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RESEARCH PAPER

Enhancing growth and yield of sweet potato (*Ipomoea batatas* L.) through fertilizer supplementation strategies

Catherine N. Payadon[*1], **Artemio A. Martin Jr.**[2]

[1]*Central Graduate School, Isabela State University, Echague, Philippines*

[2]*College of Agriculture, Isabela State University, Echague, Philippines*

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Abstract

Organic fertilizers in sweet potato cultivation enhance soil fertility, boost crop productivity, and ensure food security, especially in staple potato-producing regions. Organic sweet potatoes have improved nutritional profiles, addressing malnutrition and supporting SDG 3: Good Health and Well-being. Additionally, organic inputs reduce reliance on synthetic chemicals, aligning with SDG 12: Responsible Consumption and Production and SDG 13: Climate Action. This study evaluates various organic fertilizer sources on the growth, yield, and quality of three sweet potato varieties—Bintong, Bengueta, and Okinawan. A split-plot design was used, with variety as the main plot and six fertilizer treatments as subplots: full NPK, reduced NPK, and reduced NPK supplemented with vermichar, vermicompost, biochar, and Black Soldier Fly (BSF) frass. Results revealed that Bengueta exhibited the highest computed yield (15.43 t/ha), though differences among varieties were not statistically significant. Among fertilizer treatments, BSF frass combined with reduced NPK significantly produced the highest yield (15.94 t/ha), followed by vermicompost (15.67 t/ha), highlighting the potential of organic amendments to outperform full synthetic fertilizer in tuber production. Combinations like Bengueta × Biochar and Bintong × Vermichar demonstrated superior performance in yield and Total Soil Stability (TSS). Bengueta is recommended for high-yielding production, while BSF frass and biochar are effective organic inputs for improving yield and quality, with future research validating these findings across various environments.

* **Corresponding Author:** Catherine N. Payadon ✉ catherinepayadon67@gmail.com

Introduction

A major food crop in the world, sweet potatoes (*Ipomoea batatas*) are renowned for their versatility, nutritional value, and economic importance, particularly in areas that are tropical or subtropical. It is widely cultivated because of its edible storage roots, which are rich in carbohydrates, vitamins (especially vitamin A), and dietary fiber. However, despite its potential, sweet potato cultivation often faces challenges related to growth, yield, and root quality. One of the key factors influencing these aspects is soil fertility management. Traditionally, synthetic fertilizers have been used to enhance crop production, but they are increasingly associated with environmental concerns like soil degradation and contamination of water. Organic fertilizers, derived from plant or animal residues, offer a more sustainable alternative. These fertilizers support long-term soil fertility, increase microbial activity, and improve soil structure in addition to supplying necessary nutrients. Natural fertilizers improve sweet potato yield and growth by encouraging healthy root development, lengthening vines, and accumulating biomass. Organic fertilizers enhance soil organic matter content, promoting optimal growing conditions. They contribute to higher storage root production, larger tubers, and improved storage root quality. Organic fertilizers are sustainable for enhancing agricultural productivity and are a sustainable option for sweet potato cultivation.

The research gap regarding the organic application on sweet potato varieties highlights the need for more targeted studies that explore the specific interactions between different organic inputs and the diverse cultivars of sweet potatoes. While organic fertilizers are known to enhance growth and yield in various crops, there is limited research examining their differential effects on specific sweet potato varieties. Each variety may have unique growth requirements, nutrient uptake characteristics, and responses to organic amendments, which are not yet fully understood. Addressing these gaps could lead to more effective organic farming practices tailored to sweet potato production, ultimately enhancing yield, nutritional quality, and soil sustainability.

Organic fertilizers in sweet potato cultivation align with sustainable development principles and support SDG 2: Zero Hunger by improving soil fertility, enhancing crop productivity, and ensuring food supply stability. Organic sweet potatoes offer improved nutritional quality, combating malnutrition and promoting overall health. They also reduce chemical inputs, supporting SDG 3: Good Health and Well-Being. Using organic fertilizers in sweet potato farming promotes sustainable agriculture, reduces pollution, and supports climate action. Application of organic fertilizers contribute to life on land by improving soil health and promoting biodiversity. The enhanced microbial activity and better soil structure support a thriving ecosystem both above and below the ground. By maintaining healthy, fertile soils, organic fertilizers help prevent desertification and land degradation, ensuring the sustainability of agriculture over the long-term lands. Thus, the use of organic fertilizers in sweet potato farming fosters a sustainable agricultural system that benefits food security, environmental health, and climate resilience.

