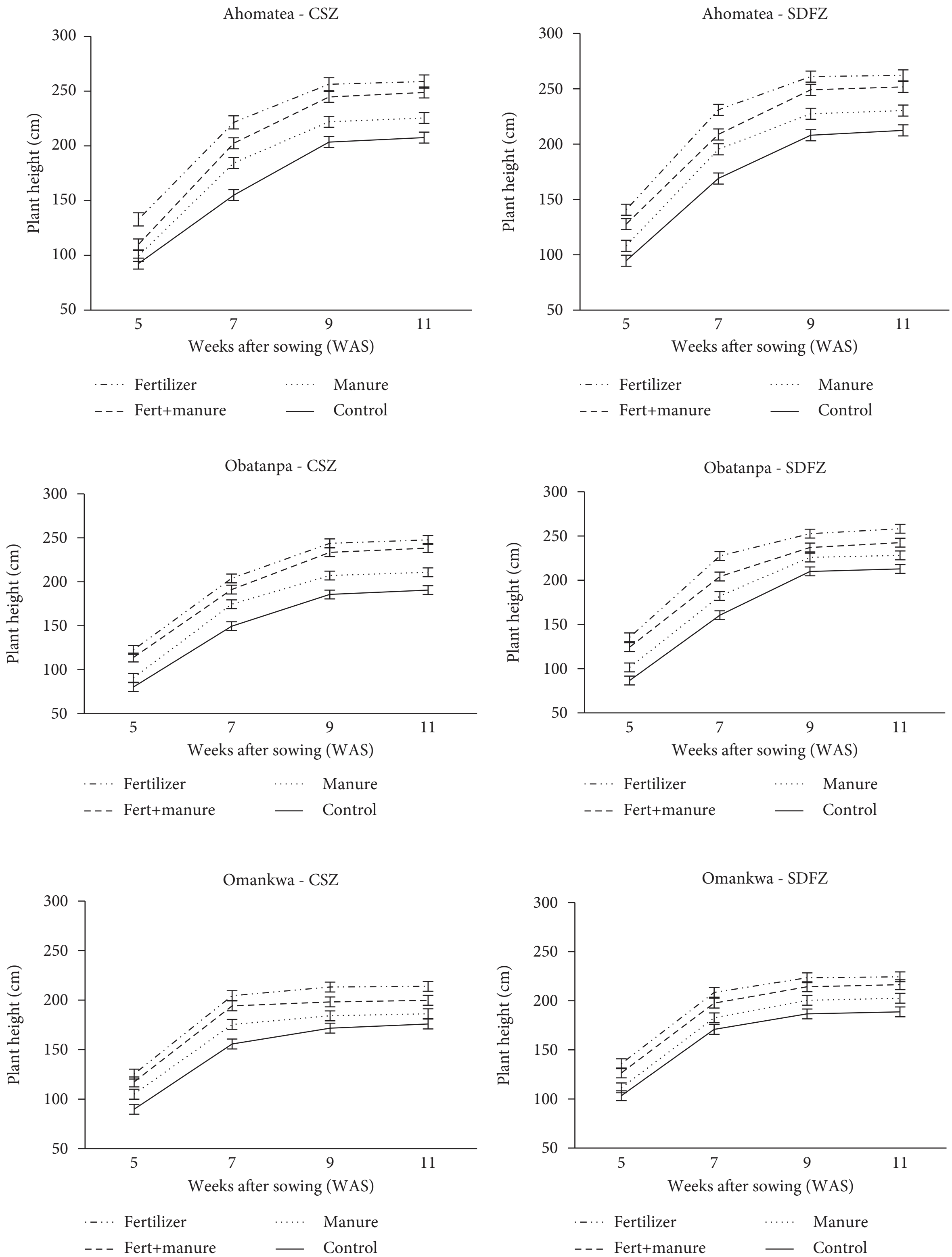
The goat manure applied at 5 t·ha^{-1} resulted in 93.5 kg·N·ha^{-1}, 75.5 kg·P·ha^{-1}, and 31 kg·K·ha^{-1} nutrient content (Table 5).

The leaf area increased rapidly from the 5 to the 7 WAS followed by a marginal increase which peaked at 9 WAS. There was a general decrease in the leaf area from 9 to 11 WAS for all varieties in both AEZs and seasons.

3.3. Effect of Variety and Soil Amendments on Phenology of Maize. Phenological features such as anthesis, silking, and anthesis-silking interval and physiological maturity of the three maize varieties under different soil amendments for both locations and seasons revealed that phenology was significantly ($p < 0.05$) influenced by variety and soil amendments (Tables 6 and 7). However, their interaction effects in both seasons and locations were not significant ($p > 0.05$).

