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Research article

IMPACT OF CATTLE MANURE ON CHEMICAL PROPERTIES AND MAIZE (*ZEA MAYS* L.) PERFORMANCE IN THE GUINEA SAVANNAH ZONE OF GHANA

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ABSTRACT

Inorganic fertilizers play a crucial role in enhancing crop growth and productivity. However, their excessive use can lead to adverse effects, including soil structure degradation and increased soil acidity. This study aimed to investigate the impact of varying cattle manure dosages on the growth and yield of maize (Zea Mays L) and the chemical properties of soil through a field trial conducted in Lahagu, Tamale Metropolis, Ghana. A completely randomized block design was used with four cattle manure treatments (0, 2, 4, and 6 t/ha), each replicated three times. The application of cattle manure greatly enhanced the growth and yield qualities of maize due to the constant supply of nutrients. The control plot exhibited significantly lower means, while the maize receiving 6 t/ha showed the highest means across all the assessed growth and yield parameters. The findings from this study revealed improved soil chemical parameter including soil pH, *organic carbon,* calcium and magnesium *following the application of cattle manure. It is recommended that resource-limited farmers apply 6 t/ha of cattle manure as an alternative to chemical fertilizers, as it notably improves the vegetative growth and yield of maize. This practice also reduces the environmental pollution from cattle manure disposal and increases the overall productivity. Since the trial was limited to a single season and location, further research across multiple sites and seasons is necessary for conclusive recommendations. The study provides valuable insights for smallholder farmers on the use of cattle manure as an organic soil amendment, promoting its adoption to enhance crop yield sustainably.*

Key words: *chemical properties, growth matrix, yield attributes, maize, physicochemical properties*

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INTRODUCTION

After rice and wheat, maize has the third-highest acreage and overall production levels worldwide (Law et al., 2022). It remains a crucial cereal and versatile crop. Although its use as animal feed is increasing, the majority of maize cultivated in Africa is still consumed by humans (Awika, 2011). In Ghana, maize is one of the most important crops for food security. Since 1965, its production has surged, making it the most widely cultivated cereal crop in the country (Nin-Pratt and Linden, 2014). In Northern Ghana, maize is the principal cereal crop, predominantly grown by resource-poor smallholder farmers and farm families in rural and peri-urban areas (Bawa, 2021). Widely consumed nationwide, maize is the second most important staple food in Ghana after cassava (Chemura et al., 2020). However, of the three major cereal crops, maize features the lowest resistance to stress (draught) (Duvick, 2005). The maize production in Ghana faces challenges due to soil degradation, low nitrogen and phosphorus levels, improper fertilizer use, and nutrient leaching, the factors that have contributed to low yields in the Guinea savannah agroecological zone (Abukari et al., 2018; Agyin-Birikorang et al., 2022). Abukari et al. (2020) and Korneeva and Alexander (2023) report that poor soil fertility limits the average maize yield to approximately 1.7 t/ha, far below the attainable yield of about 6 t/ha.

Applying organic manure to meet crop nutrient requirements is a necessary practice because organic manure typically enhance the physical, chemical, and biological properties of the soil, while simultaneously conserving the soil moisture-holding capacity, increasing crop yield and quality (Abukari et al., 2022; Jayasinghe et al., 2022). Despite containing fewer plant nutrients than chemical fertilizers, organic manures are essential for enhancing soil fertility and productivity. This is primarily due to the presence of growth-promoting factors such as enzymes and hormones, which contribute to the overall improvement of soil health. Therefore, organic manure plays a crucial role in maintaining sustainable agricultural practices (Das et al., 2022).

The present-day high costs and limited availability of chemical inputs in farming systems have resulted in increased reliance on organic amendments such as farmyard, green, and animal manures, which are the panacea to many challenges facing cropping systems of different agroecological regions (Abukari and Nasare, 2020). The primary focus of this study was to assess the effects of cattle manure application on the growth and yield productivity of maize in the Savannah ecological zone of Ghana.

