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Influence of Brewery Waste and Animal Manure-Based Compost on the Growth of Green Amaranth in Sandy Tropical Soils

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Abstract: The productivity of sandy tropical soils may be enhanced through the application of composted organic materials. This study investigates the effects of composted mixtures of brewery spent grain (BSG) and animal manures on the growth of green amaranth (*Amaranthus caudatus* L) under field conditions. Composted treatments included BSG mixed with poultry droppings (PD) or cattle dung (CD) in volumetric ratios of 1:1 and 2:1 prior to composting, resulting in four compost variants: $BSG+PD_{(1:1)}$, $BSG+PD_{(2:1)}$, $BSG+CD_{(1:1)}$, and $BSG+CD_{(2:1)}$. Additionally, composted BSG alone served as a reference. Each amendment was added at 20 t ha^{-1}, alongside an un-amended control for comparative purposes. Growth and yield assessments conducted four weeks post-sowing revealed that not all amended treatments outperformed the control. Notably, the $BSG+PD_{(1:1)}$ treatment consistently increased total biomass (fresh and dry matter yields by approximately 143% and 58%, respectively) as immediate effects, and significantly more (184% and 108%, respectively) as residual effects when compared to the control. Leaf yields under this treatment showed increases of 173-177% (immediate effects) and 122-125% (residual effects). These variations in amaranth growth and yield were primarily attributed to improvements in soil exchangeable calcium (Ca) and total nitrogen (N) content due to the compost application. The findings suggest that a composted equal-volume mix of BSG and PD may serve as an effective organic amendment for enhancing the yield of short-duration leafy vegetables like amaranth in coarse-textured soils of the humid tropics.

Keywords: Brewery spent grain; Poultry-droppings manure; Composted organic wastes; Fresh matter production; Short-duration leafy vegetables; Soil calcium-nitrogen supply; Treatment residual effects

1. Introduction

The bulk of green amaranth consumed for its high nutritional value in tropical Africa is produced by subsistence farmers, making demand exceed supply (Bisikwa et al., 2020; Nyankanga et al., 2012; Schippers, 2000). Most agricultural soils in the humid tropics have low fertility and are unable to supply plant nutrients in sufficient amounts, posing a challenge for amaranth production in the region (Akinrinde & Obigbesan, 2000; Anonymous, 2012). Specifically, the challenge is more pronounced in acidic sandy soils, which are noted for their high responsiveness to fertility-enhancing soil amendments (Umeugokwe et al., 2021).

Growers of amaranth species in sandy tropical soils thus encounter low soil fertility, a scanty supply of mineral fertilizers and insufficient funds to buy them (Nyankanga et al., 2012; Okorie et al., 2017; Olufolaji et al., 1990). Crop residues return small amounts of organic materials to the soil as a way of nutrient recycling. Agricultural waste and food/industrial by-products are organic materials that could be good sources of organic soil amendments needed to maintain soil fertility at levels that can support the growth of amaranth.

Manures serve as organic fertilizers in many agronomic production systems. They add soil organic matter (SOM) and decompose it into stable humic substances (Davison et al., 2000), while supplying macro- and micronutrients (Usman, 2015). As a reservoir of plant nutrients, SOM needs to be manipulated to promote soil fertility and ensure success in humid tropical agriculture (Obalum et al., 2011). Accretion of SOM promotes soil aggregation and structure of coarse-textured soils to enhance water retention, thereby slowing down nutrient mineralization, and favouring sustenance of beneficial soil organisms (Obalum et al., 2017).

Conventional animal manures are often used as organic soil amendments in amaranth production (Ainika, 2010; Bawa, 2010). However, poultry droppings (PD) can be scarce, and this is aggravated by its other important uses, including serving as a substrate in the bioremediation of crude-oil polluted soils (Ezenne et al., 2014). Cattle dung (CD) that is not scarce has a high carbon-nitrogen (CN) ratio and mineralises less readily in the soil (Chukwuma et al., 2024; Ndzeshala et al., 2023; Uzoh et al., 2015). Composting of organic materials before soil application ensures the stability of SOM and the release of nutrients to the soil (Baiyeri et al., 2020; Tiquia, 2003).

Amaranth growth can be increased with soil application of composted plant residue and a mix of animal waste (Dada et al., 2017). One potential constraint, however, is the short-lived nature of the compost effect on soil structure stability (Obalum et al., 2019). These prospects and constraints of composts and of PD and CD manures (in terms of availability and mineralization rates) offer an opportunity to explore the prospects of mixing plant waste with animal manures before composting, thereby developing sustainable enhanced productivity of amaranth and similar leafy vegetables all-year-round. Any lack of residual effects of conventional compost on soil structure stability (Obalum et al., 2019) and yield of vegetable crops may be compensated for by PD and CD manures (Ogunezi et al., 2019; Onah et al., 2023; Sanya & Amadji, 2018).