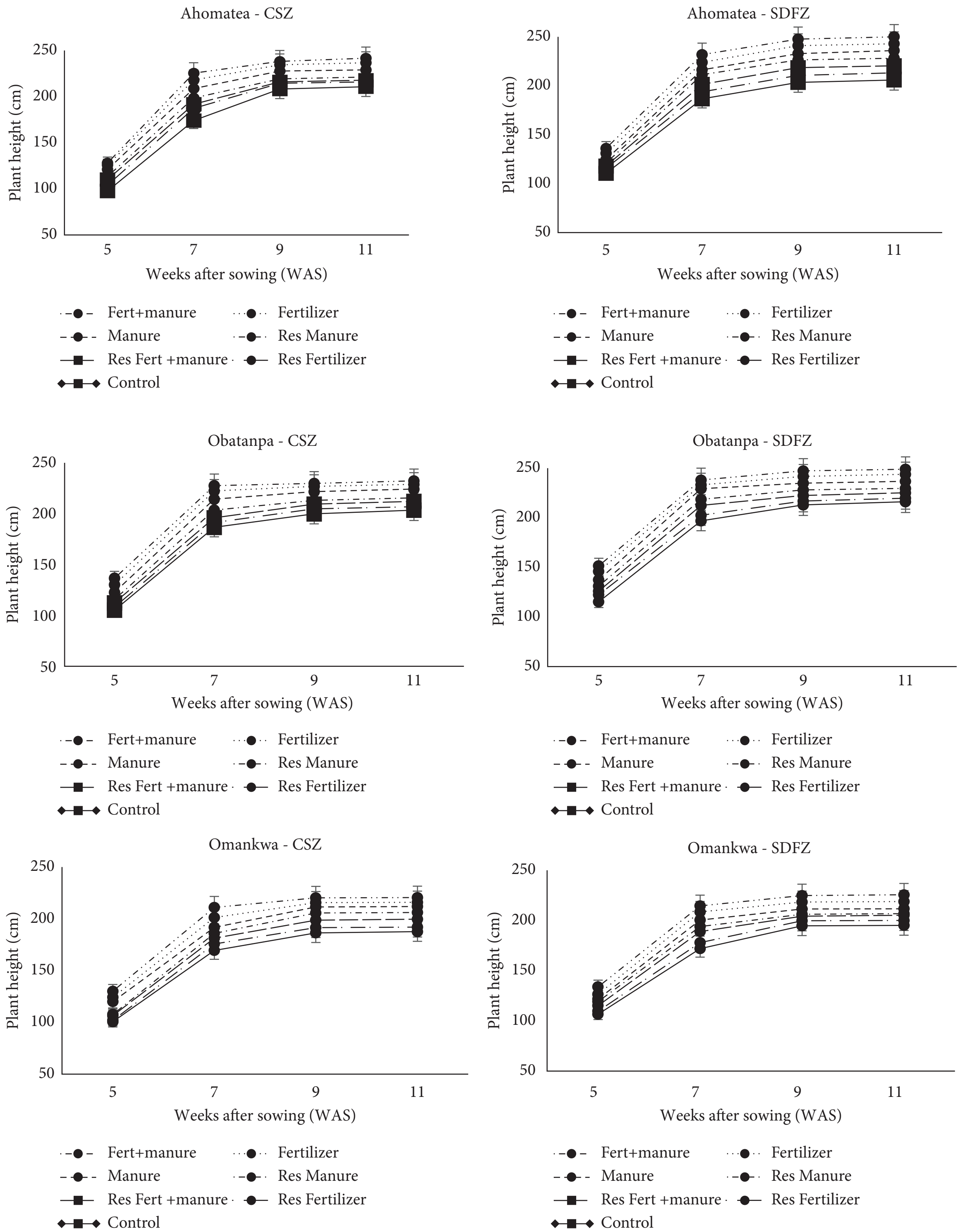
In the major season when the varieties and soil amendments were evaluated, Omankwa had significantly ($p < 0.05$) fewer days (41.2 days in CSZ and 41.4 days in SDFZ) to 50% anthesis compared to Obatanpa (53.6 days in the CSZ and 52.6 days in the SDFZ) and Ahomatea (54.6 days in the CSZ and 54.2 days in the SDFZ) in both AEZs. Ahomatea had the most number of days to 50% anthesis but was not significantly different from Obatanpa (Table 6). Similar trends were observed in the minor season when the residual effects were evaluated; Omankwa still had significantly ($p < 0.05$) fewer days (46.8 days in the CSZ and 44.9 days in the SDFZ) to 50% anthesis compared to Obatanpa (55.9 days in the CSZ and 54.8 days in the SDFZ) and Ahomatea (57.9 days in the CSZ and 56.4 days in the SDFZ). Ahomatea still had the most number of days to 50% anthesis and was significantly ($p < 0.05$) different from Obatanpa (Table 7). There were no significant ($p > 0.05$) differences for the number of days to 50% anthesis among plants under the sole fertilizer, fertilizer + manure, and sole manure-amended plots. Plants on the control plots recorded significantly ($p < 0.05$) higher number of days to 50% anthesis in both locations and seasons (Tables 6 and 7).

The number of days to 50% silking followed a similar trend as the number of days to 50% anthesis with variety and soil amendments being significantly ($p < 0.05$) different, but their interactions in both locations and seasons were not significant ($p > 0.05$). Omankwa had significantly ($p < 0.05$) fewer number of days (44–50 days in the CSZ and 44–48 days in the SDFZ) to 50% silking compared to Obatanpa and Ahomatea. Ahomatea had the highest number of days (60–63 days in the CSZ and 59–62 days in the SDFZ) to 50% silking and was significantly ($p < 0.05$)



(a)

Figure 2: Continued.