MATERIAL AND METHODS

Experimental setup and site preparation

A completely randomized design (CRD) was used for the field trial, which consisted of four treatments (0, 2, 4, and 6 t/ha of cattle manure), each replicated three times. The experiment was conducted on a 10 m x 15 m (150 m^2) plot of land in Lahagu, located in the Tamale Metropolis, Ghana, during the 2023 cropping season. The site is situated at a latitude of 9°19´39.0´´N and a longitude of 0° 43´29´´8W, within the Guinea savannah ecological zone of Ghana, an area characterized by a variety of tree and weed species, including *Azadirachta indica, Vitellaria paradoxa, Parkia biglobosa, Tectona grandis, Sida acuta, Imperata cylindrica, Boehevia difusa, and Andropogon gayanus* (Larweh and Abukari, 2022).

The soil type in the area is predominantly sand and loam, and the region experiences a mono-modal rainfall pattern, with annual rainfall ranging from 900 to 1000 mm and average temperatures between 22 °C and 34 °C (Asare et al., 2023). After manual clearing and stump removal, the land was mechanically ploughed and harrowed to create a clean, fine tilth. Each experimental plot measured 3 m x 2 m (6 m^2) with 0.5 m spacing between plots, resulting in a total of 12 plots. Two weeks after planting, cattle manure was applied to the plots using a ring method. The two-week delay allowed sufficient time for manure decomposition, ensuring nutrient release aligned with the nutrient demands of maize seedlings, which typically develop 2–3 leaves at this stage. This timing supports healthy growth by providing essential nutrients and introducing beneficial microbes that enhance soil biota and nutrient cycling (African Agriculture Research Network, 2020).

Establishment and management of crop

The ‘Dorke’ maize cultivar was obtained from Heritage Seeds Company Limited, Tamale, Ghana. Four seeds were initially planted in each hole, with a spacing of 0.2 m x 0.1 m and a depth of 3 cm. Subsequently, the number of plants per stand was reduced to two, retaining only the healthiest specimens. This setup resulted in a planting density of 400 plants/ha across all the plots. For pre-emergence weed control, Metolachlor and Atrazine were applied at a rate of 1 L/ha three days after planting. Manual weeding was performed with a hoe to maintain clean, weed-free plots.

Cattle manure and soil analysis

Prior to the experiment in 2023, topsoil samples were randomly collected from five different locations within the experimental plots at a depth of 30 cm. Following air-drying and sieving through a 2-mm mesh, the soil samples were taken to a laboratory for physicochemical property analysis. Soil organic carbon was measured via the Walkley and Black method, using sulfuric acid-dichromate digestion followed by titration with ferrous ammonium sulphate (Nelson and Sommers, 1982). Total nitrogen (N) was determined by digesting 0.3 g of soil with a mix of Se, $LiSO_4$, H_2O_2, and concentrated H_2SO_4 (Anderson and Ingram, 1993). Basic cations (K, Ca and Mg) were extracted by leaching 5 g of soil sample with 50 ml ammonium acetate at pH 7 (Anderson and Ingram, 1993). Soil pH was determined using a 1:2 soil/water ratio with a glass pH meter, and particle size analysis was conducted using the hydrometer method (Gee and Bauder, 1986).

The cattle manure applied in this study was procured from the livestock division of OSGAF farms located in Lahagu, Northern Region, Ghana. The manure was treated to allow decomposition and stacked under a shed for two weeks to promote rapid mineralization. Subsamples of approximately 4 g were air-dried, crushed to pass through a 2-mm sieve, and analyzed for organic carbon, total N, P, K, Na, Ca, and Mg. Organic carbon content was determined using the Walkley and Black dichromate wet oxidation method, total N by micro-Kjeldahl digestion with subsequent distillation and titration, while P, K, Na, Ca, and Mg levels were assessed via wet digestion using a 25-5-5 mL mixture of HNO_3-H_2SO_4-$HClO_4$ (AOAC, 2000). Phosphorus was measured colorimetrically with the molybdate blue method in an autoanalyser, K by flame photometry, and Ca and Mg by atomic absorption spectrophotometry.