Brewery waste (spent grain) is an industrial by product that is generated in large quantities and poorly disposed (Devolli et al., 2018; Nassary & Nasolwa, 2019; Onwe, 2004). One way of recycling brewery spent grain (BSG) could be by composting it into organic fertilizers, as composted BSG has a high potential for releasing essential nutrients for plant growth (Ebido & Ndubuaku, 2019; Kanagachandran & Jayaratne, 2006). Owing to the prevailing abundant discharge of its source and its ability to enhance soil fertility, composted BSG may appeal to subsistence vegetable farmers, and may be deemed a promising suitable and economically viable option for them.

Little is currently known of the efficacy of complementing composts with animal manures of varying CN ratios, or the suitable combining ratio, in organic amaranth farming. This study was undertaken to determine the agronomic effects of a composted mix of BSG with PD or CD on amaranth growth and yield in acid sandy tropical soils.

2. Materials and Methods

2.1 Characteristics of the Experimental Site

The experiment was conducted at the Organic Vegetable Garden, Teaching & Research Farm, University of Ibadan, Ibadan, Nigeria (7°24'N, 3° 54'E; 62 m asl). The farm is located in the derived savannah of southwestern Nigeria. The mean monthly temperature ranges from 24 to 30°C and the mean annual rainfall from 1,800 to 2,100 mm. The field study was conducted on an acid sandy soil. Some physicochemical properties and fertility indices of the top 0-20 cm soil before the study were assayed following standard laboratory procedures (Sparks, 1996).

2.2 Treatments, Their Preparation and Field Establishment

Field experiments were carried out to determine effects of BSG-based compost on the growth and the yield of green amaranth as organic soil amendments. The BSG was composted with and without PD and CD, involving soil application of composted BSG and a composted mix of BSG with PD or CD. The PD and CD were chosen as manures because of their known wide difference in CN ratio, with smaller values in the former than the latter (Adubasim et al., 2018), which translate into their faster and slower mineralisation, respectively in coarse-textured tropical soils (Chukwuma et al., 2024). The BSG was supplied by the Nigerian Breweries PLC, Iganmu Lagos, Nigeria; the PD and CD were obtained from the Teaching & Research Farm of the Department of Animal Science, Faculty of Agriculture and Fisheries, University of Ibadan, Ibadan, Nigeria.

The composting of BSG and its mix with PD or CD was done under controlled well-aerated environmental conditions in the Organic Vegetable Garden of the Teaching & Research Farm. In initiating the composting, these three organic wastes were used in their fresh forms as procured and were not subjected to curing by sun-drying. Each of BSG+PD and BSG+CD was composted in volume ratios of 1:1 and 2:1, each having two replications. The composted organics were designated $BSG+PD_{(1:1)}$, $BSG+PD_{(2:1)}$, $BSG+CD_{(1:1)}$, and $BSG+CD_{(2:1)}$. The composting period was six weeks with temperature readings taken daily using a compost thermometer. To ensure aeration within the compost pile, the mass was turned at the beginning of the second, fourth and fifth weeks when the pH of the compost was determined and the pile moistened. The temperature of the compost reflecting the activity of micro-organisms and the pH of the compost together were used to infer its maturity. After the composting period, composts were spread and left for curing (air-drying to reduce pathogenic load) for four weeks before use.

The field experiment, described by Ebido & Ndubuaku (2019), involved composted $BSG+PD_{(1:1)}$, $BSG+PD_{(2:1)}$, $BSG+CD_{(1:1)}$, $BSG+CD_{(2:1)}$, BSG as a reference, and an unamended control as a treatment. The experimental arrangement was a randomized complete block design with four replicates. Plots measuring 1.5 × 1.0 m were guarded against external interferences with earthen bunds (compactly prepared ridges) and were 0.50 m apart. Manual hoeing to about 20-cm depth was done in all plots. Thereafter, composted organic amendments were uniformly spread on the surface of the plots at the rate of 20 t ha^{-1}. A pack of amaranth seeds, of cv. PI 511679, was purchased from Eagle Seeds, Orogun Ibadan, Nigeria. This genotype, grown mainly for its leaves, usually grows up to 25 cm tall with about 11 leaves in about four weeks on un-amended soils in the study environment (Adeoluwa et al., 2009). Three days after hoeing the soil and spreading the composted organic amendments, seeds were sown in drills spaced 0.50 m apart. Plots were irrigated before sowing and at two-day intervals to pre-determined field capacity until harvest. Weeds were controlled manually.

