Yuzuncu Yil University
Journal of Agricultural Sciences
(Yüzüncü Yıl Üniversitesi Tarım Bilimleri Dergisi)
https://dergipark.org.tr/en/pub/yyutbd

ISSN: 1308-7576 e-ISSN: 1308-7584

Research Article

Development and Statistical Evaluation of Fortified Soil Nutrient Formulation from Sugarcane Leaves Biomass for Soil Amelioration

Catherine Ngozi EJIEJI[1], Elijah Aina ALHASSAN*[2], Joshua Olanrewaju OLAOYE[3]
Musliu Olushola SUNMONU[4], Qudus Babatunde ADEYI[5]

[1]Department of Mathematics, University of Ilorin, Ilorin, Kwara State, Nigeria
[2]Department of Agricultural and Biosystems Engineering, Landmark University, Omu Aran, Kwara State, Nigeria
[3]Department of Agricultural and Biosystems Engineering, University of Ilorin, Ilorin, Kwara State, Nigeria
[4]Department of Food Engineering, University of Ilorin, Ilorin, Kwara State, Nigeria
[5]Department of Agricultural Civil Engineering, Kyungpook National University, Daegu 41566, Republic of Korea

[1]https://orcid.org/0009-0003-1482-4238, [2]https://orcid.org/0000-0002-6628-1939, [3]https://orcid.org/0000-0002-2314-0044
[4]https://orcid.org/0000-0002-7842-4706, [5]https://orcid.org/0009-0006-1379-3443

*Corresponding author e-mail: alhassan.elijah@lmu.edu.ng

Article Info

Received: 31.03.2025
Accepted: 30.12.2025
Online published: 20.01.2026
DOI: 10.29133/yyutbd.1667829

Keywords

Durability index,
Organic farming,
Peletized fertilizer,
Soil quality,
Waste-to-products

Abstract: Soil nutrient management is vital to sustainable farming practices and productivity. This study focused on pelletizing sugar cane leaves into granular fortified organic fertilizer for soil amelioration. To achieve this, a hammer mill incorporated with a cyclone was used for size reduction of substrate biomass. This was pelletized and characterized for its proximate and mineral compositions to confirm its potency for enhancing soil quality. Three sample sizes, namely coarse, medium, and fine, were formulated with the addition of NPK (20:10:10) fertilizer using liquid starch as a binder. A pelletizer having a ring die of diameter 6 mm was used for sample production. Proximate analysis established the elemental nutrient composition of the bio-based fertilizer, including nitrogen, potassium, calcium, magnesium, phosphorus, carbohydrate, protein, moisture content, crude fibre, fat, and ash. Additionally, sample durability was measured using a tumbling apparatus. At a confidence level of $P<0.05$, experimental results revealed that all nutrients except nitrogen were present in significant quantities, with nitrogen being less abundant in the plant leaves. Furthermore, particle size influence nutrient composition, with potassium displaying the most pronounced differences. The durability results revealed that the medium sized substrate has the highest durability index (DI) of 76.35% at 10.89 mc, followed by the fine particle size, 65.78% at 11.21 mc and coarse having 56.72% at 11.47 mc. Conclusively, these findings highlight the potential of sugar cane leaves as a fortified biomass organic fertilizer. Addressing the nitrogen deficiency identified in the substrate is crucial, supporting a mixed soil ameliorating protocol for robust soil quality.

To Cite: Ejieji, C N, Alhassan, E A, Olaoye, J O, Sunmonu, M O, Adeyi, Q B, 2026. Development and Statistical Evaluation of Fortified Soil Nutrient Formulation from Sugarcane Leaves Biomass for Soil Amelioration. *Yuzuncu Yil University Journal of Agricultural Sciences*, (1): 1667829. DOI: https://doi.org/10.29133/yyutbd.1667829

1. Introduction

Recent soil ameliorating techniques recognizes the significance of soil organic matter in soil conservation management practices. A healthy soil supports plants in all their nutritional requirements for robust and quality production. Plant wastes are vital to soil nutrient formulation by recycling essential nutrients in the plants back into the soil. This support the soil physical and mechanical properties, thus creating a conducive ambience for microbial interactions (Xiao et al., 2025). Plant wastes especially the leaves contain trace elements that the soil need for plant growth. Maintaining soil quality and producing biomass sustainably depend on the proper management and efficient utilization of soil nutrients. The addition of organic manure raises the pH, major cations, phosphorus, and nitrogen concentrations of the soil (Anthonio et al., 2023). It is essential for reducing pollution in the environment and enhancing soil quality. Organic fertilization lowers waste accumulation and mitigates ecological risks like soil contamination, water pollution, and odour emission by recycling these agro-based wastes as nutrient-rich resources. By raising the amount of soil organic carbon (SOC), strengthening the soil's structure, and stimulating microbial activity, organic fertilization simultaneously improves soil fertility. In addition to increasing agricultural productivity, this sustainable practice supports the circular economy's tenets and provides eco-friendly approaches to managing agricultural wastes (Cui et al., 2025).

Inorganic fertilizer utilization is a major component of the modern farming dynamics due to the quick results from it applications (Takahashi et al., 2016; McArthur and McCord, 2017). It enhances crop yield and overall productivity, supplementing deficient nutrients in the soil resulting from excessive and improper farming practices that impede soil health and microbial nexus (Ostadi et al., 2020; Abioye et al., 2024). Excessive use of mineral fertilizer over an extended period can degrade soil health and quality. This process is characterized by phenomena like low soil pH and acidic conditions that decrease the availability of vital soil nutrients to the plants. (Singh and Ryan, 2015; Rehman and Farooq, 2023). Chemical fertilizer represents a major contributor to carbon footprint with the release of high levels greenhouse gas (GHG). This result in low rate decomposition of organic matter that leads to the depletion of micro nutrients negating food production quality and capacity. Ultimately, this produce a senile soil which render once fertile soil unsuitable for active farming operations. Harnessing organic matter through incorporation into the soil enhances the buffering capacity and mineralization. It portrayed an effective measures to stimulate the growing environment of plant. Creating value addition from agro-based wastes for soil quality enhancement should be promoted at all fronts. This will foster both environmental sustainability and economic reward to the farming community. These sustainable practices displayed crucial significant GHG emissions reduction in the farming domain (Holka et al., 2022; Wen et al., 2024; Zhao et al., 2024).

