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Research Article

Instantaneous Agricultural Waste Valorisation: A Novel Approach to Sustainable Organic Fertilization for Enhanced Maize Yield in Comparison to NPK Fertilizer

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Graphical Abstract

Abstract: Inorganic fertilizers are known for their environmental harm, leading to a search for sustainable alternatives. Global population growth demands sustainable agriculture, yet dependence on synthetic fertilizers risks soil degradation, pollution, and climate change. In Nigeria, agricultural waste management is challenging, with most waste burned, increasing greenhouse gas emissions. This study explores converting agricultural residues into organic fertilizers, offering an eco-friendly alternative. The effects on maize growth were compared to NPK 20:10:5 and rabbit manure. Three unique organic fertilizers were synthesized from a blend of eleven types of residual dry plant biomass. Impressively,

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maize plants treated with this synthesized fertilizer reached a maximum height of 171.45 cm, outperforming both NPK fertilizer (134.0 cm) and rabbit manure (121.92 cm). Moreover, maize yield was significantly enhanced with the synthesized fertilizer, particularly with fertilizer C boasting a weight of 287.38 g. Notably, this fertilizer exhibited both rapid and slow nutrient release dynamics, with 11% thiourea incorporation yielding superior results. This study demonstrates that a small amount of organic fertilizer can yield more than NPK, contrary to other reports. This highlights the potential of using agricultural residues for organic fertilization, offering sustainable waste management and soil fertility improvement. Organic fertilizers can reduce reliance on synthetic fertilizers, decrease environmental pollution, and promote sustainable agriculture. They enhance crop yields while minimizing environmental impacts, providing a viable alternative for farmers in Nigeria and similar regions. Future research should optimize biofertilizer formulation and application methods for diverse agricultural settings.

***Keywords*:** plant biomass, organic fertilizer, soil amendments, maize, NPK fertilizer, manure

1. Introduction

Agriculture has been a cornerstone of global economic development, providing sustenance, income, and employment opportunities. As we strive for enhanced agricultural productivity to alleviate hunger, it is imperative to address sustainable waste management (Tilman et al., 2011; Food Tank, 2023). Low-income countries are projected to witness a 40% surge in waste generation, with agriculture accounting for a significant share of this increase. In Nigeria, approximately 70% of the population relies heavily on subsistence agriculture for their daily sustenance (Osabohien et al., 2019; Oluwatoyese et al., 2021). With 70.8 million hectares of arable land, Nigeria's major crops encompass cassava, maize, guinea corn, beans, yam, rice, and millet (FAO, 2008; Simeon et al., 2020; Chukwuebuka et al., 2022; Collins et al., 2022). Agricultural residues, comprising various organic materials derived from crop harvesting and processing, encompass diverse components such as corn stalks, husks, fruit flesh, and seeds. Their characteristics, including particle size, moisture content, and bulk density, vary depending on geographical location and handling methods (Svanbäck et al., 2019). Escalating prices of inorganic fertilizers, driven by factors like surging energy costs and geopolitical tensions, have led farmers to seek sustainable alternatives to maintain yields (Food Tank, 2023). Notably, fertilizer production consumes substantial energy, relying on fossil fuels (as seen in N-fertilizers using the Haber-Bosch process) or fossil ore deposits (e.g., phosphate rock) (Sigurnjak et al., 2013; Svanbäck et al., 2019).

Synthetic fertilizers pose considerable environmental risks, including soil degradation, reduced organic matter content, leaching, pollution, and climate change exacerbation. As the global population expands, there is heightened pressure to augment food production, potentially surpassing the continent's capacity to meet demand, especially in Africa (Nizami et al., 2017; Britt et al., 2018). The Circular Economy (CE) concept, introduced by the European Commission, advocates for material recovery to combat environmental and social challenges (Ritzén & Sandström, 2017). While postharvest residues hold potential as substitutes for raw materials in fertilizer production, the fertilizer industry has yet to fully exploit this renewable resource. Encouraging the fertilizer industry to integrate biomass valorization in their technologies could be facilitated through direct subsidies (Scholz, 2017; Katarzyna et al., 2020).