(b)

Figure 2: (a) Plant height (cm) of Ahomatea, Obatanpa, and Omankwa maize varieties at 5, 7, 9, and 11 weeks after sowing (WAS) under different soil amendments in the coastal savannah (CSZ) and semi deciduous forest (SDFZ) zones of Ghana during the 2017 major cropping season. (b) Plant height (cm) of Ahomatea, Obatanpa, and Omankwa maize varieties at 5, 7, 9, and 11 weeks after sowing (WAS) under different soil amendments in the coastal savannah (CSZ) and semi deciduous forest (SDFZ) zones of Ghana in the 2017 minor cropping season.

different from Obatanpa in both locations and seasons. The use of sole fertilizer and fertilizer + manure resulted in a similar but significantly ($p < 0.05$) less number of days to 50% silking than the control and use of sole manure in both AEZs and seasons (Tables 6 and 7).

The anthesis-silking interval (ASI) was significantly ($p < 0.05$) affected by variety but not soil amendments and their interactions in both AEZs and seasons. Omankwa had the shortest ASI (3 days in the CSZ and 2–3 days in the SDFZ) and was significantly ($p < 0.05$) different from Obatanpa and Ahomatea. Ahomatea had the longest ASI (5–6 days in the CSZ and 5 days in SDFZ) but was not significantly different from Obatanpa in both AEZs (Tables 6 and 7).

The number of days to physiological maturity was only influenced by variety but not soil amendments or their interactions in both locations in the major cropping season. However, in the minor cropping season, variety and soil amendments significantly ($p < 0.05$) influenced days to physiological maturity but not their interaction in both locations. Ahomatea took significantly ($p < 0.05$) more days (120–124 days in the CSZ and 120–122 days in the SDFZ) to attain physiological maturity, while Omankwa took significantly ($p < 0.05$) fewer number of days (91–93 days in the CSZ and 90–91 days in the SDFZ) to attain physiological maturity. In the minor season, plants on plots amended with sole fertilizer and fertilizer + manure had similar and significantly ($p < 0.05$) fewer days to physiological maturity compared to the control in both locations (Tables 6 and 7).

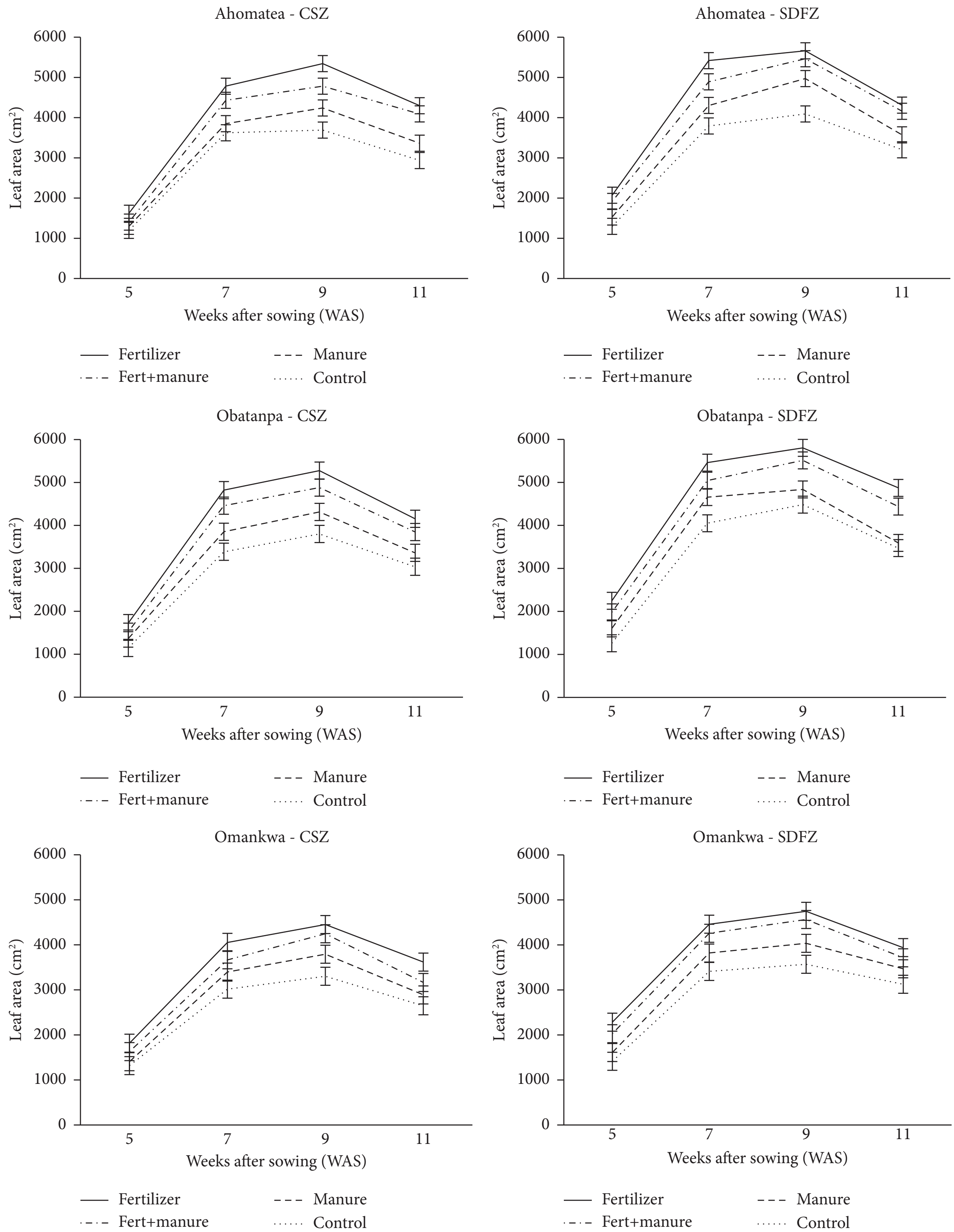
3.4. Yield and Yield Components of Maize as Influenced by Variety and Soil Amendments