Data collection and statistical analysis

To assess vegetative growth and yield parameters, data were collected from five randomly selected plants in the two central rows of each plot. Measurements included leaf count, leaf area, stem circumference, plant height, number of grains per cob, cob girth, grain mass, and husk mass at the end of the crop growth cycle. The collected data were analyzed by analysis of variance (ANOVA) using the GenStat 18th edition software. Treatment means showing statistical significance were further analyzed with the Least Significant Difference (LSD) test at a 5% significance level.

RESULTS AND DISCUSSION

Physiochemical properties of soil and cattle manure

Table 1 provides an overview of the physical and chemical characteristics of the soil in the field trial area prior to cultivation. The findings indicate that the soil can be classified as sandy loam, exhibiting a slightly acidic nature with a pH value of 5.58. Moreover, the soil's fertility is notably low, as evidenced by the insufficient presence of organic carbon, organic matter, total nitrogen, available phosphorus, and exchangeable cations. Enhancing productivity requires supplementing nutrient-deficient soils with amendments, such as organic or inorganic fertilizers. Cattle manure application is anticipated to address the soil's low fertility and acidity (Table 2). The low nutrient levels observed in the experimental soil likely result from its high sand content, which affects cation retention and promotes leaching (Nabayi et al., 2023). Moreover, the insufficient levels of nitrogen, phosphorus, and potassium (NPK) in the soil can be attributed to continuous cropping practices and intensive land utilization.

Table 1. Physiochemical properties of soil before planting and after harvest

Parameters	Before planting	After harvest			
		0t/ha	2t/ha	4t/ha	6t/ha
pH (H_2O)	5.58 ± 0.16	5.58 ± 0.17	5.72 ± 0.23	5.87 ± 1.17	5.96 ± 1.19
Organic carbon (%)	0.64 ± 0.06	0.64 ± 0.06	0.86 ± 0.36	0.97 ± 0.62	1.47 ± 0.46
Total Nitrogen (%)	0.09 ± 1.10	0.09 ± 0.02	0.14 ± 0.34	0.27 ± 0.09	0.39 ± 0.18
Available P (mg/kg)	9.28 ± 0.03	9.28 ± 1.14	5.48 ± 1.27	4.36 ± 0.67	4.68 ± 0.34
Na (cmol/kg)	0.2 ± 0.13	0.2 ± 0.03	0.14 ± 0.02	0.17 ± 0.04	0.19 ± 0.02
Ca (cmol/kg)	0.54 ±1.24	0.54 ± 0.17	0.73 ± 0.09	0.98 ± 0.07	1.34 ± 0.13
K (cmol/kg)	0.98 ± 0.16	0.98 ± 0.19	0.67 ± 0.12	0.48 ± 0.03	0.29 ± 0.05
Mg (cmol/kg)	0.24 ± 0.03	0.24 ± 0.16	0.63 ± 0.06	0.82 ± 0.04	1.45 ± 0.19
Sand (%)	63.6 ± 1.38	63.6± 1.26	66.8 ± 1.31	68.7 ± 2.10	70.5 ± 1.45
Silt (%)	33.3 ± 1.09	33.3 ± 01.16	23.5 ± 0.86	20.6 ± 0.11	20.4 ± 0.05
Clay (%)	3.1 ± 0.11	3.1 ± 0.09	9.7 ± 0.34	10.7 ± 1.11	9.1 ± 0.14
Textural class	Sandy loam	Sandy loam	-	-	-

The application of varying rates of cattle manures led to a slight increase in the soil pH value and total nitrogen levels, ranging from 5.58 to 5.96 and 0.09-0.39 respectively, at crop maturity. The addition of cattle manure to the soil significantly improved the organic carbon, calcium (Ca), and magnesium (Mg) concentrations compared to the control plots. These findings align with those of Zhang et al. (2021) and Yagüe et al. (2016) who found that the application of cattle manure improved soil organic carbon, calcium and magnesium. This consistency with previous research reinforces the validity of our results and underscores the potential of cattle manure as a valuable soil amendment. Among the plots, the highest improvements were observed in those treated with 6t/ha of cattle manure.