On the other hand, using organic amendments such as cattle manure is a viable alternative to the negative effects of inorganic fertilizers due to its widespread availability, additional value for soil carbon sequestration, and ability to store and release nutrients over a prolonged period. In Nigeria, some farmers have adopted the use of cattle manure and dumpsite compost on their farms, typically using it untreated and directly from animal barns or dumpsites. This practice poses risks to human health and crops because untreated manure often contains a high prevalence of pathogens and elevated levels of heavy metals. Additionally, manure emits carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), ammonia (NH_3), and other volatile substances. Such emissions contribute to environmental issues such as global warming, eutrophication, and acidification of ecosystems (Jjagwe et al., 2020).

Agriculture is responsible for approximately 21% of greenhouse gas emissions, intensifying the effects of climate change. The indiscriminate burning of agricultural waste exacerbates these issues, with only a small portion utilized for fodder, erosion control, and fertilizer. Most agricultural waste is disposed of through burning because, during the harvest season-mostly the dry season-agricultural residues do not decompose easily before the next planting season. If accumulated, they consume space that could otherwise be used for farming activities, so farmers burn them and use the ash as a soil amendment. This practice can have severe health consequences due to the inhalation of toxic fumes and air pollution (Adeoye et al., 2011; Simonyan et al., 2013; Oladipo et al., 2013). This method also significantly contributes to carbon emissions, exacerbating global warming. Implementing innovative waste management techniques that prioritize environmental and human health is crucial, yet not all waste categories are addressed, and widespread adoption faces certain challenges (Mojisola, 2023).

Various plant biomass resources have been utilized to produce different types of manures worldwide, primarily as compost, biochar, or liquid fertilizers derived from fruit waste (Soen et al., 2023; Abidin et al., 2024), biochar (Muhammad et al., 2018; Bindar et al., 2024; Putri et al., 2024), and compost and organic manure (Alessandra et al., 2013; Rajkhowa et al., 2019; Kit et al., 2019; Udara et al., 2020; Noor et al., 2021). While converting plant biomass to biochar or compost holds promise for carbon sequestration and soil enhancement, concerns such as high energy requirements, emissions during production, limited scalability, environmental trade-offs, nutrient loss, long processing times, potential odor and pathogen issues, and the need for significant space and infrastructure must be addressed (Clough et al., 2013; Muhammad et al., 2023; Grgas et al., 2023).

This study aims to develop eco-friendly and cost-effective methods for rapidly converting agricultural residues (plant biomass) into organic fertilizer without losing much of their biomass composition and processing time compared to biochar and compost. The objective is to synthesize this fertilizer and compare its application alongside NPK fertilizer and manure on an open field cultivated with the maize of the same species, ensuring consistent treatment conditions for all maize except for the fertilizers applied.

2. Materials and methods

2.1 *Collection of agricultural residue*

Dry maize stalks, sorghum stalks, rice straw, groundnut shells, sugarcane straw, polyaltha logifolia leaves, elephant grass, palm tree bark, sawdust, and two other weed plants were obtained from agricultural lands along the Kaduna refinery axis, Kaduna South, Kaduna State, Nigeria.

2.2 *Sample collection*

Clay soil samples were collected using a shovel to a depth of more than two feet for less organic matter and nutrient content. Each sample was then placed in five sacks, each 20 cm deep and weighing 30 kg. This was carried out in the month of March, during a period of no rainfall and minimal weed growth, at Tsuanin Kura GRA Sabon Tasha, Kaduna South, Kaduna State. A 1kg bag of Maize seedlings (AS-SAMAD Agro Allied Co., PZ Kaduna State) was purchased from an agrochemical store in Kaduna Metropolis, Kaduna State, Nigeria. NPK 20:10:5 Matrix Fertilizer (KM 3 Dumbin Duste Zaria, Kaduna) was also obtained from an agrochemical store in the Kaduna Metropolis. Rabbit manure was collected from a garden at Tsuanin Kura GRA. Calcium hydroxide, Sodium Hydroxide, thiourea, Nitric, and Sulfuric acids were procured from chemical vendors, in Kaduna Metropolis, Kaduna State, Nigeria.