3.4.1. Yield Components. The number of cobs per plant was significantly ($p < 0.05$) influenced by the interactions between variety and soil amendments in both locations in the major cropping season but not in the minor season (Tables 8 and 9). Omankwa and Obatanpa plants on plots amended with sole fertilizer or fertilizer + manure had significantly ($p < 0.05$) higher and similar number of cobs per plant than when only manure or no soil amendments (control) were applied in both locations. The number of kernel rows per cob, number of kernels per row, and number of kernels per cob were significantly ($p < 0.05$) influenced by variety and soil amendments but not their interactions in both locations and seasons. Generally, Omankwa and Obatanpa had significantly ($p < 0.05$) higher and similar number of kernel rows per cob, number of kernels per cob, and number of kernels per row than Ahomatea, the local variety (Tables 8 and 9).

3.5. Grain Yield. Grain yield was significantly ($p < 0.05$) influenced by the interactions between variety and soil amendments in both locations and seasons (Figures 4(a) and 4(b)). Omankwa and Obatanpa plants grown on plots amended with sole fertilizer or fertilizer + manure had similar and significantly ($p < 0.05$) higher grain yields than Ahomatea planted on all the soil amended plots in the major season (Figure 4(a)). A similar observation was made in the minor season for maize plants on plots with residual nutrients. Omankwa and Obatanpa plants grown on plots amended with fertilizer + manure and sole fertilizer had significantly ($p < 0.05$) higher grain yields than Ahomatea irrespective of the soil amendment used (Figure 4(b)). The use of sole manure resulted in relatively higher grain yield than the control for all the maize varieties in the major season in both locations (Figure 4(a)). Likewise, in the minor season, the use of sole manure resulted in significantly ($p < 0.05$) higher grain yields in all maize varieties than the residual and control treatments in both locations (Figure 4(b)). Grain yields for all the varieties in the major season increased in the minor season for all the soil amendments except for plants grown on the unamended/control plots (Figures 4(a) and 4(b)). In both seasons, grain yields were generally higher in the SDFZ than the CSZ.