2.3 Assessment of Growth and Yield of Amaranth

Just before crop harvest at four weeks after sowing, plant height, stem diameter and number of leaves were determined on three randomly selected plants per bed. Plant height was measured as the vertical length of the shoot, stretching from the base of the stem at the soil level to the tip of the meristem. Stem diameter was measured as the diameter of the stem at its base just above the soil level. To assess crop yield, the entire plant (roots and shoot) was harvested, after which the roots were detached and the shoot separated into stems and leaves. Both fresh and dry weights of roots, stems and leaves were measured. Fresh weights were determined at the separation of stems and leaves. Dry weights were determined after drying the plant materials at 70°C in a forced air oven for 24 h.

2.4 Checking the Residual Agronomic Effects of Treatments

Agronomic data collection was completed at crop harvest. Plots were clean-weeded and the earthen bunds strengthened for a second cropping to assess the residual agronomic effects of treatments. This involved repetition of the entire field procedure from seed sowing through the separation of harvested biomass to the weighing of the different portions of the biomass on both fresh- and dry-weight bases.

2.5 Statistical Analysis

The data were analysed using the software Statistical Analytic System (ver. 22, SAS Inc., Cary, NC). First, a one-way analysis of variance was used to test the data for differences among treatments. Duncan's multiple range test was used to separate means. Thereafter, agronomic data for the immediate and the residual effects of treatments were pooled and related to the earlier published data on treatment effects on some fertility indices of the soil (Ebido & Ndubuaku, 2019) by multiple linear regressions.

3. Results

3.1 Physicochemical Properties of the Soil Before Treatment and Sowing of Amaranth

The physicochemical properties of the soil before organic amendment are shown in Table 1. The soil is sandy, belonging to the texture class of loamy sand. The soil had a slightly acidic pH and a high level of exchangeable acidity. The available phosphorus (P) level was slightly high; the exchangeable potassium (K) and sodium (Na) indicated very low to low values according to the rating of Landon (1991).

Table 1. Selected chemical properties of the soil before treatment application

Soil Properties		Value
Texture class		Loamy sand
Soil pH-H_2O		5.3
Soil organic carbon (g kg^{-1})		19.20
Total N (g kg^{-1})		2.31
Available P (mg kg^{-1})		23.00
Exchangeable bases and acidity (cmol kg^{-1})	K^+	0.10
	Ca^{2+}	1.80
	Mg^{2+}	0.40
	Na^+	0.10
	H^+	0.40
	Al^{3+}	0.50

3.2 Treatment Effects on Morphological Growth Parameters of Amaranth

The immediate effects of the composted BSG-based organic soil amendments showed that the treatment affected amaranth growth (Table 2). Treatment generally increased plant height, stem diameter and the number of leaves of amaranth plants compared with the un-amended control. Composted BSG+PD$_{(1:1)}$ produced taller plants and more leaves compared with the control; composted BSG+CD$_{(2:1)}$ gave the widest stem of the amaranth plants and the control the narrowest. For this stem diameter, composted BSG+PD$_{(1:1)}$ and BSG+PD$_{(2:1)}$ showed similar values. In addition, composted BSG+CD$_{(1:1)}$ and BSG+CD$_{(2:1)}$ had similar stem diameters, with the former being similar to the rest of the treatments excluding the control. Composted BSG+PD$_{(1:1)}$ and BSG+CD$_{(1:1)}$ were similar in all three growth indices; so too were composted BSG+PD$_{(2:1)}$, composted BSG (the reference) and the control, and composted BSG+CD$_{(1:1)}$, composted BSG+CD$_{(2:1)}$ and composted BSG.

Table 2. Effects of composted BSG-based organic soil amendments on amaranth growth as evaluated in the first cropping

Treatment	Plant Height (cm)	Stem Diameter (cm)	Number of Leaves
BSG+PD$_{(1:1)}$[a]	30.42ab	2.81bc	18.52a
BSG+PD$_{(2:1)}$	29.21ab	2.79bc	13.46c
BSG+CD$_{(1:1)}$	24.96ab	3.27ab	17.71ab
BSG+CD$_{(2:1)}$	29.25ab	3.43a	15.50ab
BSG	26.53ab	2.99abc	14.67bc
Control	22.00b	2.64c	12.21c

Note: [a]BSG+PD$_{(1:1)}$ - BSG plus PD in the volume ratio of 1:1; BSG+PD$_{(2:1)}$ - BSG plus PD in the volume ratio of 2:1; BSG+CD$_{(1:1)}$ - BSG plus CD in the volume ratio of 1:1; BSG+CD$_{(2:1)}$ - BSG plus CD in the volume ratio of 2:1; Control: No amendment applied. Statistical analysis was conducted using one-way analysis of variance, with means sharing the same letters within each column not differing significantly at the 5% probability level.