Sugarcane cultivation is prominent in Nigeria farming context. This plant produce lots of biomass after harvesting the useful part that contain the juice. These wastes are left on the open field and most time burnt constituting hazardous environmental pollutants (Alhassan et al., 2019; Lan et al., 2022; Erbaugh et al., 2024). Proper agro-wastes management is fundamental to the sustainability of the modern farming eco-systems. Sugarcane leaves are very rich in nutrients suitable for soil nutrients fortification. It pelletizing into granular biomass can be used as soil amendment to supplement the chemical fertilizers for a balanced and enhanced soil health vital for increased yield. The conversion of crop residues to organic fertilizer is both waste management mechanism and the promotion of conservation agriculture the cradle of agricultural sustainability. This will assist farmer to thrive in a changing climate to maximize yields and profits. It adoption will mitigate the over-dependence on chemical fertilizers where it excessive usage is counter-productive and subsequently procurement is getting out of the reach of the peasant farmers resulting from incessant price increases (Al-Budairy, and Al-Taweel, 2025; Karataş, and Boyacı, 2025). Farmland soil receives a lot of organic carbon and nutrients from organic fertilizer. This could provide the nutrients and energy needed by microorganisms to break down soil organic carbon (SOC) (Meena et al., 2016). Following this, phosphorus and nitrogen will be released and used as nutrients by the plants, while easily soluble phosphorus and nitrogen may move to nearby waterways with surface runoff (Cui et al., 2025).

The investigation into organic fertilizer production from sugar cane leaves was premised on the plant leaves containing rich minerals comparable to other manure. Similar to this, because the plants have deep roots, they take up minerals from the soil, with a significant amount of these minerals ending up being stored in the leaves. Nitrogen deficiency in the leave can be supplemented with NPK fertilizer profiling robust nutrient package for plant consumption during growth. Long-term use of organic fertilizer has been shown to improve wheat yield, starch particle diameter, and protein content, but it is insufficient on its own to provide the nutrients required for wholesome crop growth (Lin et al., 2015; Wen et al., 2024). This prompted supplementing the organic fertilizers with the chemical fertilizers to compliment the deficient nutrient in the plant environment. Xiao et al. (2025) echoed that by lowering soil salt and salinity, and boosting soil biochemical qualities in coastal saline soil, the organic fertilizer combined with soil amendments improved overall soil quality and increased rice growth and yield. The study revealed that, when compared to no amendments, organic treatments considerably improved the plant height, leaf area, 1000-grain weight (4–7%), and rice yield (4–15%). To increase crop productivity, soil microbial activity, and soil nutrient content, a number of organic materials have been created and implemented (D'Hose et al., 2014; Zhang et al., 2019). Bio-organic fertilizer represent biodegradable material primarily made from the decomposition of crop straw and animal manure. Many documented studies corroborate the significance of organic fertilizer to increase the soil organic matter content and nutrients present in saline soil, improved soil structure, and promote soil desalinization (Sheoran et al., 2021; Yan et al., 2021). The potency of organic fertilizer to increase microbial biomass and related actions in addition to crop productivity and soil fertility were established in many investigations (Shu et al., 2022; Cui et al., 2024).

Environmental problems such as nutrient leaching, greenhouse gas emissions, and possible pathogen infection arise when organic fertilizer is applied incorrectly. In order to reduce these risks and guarantee sustainable agricultural development, effective strategies are essential. The study developed a fortified organic soil nutrient from sugarcane leaves, and statistically analysed its inherent properties for soil amelioration. The guiding hypothesis stemmed from the fact that fortified sugarcane leaves biomass fertilizer with complimentary nutrients will exhibit characteristics that can significantly enhance soil overall productive capacity. This offer potent alternatives to the inorganic fertilizer that have become expensive with detrimental effects on the soil properties, plant health, microfauna and microflora populations and interactions. This study therefore provide insights into waste-to-product dynamic with interplay in many of the UN's sustainable development goals for enhanced productivity, quality products and economic emancipation to the rural farmers. It is designed to promote the ecological environment and agriculture economic sustainability. Ultimately, this investigation create value chain around sugarcane leaves for soil improvement, foster climate resilience agriculture, economic emancipation and inclusion; environmental and farming ecosystems sustainability.

2. Materials and Methods

2.1. Experimental materials, equipment and sample size reduction

Sugarcane leaves the basement substrate was gathered through hand picking and raking from the freshly harvested sugarcane plantation field of University of Ilorin school farm, (Latitude: 8°29'47.90"N and Longitude: 4°32'31.70"E). Key equipment used were the hammer mill with cyclon for size reduction along with motorized sieve shaker having different sizes. Others were weighing balance, liquid starch as binder, beakers, buckets, NPK (20:10:10) inorganic fertilizer, pelleting machine, tumbling apparatus for obtaining the durability index. In order to increase the surface area for bonding, which is accomplished through grinding, the size reduction is necessary. Grinding is impacted by variables such as moisture content, melting or softening point, stickiness, slipperiness, hardness, and toughness. These were taken into consideration to obtain a suitable base material. The samples were characterized after milling into coarse, medium and fine particles. This help to establish the effects of the different sizes on the field as organic manure and to establish the most suitable conditions for applications (Figure 1 and Figure 2).

After being fed into the hammer mill, the material fell into the milling chamber by gravity. Flailing ganged hammers, which are connected to a shaft that rotates at a certain speed, repeatedly struck the material. A 5 hp two-phase electric motor was used to power the machine. The sieve screen used for the operation was a 5 mm ring diameter. The fine particles was subjected to pneumatic suction effective discharge. The cyclone operation of the hammer mill further enhance particle size reduction.