Materials and methods

A field study was conducted at Bautista. San Agustin, Isabela from November 8, 2024 to March 8, 2025. It follows a split-plot layout with six treatments and three replications. Cuttings of sweet potato such as Bintong with orange flesh, Bengueta with yellow flesh, and Okinawan with purple flesh were procured at Aglipay Quirino. Vine tip cuttings from healthy plants were cut before planting approximately 2-3 nodes.

Soil collection and analysis

Samples of soil were gathered from the four corners and at the center of the experimental area before the conduct of the study to determine the natural soil fertility. We conducted soil sampling by using a shovel to collect five soil cores at a depth of six (6) inches. The soil samples were spread on newspaper and air-dried. One kilogram of composite soil sample was thoroughly pulverized and cleaned to separate foreign matter, packed in a plastic bag, properly labeled, and submitted to Cagayan Valley Research Center (CVRC), Department of Agriculture, Ilagan City, Isabela for analysis of soil pH, nitrogen, extractable phosphorus, available potassium, and organic matter. The result of the analysis was the basis for fertilizer recommendation.

Experimental design, and treatment application

An experimental area of 848 m^2 was divided into three blocks, each block measuring 4 m by 32 m with an alleyway of 1 m between blocks. Each block was divided into 18 plots, each plot measuring 3 m by 4 m with an alleyway of 0.5 m between plots and it follows a split-plot design with different variety of sweet potato as plot and sub-plot for fertilizer application. The main plot treatments include the different variety of sweet potato: A_1 (Bintong), A_2 (Bengueta), and A_3 (Okinawan) while in sup-plot treatments it consists six treatments: T1 50-60-30kg NPK ha-1; T2 25-30-15kg NPK ha-1; T3 25-30-15kg NPK ha-1 + Vermichar; T4 25-30-15kg NPK ha-1 + Vermicompost; T5 25-30-15kg NPK ha-1 + Biochar; and T6 25-30-15kg NPK ha-1 + BSF Larvae Frass. The furrows established at 75 cm apart and rate of fertilizer base on soil analysis were mixed together accordingly with the organic fertilizer at the rate of 10 bag/ha. Each treatment was applied in their designated plots before planting.

Data gathering

Ten sample plants per plot were randomly taken in measuring the length of primary vine after harvest while number of branches attached in the primary vine, number of marketable and weight in grams of small, medium, and large tubers, the weight of each plot in kilogram, and computed yield/ha in tons were counted and recorded after termination.

Statistical analysis

The split-plot designs were analyzed using analysis of variance examine the gathered data. The Agricultural Research Statistical Tool (STAR) was used for data analysis. The treatments with significant result was compared using the Tukey's Honestly Significant Difference (HSD) Test.

Results and discussion

Chemical analysis of the vermichar, vermicompost, biochar and black soldier fly larvae frass

Table 1 presents a comparative analysis of the nutrient composition and elemental content of four organic soil amendments: vermichar, vermicompost, biochar, and BSF frass. Each material exhibits unique strengths, making them suitable for specific agronomic goals.

BSF frass exhibits the highest total nitrogen at 5.04%, significantly surpassing vermichar (0.75%), vermicompost (0.81%), and biochar (0.22%). This makes BSF frass a potent nitrogen source, ideal for promoting early vegetative growth. In contrast, biochar is richest in total phosphorus (6.49%), beneficial for root development and flowering, while BSF frass and vermichar provide moderate phosphorus levels. For potassium, BSF frass (4.38%) again stands out, suggesting potential benefits for enhancing crop resilience and fruit quality.

Biochar contains the highest levels of calcium oxide (9.45%) and magnesium oxide (1.15%), supporting cell wall strength and photosynthesis, respectively. Vermichar also provides a considerable amount of CaO (4.75%) and MgO (0.67%), making it a balanced option when targeting both fertility and pH buffering.

BSF frass has the highest organic matter content (39.76%), indicating strong potential for improving soil structure, water retention, and microbial activity. Vermichar (11.03%) and biochar (11.05%) contain similar but significantly lower OM levels. However, vermicompost shows the highest moisture content (50.05%), which may influence microbial activity and decomposition rates during soil application.