3.3 Residual Effects of Treatments on the Growth Parameters of Amaranth

In the second cropping when the residual effects of composted BSG-based organic soil amendments on amaranth growth were tested, the results mirrored the initial growth patterns observed (Table 3). Composted BSG+PD$_{(1:1)}$ gave taller plants with wider stems compared with the control, while treatment had no residual effect on the number of leaves. Composted BSG+PD$_{(1:1)}$ and BSG+PD$_{(2:1)}$ still had similar stem diameters; the latter was similar to the other composted BSG-based treatments (BSG+CD$_{(1:1)}$, BSG+CD$_{(2:1)}$ and BSG) but was higher than the control.

Table 3. Residual effects of composted BSG-based organic soil amendments on amaranth growth as evaluated in the second cropping

Treatment	Plant Height (cm)	Stem Diameter (cm)	Number of Leaves
BSG+PD$_{(1:1)}$[a]	26.98ab	2.68a	12.88a
BSG+PD$_{(2:1)}$	21.63ab	2.35ab	11.75a
BSG+CD$_{(1:1)}$	19.50ab	2.04bc	10.88a
BSG+CD$_{(2:1)}$	17.38ab	1.86bc	13.13a
BSG	18.88ab	1.88bc	10.88a
Control	16.75b	1.63c	10.75a

Note: For definitions of abbreviations and related explanations, see the note under Table 2.

3.4 Treatment Effects on Total and Discreet Biomass Yields of Amaranth

When amaranth yield was discreetly computed, root and leaf yields indicated that composted BSG+PD$_{(1:1)}$ was the only treatment that out-yielded the control (Table 4). This treatment had similar but nominally higher values than the other four amended plots which, in turn, were similar to un-amended control. Fresh- and dry-matter stem yields were highest in composted BSG+PD$_{(1:1)}$ (its close substitute being composted BSG+PD$_{(2:1)}$), while every other treatment was superior to composted BSG+CD$_{(1:1)}$ and the control for which values were similar.

Data for the total biomass yield of amaranth in response to treatment varied (Figure 1). The highest biomass yields on both fresh- and dry-matter bases were in the composted BSG+PD$_{(1:1)}$, while the lowest biomass yields were in the un-amended control. The remaining four amended plots produced similar total biomass yields on both fresh- and dry-matter bases (Figure 1). On a fresh-matter basis, only composted BSG+PD$_{(2:1)}$ did not out-yield the control; on a dry-matter basis, the best-performing composted BSG+PD$_{(1:1)}$ was similar to the other amended plots except for composted BSG+CD$_{(1:1)}$ which gave a similar value to the control.

Table 4. Effects of composted BSG-based organic soil amendments on yields of amaranth (t ha^{-1}) on fresh- and dry-matter bases

Treatment	Fresh-Matter Yield			Dry-Matter Yield		
	Root	Stem	Leaf	Root	Stem	Leaf
BSG+$PD_{(1:1)}$[a]	7.09ab	16.33a	25.94a	1.06a	1.92a	4.04a
BSG+$PD_{(2:1)}$	4.94ab	14.69a	18.91ab	0.67ab	1.93a	3.29ab
BSG+$CD_{(1:1)}$	4.43ab	8.24b	12.91ab	0.67ab	1.17b	2.68ab
BSG+$CD_{(2:1)}$	5.41ab	12.47a	14.14ab	0.87ab	1.79a	3.11ab
BSG	5.12ab	12.83a	13.29ab	0.86ab	1.43a	3.00ab
Control	3.42b	7.43b	9.50b	0.61b	0.97b	1.82b

Note: For definitions of abbreviations and related explanations, see the note under Table 2.