The sieve analysis helps to describe the substrate's particle size distribution. By passing through several sieves with varying mesh sizes, the procedure separates fine particles from coarse particles. In order to measure the mass fraction of particles within each size range and create a cumulative distribution, the Tap Sieve Shaker AS 200 was utilized in this investigation (Figure 3). The standard sieve used for the project are screen sizes of 4 mm, 2 mm, 1.75 mm, 1.4 mm, and 0.7 mm. This was used to characterize the coarse, medium and fine aggregates used for pellet formation.

Figure 1. Dried sugarcane leaves sample.

Figure 2. Hammer mill wih cyclone.

Figure 3. Tap sieve shaker AS 200 Tap.

The percentage particle size retained is described in Equation 1.

$$\%\text{particle size retained} = \frac{\text{Weight of particle retained}}{\text{Total weight}} \text{x}100 \quad (1)$$

The cumulative percent of sieve retained on the sieve = Total sum of % particle retained on each sieve size.

The cumulative percent of sieve passing through the sieve = 100 – Cumulative percent retained

2.2. Soil nutrient biomass formulation and pellet production

The characterized samples was each thoroughly mixed with liquid starch used as binder. The binder help to achieve the desired green strength and the tackiness needed for the material to stick to itself because it requires wet strength to hold up the rolling, tumbling, and dropping impact the pellet is made to undergo. This is significant because it ensures that the bonded materials remain secure and can be handled without slipping or shifting. The choice of binder used depend on the availability, cost and end use. Starch being an organic binders can break down quickly and also add micro-nutrients to the soil. Achieving the right sample to starch mix ratio will help to produce pellet that satisfy conditions such as durability and the gradual release of nutrient into the soil.

1 kg of milled sample was mixed with 100 ml of liquid starch to effectively bind the material and increase their strength. The binder fuse the substrate together and help to reduce the hardness of the material to allow easy and fast disintegration into the soil. Organic fertilizers from plant residues exhibit limited nitrogen (N) when compared with NPK inorganic fertilizer. The fortification with NPK helps increase the nitrogen percentage over the unfortified compost for increased yield and productivity. This process enhances agronomic effectiveness of both the organic matter and the nutrient by reducing the amount of fertilizer and quality improvement of the organic compost (Chen et al., 2021; Cui et al., 2025). The NPK fertilizer used for fortification must possess higher percentage of nitrogen which represent the major nutrient lacking in the plant. NPK fertilizer with ratio 20:10:10 was used in this study. Similarly, the mixing ratio and formulation of NPK with the bind organic plant particle to get the fortified biomass soil nutrient was in the ratio of 2:1.

Pelleting represent a mechanical procedure that helped in the production of agglomerated substance through compaction and passage of substrate through a die (Okonkwo et al., 2023). The pelleting machine used for this operation was locally fabricated having small orifice or aperture. After thoroughly mixing all the substrates namely plant particles, binders and NPK fertilizer in correct proportion, the mixture was fed into the pelleting machine to produce the solid fortified biomass soil nutrients. A ring die of 6 mm diameter was used in this experiment. The produced pellet and the pelleting machine are presented in Figure 4 and Figure 5.

Figure 4. Produced pelletized fertilizer.

Figure 5. The pelleting machine used for the work.

2.3. Proximate and durability analysis

The pelletized soil nutrient biomass was examined analytically following standard procedures for proximate composition to establish the minerals and the percentage of nutrients present in the fortified biomass formed (AOAC, 2012). Moisture content was expressed on a wet weight basis, while ash, crude protein, crude fat, crude fiber, and carbohydrate contents were expressed on a dry weight basis. In accordance with ASAE S269.4 standard, the durability test was also conducted using the tumbling apparatus. The experimental samples were weighed before tumbling and also after the particle has been tumbled. The material was then sieved to remove the finer particle below the sieve size used and then weighed again. This is for checking the strength and the force the pelletized organic fertilizer can withstand during handling and its application on the field (Kaliyan and Morey, 2009), as examined for the fine, medium and coarse granules/samples (Equation 2).

$$\text{Pellet Duarbility (PDI, \%)} = \frac{\text{Final Pellet Weight}}{\text{Initial Pellet Weight}} \text{ x } 100 \tag{2}$$

2.4. Experimental data statistical analysis

Obtained experimental data were subjected to statistical analysis. This help to affirm treatment significance effects. A one-way analysis of variance (ANOVA) was performed to evaluate differences among fertilizer treatments. Similarly, treatment means were separated using Duncan's New Multiple Range Test (DNMRT) test at $p \leq 0.05$ and results are presented as mean ± standard error (SE). IBM SPSS Statistics version versions 29.0.0.0 was used following established procedure for data analysis to gain scientific inference from the study. To enhance visualization and overall scientific results presentation, graphical aids used in the study was achieved using Microsoft Excel 2016 v16.0.

3. Results and Discussion

The results of the proximate composition and the one-way ANOVA of the proximate parameters composition as analysed are presented in this section. Likewise, some minerals that are important for plant growth and healthy soil were investigated. The essential components of both organic and inorganic fertilizer formulations are nitrogen, phosphorus, potassium, calcium, and magnesium (Estrada-Bonilla et al., 2021). The pellet durability index (PDI) results were obtained for all the fortified biomass soil nutrients formulation. Correspondingly, Analysis of Variance (ANOVA) was carried out to affirm the effect of the proximate analysis on the samples. Conversely, Duncan's New Multiple Range Test (DNMRT) help to compare the significance of the mean values. The results of the proximate composition and one-way ANOVA of parameters composition based on dry weight basis are presented in Tables 1 and 2.

Table 1. Proximate Composition of the formed pelletized organic fertilizer

Component (%)	Content (%) (Mean ± SD)
Moisture Content	8.25 ± 0.05
Ash	2.10 ± 0.01
Crude protein	14.65 ± 0.12
Crude fat	3.90 ± 0.03
Crude fiber	4.75 ± 0.08
Carbohydrate	66.35
Total	100.00

Values represent triplicates of Means determination ± Standard Deviation.