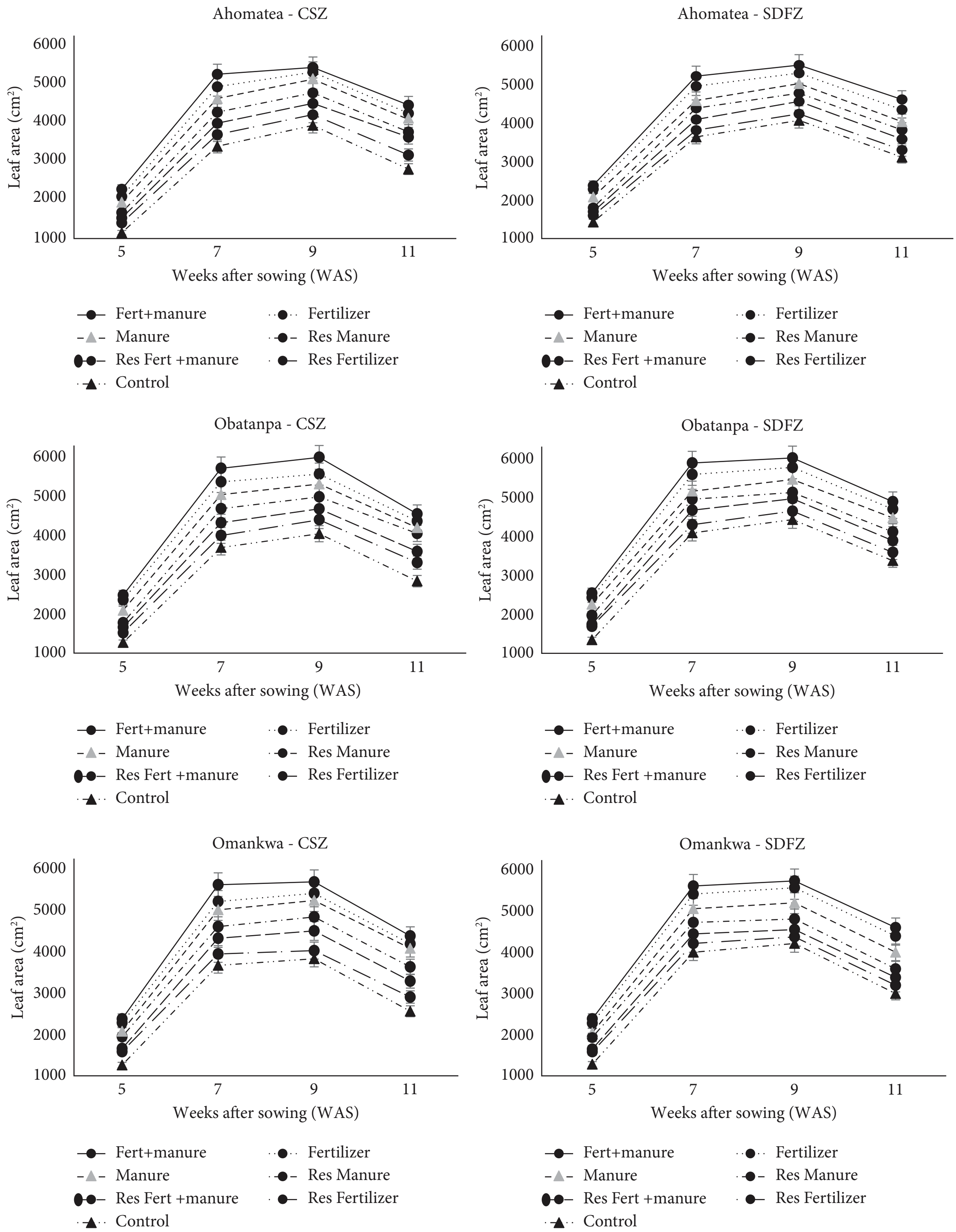
4. Discussion

4.1. Growth and Yield Performance of Maize as Influenced by Soil Amendments. The soils of the study areas were sandy loam and loamy sand, slightly acidic with relatively low soil nutrient attributes to support crop production [24]. Thus, the application of soil amendments on these soils would be a requirement for the growth and development of crops. Regardless of the maize variety, plants on either sole fertilizer or fertilizer + manure-amended plots showed better growth, physiological development, and yield than the control in the major season. In the minor season, maize plants on plots amended with fertilizer + manure or sole fertilizer performed better than those on plots with residual nutrients and the control. These trends seem to suggest that the soils in the study areas were deprived, and hence, there is a need for amendments for sustainable maize production. This observation of better growth and grain yield on fields with inorganic fertilizer either alone or in combination with manure than sole manure in both locations and seasons could be attributed to the low soil fertility status of the soils and the fact that the presence of the inorganic fertilizer made nutrients readily available for easy and quick uptake by the plants. These readily available nutrients from the inorganic fertilizer might have enhanced photosynthetic efficiency of the plants boosting growth and development. On the sole manure fields, it might have taken time before nutrients were made available to the plant. This agrees with the observation that the presence of inorganic fertilizer significantly increased growth and yield of maize than sole manure [13, 25]. The relatively higher grain yields observed for all the varieties for fertilizer + manure treatments than sole fertilizer in the minor season suggest that the manure applied in the major season might have improved the soil physics or left some residual nutrients that benefitted the plants in the minor season. The combination of organic and inorganic fertilizer is known to contain considerable quantities of plant nutrients, including micronutrients, and builds up soil organic matter and soil fertility [26]. Hence, we have relatively higher yields by plants on fertilizer + manure plots in the minor season. Some studies have shown that the use of manure could enhance efficiency of chemical fertilizers through synergistic effect and thereby increase maize yields [27, 28]. In [29], it was also



(a)

Figure 3: Continued.



(b)

Figure 3: (a) Leaf area of Ahomatea, Obatanpa, and Omankwa maize varieties at 5, 7, 9, and 11 weeks after sowing (WAS) under different soil amendments in the coastal savannah (CSZ) and semi deciduous forest (SDFZ) zones of Ghana during the 2017 major cropping season. (b) Leaf area of Ahomatea, Obatanpa, and Omankwa maize varieties at 5, 7, 9, and 11 weeks after sowing (WAS) under different soil amendments in the coastal savannah (CSZ) and semi-deciduous forest (SDFZ) zones of Ghana during the 2017 minor cropping season.

Table 6: Phenology of three maize varieties as influenced by different soil amendments in the coastal savannah (CSZ) and semi deciduous forest zone (SDFZ) in the major cropping season.

Maize varieties	No. of days to 50% anthesis		No. of days to 50% silking		Anthesis-silking interval (ASI)		Days to physiological maturity	
	CSZ	SDFZ	CSZ	SDFZ	CSZ	SDFZ	CSZ	SDFZ
Ahomatea	54.6	54.2	59.9	59.3	5.3	5.0	120.5	120.3
Obatanpa	53.6	52.6	58.6	57.2	5.0	4.6	105.2	104.2
Omankwa	41.2	41.4	44.2	43.9	3.0	2.5	90.6	89.7
Tukey (5%)	1.26	1.26	1.25	1.25	0.78	0.78	2.89	2.89
Soil amendments								
Fertilizer	48.5	48.6	52.9	52.2	4.3	3.5	104.2	103.5
Fert + Man	48.7	48.6	52.5	52.1	3.8	3.4	104.2	103.9
Manure	49.9	49.4	54.8	53.9	4.8	4.4	106.5	105.4
Control	52.0	50.8	56.8	55.7	4.8	4.8	106.8	106.2
Tukey (5%)	1.60	1.60	1.59	1.59	0.98	0.98	—	—

No.: number; Fert + Man: fertilizer + manure.