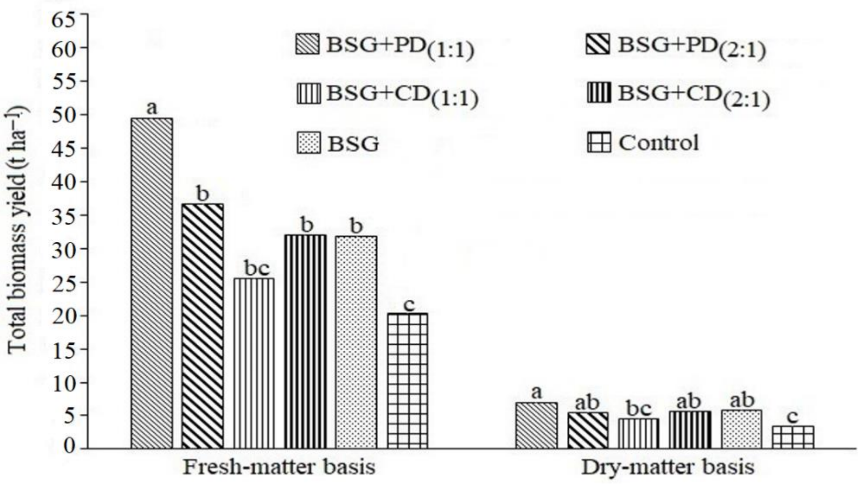

Figure 1. Effects of composted BSG-based organic soil amendments on total biomass (root + stem + leaf) yield of amaranth on fresh- and dry-matter bases

Note: For definitions of abbreviations and related explanations, see the note under Table 2.

3.5 Residual Effects of Treatments on Total and Discreet Biomass Yields of Amaranth

The residual effects of the composted BSG-based organic soil amendments on the total biomass yield of amaranth as computed on both fresh- and dry-matter bases varied (Figure 2). The best-performing composted BSG+$PD_{(1:1)}$ yielded higher than the rest of the treatments (including the control) for which values were similar. Total biomass yields in composted BSG+$PD_{(2:1)}$, BSG+$CD_{(1:1)}$, BSG+$CD_{(2:1)}$ and the reference composted BSG were similar to those in the un-amended control. For a discreet assessment of treatment residual effects on amaranth's yield, composted BSG+$PD_{(1:1)}$ generally had higher root, stem and leaf yields compared with the rest of the treatments (including the control) for which values were similar (Table 5). Composted BSG+$PD_{(1:1)}$ produced similar effects as composted BSG+$PD_{(2:1)}$, but for only root and stem yields on a dry-matter basis.

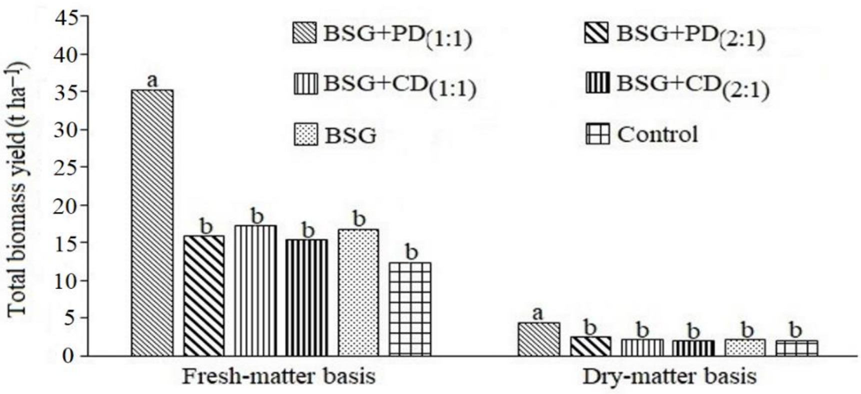

Figure 2. The residual effects of composted BSG-based organic soil amendments on total biomass (root + stem + leaf) yield of amaranth on fresh- and dry-matter bases

Note: For definitions of abbreviations and related explanations, see the note under Table 2.

Table 5. Residual effects of composted BSG-based organic soil amendments on yields of amaranth (t ha^{-1}) on fresh- and dry-matter bases

Treatments	Fresh-Matter Yield			Dry-Matter Yield		
	Root	Stem	Leaf	Root	Stem	Leaf
$BSG+PD_{(1:1)}$[a]	4.20ab	8.03a	23.09a	0.59a	0.97a	2.79a
$BSG+PD_{(2:1)}$	2.31b	3.39b	12.29b	0.41ab	0.51ab	1.59b
$BSG+CD_{(1:1)}$	2.22b	2.71b	10.05b	0.34b	0.32b	1.60b
$BSG+CD_{(2:1)}$	2.01b	2.99b	11.05b	0.27b	0.30b	1.60b
BSG	2.16b	3.25b	10.56b	0.28b	0.32b	1.58b
Control	1.76b	2.34b	8.33b	0.25b	0.23b	1.24b

Note: For definitions of abbreviations and related explanations, see the note under Table 2.