Carbohydrate was evaluated using established standard procedure (Difference: 100 – (Moisture content + Ash + Crude Protein + Crude fat + Crude fibre)

The results depict the composition in the order of 66.35% > 14.65% > 8.25% > 4.75% > 3.90% > 2.10% respectively for carbohydrate, crude protein, moisture content, crude fibre, crude fat and ash. The rich sources of especially the carbohydrate and protein emphasied the potential nutritive capability of the fortified biomass ferilizer for soil improvement. The rich carbohydrate content is an indication of easily decomposable organic matter that can serve as a source of energy for soil microorganism providing ambient for microbial activities, interaction and nutrient mineralization. Similarly, the potent amount of protein reveal the positive impact of organic nitrogen to the soil, while the component of the crude fibre is a reflection of slow decomposing of the organic matter vital to improve soil structure, porosity, and long-term fertility. The ash and moisture content are similarly essential. Ash content is the symbol of the mineral residues depicting the presence of inorganic nutrients that are vital for plant growth. The reasonably low moisture content of the fortified biomass based soil nutrient formulation reveal reduced microbial spoilage, extended shelf life and ease of handling.

Table 2. One-way ANOVA of proximate parameters composition

Parameter	Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Carbohydrate	Between Groups	2.517	2	1.258	2633.884	.000*
	Within Groups	0.003	6	0.000		
	Total	2.520	8			
Protein	Between Groups	0.968	2	0.484	1062.610	.000*
	Within Groups	0.003	6	0.000		
	Total	0.971	8			
Crude fibre	Between Groups	0.506	2	0.253	740.268	.000*
	Within Groups	0.003	6	0.000		
	Total	0.508	8			
Ash	Between Groups	0.009	2	0.004	14.333	.005*
	Within Groups	0.002	6	0.000		
	Total	0.011	8			
Moisture content	Between Groups	0.498	2	0.249	1018.682	.000*
	Within Groups	0.002	6	0.000		
	Total	0.500	8			
Crude Fat	Between Groups	0.003	2	0.001	6.500	.031*
	Within Groups	0.001	6	0.000		
	Total	0.004	8			

*Significant at $p < 0.05$.

Table 2 shows the statistical significance across groups of the studied parameters in the fortified biomass organic fertilizer. A highly significant difference at $P < 0.05$ can be inferred among groups for all the proximate parameters under investigation. The significant p-values across all the parameters is a reflection that sample treatment exhibited quantifable impacts on the nutrient composition required for soil amelioration characteristics. The implication is that the fortification process and biomass treatment exhibit a measurable influence on the nutrient profile of the formulation. This difference emphasises the role of formulation techniques in defining the balance between readily available nutrients and structural organic matter, which in turn affect soil amelioration potential.

Similarly, high F value as seen with carbohydrate (2633.88) revealed a highly significant deviation depicting the remarkably different carbohydrate levels between the groups. This is also pronouced among the other parameters with varied levels of disparities. The F values are 1062.61 for crude protein, 1018.68 for moisture content, 740.27 for crude fibre, 14.33 for ash and 6.50 for crude fat. These highlight the importance of these parameters to the plant healthy growth and robust output. It was observed from Table 2 that the formulation composition has significant effect on the pellet formed. This validate that nutirient profile differ considerably among groups. This suggest that the choice of feedstock and processing treatment is vital to the inherent nutiritional quality that is obtainable from the process. The fortified biomass exhibit rich nutrient composition such as dense carbohydrate, significant protein and other nutrients as examined with disparities across the groups affirmed from the significant ANOVA results.

With regard to mineral composition, Table 3 showed that, with the exception of nitrogen, which is not significant, the formulations had a significant effects on all of the minerals tested for at $P<0.05$, including phosphorus, calcium, potassium, and magnesium.

Table 3. ANOVA for Mineral Composition of the fortified biomass-based soil nutrient formulations

Mineral	SV	Sum of Squares	df	Mean Square	F	Sig.
Nitrogen	Between Groups	0.000	2	0.000	2.333	0.178ns
	Within Groups	0.001	6	0.000		
	Total	0.001	8			
Phosphorus	Between Groups	0.742	2	0.371	1669.850	0.000*
	Within Groups	0.001	6	0.000		
	Total	0.743	8			
Potassium	Between Groups	0.181	2	0.090	135.450	0.000*
	Within Groups	0.004	6	0.001		
	Total	0.185	8			
Calcium	Between Groups	0.007	2	0.004	40.875	0.000*
	Within Groups	0.001	6	0.000		
	Total	0.008	8			
Magnesium	Between Groups	0.003	2	0.001	19.000	0.003*
	Within Groups	0.000	6	0.000		
	Total	0.003	8			

* = significant at $p < 0.05$; ns = not significant; SV – Source variation.

Muchukuri et al. (2004) hinted that the nitrogen content of plant leaves is only 14–18%. This is due to the ease with which nitrogen can be released into the atmosphere. This result corroborated what was obtained in this investigation where the base material has little amount of nitrogen. The significant minerals at $P < 0.05$ typify the potency in the mineral content of the sample after the formulation. Liu et al. (2021) alluded that the application of carbon rich organic fertilizer in higher proportion can help to achieve bounty soil organic carbon in soil. Similarly, Cui et al. (2025) recorded a significant rise in NH_4^+-N and NO_3^--N content in treatment regarding 30% decline in chemical fertilizer, 735 kg ha^{-1} inorganic fertilizer and 315 kg ha^{-1} organic fertilizer at $P < 0.05$. Similarly, Saikia et al. (2015) affirmed that replacing 20% of mineral fertilizer with organic manure for wheat grown in alluvial soil in a subtropical zone, increased soil carbon stock and promoted crop growth and development. In order to address this inadequacy, Wang et al. (2024) asserted that after organic fertilization, increased nitrogen-fixing microorganisms may immobilize soil endogenous nitrogen and absorb more nitrogen oxides from the atmosphere, compensating for the nitrogen content difference between mineral and organic fertilizers.