2.3 *Organic fertilizer preparations*

Eleven of the collected plant residues were washed with running tap water to remove soil debris, sundried for 24 hours, chopped into small pieces, ground to fine particles, and sieved to achieve homogenized sizes.

2.3.1 *Fertilizer A*

To prepare Fertilizer A, 50 g of the homogenized plant residue was placed in a 250 mL beaker. Subsequently, 25 mL of 50% Nitric acid was added, and the mixture was heated at 120 °C for 20 minutes. After cooling to 60 °C, 10 g of wood ash was added while stirring for 10 minutes. The mixture was then transferred to an aluminum foil and oven-dried at 80 °C for 24 hours, as illustrated in Figure 1.

Figure 1. a = biofertilizer A; b = biofertilizer B; c = biofertilizer C; d = NPK 20:10:10 and e = Rabbit Manure

2.3.2 *Fertilizer B*

For the preparation of Fertilizer B, 50 g of the homogenized plant residue was placed in a beaker containing 20 mL of 20% sodium hydroxide. The mixture was heated at 100-110 °C for 10 minutes, after which 15 mL of 30% sulphuric acid was added on continual heating for 10 minutes. Following cooling to room temperature, and mixture was oven-dried at 47 °C for 1 hour, as shown in Figure 1.

2.3.3 *Fertilizer C*

To produce Fertilizer C, 50 g of the homogenized plant residue was transferred into a beaker containing 30 mL of 50% Nitric acid. The mixture was heated at 100-110 °C for 20 minutes, and 20 g of wood ash was added. After cooling to room temperature, the mixture was oven-dried at 47 °C for 1 hour, as depicted in Figure 1.

2.4 *Characterization*

The sample fertilizer C, manure, NPK fertilizer and soil before planting and after harvest were collected for chemical and physical analyses. Moisture content was determined as weight loss upon drying at 105 °C in an oven for 24 hrs. Total nitrogen (TN) by the Kjeldhal method. Flame atomic absorption spectroscopy was used to measure total potassium (TK) on acid digested samples (Altieri et al., 2010), Total Phosphorus (TP) was determined using the H_2SO_4 and H_2O_2 digestion method, total carbon (TC) was determined by dry combustion method (Ben et al., 2016). For soil samples after collection to a depth of 15-20 cm and combined into a composite sample. Air-dried and sieve them through a 2 mm mesh for analysis.

2.5 *Formulation for maize application*

For the irrigation process, 700 cm^3 of water was sprinkled on each pot in morning and evening at four days interval for two months before adequate rainfall in the month of May. For the initial application, two weeks after germination, equal quantities of each fertilizer were used, with individual weights as follows: 20.0 g of Fertilizer A was applied near the roots of maize A and maize B, 32.80 g of NPK 20:10:5 fertilizers was applied to maize C, and 12.2 g of rabbit manure was applied to maize E. No fertilizer was applied to maize D, which served as the control reason is to observe how the maize respond to only the soil nutrient and it yield for better comparison with the others. Fourteen days after the first application, a mixture of 17.2 g of Fertilizer B, calcium hydroxide (solid), and clay soil was applied to maize A, while a mixture of 21.0 g of Fertilizer C, calcium hydroxide (solid), and clay soil was applied to maize B. Maize C received 49.2 g of NPK 20:10:5 fertilizers, and maize E was given 18.3 g of rabbit manure (see Figure 3). Fourteen days after the second application, maize A received a mixture of 21.8 g of Fertilizer C, calcium hydroxide (solid), clay, and a pinch of thiourea, while maize B received a mixture of 21.0 g of Fertilizer C, calcium hydroxide (solid), and clay soil. Maize C was treated with 49.2 g of NPK 20:10:5 fertilizers, and maize E received 18.3 g of rabbit manure. All the maize plant was exposed to the same environmental conditions and the same treatments except for the type of fertilizer applied and the average parameters of each maize per pot were recorded (see Figure 2).

$$\% \text{ Increase to reference application} = \frac{\text{New plant height-Previous plant height}}{\text{Previous plant height}} \times 100 \quad (1)$$

$$\% \text{ Increase in reference sample D} = \frac{\text{Sample plant height-Sample D plant height}}{\text{Sample D plant height}} \times 100 \quad (2)$$

3. Results and discussion

3.1 *Plant growth and development*

The data presented in Table 1, 2, and Figure 3 reveals notable trends in plant height, growth, and yield in response to different sample applications over a series of 14-day intervals. It explores these trends by examining how each sample influences plant height, growth rates over time, and yield.