However, the levels of available phosphorus (P), sodium (Na), and potassium (K) slightly decreased across different application rates, as shown in Table 1. This may be due to nutrient immobilization, whereby microbes breaking down organic matter temporarily sequester nutrients. Additionally, cattle manure may alter soil pH, impacting nutrient availability. The modest increase in the soil pH level indicates the buffering potential of cattle manure in reducing soil acidity. These findings contrast with those of Adekiya et al. (2021) and Godonu et al. (2023), who reported that increasing quantities of poultry and cattle manure decrease the soil pH through acidifying effects. At crop maturity, the addition of cattle manure at different dosages increased soil organic carbon, Ca, and Mg. This could be attributed to the gradual release of cattle manure nutrients into the soil (Godonu et al., 2023) or the increase in nitrogen quantities present in different amounts of the cattle manure applied, which enhances microbial activity and leads to the increased production and mineralization of organic matter from natural sources in the soil (Adekiya et al., 2021). The treatments with cattle manure exhibited higher organic carbon content than the control treatments, which aligns with the findings of Mahmoud et al. (2009), who observed increased organic matter with rice straw compost application.

Table 2. Chemical composition of cattle manure used in the experiment expressed per kg of dry matter

Cattle manure	Value
pH (H_2O)	5.78 ± 0.36
Organic carbon (%)	2.63 ± 0.12
Organic matter (%)	4.68 ± 0.86
Total N (mg/kg)	1.20 ± 0.15
Available P (mg/kg)	24.58 ± 2.23
K (mg/kg)	1.13 ± 0.04
Na (mg/kg)	3.68 ± 0.13
Ca (mg/kg)	0.89 ± 0.03
Mg (mg/kg)	0.43 ± 0.05

Effect of cattle manure on mean vegetative growth parameters of maize

Table 3 illustrates the impact of varying doses of cattle manure on plant height, leaf number, leaf area, and stem girth in maize. A consistent trend was observed, with control plants exhibiting the lowest growth values and manure-treated plants showing higher values in proportion to the amount of cattle manure applied. This pattern suggests that increasing cattle manure dosage positively influences the mean values of vegetative growth parameters. The results indicate that the availability of nutrients, particularly N, P, and K, plays a crucial role in promoting plant vegetative growth and development (Yang and Zhang, 2022). The consistently reduced growth in the control plots and those receiving low manure dosages suggests that an optimal nutrient balance is essential for maximizing plant growth potential. This study observed significant growth enhancements at higher manure application rates, consistent with the findings of Eleduma et al. (2020). The leaf area index (LAI), a key growth indicator reflecting the plant's capacity for solar energy capture in photosynthesis, was significantly affected by manure application. The highest LAI was recorded at 6 t/ha (423.4), markedly exceeding those at 4 t/ha (388.2), 2 t/ha (368.7), and 0 t/ha (321.3). Nitrogen (N), a primary growth nutrient, is known to expand leaf area as its availability increases (Das et al., 2022). The nitrogen provided by cattle manure likely promoted the leaf area expansion during vegetative growth and helped maintain the functional leaf area throughout the growth phase (Nabayi et al., 2023). The application of varying doses of cattle manures significantly ($p < 0.05$) influenced the stem diameter.

Table 3. Effect of cattle manure on mean vegetative growth parameters of maize

Treatment	Plant height (cm)	Number of leaves	Leave area (cm^2)	Stem girth (cm)
0t/ha	98.34a	11.04a	321.3a	21.3a
2t/ha	106.2b	12.03b	368.7b	23.4b
4t/ha	112.3c	12.84c	388.2c	23.8c
6t/ha	120.4d	13.45d	423.4d	24.6d
LSD (0.05)	2.45	0.29	0.36	0.34

Legend: Mean values sharing the same letter (s) within a column do not exhibit statistically significant differences at $p < 0.05$.