3.1 Proximate analysis statistics characteristics of the granular organic fertilizer samples based on sizes

The results based on the output characteristics of the obtained data for the proximate analysis premised on the coarse, medium and fine sample sizes (Table 4). The medium size depict the highest carbohydrate content of 72.62%, followed by the coarse 71.37% and fine sample size has the least of 71.71%. Similarly, the coarse sample has the highest moisture content 11.47, fat 2.02, crude fibre 4.81 and ash 2.86. Fine particle of the formulated fertilizer had the highest content of protein 8.05. The implications are sizes influences the rich content present the granular organic fertilizer. The medium-sized pelletized fertilizer with 72.62% carbohydrate depicts that it holds higher polysaccharide fractions which is vital for assisting nutirent mineralization and microbial energy supply during soil incorporporation.

Similarly, the fine particle size exhibited the highest protein content (8.05%), an indication of higher organic nitrogen contribution. Finely ground particle show greater surface area with high proteinaceous fractions. The 11.47% of coarse particle for the crude fibre reveal the greatest fibre content, aligning with structural residue retention in larger granules which is fundamental at enhancing soil structure and long-term organic matter buildup.

Table 4. Statistical presentation of the proximate composition of the pelletized organic fertilizer samples based on particle sizes

Proximate Component	Particle Size	Mean (%)	Std. Deviation	Std. Error
Carbohydrate	Coarse	71.37	0.025	0.015
	Fine	71.71	0.026	0.015
	Medium	72.62	0.010	0.006
	Total	71.90	0.020	0.012
Protein	Coarse	7.49	0.030	0.017
	Fine	8.05	0.015	0.009
	Medium	7.27	0.015	0.009
	Total	7.60	0.020	0.012
Crude Fibre	Coarse	11.47	0.010	0.006
	Fine	11.21	0.005	0.003
	Medium	10.89	0.030	0.017
	Total	11.19	0.015	0.009
Ash	Coarse	2.02	0.026	0.015
	Fine	1.95	0.010	0.006
	Medium	2.01	0.010	0.006
	Total	1.99	0.015	0.009
Moisture Content	Coarse	4.81	0.010	0.006
	Fine	4.27	0.015	0.009
	Medium	4.36	0.020	0.012
	Total	4.48	0.015	0.009
Fat	Coarse	2.86	0.020	0.012
	Fine	2.82	0.010	0.006
	Medium	2.85	0.010	0.006
	Total	2.84	0.013	0.008

Though the ash content characteristics are similar across all sizes from 1.95 – 2.02%, the coarse granules is the highest showing rich mineral residues retention. The fairly consistent values across all sizes may suggest a non-significant effect in term of mineral contribution during application. Also, the moisture content varies across sizes with coarse having the highest of 4.81% and the fine with least of 4.27%. Mositure content is critical to drying, storage stability, and microbial colonization rate in the soil. The fat content values are fairly consistent (2.82 – 2.86%), depicting lipid fractions are unaffected by granulation and energy-dense components uniformity across board. Collectively, the results suggest that granule size influences nutrient dynamics, and a blend of sizes could balance quick nutrient release (fine), sustained microbial energy (medium), and long-term soil health (coarse).

Also, the analysed overview of the obtained data for the selected minerals for the three sample sizes investigated is depicted in Table 5. This shows the percentage dry weight basis composition of nitrogen, phosphorus, potassium, calcium and magnesium, their mean values, and standard deviation and their level of impact and contribution to soil fertility. The study emphasied the effect of sample size on the selected mineral content. The results highlight that particle size strongly influenced nutrient distribution within the fertilizer granules. The medium sample size possess high concentrations of Nitrogen (0.22%), Potassium (1.75%) and Magnesium (0.65%) as the highest content. Similarly, Phosphorus (4.62%) and Calcium (0.80%) was obtained for the fine particle as the highest content. Estrada-Bonilla et al., 2017 reported that the availability of phosphorus in farmland soil is determined by its chemical fractions rather than its overall content. The findings presented supported the conclusion made by Muchukuri et al. (2004) that plant leaves are very rich in other nutrients, particularly phosphorus, but have less nitrogen because plants can lose a significant amount of nitrogen to the atmosphere thereby prompting the witnessed nitrogen deficiency.

Coarse particles, although lower in most nutrient concentrations, may contribute to slower nutrient release and long-term soil amelioration. This distribution pattern is agronomically significant. Fine granules may provide rapid nutrient availability, medium granules may offer balanced and sustained release, while coarse granules could contribute to long-term soil fertility improvement through gradual nutrient mineralization. Such a multi-scale nutrient release mechanism is particularly advantageous in tropical soils, where leaching, fixation, and nutrient depletion are prevalent and resulted in many senile arable lands.

Table 5. Statistics characteristics of the mineral composition of the fertilizer particle types

Mineral Composition (%)		**Mean**	**Std. Deviation**	**Std. Error**
	Coarse	0.205	0.005	0.003
Nitrogen	Fine	0.210	0.010	0.006
	Medium	0.220	0.010	0.006
	Total	0.212	0.008	0.005
	Coarse	3.960	.020	.012
Phosphorus	Fine	4.617	.012	.007
	Medium	4.507	.012	.007
	Total	4.361	.015	.009
	Coarse	1.437	.021	.012
Potassium	Fine	1.457	.025	.015
	Medium	1.747	.031	.018
	Total	1.547	.026	.015
	Coarse	.740	.010	.006
Calcium	Fine	.797	.012	.007
	Medium	.733	.006	.003
	Total	.757	.045.	.005
	Coarse	.620	.010	.006
Magnesium	Fine	.607	.006	.003
	Medium	.650	.010	.006
	Total	.626	.009	.005

Unlike other nutrients such as phosphorus, calcium, magnesium and potassium, the nitrogen content of the sugarcane leaves used in this research revealed a very low value. Due to the important of nitrogen to the plant productivity, the need to supplement the nitrogen content become imperative. This was achieved by the addition of inorganic fertilizer with high nitrogen percentage. NPK 20:10:10 fertilizer was used to supplement for the nitrogen deficiency amendment. The difference in nutrients composition of the various feedstocks for organic bio-fertilizer may be due to the difference in plant leaves used, the state of the plant (green or dry) and also the soil condition of the environment that grow the plant. This may be fundamentally anchored on variation in plant genetic, environmental factors and feedstock processing techniques (Aremu et al., 2019).