For zinc (Zn) and copper (Cu), biochar provides the highest concentrations (200.05 ppm and 91.46 ppm, respectively), potentially addressing micronutrient deficiencies in crops. Vermichar follows with moderate Zn (135.32 ppm) and Cu (19.65 ppm) levels. However, BSF frass shows non-detectable Cu levels (<MDL), which may necessitate supplementation if copper is deficient in soil. Manganese (Mn) is most abundant in vermicompost (703.64 ppm) and vermichar (644.35 ppm), while iron (Fe) is highest in vermichar (21,098.64 ppm), which could influence chlorophyll synthesis and plant vigor.

Table 1. Chemical analysis of the vermichar, vermicompost, biochar and black soldier fly larvae frass

Determination	Vermichar	Vermicompost	Biochar	BSF Frass
*Total Nitrogen (N), %	0.75	0.81	0.22	5.04
*Total Phosphorus (P_2O_5), %	1.35	0.60	6.49	0.90
*Total Potassium (K_2O), %	0.82	0.75	0.49	4.38
Total Calcium Oxide (CaO), %	4.75	0.23	9.45	1.41
Total Magnesium Oxide (MgO)	0.67	0.48	1.15	0.82
Moisture Content (MC), % (For solid samples)	33.16	50.05	4.05	8.81
Organic Matter (OM), %	11.03	10.91	11.05	39.76
Zinc (Zn), ppm	135.32	66.68	200.05	131.20
Copper (Cu), ppm	19.65	5.26	91.46	<MDL
Manganese (Mn), ppm	644.35	703.64	313.77	259.39
Iron (Fe), ppm	21098.64	12654.47	15,531.58	2985.72

Table 2. Length of primary vines (cm) of sweet potato varieties as affected by organic fertilizer supplementation

Treatments	Length of vines (cm)
Main plot (Variety)	
A_1 – Bintong	189.63
A_2 – Bengueta	205.06
A_3 – Okinawan	217.04
Result	ns
Sub plot (Fertilizer)	
T_1 – 50-60-30kg NPK ha-1	194.93
T_2 – 25-30-15kg NPK ha^{-1}	202.91
T_3 – 25-30-15kg NPK ha^{-1} + Vermichar	205.07
T_4 – 25-30-15kg NPK ha^{-1} + Vermicompost	202.21
T_5 – 25-30-15kg NPK ha^{-1} + Biochar	218.04
T_6 – 25-30-15kg NPK ha^{-1} + BSF Frass	200.28
Result	ns
Variety × Fertilizer	
A_1 – Bintong x T_1 – 50-60-30kg NPK ha^{-1}	182.07
A_1 – Bintong x T_2 – 25-30-15kg NPK ha^{-1}	189.40
A_1 – Bintong x T_3 – 25-30-15kg NPK ha^{-1} + Vermichar	200.23
A_1 – Bintong x T_4 – 25-30-15kg NPK ha^{-1} + Vermicompost	179.60
A_1 – Bintong x T_5 – 25-30-15kg NPK ha^{-1} + Biochar	198.03
A_1 – Bintong x T_6 – 25-30-15kg NPK ha^{-1} + BSF Frass	188.43
A_2 – Bengueta x T_1 – 50-60-30kg NPK ha^{-1}	196.80
A_2 – Bengueta x T_2 – 25-30-15kg NPK ha^{-1}	206.03
A_2 – Bengueta x T_3 – 25-30-15kg NPK ha^{-1} + Vermichar	192.77
A_2 – Bengueta x T_4 – 25-30-15kg NPK ha^{-1} + Vermicompost	218.30
A_2 – Bengueta x T_5 – 25-30-15kg NPK ha^{-1} + Biochar	218.43
A_2 – Bengueta xT_6 – 25-30-15kg NPK ha^{-1} + BSF Frass	198.00
A_3 – Okinawan x T_1 – 50-60-30kg NPK ha^{-1}	204.40
A_3 – Okinawan x T_2 – 25-30-15kg NPK ha^{-1}	213.30
A_3 – Okinawan x T_3 – 25-30-15kg NPK ha^{-1} + Vermichar	222.20
A_3 – Okinawan x T_4 – 25-30-15kg NPK ha^{-1} + Vermicompost	208.73
A_3 – Okinawan x T_5 – 25-30-15kg NPK ha^{-1} + Biochar	237.67
A_3 – Okinawan x T_6 – 25-30-15kg NPK ha^{-1} + BSF Frass	214.40
Result	ns

This implies that BSF frass is a powerful organic amendment for rapid nutrient release and boosting fertility, particularly in nitrogen-deficient soils. Biochar excels as a long-term soil conditioner due to its high phosphorus, calcium, and micronutrient content, though its low N content limits its sole use for fertility improvement. Vermichar provides a balanced mix of macro and micronutrients, suitable for improving both nutrient status and soil physical and chemical properties. Vermicompost supports biological activity and slow nutrient release, ideal for sustained soil fertility in organic systems.