Table 1. Physical and Chemical parameters of samples

Parameters/ Sample	Moisture (%)	pH	Total nitrogen, N (%)	Total phosphorus, P (%)	Total potassium, K (%)	Total carbon, C (%)	Plant height (cm)	Total quantity applied (g)	Maize with Cob weight (g)	Dry crain weight (g)
Fertilizer C1 (Maize A)	87.20	6.2	13.18	1.80	3.77	47.40	99.90	29.60	316.24	274.30
Fertilizer C2 (Maize B)	13.24	5.0	2.18	1.80	3.77	37.40	107.83	31.0	173.17	148.51
NPK/ (Maize C)	ND	6.85	20.0	10.0	5.0	ND	92.93	65.60	287.38	193.90
Control (Maize D)	ND	ND	ND	ND	ND	ND	70.10	0.00	78.41	0.00
Manure (Maize E)	21.30	7.30	1.26	1.05	2.10	18.60	79.21	24.50	91.72	0.00

ND = Not Determine, Nitrogen, N% of C1 = N% of C2 + % Thiourea, Carbon, C% of C2 = C% of C1 + % Thiourea

Prior to the initial application, maize plants (two per bag) exhibited similar physiological characteristics being the same species and soured from one producer and in one pack, some germinated earlier than others. The maximum recorded plant height was 61.98 cm, while the minimum was 44.70 cm (Table 2). Fourteen days after the first application. Four days after the second application, Maize A showed signs of stunted growth, yellowing leaves, and leaf burns, which can be attributed to the pH of Fertilizer B (as shown in Table 1) (Muhammad et al., 2018). To counteract these effects, calcium hydroxide was added to adjust the pH, and clay soil was used to reduce the floating of the biofertilizer during irrigation or rainfall.

Figure 2. Yield of maize A, B, C, D and E after harvest

Table 2. Plant parameter in response to days of sample application

Sample	Before application	14 days after 1st application	14 days after 2nd application	14 days after 3rd application
A				
Volume (cm^{-3}) or weight applied (g)		15/10	15/8.6	15/11
Plant height (cm)	49.02	83.82	95.50	171.45
% increase to reference application		70.98	13.90	79.50
% increase with reference to sample D		29.40	39.20	68.11
B				
Volume (cm^{-3}) or weight applied (g)		15/10	15/8.6	15/8.6
Plant height (cm)	61.98	93.35	117.9	158.12
% increase to reference application		50.61	26.2	34.15
% increase with reference to sample D		44.10	71.85	55.04
C				
Volume (cm^{-3}) or weight applied (g)		15/16.4	15/24.6	15/24.6
Plant height (cm)	58.67	82.55	95.89	134.62
% increase to reference application		40.69	16.15	40.39
% increase with reference to sample D		27.40	39.81	32.00
D				
Volume (cm^{-3}) or weight applied (g)		0/0	0/0	0/0
Plant height (cm)	44.70	64.77	68.58	101.98
% increase to reference application		42.04	5.80	48.70
E				
Volume (cm^{-3}) or weight applied (g)		15/6.1	15/9.2	15/9.2
Plant height (cm)	48.51	66.04	80.39	121.92
% increase to reference application		36.12	21.70	51.65
% increase with reference to sample D		1.90	17.22	19.55

The clay soil used was the same as that on which the maize was planted. Despite these challenges, Maize A demonstrated significant growth in plant height across all application stages. Initially, the plant height was 49.02 cm before any application, which increased to 83.82 cm, 95.50 cm, and finally 171.45 cm after the first, second, and third applications, respectively. After the second application, there were still slight leaf burns on Maize A, prompting the use of Biofertilizer C with thiourea and clay. This combination fully restored the leaf burn and resulted in greater plant height and dark green leaf coloration, likely due to the balanced pH and additional nitrogen content from thiourea. The largest percentage increase compared to the reference application was between the second and third applications at 79.50%, indicating that Biofertilizer C had a substantial and cumulative effect on plant growth, particularly after the third application. This consistent growth suggests that the nutrients in Biofertilizer C, in combination with small amounts of thiourea, were effective in promoting plant growth and biomass accumulation over time.