3.6 Relationship Between Amaranth Yields and Soil Fertility Indices

The multiple linear regressions of the amaranth yields on treatment effects on some fertility indices of the soil (Ebido & Ndubuaku, 2019) indicate that growth and yields of amaranth were highly dependent on treatment-induced variations in the ability of the sandy soil to retain plant nutrients against leaching losses. Plant height, stem diameter and number of leaves, including total biomass, root and stem yields (on fresh- and dry-matter bases), all depended on the soil's contents of the exchangeable bases (particularly exchangeable Ca, i.e., Ca^{2+}), with a coefficient of determination (R^2) in the range of 0.683-0.794. Leaf yield of amaranth on a fresh-matter basis depended on soil content of total N ($R^2 = 0.776$), while leaf yield on a dry-matter basis depended on soil content of Ca^{2+} ($R^2 = 0.850$), as with the bulk of the yield indices included in this study.

4. Discussion

The data attained in this study indicate the agronomic benefit of mixing BSG with a promising animal manure, such as PD, in the appropriate ratio, before composting into organic amendments for application to sandy tropical soils used for organic production of vegetable crops. Composted $BSG+PD_{(1:1)}$, unlike the other treatments, always produced better results than the control wherever treatment had effects, with stem diameter as an exception. A similar trend prevailed for the residual effects of treatment. The PD enriches the soil with SOM and most plant nutrients compared with other types of animal manure (Afriyie et al., 2013; Chukwuma et al., 2024). Therefore, its complementing BSG in the compost used would largely explain the results.

Taller plants in composted $BSG+PD_{(1:1)}$ than the control for both immediate and residual effects of treatment suggest the presence of some growth-promoting substances such as cytokinin, indole-3-acetic acid (IAA), and gibberellic acid (GA3) in BSG-based organic amendments (Miezah et al., 2008), which can elongate plant stems and increase the growth of plants. The overall best agronomic results in composted $BSG+PD_{(1:1)}$ are attributed to PD's ability to modify soil properties, leading to increased water retention and plant uptake of nutrients (Nwachukwu & Ikeadigh, 2012). However, corresponding to the earlier report, this treatment provoked an increased release of plant nutrients, especially N in its available forms, in the soil compared to the rest of the treatments (Ebido & Ndubuaku, 2019). Soil N usually promotes vigorous growth of plants via increased photosynthetic activities (Hussain et al., 2006), and is particularly critical for amaranth production in the tropics (Adeoluwa et al., 2009; Nyankanga et al., 2012). The PD enhanced soil total N even more than NPK fertilizers in sandy tropical soils (Umeugokwe et al., 2021), pointing to the possible contribution of PD to the enhanced N status of $BSG+PD_{(1:1)}$ and the possible role of such status in its performance in the present study.

With composted $BSG+PD_{(1:1)}$ as soil amendment, the total biomass yield of amaranth on a fresh-matter basis four weeks after sowing in the first cropping was 46.51 t ha^{-1}, achieved with 20 t ha^{-1} being the application rate of the composted BSG-based amendments in this study. From the same study site, the highest amaranth yields of 4.30 and 8.30 t ha^{-1} were achieved, respectively, with 10 t ha^{-1} *Gliricidia sepium* and 60% organic fertilizer (composted market waste plus CD in the ratio of 3:1) complemented with 40% N urine (Adeoluwa et al., 2006; Adeoluwa et al., 2009). In northeastern Nigeria, a corresponding amaranth yield of 7.10 t ha^{-1} was achieved with PD manure at 20 t ha^{-1} (Mshelia & Degri, 2014). The much higher yield attained in the present study thus points to the prospects of composted $BSG+PD_{(1:1)}$ in growing amaranth in sandy tropical soils.

Generally, mixing BSG with PD manure proved to be superior to mixing BSG with CD manure. However, composted $BSG+PD_{(1:1)}$ could not always find a good substitute in composted $BSG+PD_{(2:1)}$, especially with respect to fresh-matter yields. The overall poor results due to complementation of BSG with CD are attributed to the slow mineralisation rate of CD in coarse-textured tropical soils, about 1.75 times slower than that of pig-slurry manure (Uzoh et al., 2015), which in itself usually shows a higher CN ratio than PD (Adubasim et al., 2018). This observation for CD reflects its low population of bacterial species known to drive its decomposition and hence mineralisation (Oraegbunam et al., 2023). The apparent lack of similarity between composted $BSG+PD_{(1:1)}$ and $BSG+PD_{(2:1)}$ suggests a suppression of PD's effect in the latter due to an unfavourable BSG-PD ratio. Again, composted BSG+$PD_{(1:1)}$ and BSG+$CD_{(1:1)}$ were not similar because of the expected greater mineralisation of the former than the latter to release P (Chukwuma et al., 2024), and perhaps other essential plant nutrients. In amaranth production with BSG, therefore, there is a need to compost a mix of BSG with compatible animal manure in the suitable mixing ratio; otherwise, the desirable changes in nutrient status and physical and biological attributes of the mix that would lead to enhanced amaranth productivity may not occur.