Length of primary vines (cm)

The data in Table 2 show the effects of different sweet potato varieties and organic fertilizer treatments on vine length.

Main plot (Variety)

Among the varieties, Okinawan (A3) exhibited the longest mean vine length (217.04 cm), followed by Bengueta (A2, 205.06 cm) and Bintong (A1, 189.63 cm). Although not statistically significant, this trend suggests that Okinawan has a naturally more vigorous vegetative growth potential, which may translate into enhanced ground coverage and weed suppression.

Sub-plot (Fertilizer)

Among the fertilizer treatments, the application of 25-30-15kg NPK ha^{-1} + Biochar (T5) resulted in the longest average vine length (218.04 cm). This is followed by the 25-30-15kg NPK ha^{-1} + Vermichar (T3: 205.07 cm) and 25-30-15 kg NPK ha^{-1} (T2: 202.91 cm). The combination with BSF Frass (T6: 200.28 cm) yielded lower vine lengths than other organic amendments, suggesting it may prioritize root development or yield over vine elongation. The highest NPK rate (T1: 50-60-30kg) yielded only 194.93 cm, indicating that a reduced NPK rate complemented with bio-organic inputs may support better vegetative growth.

Variety × Fertilizer

When interactions are considered Okinawan x Biochar (A3T5) produced the longest vine length (237.67 cm), followed by A3 x Vermichar (222.20 cm), indicating that Okinawan responds exceptionally well to carbon-rich amendments. Bengueta x Biochar (A2T5: 218.43 cm) and Bengueta x Vermicompost (A2T4: 218.30 cm) also showed strong growth, highlighting that organic supplements enhance Bengueta's performance. Bintong, being the shortest among the varieties, responded best with Vermichar (A1T3: 200.23 cm) and Biochar (A1T5: 198.03 cm), although still less vigorous than other varieties. The results imply that even though statistical significance was not achieved, the trend consistently shows that biochar, when combined with reduced NPK, promotes the greatest vine elongation across varieties, possibly due to its improved soil aeration, water-holding capacity, and nutrient retention (Lehmann and Joseph, 2015). Vermichar and vermicompost also enhance vine growth, supporting findings from Domínguez and Edwards (2011) that such amendments improve microbial activity and nutrient cycling. The slightly lower performance of BSF frass, despite its high nitrogen content (Table 1), may be due to its rapid nutrient release or lower micronutrient diversity, suggesting it may be more suited for early growth or tuber yield rather than vegetative expansion.

Among the varieties, Okinawan shows superior vine elongation potential. Biochar-amended treatments consistently support the longest vines, indicating synergistic effects with NPK even at reduced rates. Organic amendments (especially vermichar and biochar) can offset reduced chemical fertilizer inputs while sustaining or improving vine growth. These trends provide insight into variety-specific nutrient responses and suggest biochar or vermichar as potential soil enhancers for sweet potato vine development.

Number of branches attached in the primary vine

Table 3 highlights the effects of variety, fertilizer, and their interaction on the number of branches attached to the primary vine of sweet potato plants. While the main plot (variety) and interaction effects were not statistically significant, a significant difference was observed among fertilizer treatments, indicating that organic inputs influence vine branching more than genetic variety alone.

Main plot (Variety)

Although the effect of variety was not significant, Okinawan (A3) had the highest mean number of branches (5.17), followed closely by Bengueta (A2:

5.05) and Bintong (A1: 4.76). This trend suggests a marginally higher branching potential for Okinawan, which could enhance photosynthetic area and potentially contribute to tuber yield, although differences were statistically inconclusive.