Maize B also experienced significant growth, with plant height increasing from an initial 61.98 cm to 93.35 cm after the first application, 117.9 cm after the second, and 158.12 cm after the third. The greatest percentage increase compared to the reference application was after the second application (26.2%), indicating steady and sustained growth with moderate green leaf coloration due to the nutrient content, as shown in Table 1 and Figure 2. Compared to Maize D, the total percentage increase was substantial, peaking at 71.85% after the second application. These findings suggest that Biofertilizer C was particularly effective in enhancing growth early in the application schedule, with a notable impact after the second application. Maize C exhibited moderate growth, with plant height increasing from 58.67 cm initially to 134.62 cm by the end of the third application.

The greatest percentage increase compared to the reference application occurred between the second and third applications (40.39%). Compared to the control, Maize D, the growth percentages were consistently lower, indicating that NPK was less effective than Biofertilizers A and B but still provided a significant boost in plant height over time. Maize C exhibited a dark green leaf coloration, indicative of higher chlorophyll content, attributed to the nitrogen content present, as shown in Table 1. This suggests that while NPK facilitated growth, nutrient leaching may have prevented a steady supply of nutrients over time. Maize D served as the control, with no additional fertilizer applied. Plant height increased from 44.70 cm to 101.98 cm throughout the observation period. The percentage increase compared to the reference application was relatively low, with the highest increase occurring between the second and third applications (48.70%). These results highlight that, without additional nutrient supplementation, plant growth was limited compared to other samples, emphasizing the importance of nutrient application in promoting plant growth and development. Maize D also displayed the least green leaf coloration due to low nitrogen content. Maize E showed a steady increase in plant height, from an initial 48.51 cm to 121.92 cm after the third application. The greatest percentage increase compared to the reference application was after the third application (51.65%). Growth percentage increases compared to the control, D, were modest, peaking at 19.55% after the third application. This suggests that Maize E had a moderate impact on plant growth due to limited nutrient content, as shown in Table 1, and displayed a light green leaf coloration with noticeable improvements over time due to its slow nutrient release, although not as pronounced as Maize A, B, and C. Parameters such as plant height, stem diameter, leaf length and width, leaf color, and number of leaves do not necessarily correlate with the fertilizer used and are not direct determinants of maize yield, as demonstrated in studies by Altieri et al. (2010), Ubi et al. (2016), Mahmood et al. (2017), Ogunwole et al. (2019), Jjagwe et al. (2020), and Bekolo et al. (2022).