The fortified sugarcane leaf-based formulation demonstrated appreciable levels of both primary (N, P, K) and secondary (Ca, Mg) macronutrients, with particle size optimization enhancing nutrient partitioning. By combining rapid nutrient availability from fine granules with the sustained release of medium and coarse particles, the fertilizer formulation has the potential to improve soil nutrient status, reduce dependence on synthetic inputs, and contribute to sustainable soil fertility management. Though, the investigation is limited to the production and statistical characterization of a fortified organic fertilizer from sugarcane leaves biomass, it is recommended that field experimentation be carried out to determine its impact on crop yield and soil quality enhancement.

3.2 Durability test of pellet samples

This test was carried out to determine the strength of the pellet formed and to establish the force it can withstand during handling and application on the field. Also, this help to establish the level of disintegration and the duration it will take for the pelletized fertilizer to decompose into the soil. The test is important in mechanical stability and field handling of the biomass-based formulation. After tumbling for 60 seconds, the obtained results are presented in Table 6. From the table, the samples based on sizes had different pellet durability index because of the difference in moisture content composition. The medium particle size had the highest pellet durability index of 76.35 at the lowest moisture content of 10.89, while the fine and coarse has 65.79 and 56.72 respectively. The implication is that the medium size pellet would withstand more stress than coarse and fine pellets and also have more extended time for nutrients released into the soil.

Table 6. Durability analysis from sample tumbling based on particle sizes

Particle Size	Weight of sample before tumbling (g)					Pellet Durability Index (PDI, %)
		1st	2nd	3rd	Mean	
Fine	2000	1337	1320	1290	1315.67	65.78
Medium	2000	1550	1610	1421	1527	76.35
Coarse	2000	1178	1200	1025	1134.33	56.72

The PDI of 65.78% for the fine-sized granules depict moderate resistance to crumbling during durability test. Although finer particles exhibited improved surface cohesion due to their compact structure, they are more susceptible to attrition and dust formation under mechanical stress. While such breakdown can accelerate nutrient release in the soil, it also poses challenges during storage, packaging, and transportation where mechanical strength is critical. Also, the medium-sized granules exhibited the highest PDI of 76.35%, signifying superior durability and resistance to mechanical disintegration. This higher durability is likely a result of optimal particle binding and internal cohesion, allowing the granules to maintain structural integrity under tumbling conditions. Agronomically, this suggests that medium granules provide a balance between handling stability and gradual nutrient release, reducing losses from dust and fines, while ensuring sustained soil nutrient availability. Such stability is highly desirable for large-scale field applications where uniform particle integrity contributes to ease of mechanical spreading and predictable nutrient distribution. A PDI of 56.72% as obtained for coarse granules show weak structural strength and high susceptibility to breakage during tumbling.

This could be attributed to their less compacted internal matrix, which predisposes them to fragmentation and irregular size reduction. While this may enhance the release of nutrients upon soil incorporation, it compromises their handling properties and may lead to significant losses during transport and application. Additionally, the inconsistency of fragmentation could result in uneven nutrient delivery across soil surfaces.

The results demonstrate that particle size significantly influences granule durability, with medium particles outperforming both fine and coarse fractions. From a soil fertility management perspective, durability is not merely a mechanical property but also determines the release dynamics of nutrients and the practicality of field application. Medium-sized granules, by virtue of their superior PDI, are more likely to withstand handling stress while still offering a gradual release of nutrients. Fine particles, though moderately durable, may serve as a source of more immediate nutrient availability, whereas coarse particles, despite their potential for long-term release, face limitations due to poor durability.

In the context of soil amelioration, the durability analysis underscores the advantage of formulating the fertilizer predominantly in medium particle sizes**.** Their combination of high structural integrity and balanced nutrient profile enhances their suitability for correcting soil fertility constraints in tropical soils. By ensuring both mechanical stability and agronomic efficiency, medium-sized granules can contribute to improved fertilizer efficiency, reduced nutrient losses, and sustainable soil management.

Conclusion

Organic fertilizers are renewable soil amendment resource that contains abundant nutrient elements required for healthy plant growth. Organic farming technique being embraced in modern farming domain is anchored on the derived healthy products and soil conservation characteristics associated with it adoptions. The study provides significant opportunities and benefits such as improving soil quality through organic manure from agro-based biomass, enhancing quality of life of farmers, and fostering the country's food security agenda. It revealed the substantial macro nutrients inherent in plant leaves with varied nutrient compositions based on the different substrate sizes examined through proximate analysis. The statistical evaluations help to establish a strong and data–driven inferences suitable for understanding the dynamic interaction among the samples. The medium size pellet has more nitrogen content 0.22 than the fine and coarse with 0.21. The two highest nutrients present in the sugarcane leaves are phosphorus and potassium, which varies depending on the sample size. In case of phosphorus, the coarse has 3.96, while the medium and fine have 4.62 and 4.51 respectively. For potassium, the fine particle has 1.75, medium 1.46 and coarse has 1.44. Based on the observed indicators from the study, the blend of the sizes provide a dynamic soil ameliorating mechanism for healthy crop production. The adoption of organic fertilizer should be promoted among the farmers because of the benefits to the farming eco-systems. This will reduce over-dependency on chemical fertilizers that have the capacity to increase the soil acidity and huge economic impact on the food production process.

Acknowledgements

The authors wish to appreciate our individual institution's for the conducive ambient to conduct this research. The assistance of the personnel and the various equipment made available in the laboratory used are well acknowledged

Ethical Statement

Ethical approval is not required for this study because the study used agro-waste biomass to produce peletized fertilizer. Hence, it involved inanimate objects

Conflict of Interest

The authors declare that there are no conflicts of interest.

Artificial Intelligence Declaration

The authors declare that generative artificial intelligence tools were ethically and responsibly used during the preparation of this article for activities including, language editing, sentence refinement and technical concept guidance. ChapGPT was consulted for a robust technical insights and QuillBot was used for language editing, and sentence refinement. The integrity and quality of the final research output was affirmed using Turnitin for the Plagiarism and AI Checks.

Funding Statement

The study is a self sponsored and no financial assistance was received for the research.