Composted BSG (representing BSG that was not complemented before composting) applied at a higher rate of 20 t ha^{-1} in the present study was mostly similar to the un-amended control. In a soil with high clay content in north-central Nigeria, amaranth yield was found to be higher in compost complemented with NPK-15:15:15 fertilizer compared with non-complemented compost which, however, out-yielded the un-amended control (Abayomi & Adebayo, 2014). Differences in soil texture, compost source and environmental settings between the cited research and this study may partially explain these seemingly conflicting reports.

Treatment effects on some important fertility parameters of the soil (Ebido & Ndubuaku, 2019) showed that, for the immediate and the residual effects, there were reductions in exchangeable acidity to varying degrees and slight to moderate increases in soil pH, soil organic carbon, total N, available P and cations exchange in amended plots relative to the control. Notably, the highest reductions in exchangeable acidity occurred in composted BSG+$PD_{(1:1)}$. This reduction, which may not be unconnected with its excellent performance in this study, can be attributed to the liberation and loss via leaching of Al^{3+} chelated with base-forming cations during PD mineralisation in this acidic sandy soil (Garzón et al., 2011; Tang et al., 2007). The data further showed nominally higher values of soil organic carbon, total N, available P and base-forming cations (except Mg^{2+}) in composted BSG plus PD than composted BSG plus CD, regardless of mixing ratio (Ebido & Ndubuaku, 2019).

Amaranth growth and yield were influenced mostly by the soil content of Ca^{2+}. Calcium is a crucial plant nutrient for the growth and development of plants (McLaughlin and Wimmer, 1999), particularly vegetable crops (Hao & Papadopoulos, 2003; Parra-Terraza et al., 2008). Soil structure enhancement due to organic amendment mediates increased yields of short-duration vegetables in coarse-textured tropical soils (Ogunezi et al., 2019). The Ca^{2+} makes similar prominent contributions to the vegetative growth of short-duration arable crops grown with mineralisation-enhanced organic amendments in such soils (Ndzeshala et al., 2023; Ugwu et al., 2024). The Ca^{2+} control of amaranth yield in the present study could thus be linked to its widely known role as a peptizing agent in soil aggregation and/or to the short-duration nature of amaranth growth. Since Ca facilitates mitotic cell division and meristem development (Habbasha & Ibrahim, 2015), its deficit may hinder cell division and the formation of new root and shoot tissues. The change of soil ammonium to nitrate induces a gradual re-solubilisation of the precipitated Ca which adds to the available soluble Ca and results in increased crop yield (Feagley & Fenn, 1998).

Leaf fresh-matter yield was the only yield index of this study that depended on soil content of total N. Soil total N content could influence leaf yield in leafy vegetables three months after planting (Nwite et al., 2013), but may not influence the growth of short-duration leafy vegetables (Ebido et al., 2021). However, with Ca that controlled amaranth yield in this study also being involved in plant absorption of soil nitrate (Habbasha & Ibrahim, 2015) and ammonium (Feagley & Fenn, 1998), leaf fresh-matter yield depending on soil total N here would be understandable. Beyond Ca's role in N transport, it interacts with P and K, enhancing the absorption of ammonium, P, and K (Acosta-Durán et al., 2007; Habbasha & Ibrahim, 2015). The excess accumulated N is stored, and its adsorption stimulates photosynthetic processes and increases plant growth and leafiness. This relationship between N and Ca in soils would, therefore, explain the dependence of leaf fresh-matter yield on soil total N content.

Indeed, composts have elevated pH and supply N (mostly in the form of nitrates) as well as the base-forming nutrient elements (Rosen & Bierman, 2005; Tiquia, 2003). In this study, composted BSG+$PD_{(1:1)}$ was the best treatment in terms of vegetative growth and yields of amaranth. This is most likely because amaranth production in the tropics depends on the N-fertility of the soil (Adeoluwa et al., 2009; Nyankanga et al., 2012), and this composted BSG+$PD_{(1:1)}$ had the highest total N in the two cropping cycles (Ebido & Ndubuaku, 2019). Also, soil N through the aforestated mechanisms influenced Ca^{2+} content on which amaranth productivity largely depended. It is thus recommended that BSG be complemented with PD in an equal-volume mix before composting to enhance the bioavailability of N and Ca, and to optimally express the relationship between these two nutrients, thereby increasing the productivity of amaranth in acidic sandy tropical soils.