3.2 *Yield of maize*

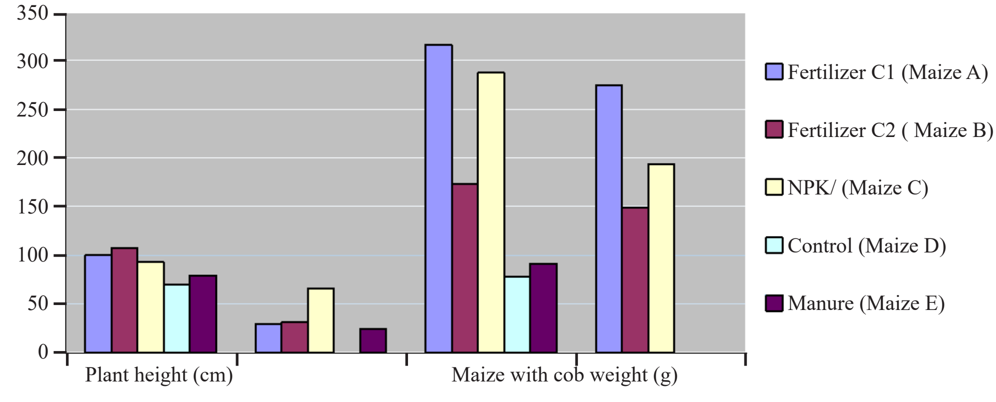

Figure 3. Plant height and yield of Maize A to E in response to fertilizer used

The yield of Maize A was the highest (Table 1 and Figure 3), with a total weight of 316.24 g, primarily due to the addition of thiourea. This was followed by Maize C, which weighed 287.38 g, and Maize B at 173.17 g. In contrast, Maize D and Maize E showed minimal differences, with neither producing grains, suggesting limited nutrients and potentially still being in the developmental phase. However, Maize E had a slightly larger and taller cob compared to Maize D, likely due to the slow nutrient release from rabbit manure, which provided insufficient nitrogen and phosphorus compared to Maize A, B, and C. Adequate nitrogen is essential for optimal maize growth and yield potential. Studies by Prasad et al. (2017) indicate that nitrogen application significantly increases grain yield and biomass production in maize. Furthermore, phosphorus is vital for root development, seedling growth, and flowering (Ogunwole et al., 2013). Maize A (treated with Fertilizer C1) achieved the highest yield, weighing 316.24 g. This was attributed to the enhanced nitrogen content from thiourea, which is crucial for optimal maize growth. The nitrogen content in Maize A was significantly higher at 13.18%, compared to Maize B (Fertilizer C2) at 2.18% and Maize E (Manure) at 1.26%. The combination of high nitrogen content and a balanced pH of 6.2 contributed to the superior growth and yield of Maize A, as soil pH levels between 7.0 and 7.4 increase grain yield, while levels outside this range decrease yield (Mahmood et al., 2017). Additionally, combining inorganic fertilizer with manure can produce higher cob and grain yields (Ubi et al., 2016; Mahmood et al., 2017; Jjagwe et al., 2020; Bekolo et al., 2022). This finding aligns with Mahmood et al. (2017), who observed that nitrogen application significantly boosts grain yield and biomass production in maize. Maize C (treated with NPK) also had a high yield of 287.38 g, despite a lower plant height of 92.93 cm compared to Maize B's 107.83 cm. The balanced nutrient content in NPK fertilizer, with 20% nitrogen, 10% phosphorus, and 5% potassium, supported substantial grain production. The importance of phosphorus for root development and flowering, as highlighted by previous studies (Ubi et al., 2016; Mahmood et al., 2017), was evident in the improved yield compared to Maize B, which had less phosphorus content.

Maize B showed early maturity but faced environmental challenges. The tallest plant in Maize B failed to produce cobs due to wind damage, which caused nutrient concentration shifts leading to acidic conditions and plant stress. Despite having the tallest plants, Maize B yielded less (173.17 g) compared to Maize A and Maize C. This emphasizes that plant height and other morphological traits do not necessarily correlate with higher yields, as supported by studies like Ubi et al. (2016) and Jjagwe et al. (2020). Maize E, grown with manure, exhibited minimal differences in yield compared to the control (Maize D). Both lacked grain production, indicating that the nutrients provided by manure were insufficient for optimal growth and development. However, the slightly larger cob size in Maize E suggests some benefit from the slow nutrient release in manure, though not enough to match the nutrient-rich conditions provided by fertilizers A, B, and C. The study results showed significant variation compared to Mahmood et al. (2017), where the application of NPK at 250-250-125 kg/ha resulted in a much higher grain yield of 7.50 t/ha. Similarly, Bekolo et al. (2022) reported a grain yield of 1,746 kg/ha with NPK, which was lower than yields achieved with organic manures. In this study, the grain yield for Maize B and C was considerably lower, indicating that nutrient concentration and application methods significantly impact yield outcomes.