Sub-plot (Fertilizer)

A significant effect was observed among fertilizer treatments, highlighting the importance of organic inputs in stimulating branch development: T5 (25-30-15kg NPK + Biochar) resulted in the highest number of branches (5.59) and was significantly different from T1 and T3. This was followed by T6 (BSF Frass: 5.18) and T2 (Reduced NPK alone: 4.93), both statistically comparable to each other and the control. The lowest values were recorded in T1 (full NPK: 4.60) and T3 (NPK + Vermichar: 4.77), indicating that simply reducing fertilizer or adding certain amendments like vermichar does not guarantee increased branching unless synergized with appropriate organic material like biochar.

Table 3. Number of branches attached in the primary vine of sweet potato varieties as affected by organic fertilizer supplementation

Treatments	Number of branches attached in the primary vine
Main plot (Variety)	
A_1 – Bintong	4.76
A_2 – Bengueta	5.05
A_3 – Okinawan	5.17
Result	ns
Sub plot (Fertilizer)	
T_1 – 50-60-30kg NPK ha^{-1}	4.60^{b}
T_2 – 25-30-15kg NPK ha^{-1}	4.93^{ab}
T_3 – 25-30-15kg NPK ha^{-1} + Vermichar	4.77^{b}
T_4 – 25-30-15kg NPK ha^{-1} + Vermicompost	4.90^{ab}
T_5 – 25-30-15kg NPK ha^{-1} + Biochar	5.59^{a}
T_6 – 25-30-15kg NPK ha^{-1} + BSF Frass	5.18^{ab}
Result	*
Variety × Fertilizer	
A_1 – Bintong x T_1 – 50-60-30kg NPK ha^{-1}	4.27
A_1 – Bintong x T_2 – 25-30–15kg NPK ha^{-1}	4.67
A_1 – Bintong x T_3 – 25-30–15kg NPK ha^{-1}+ Vermichar	4.60
A_1 – Bintong x T_4 – 25-30–15kg NPK ha^{-1}+ Vermicompost	5.07
A_1 – Bintong x T_5 – 25-30–15kg NPK ha^{-1}+ Biochar	5.07
A_1 – Bintong x T_6 – 25-30–15kg NPK ha^{-1}+ BSF Frass	4.90
A_2 – Bengueta x T_1 – 50-60-30kg NPK ha^{-1}	4.60
A_2 – Bengueta x T_2 – 25-30–15kg NPK ha^{-1}	4.80
A_2 – Bengueta x T_3 – 25-30–15kg NPK ha^{-1}+ Vermichar	4.60
A_2 – Bengueta x T_4 – 25-30–15kg NPK ha^{-1}+ Vermicompost	5.17
A_2 – Bengueta x T_5 – 25-30–15kg NPK ha^{-1}+ Biochar	5.77
A_2 – Bengueta xT_6 – 25-30–15kg NPK ha^{-1}+ BSF Frass	5.37
A_3 – Okinawan x T_1 – 50-60-30kg NPK ha^{-1}	4.93
A_3 – Okinawan x T_2 – 25-30–15kg NPK ha^{-1}	5.33
A_3 – Okinawan x T_3 – 25-30–15kg NPK ha^{-1}+ Vermichar	5.10
A_3 – Okinawan x T_4 – 25-30–15kg NPK ha^{-1}+ Vermicompost	4.47
A_3 – Okinawan x T_5 – 25-30–15kg NPK ha^{-1}+ Biochar	5.93
A_3 – Okinawan x T_6 – 25-30–15kg NPK ha^{-1}+ BSF Frass	5.27
Result	ns

Note: According to the Honestly Significant Difference test, means with similar letters do not differ significantly from one another. At the five percent level, **-significant Not significant (ns)

Biochar's significant performance may be attributed to its porous structure and nutrient-retention capacity, improving root-zone aeration and microbial interactions that stimulate lateral shoot growth (Lehmann and Joseph, 2015). BSF frass, rich in nitrogen and organic matter (as shown in Table 1), also enhanced branching, suggesting its effectiveness in promoting vegetative growth.