Table 7: Phenology of three maize varieties as influenced by different soil amendments and their residual effects in the coastal savannah (CSZ) and semi deciduous forest zone (SDFZ) in the minor cropping season.

Maize varieties	No. of days to 50% anthesis		No. of days to 50% silking		Anthesis-silking interval (ASI)		Days to physiological maturity	
	CSZ	SDFZ	CSZ	SDFZ	CSZ	SDFZ	CSZ	SDFZ
Ahomatea	57.9	56.4	63.4	61.7	5.5	5.3	124.1	121.8
Obatanpa	55.9	54.8	61.0	59.9	5.1	5.1	106.9	105.4
Omankwa	46.8	44.9	50.1	47.8	3.3	2.9	93.1	91.4
Tukey (5%)	0.90	0.90	1.08	1.08	0.53	0.53	1.22	1.22
Soil amendments								
Fert + man	53.0	50.8	57.1	54.8	4.1	3.9	105.9	104.1
Fertilizer	52.0	51.8	56.3	55.8	4.3	3.9	106.0	104.2
Manure	53.2	51.5	58	56.0	4.7	4.4	107.4	105.7
Res man	53.9	52.4	58.7	57.1	4.7	4.6	108.8	107.3
Res. fert + man	53.8	52.7	58.6	57.4	4.9	4.8	109.0	106.8
Res. fert	54.0	51.4	58.8	56.2	4.8	4.7	109.2	106.8
Control	54.7	53.5	59.6	58.2	4.9	4.7	109.8	108.3
Tukey (5%)	1.44	1.44	1.38	1.38	—	—	3.02	3.02

No.: number; Fert + Man: fertilizer + manure; Res. Fert + man: residual fertilizer + manure; Res. Fert: residual fertilizer; Res man: residual manure.

reported that the combined applications of organic and inorganic fertilizer produce yields, which are significantly higher than the organic or inorganic fertilizer alone.

The relatively better growth and yield performance of all the maize varieties under sole manure than those on the control and on residual fields in both locations and seasons give an indication that where a farmer has no money for the purchase of inorganic fertilizer, at least goat manure or other available livestock manure could be used for sustainable maize yields. This study has shown that the use of only manure resulted in average maize yields of about 2.5 $t{\cdot}ha^{-1}$, above the national average maize yields of 2.26 $t{\cdot}ha^{-1}$ reported in Ghana [7]. The goat manure used for this study had a C : N ratio of 12.03 suggesting that it could potentially release N to increase the low N content of the soil for improved crop growth and yield as reported by [30]. In [30], it was observed that sheep and goat manure with a C : N ratio below the critical level of 20 is of good quality and its decomposition could release mineral N to support crop growth and development.

The observation that residual nutrients from the previous application of the organic and inorganic fertilizers and their combinations alone did not significantly improve maize yields, which seems to suggest that on continuously cropped fields, continuous balancing of the soil nutrients with both inorganic and organic soil amendments (manure) would be needed for sustainable maize production. In [31], it was also found that restoration of soil fertility through balanced fertilization and organic matter additions is necessary to achieve high crop productivity in sub-Saharan Africa.

The fact that Omankwa reached physiological maturity approximately 15 and 30 days before Obatanpa and Ahomatea (local variety), respectively, suggests varietal influence on growth and phenological attributes of maize. This is in line with the observation that hybrids, open pollinated varieties (OPVs), and local and inbred lines have varying days for phenological traits [14, 32]. The higher grain yields by Omankwa and Obatanpa, which are all OPVs compared to the local variety (Ahomatea) in all

Table 8: Yield components of three maize varieties under four soil amendments in the coastal savannah zone (CSZ) and semideciduous forest zone (SDFZ) in the major cropping season.