Author Contributions

Conceptualization, J.O.O. and M.O.S.; methodology, C.N.E., J.O.O., and E.A.A.; investigation and data analysis, J.O.O. E.A.A., M.O.S., C.N.E. and Q.B.A.; writing- review and editing, C.N.E., E.A.A., J.O.O., M.O.S and Q.B.A. All authors have read and agreed to the submitted version of the manuscript.

References

Abioye, O. M., Okunola, A. A., Amodu, M. F., Olaseheinde, D. A., & Yusuf, K. O. (2024). Nanobiofertilizer and its application in sustainable agriculture, crop specific nutrients delivery and environmental sustainability: A review. *Applied Science and Engineering Progress*, *17*(3), 7339. https://doi.org/10.14416/j.asep.2024.05.001

Al-Budairy, Z. J., & Al-Taweel, L. S. (2025). Role of adding bio-inoculation, mushroom farm waste, and nano-fertilizers on the content of stevia leaves of total carbohydrate active compounds. *Yuzuncu Yil University Journal of Agricultural Sciences, 35*(4), 707-727. https://doi.org/10.29133/yyutbd.1675195

Alhassan, E. A., Olaoye, J. O., Olayanju, T. M. A., & Okonkwo, C. E. (2019). An investigation into some crop residues generation from farming activities and inherent energy potentials in Kwara State, Nigeria. *IOP Conference Series: Materials Science and Engineering*, *640*, 012093. https://doi.org/10.1088/1757-899X/640/1/012093

Anthonio, C. K., Huang, J., Chen, J., Khan, M. N., Du, J. X., Garba, H. N., Li, D. C., Liu, G. R., Liu, S. J., Liu, L. S., & Zhang, H. M. (2023). Impact of long-term fertilization on phosphorus fractions and manganese oxide with their interactions in paddy soil aggregates. *Journal of Environmental Management*, *333*, 117440. https://doi.org/10.1016/j.jenvman.2023.117440

AOAC. (2012). *Official methods of analysis of AOAC International* (19th ed.). AOAC International.

Aremu, C. O., Olayanju, T. A., Alhassan, E. A., Ojo, A., Stephen, A., Henry, I., Asaleye, A. J., Segun, A., & Ake, M. (2019). Predictive analysis of the effect of tillage system on the growth and yield of rice plant under lowland plantation. *Journal of Engineering and Applied Sciences*, *14*(10), 3422–3429.

Chen, M. M., Zhang, S. R., Liu, L., Wu, L. P., & Ding, X. D. (2021). Combined organic amendments and mineral fertilizer application increase rice yield by improving soil structure, P availability and root growth in saline-alkaline soil. *Soil and Tillage Research*, *212*, 105060. https://doi.org/10.1016/j.still.2021.105060

Cui, H., Hou, S. N., Wang, X. Y., & Zhu, H. (2025). Organic fertilizer-mediated cultivated land conservation and pollution source control in agricultural ecosystem, Northeast China. *Environmental Technology & Innovation*, *37*, 103945. https://doi.org/10.1016/j.eti.2024.103945

Cui, H., Shutes, B., Hou, S. N., Wang, X. Y., & Zhu, H. (2024). Long-term organic fertilization increases phosphorus content but reduces its release in soil aggregates. *Applied Soil Ecology*, *203*, 105684. https://doi.org/10.1016/j.apsoil.2024.105684

D'Hose, T., Cougnon, M., De Vliegher, A., Vandecasteele, B., Viaene, N., Cornelis, W., Van Bockstaele, E., & Reheul, D. (2014). The positive relationship between soil quality and crop production: A case study on the effect of farm compost application. *Applied Soil Ecology*, *75*, 189–198. https://doi.org/10.1016/j.apsoil.2013.11.013

Erbaugh, J., Singh, G., Luo, Z., Koppa, G., Evans, J., & Shyamsundar, P. (2024). Farmer perspectives on crop residue burning and sociotechnical transition in Punjab, India. *Journal of Rural Studies*, *111*, 103387. https://doi.org/10.1016/j.jrurstud.2024.103387

Estrada-Bonilla, G. A., Durrer, A., & Cardoso, E. J. B. N. (2021). Use of compost and phosphate-solubilizing bacteria affect sugarcane mineral nutrition, phosphorus availability, and the soil bacterial community. *Applied Soil Ecology*, *157*, 103760. https://doi.org/10.1016/j.apsoil.2020.103760

Estrada-Bonilla, G. A., Lopes, C. M., Durrer, A., Alves, P. R. L., Passaglia, N., & Cardoso, E. J. B. N. (2017). Effect of phosphate-solubilizing bacteria on phosphorus dynamics and the bacterial community during composting of sugarcane industry waste. *Systematic and Applied Microbiology*, *40*, 308–313. https://doi.org/10.1016/j.syapm.2017.05.003

Holka, M., Kowalska, J., & Jakubowska, M. (2022). Reducing carbon footprint of agriculture—can organic farming help to mitigate climate change? *Agriculture*, *12*(9), 1383. https://doi.org/10.3390/agriculture12091383

Kaliyan, N., & Morey, R. V. (2009). Factors affecting strength and durability of densified biomass products. *Biomass and Bioenergy*, *33*(3), 337–359. https://doi.org/10.1016/j.biombioe.2008.08.005

Karataş, A., & Boyacı, H. (2025). The usage of tea factory waste as soil substrate for the production of snap bean *(Phaseolus vulgaris* L.). *Yuzuncu Yil University Journal of Agricultural Sciences, 35*(4), 576-586. https://doi.org/10.29133/yyutbd.1672948

Lan, R., Eastham, S. D., Liu, T., Norford, L. K., & Barrett, S. R. H. (2022). Air quality impacts of crop residue burning in India and mitigation alternatives. *Nature Communications*, *13*, 6537. https://doi.org/10.1038/s41467-022-34093-z

Lin, Z., Chang, X., Wang, D., Zhao, G., & Zhao, B. (2015). Long-term fertilization effects on processing quality of wheat grain in the North China Plain. *Field Crops Research*, *174*, 55–60. https://doi.org/10.1016/j.fcr.2015.01.008