The study data suggests a complex relationship between maize yield, the type and amount of fertilizer applied, and plant height. Maize A, treated with Fertilizer C1, achieved the highest yield at 316.24 g, despite a plant height of 99.90 cm. This outcome was attributed to the enhanced nutrient profile from thiourea addition, particularly the high nitrogen content, which is crucial for maize growth. In contrast, Maize B, although the tallest at 107.83 cm, yielded only 173.17 g. This discrepancy indicates that plant height alone is not a reliable predictor of yield. Maize C, treated with NPK fertilizer, had a lower plant height of 92.93 cm but still produced a substantial yield of 287.38 g. This highlights the importance of balanced nutrient content, such as the NPK mix providing essential nitrogen, phosphorus, and potassium, which are pivotal for grain development and yield. The effectiveness of NPK fertilizer in promoting high yield despite lower plant height further emphasizes that nutrient balance is more critical to yield than height. Maize E, grown with manure, had a plant height of 79.21 cm and did not produce any grain, similar to the control Maize D, which had a plant height of 70.10 cm (Onasanya et al., 2009). This suggests that while manure may contribute to plant growth in terms of height, it was insufficient in providing the necessary nutrients for grain production compared to synthetic fertilizers. Results obtained indicate that while taller plants like those in Maize B may suggest vigorous growth, they do not necessarily correlate with higher yields. This conclusion aligns with findings from previous research (Ubi et al., 2016; Jjagwe et al., 2020), which also found that plant height is not a direct determinant of yield. Instead, factors such as nutrient availability, balance, and proper fertilization are more crucial for optimizing maize yield. Therefore, while plant height can indicate health and growth conditions, it is not a direct determinant of maize yield, as evidenced by the superior yields of Maize A and C, despite their shorter stature compared to Maize B.

3.3 *Residual soil physical characteristics*

The residual soil appearance and NPK ratio of the residual soil after harvest are depicted in Table 4. To find the percentage of nutrients consumed, we subtract the residual amount from the initial application (Table 3) for each nutrient and express it as a percentage of the initial application.

For Fertilizer C Nitrogen ≈ 91.25%, Phosphorus ≈ 76.11%, Potassium ≈ 90.64%.

For NPK Nitrogen ≈ 99.95%, Phosphorus ≈ 99.94%, Potassium ≈ 99.77%.

For Manure Nitrogen ≈ 95.04%, Phosphorus ≈ 90.48%, Potassium ≈ 91.19%.

Table 3. Nitrogen Phosphorous and Potassium ratios of samples at 1st application and of soil after harvest

Parameters	Fertilizer C		NPK		Manure	
	At 1st App	Soil after harvest	At 1st App	Soil after harvest	At 1st App	Soil after harvest
Total nitrogen (%)	2.18	0.190	20.00	0.0101	1.26	0.0626
Total phosphorus (%)	1.80	0.430	10.00	0.0106	1.05	0.1050
Total potassium (%)	3.77	0.353	5.00	0.0115	2.10	0.1810

The residual nutrients present in the soil after harvesting can be attributed to the nutrient composition and availability of fertilizers. NPK fertilizers are formulated to provide a balanced ratio of nitrogen, phosphorus, and potassium in water-soluble forms that plants can easily absorb. These nutrients are quickly taken up by plants, leading to efficient growth. In contrast, Fertilizer C and manure may contain a broader range of nutrients, including micronutrients and organic matter, which are not immediately available to plants. These nutrients often require microbial decomposition to be converted into plant-available forms, resulting in slower uptake and higher residual levels in the soil after harvest (Wang et al., 2023). The solubility and leaching properties of these fertilizers also influence nutrient retention. NPK fertilizers are highly soluble, dissolving readily in water, which can lead to efficient plant uptake but also results in nutrient losses through leaching beyond the root zone. On the other hand, Fertilizer C and manure contain nutrients that may be less soluble or bound within organic matter, making them less susceptible to leaching and contributing to higher residual levels after harvest (Pathma & Sakthivel, 2012). Plant efficiency in nutrient uptake varies depending on factors like crop type, growth stage, and environmental conditions. NPK fertilizers, with their balanced nutrient ratios, promote optimal growth, leading to efficient nutrient uptake. Conversely, Fertilizer C and manure may provide nutrients in ratios or forms that don't precisely match the crop's needs, resulting in lower uptake efficiency and higher residual soil levels. Nutrient release from manure relies on microbial decomposition, a slower process that continues post-harvest, sustaining nutrient availability in the soil. In contrast, NPK fertilizers offer rapid nutrient release, leading to lower residual soil levels. However, fertilizers B and C demonstrated distinct nutrient release patterns, surpassing NPK in effectiveness. The organic matter, reflected in total carbon content, enhances soil structure, water retention, nutrient holding, and microbial activity, crucial for maize growth (Wang et al., 2023; Pathma & Sakthivel, 2012). The accumulated nutrients could be beneficial for future crops planted in such soil.