Treatments	No. of cobs per plant		No. of kernel rows per cob		No. of kernels per row		No. of kernels per cob		Weight per cob (g)		Cob diameter (cm)		Cob length (cm)	
Maize varieties	CSZ	SDFZ	CSZ	SDFZ	CSZ	SDFZ	CSZ	SDFZ	CSZ	SDFZ	CSZ	SDFZ	CSZ	SDFZ
Ahomatea	1.04	1.05	13.2	13.5	30.3	31.3	412	429.5	161	167	3.45	3.93	14.3	14.8
Obatanpa	1.05	1.10	13.7	13.9	32.2	32.5	435	448.8	189	200	4.17	4.30	15.5	15.8
Omankwa	1.07	1.17	14.0	14.7	33.4	33.7	454	463.1	205	220	4.10	4.23	15.4	15.7
Tukey (5%)	0.03	0.03	0.49	0.49	1.11	1.11	21.1	21.1	13.4	13.4	0.11	0.11	0.53	0.53
Soil amendments														
Fertilizer	1.12	1.18	14.1	14.8	33.4	34.2	474	479	200	211	4.10	4.35	16.2	16.4
Fert + Man	1.08	1.16	13.9	14.3	32.6	33.6	443	468	198	209	4.09	4.23	15.9	16.1
Manure	1.01	1.07	13.5	13.9	31.9	32.0	422	441	177	192	3.82	4.06	14.8	15.2
Control	1.00	1.01	12.9	13.2	29.9	30.1	399	401	163	170	3.61	4.03	13.4	14.1
Tukey (5%)	0.03	0.034	0.62	0.62	1.39	1.39	26.7	26.7	17.0	17.0	0.13	0.13	0.67	0.67
A × Fert	1.07	1.09	13.7	14.2	32.1	33.5	465	471.8	181	188.1	3.63	4.13	15.8	16.0
A × F + M	1.06	1.08	13.6	13.6	31.1	32.7	430	459.9	181	186.0	3.62	4.12	15.4	15.5
A × M	1.00	1.02	13.0	13.3	30.4	30.3	390	422.0	146	157.2	3.37	3.79	13.5	14.2
A × C	1.00	1.00	12.3	12.8	27.4	28.5	364	364.2	136	135.9	3.19	3.67	12.4	13.6
Obt × Fert	1.14	1.17	14.2	14.3	33.5	34.0	471	476.7	204	214.3	4.37	4.53	16.5	16.9
Obt × F + M	1.08	1.18	13.8	14.1	32.0	33.3	437	465.8	200	209.1	4.35	4.33	16.4	16.4
Obt × M	1.00	1.04	13.6	14.0	32.0	32.2	427	435.9	184	192.2	4.14	4.23	15.4	15.4
Obt × C	1.00	1.02	13.1	13.4	31.2	30.5	414	416.7	166	182.9	3.81	4.12	13.8	14.4
Omk × fert	1.14	1.29	14.5	15.8	34.7	35.0	487	489.2	216	231.0	4.32	4.39	16.2	16.3
Omk × F + M	1.09	1.24	14.4	15.3	34.8	34.9	462	476.8	214	230.8	4.30	4.24	1.61	16.2
Omk × M	1.03	1.13	14.0	14.5	33.2	33.5	448	464.2	202	227.0	3.96	4.18	15.4	15.9
Omk × C	1.01	1.02	13.3	13.4	31.0	31.4	419	422.1	188	191.3	3.83	4.10	13.8	14.4
Tukey (5%)	0.02	0.016	0.87	0.867	0.662	0.662	0.51	0.508	0.70	0.704	0.89	0.892	0.43	0.432

A: ahomatea; Obt: obatanpa; Omk: omankwa; Fert: fertilizer; Fert + Man: fertilizer + manure; M: manure; C: control; No.: number.

Table 9: Yield components of three maize varieties as influenced by residual effects/application of soil amendments in the coastal savannah zone (CSZ) and semi deciduous forest zone (SDFZ) in the minor cropping season.

Treatments	No. of cobs per plant		No. of kernel rows per cob		No. of kernels per row		No of kernels per cob		Weight per cob (g)		Cob diameter (cm)		Cob length (cm)	
Varieties	CSZ	SDFZ	CSZ	SDFZ	CSZ	SDFZ	CSZ	SDFZ	CSZ	SDFZ	CSZ	SDFZ	CSZ	SDFZ
Ahomatea	1.03	1.04	13.2	13.4	29.1	30.1	391.0	405.5	132.0	147.9	3.33	3.49	13.0	14.5
Obatanpa	1.03	1.05	13.5	13.7	29.4	31.0	393.9	424.8	178.6	188.7	4.04	4.19	13.9	14.8
Omankwa	1.05	1.06	14.0	14.4	30.4	32.1	427.6	447.3	182.2	190.9	4.11	4.29	14.1	15.2
Tukey (5%)	0.02	0.02	0.22	0.22	0.62	0.62	17.17	17.17	8.00	8.00	0.094	0.094	0.25	0.25
Soil amendments														
Fert + Man	1.10	1.13	14.4	14.7	33.8	34.0	477.0	491.0	219.6	234.2	4.30	4.35	15.2	16.4
Fertilizer	1.09	1.09	14.2	14.5	32.6	33.5	470.1	481.0	211.5	225.3	4.14	4.30	15.0	15.9
Manure	1.03	1.05	14.1	14.2	31.1	31.5	435.1	447.4	194.0	210.7	3.87	4.12	14.5	15.3
Res. Man	1.02	1.04	13.4	13.7	30.0	30.8	397.8	405.7	151.1	158.4	3.80	3.94	13.7	14.7
Res. Fert + Man	1.01	1.03	13.3	13.5	28.1	29.9	366.2	402.0	150.3	147.6	3.68	3.82	13.0	14.4
Res. Fert	1.00	1.02	12.8	13.4	26.6	29.4	354.9	388.2	129.2	141.7	3.61	3.75	12.4	14.0
Control	1.00	1.01	13.0	12.9	25.2	28.4	327.9	365.8	107.9	112.8	3.38	3.65	11.7	13.0
Tukey (5%)	0.03	0.03	0.47	0.47	0.94	0.94	20.49	20.49	10.52	10.52	0.13	0.13	0.51	0.51

Fert + Man: fertilizer + manure; Res. Man: residual manure; Res. Fert + Man: residual fertilizer + manure; Res. Fert: residual fertilizer; No.: number.

the locations and seasons, are in conformity with the observations made by [14, 33] who found that OPVs yield higher than local varieties [33] reported a 40.5% yield advantage of Obatanpa over the "*Ohawu*" local variety, and this is corroborated in this current work where Obatanpa produced yield advantage (33.3 to 39.8%) over the Ahomatea local variety. This study has revealed that improved maize varieties can be used to achieve higher grain yields when the appropriate soil amendments are applied.