Liu, J., Shu, A., Song, W., Shi, W., Li, M., Zhang, W., Li, Z., Liu, G., Yuan, F., Zhang, S., Liu, Z., & Gao, Z. (2021). Long-term organic fertilizer substitution increases rice yield by improving soil properties and regulating soil bacteria. *Geoderma*, *404*, 115287. https://doi.org/10.1016/j.geoderma.2021.115287

McArthur, J. W., & McCord, G. C. (2017). Fertilizing growth: Agricultural inputs and their effects in economic development. *Journal of Development Economics*, *127*, 133–152. https://doi.org/10.1016/j.jdeveco.2017.02.007

Meena, M. D., Joshi, P. K., Jat, H. S., Chinchmalatpure, A. R., Narjary, B., Sheoran, P., & Sharma, D. K. (2016). Changes in biological and chemical properties of saline soil amended with municipal solid waste compost and chemical fertilizers in a mustard-pearl millet cropping system. *Catena*, *140*, 1–8. https://doi.org/10.1016/j.catena.2016.01.009

Muchukuri, K., Kungu, N., Ayaga, G. O., and Gachini, G. N. (2004). Training Notes for KARI laboratory staff on soil and plant analysis course held at NARL Kabete (unpublished). (pp. 62-74, 82-88).

Okonkwo, C. E., Isaac, M. O., Alhassan, E. A., Ogbevire, M., Alake, A. S., Ajao, F. O., & Olayanju, A. T. (2023). Design and fabrication of a fish feed mixing cum pelleting machine for small-medium scale aquaculture industry. *Open Agriculture*, *8*(1), 20220124. https://doi.org/10.1515/opag-2022-0124

Ostadi, A., Javanmard, A., Machiani, M. A., Morshedloo, M. R., Nouraein, M., Rasouli, F., & Maggi, F. (2020). Effect of different fertilizer sources and harvesting time on the growth characteristics, nutrient uptakes, essential oil productivity and composition of *Mentha x piperita* L. *Industrial Crops and Products*, *148*, 112290. https://doi.org/10.1016/j.indcrop.2020.112290

Rehman, A., & Farooq, M. (2023). Challenges, constraints, and opportunities in sustainable agriculture and environment. In *Sustainable agriculture and the environment* (pp. 487–501). Academic Press. https://doi.org/10.1016/B978-0-323-90500-8.00012-9

Saikia, P., Bhattacharya, S. S., & Baruah, K. K. (2015). Organic substitution in fertilizer schedule: Impacts on soil health, photosynthetic efficiency, yield and assimilation in wheat grown in alluvial soil. *Agriculture, Ecosystems & Environment*, *203*, 102–109. https://doi.org/10.1016/j.agee.2015.02.003

Sheoran, P., Basak, N., Kumar, A., Yadav, R. K., Singh, R., Sharma, R., Rathore, S., & Sharma, P. C. (2021). Ameliorants and salt tolerant varieties improve rice-wheat production in soils undergoing sodification with alkali water irrigation in Indo–Gangetic Plains of India. *Agricultural Water Management*, *243*, 106492. https://doi.org/10.1016/j.agwat.2020.106492

Shu, X., He, J., Zhou, Z., Xia, L., Hu, Y., Zhang, Y., Zhang, G., & Wang, C. (2022). Organic amendments enhance soil microbial diversity, microbial functionality and crop yields: A meta-analysis. *Science of the Total Environment*, *829*, 154627. https://doi.org/10.1016/j.scitotenv.2022.154627

Singh, B., & Ryan, J. (2015). Managing fertilizers to enhance soil health Paris. *France: International Fertilizer Industry Association (IFA)*.

Takahashi, S., Ihara, H., & Karasawa, T. (2016). Compost in pellet form and compost moisture content affect phosphorus fractions of soil and compost. *Soil Science and Plant Nutrition*, *62*, 399–404. https://doi.org/10.1080/00380768.2016.1198680

Wang, Y., Cai, J., Chen, X., Guo, B., Liu, J., Qiu, G., & Li, H. (2024). The connection between the antibiotic resistome and nitrogen-cycling microorganisms in paddy soil is enhanced by application of chemical and plant-derived organic fertilizers. *Environmental Research*, *243*, 117880. https://doi.org/10.1016/j.envres.2023.117880

Wen, J., Li, Z., Yao, J., Wang, S., Liu, Y., & Liu, Y. (2024). The combined application of organic and inorganic fertilizers improved the quality of colored wheat by physicochemical properties and rheological characteristics of starch. *International Journal of Biological Macromolecules*, 137175. https://doi.org/10.1016/j.ijbiomac.2024.137175

Xiao, M., Jiang, S., Li, J., Li, W., Fu, P., Liu, G., & Chen, J. (2025). Synergistic effects of bio-organic fertilizer and different soil amendments on salt reduction, soil fertility, and yield enhancement in salt-affected coastal soils. *Soil and Tillage Research*, *248*, 106433. https://doi.org/10.1016/j.still.2024.106433

Yan, S., Gao, Y., Tian, M., Tian, Y., & Li, J. (2021). Comprehensive evaluation of effects of various carbon-rich amendments on tomato production under continuous saline water irrigation: Overall soil quality, plant nutrient uptake, crop yields and fruit quality. *Agricultural Water Management*, *255*, 106995. https://doi.org/10.1016/j.agwat.2021.106995

Zhang, J., Bai, Z., Huang, J., Hussain, S., Zhao, F., Zhu, C., Zhu, L., & Jin, Q. (2019). Biochar alleviated the salt stress of induced saline paddy soil and improved the biochemical characteristics of rice seedlings differing in salt tolerance. *Soil and Tillage Research*, *195*, 104372. https://doi.org/10.1016/j.still.2019.104372

Zhao, T., He, A., Khan, M. N., Yin, Q., Song, S., & Nie, L. (2024). Coupling of reduced inorganic fertilizer with plant-based organic fertilizer as a promising fertilizer management strategy for colored rice in tropical regions. *Journal of Integrative Agriculture*, *23*(1), 93–107. https://doi.org/10.1016/j.jia.2023.04.035