The application of cattle manure at a rate of 6 t/ha resulted in the highest performance in terms of plant stem diameter, followed by applications of 4 t/ha and 2 t/ha, with the control treatment exhibiting the smallest diameter. The mean values of maize growth parameters following the application of 6, 4, and 2 t/ha of cattle manure, as well as the control treatment, were comparable yet significantly different. These findings suggest that organic manure applications, such as cattle manure, can enhance soil fertility by stimulating soil microbial biomass, thus promoting crop growth and development (Eleduma et al., 2020). The increase in stem diameter observed with manure application may be attributed to this mechanism, as larger stem diameters can enhance resistance to lodging during fruiting by reducing the risk of collapse under the weight of fruits or strong winds. The maize plants treated with 6 t/ha of cattle manure exhibited significantly greater height compared to the control plots and other manure treatments ($p < 0.05$). This finding indicates that the amount of cattle manure applied directly influences the availability of nutrients for plant absorption, thereby supporting plant growth through photosynthesis (Hariadi et al., 2016). Furthermore, the highest number of leaves per plant was observed at the 6 t/ha application rate, which was significantly greater than those with 4 t/ha, 2 t/ha, and the control treatment. The addition of cattle manure at different dosages increased soil organic matter, enhanced microbial activity, and improved soil fertility and structure (Holatko et al., 2022). Consequently, the nutrients provided by cattle manure contribute to root development (Sisouvanh et al., 2021), likely supporting enhanced leaf growth.

Effect of cattle manure application on mean yield attributes of maize

Table 4 presents the effect of cattle manure application on the mean yield attributes of maize. Significant treatment effects were observed for the number of harvested cobs per plant and cob diameter, while the husk weight remained unaffected. The maize plants treated with 6t/ha of cattle manure exhibited the highest mean values across most yield parameters, including grain count per cob, cob length, and grain weight. These values were significantly greater than those in the 0 t/ha and 2 t/ha treatments, with the lowest mean values recorded at 0 t/ha. The mean values for cob and grain characteristics increased with higher dosages of cattle manure, supporting the previous findings by Iqbal et al. (2022) and Chahal et al. (2020), which associate nutrient-rich manure applications with enhanced crop weight and volume. The enhanced yield observed in the maize treated with 6 t/ha of cattle manure is attributed to the nutrient-rich composition of the manure, which supplies essential nutrients and improves soil quality. The treatments with 4 t/ha and 2 t/ha of cattle manure also demonstrated significant improvements over the control. The increased nutrient availability, enhanced soil ecosystem conditions, and improved moisture retention at higher manure dosages likely contributed to the increased crop yield and quality, as similarly noted by Roy et al. (2022).

Table 4. Effect of cattle manure application rates on mean yield attributes of maize

Treatments	Number of cobs	Quantity of grains/cobs	Cob length (cm)	Cob diameter (cm)	Grain weight (kg)	Husk weight (kg)
0t/ha	5.13a	389.08a	14.54a	3.23a	1.05a	0.10a
2t/ha	5.23b	424.45b	15.57b	3.89b	1.32b	0.19a
4t/ha	5.98c	467.58c	15.92c	4.32c	1.84c	0.27a
6t/ha	6.35d	500.45d	16.87d	4.73d	2.31d	0.34a
LSD (0.05)	0.80	0.48	0.32	0.38	0.36	0.32

Legend: Mean values sharing the same letter (s) within a column do not exhibit statistically significant differences at $p < 0.05$.

CONCLUSION

This study confirms that cattle manure application enhances maize performance and soil fertility. Therefore, it is recommended that resource-limited farmers in the Guinea savannah zone of Ghana apply cattle manure at 6 t/ha to promote sustainable cropping, optimize maize yields, and ameliorate the region's low soil fertility. In light of the significant benefits of cattle manure application, extension officers should actively promote best practices by educating farmers on its advantages and appropriate application rates. Training programs, including workshops and demonstrations on proper manure handling, storage, and application techniques, are essential. Moreover, policymakers, stakeholders, and agricultural experts must collaborate to advance sustainable agricultural practices through cattle manure application, fostering a more resilient and environmentally sustainable food system.

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P.C; Writing – original draft - A.A., and P.C; Writing – review & editing - A.A., and P.C. All authors have read and agreed to the published version of the manuscript.

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