Besides the potential of composted BSG+$PD_{(1:1)}$ for increasing the productivity of amaranth and similar short-duration vegetables in the tropics, its wide adoption could be one way to enhance the utilisation and productive recycling of brewery waste, thereby promoting the concept of circular economy. There are indications that this composted BSG+$PD_{(1:1)}$ can produce higher crop yields than compound mineral fertilizers (Alayu & Leta, 2020; Moyin-Jesu, 2003; Ojeniyi et al., 2007). Considering the abundance and cheap availability of BSG compared to mineral fertilizers, the adoption of composted BSG+$PD_{(1:1)}$ in crop production can also be more cost-effective. It could also help to reduce the prevailing pressure on PD, sparing it for other purposes such as bioremediation of crude oil-polluted soils (Ezenne et al., 2014), to the benefit of the environment.

The soil data showed a slightly higher content of exchangeable Na (Na^{+}) of 0.15 cmol kg^{-1} in both composted BSG+$PD_{(1:1)}$ and BSG+$PD_{(2:1)}$ than the rest in the two cropping cycles (Ebido & Ndubuaku, 2019). However, from the perspective of the tendency for microaggregate breakdown and colloidal dispersion in humid tropical soils to increase with an increasing amount of Na^+ relative to the entire cations or the other base-forming cations (Igwe & Obalum, 2013), these two treatments of pre-composting complementation of BSG with PD potentially cannot have negative implications for the environment. When its absolute level is considered, the soil Na^+ content due to them is far below the critical value of 1.0 cmol kg^{-1} above which agricultural soils can experience undesirable sodicity and associated colloidal dispersion, predisposing them to water erosion (Oluwatuyi et al., 2020).

For one-time soil application in agronomic production, the chances of realising residual effects in the soil are generally greater with organic amendments than mineral fertilizers (Ndzeshala et al., 2023; Unagwu et al., 2013). However, mineralisation-enhanced organic amendments like composted biowaste and liquid fermentate sometimes do not have residual effects in the soil (Ndzeshala et al., 2023; Obalum et al., 2019). This constraint with organic amendments is particularly the case in the humid tropics due to the prevailing high temperatures, and is true not only for effective manures like PD, but also for those that mineralise rather slowly in the soil like CD (Ezenne et al., 2019; Obalum et al., 2020). In the present study, the best-performing composted $BSG+PD_{(1:1)}$ had residual effects, out-yielding all the other treatments (Figure 2). This, which could be caused by amaranth's short life cycle, offers the farmer the invaluable opportunity of double cropping without compost re-application. Smallholder farmers of short-duration vegetables in coarse-textured and low-fertility soils of the derived savannah and similar tropical locations can take advantage of these findings to produce the increasingly highly sought-after 'organic' vegetables for improved farm income and livelihood on a sustainable basis.

5. Conclusions

The study explored the prospects of complementing BSG with PD and CD before composting for amaranth production in low-fertility sandy tropical soils. With the exception of BSG plus PD at an equal volume ratio ($BSG+PD_{(1:1)}$), the composted BSG-based organic soil amendments were generally ineffective in increasing amaranth productivity. The BSG was not compatible with the manure components of the compost including poultry droppings (PD), except when mixed with PD in a favourable 1:1 ratio. The differences between composted $BSG+PD_{(1:1)}$ and others were mostly a reflection of their relative abilities to supply Ca and N in the soil. A composted mix of equal volumes of BSG and PD could thus be beneficially explored in overcoming Ca- and N-deficiencies for increased production of amaranth and similar leafy vegetables in low-fertility, sandy tropical soils.

Author Contributions

Conceptualization, O.O.A.; methodology, O.O.A.; software, S.E.O.; validation, U.M.N. and K.P.B.; formal analysis, A.L.N., S.E.O., C.L.U. and G.M.A.; investigation, N.E.E.; data curation, A.L.N., S.E.O. and G.M.A.; data screening, C.L.U.; writing—original draft preparation, N.E.E.; writing—review and editing, A.L.N., S.E.O., C.L.U., G.M.A. and K.P.B.; visualization, S.E.O. and K.P.B.; supervision, O.O.A; Conducted experiments, N.E.E.; designed the study, O.O.A.; analysed data, U.M.N.; performed the statistical analysis, U.M.N. All authors read and approved the final manuscript.

Ethical Approval

For researches involving animals or humans: Not applicable.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

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Conflicts of Interest

The authors declare that there are no conflicts of interest related to this article.

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