3.4 *Agricultural residues conversion industrial applications and benefits*

The conversion of agricultural waste into organic fertilizers presents a highly practical and scalable solution to modern agricultural and environmental challenges. Industries can leverage the abundant agricultural residues such as maize stalks, groundnut shells, and other plant biomass available in large quantities in farming regions. By establishing collection systems to gather these materials directly from farms, fertilizer companies can reduce raw material costs while addressing waste disposal issues. The processes involved in washing, drying, grinding, and chemically treating plant residues are simple and adaptable to existing industrial operations. With minimal technological modification, fertilizer production plants can incorporate these methods, allowing the process to scale efficiently. This approach offers a streamlined and cost-effective production system, with lower energy consumption compared to synthetic fertilizer manufacturing. The production of organic fertilizers can be scaled to meet local and global demand, catering to diverse agricultural needs, from smallholder farmers to large-scale enterprises. The use of fewer inputs compared to synthetic fertilizers reduces the overall carbon footprint, making the process more sustainable. Given the growing global demand for eco-friendly agricultural products, these organic fertilizers hold immense potential across various markets. Organic fertilizers derived from agricultural waste provide a high-performance alternative to synthetic fertilizers, offering benefits in crop yield and soil health. Industries can market these products as sustainable, eco-friendly options for farmers, tapping into the increasing interest in organic farming. Additionally, the cost of producing organic fertilizers is lower than that of synthetic fertilizers, particularly nitrogen-based ones, as the process requires fewer expensive chemicals and less energy. Local production using readily available raw materials further reduces transportation costs, offering an affordable solution for farmers, especially in developing countries where the high cost of synthetic fertilizers limits agricultural productivity.

4. Conclusion

A successful conversion of plant biomass to organic fertilizer for maize cultivation was achieved, and its performance was compared to inorganic fertilizers, NPK 20:10:5, and rabbit manure. In this study, the results highlight the intricate relationship between fertilizer type, nutrient content, and maize growth and yield, emphasizing the role of biofertilizers in enhancing plant productivity. Maize A, treated with Fertilizer C1, showed the highest yield of 316.24 g, attributed to its enriched nitrogen content from thiourea, which is crucial for plant growth and chlorophyll production. The findings indicate that despite having the tallest plants, as observed in Maize B, yield does not necessarily correlate with plant height, as Maize B's yield was lower at 173.17 g, possibly due to environmental stress and nutrient imbalance. Maize C, treated with NPK fertilizer, achieved a significant yield of 287.38 g despite a moderate plant height, underscoring the effectiveness of the balanced nutrient content provided by the NPK formula in promoting grain development. The study also demonstrates that while plant height and morphological traits are important, they are not the sole determinants of yield, as observed in Maize E, which, despite moderate height, did not produce grain, highlighting the inadequacy of manure alone in meeting the nutrient demands of maize. These outcomes suggest that strategic nutrient management, combining organic and inorganic fertilizers, can optimize growth and yield, aligning with previous research emphasizing the importance of nitrogen and phosphorus in maize productivity. Ultimately, the study illustrates the potential of biofertilizers to enhance soil fertility and crop yield, supporting sustainable agricultural practices and the development of environmentally friendly fertilization strategies.

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Author contributions

Gideon Mathew: Experimental Design, Experiment and Type setting.
Emmanuel Duniya: Experiment, Logistics and Supply.
Mamman Abakeyah James: Experiment, Green farm Design and Set up.

Conflict of interest

The authors declare no competing financial interest.

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