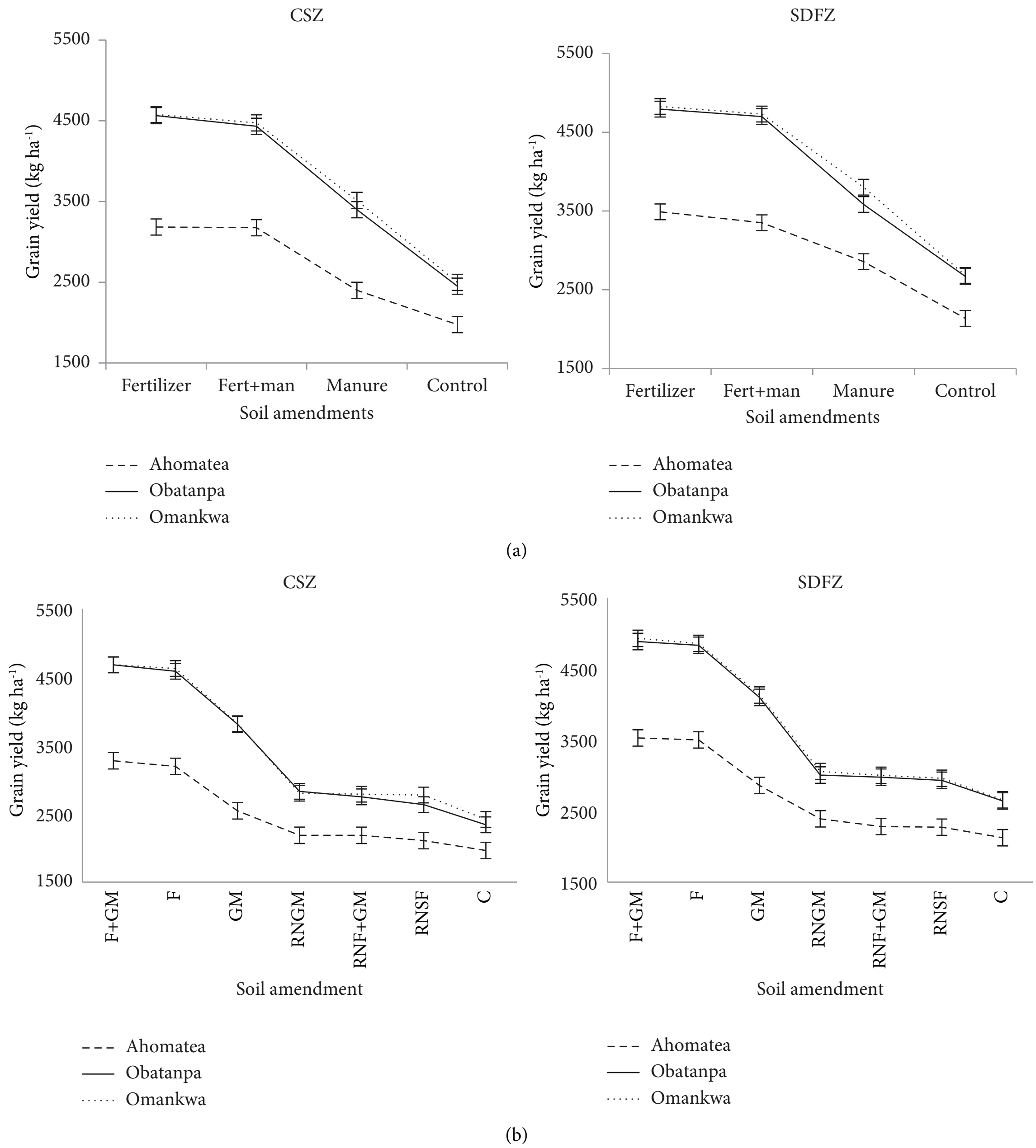


Figure 4: (a) Grain yield (kg ha^{-1}) of three maize varieties under different soil amendments in the coastal savannah (CSZ) and semi deciduous forest zones (SDFZ) in the major cropping season of 2017. (b) Grain yield (kg ha^{-1}) of three maize varieties as influenced by residual effects/application of soil amendments in the coastal savannah zone (CSZ) and semi deciduous forest zones (SDFZ) in the minor cropping season of 2017.

5. Conclusion

The Omankwa variety, which is early maturing and drought tolerant, had the highest grain yields. These qualities make Omankwa a versatile variety especially in this era of climate change. The application of goat manure in combination with inorganic fertilizers increased the grain yield of maize in the semi deciduous forest and coastal savannah agroecological zones. In this study, the application of 2.5 t·ha^{-1} goat manure in combination with NPK 15-15–15 at 125 kg·ha^{-1} and urea at 62.5 kg·ha^{-1} produced the highest grain yields in the second season. For sustainable maize production, varietal selection and appropriate soil amendments play a critical role.

Data Availability

The data used to support the findings of this study are available from the corresponding author (esthahenkrora@yahoo.co.uk) upon reasonable request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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