Table 4. Quantity of large, medium, and small tubers of sweet potato affected by organic fertilizer supplementation

Treatments	Number of tubers		
	Large	Medium	Small
Main plot (Variety)			
A_1 – Bintong	1.55	1.77	1.33
A_2 – Bengueta	1.68	1.64	1.06
A_3 – Okinawan	1.55	1.62	1.59
Result	ns	ns	ns
Sub plot (Fertilizer)			
T_1 – 50-60-30kg NPK ha-1	1.59^{ab}	1.48^{b}	1.28
T_2 – 25-30-15kg NPK ha^{-1}	1.50^{ab}	1.43^{b}	1.37
T_3 – 25-30-15kg NPK ha^{-1} + Vermichar	1.66^{ab}	1.62^{ab}	1.35
T_4 – 25-30-15kg NPK ha^{-1} + Vermicompost	1.56^{ab}	1.85^{a}	1.31
T_5 – 25-30-15kg NPK ha^{-1} + Biochar	1.39^{b}	1.87^{a}	1.40
T_6 – 25-30-15kg NPK ha^{-1} + BSF Frass	1.86^{a}	1.78^{ab}	1.23
Result	*	**	ns
Variety × Fertilizer			
A_1 – Bintong x T_1 – 50-60-30kg NPK ha^{-1}	1.40	1.43	1.17
A_1 – Bintong x T_2 – 25-30–15kg NPK ha-^{1}	1.30	1.50	1.37
A_1 – Bintong x T_3 – 25-30–15kg NPK ha-^{1}+ Vermichar	1.70	1.63	1.30
A_1 – Bintong x T_4 – 25-30–15kg NPK ha-^{1}+ Vermicompost	1.70	2.13	1.27
A_1 – Bintong x T_5 – 25-30–15kg NPK ha-^{11} + Biochar	1.37	2.10	1.47
A_1 – Bintong x T_6 – 25-30–15kg NPK ha-^{1}+ BSF Frass	1.83	1.80	1.37
A_2 – Bengueta x T_1 – 50-60-30kg NPK ha^{-1}	1.67	1.47	1.30
A_2 – Bengueta x T_2 – 25-30–15kg NPK ha-^{1}	1.63	1.37	1.23
A_2 – Bengueta x T_3 – 25-30–15kg NPK ha-^{1}+ Vermichar	1.70	1.67	1.27
A_2 – Bengueta x T_4 – 25-30–15kg NPK ha-^{1}+ Vermicompost	1.77	1.73	0.83
A_2 – Bengueta x T_5 – 25-30–15kg NPK ha-^{1}+ Biochar	1.33	1.67	0.90
A_2 – Bengueta xT_6 – 25-30–15kg NPK ha-^{1}+ BSF Frass	1.97	1.90	0.80
A_3 – Okinawan x T_1 – 50-60-15kg NPK ha^{-1}	1.70	1.53	1.37
A_3 – Okinawan x T_2 – 25-30–15kg NPK ha-^{1}	1.57	1.43	1.50
A_3 – Okinawan x T_3 – 25-30–15kg NPK ha-^{1}+ Vermichar	1.57	1.57	1.47
A_3 – Okinawan x T_4 – 25-30–15-kilogram NPK ha-^{1}+ Vermicompost	1.20	1.70	1.83
A_3 – Okinawan x T_5 – 25-30–15kg NPK ha-^{1}+ Biochar	1.47	1.83	1.83
A_3 – Okinawan x T_6 – 25-30–15kg NPK ha-^{1}+ BSF Frass	1.77	1.63	1.53
Result	ns	ns	ns

Note: According to the Honestly Significant Difference test, means with similar letters do not differ significantly from one another. At the five percent level, *-significant, At the one percent level, **-significant, Not significant (ns)

Variety x Fertilizer

Even though the interaction was not statistically significant, the combinations still revealed interesting patterns: A3 (Okinawan) with Biochar (T5) produced the highest number of branches (5.93), followed by A2 × T5 (5.77), indicating that biochar consistently supports branching regardless of variety. For Bintong (A1), T4 and T5 (both 5.07) showed the highest values, reflecting that even less vigorous varieties respond well to certain organic enhancements. The lowest interaction values were seen in combinations like A1 × T4 (4.60) and A2 × T3 (4.60), indicating that vermichar may be less effective at enhancing branching when used alone with reduced NPK.

This data implies that organic fertilizers, particularly biochar and BSF frass, can significantly increase the number of branches attached to sweet potato vines, which could improve canopy development and photosynthetic efficiency. Biochar, in particular, demonstrated a strong and consistent effect across all varieties, suggesting its utility as a soil amendment for improving plant architecture. Reduced NPK alone (T2) performed better than the full rate (T1), and in some cases, combining low rates of NPK with organic inputs outperformed conventional fertilizer use, reinforcing the potential of integrated nutrient management.

Okinawan variety shows the highest branching tendency overall, although varietal effects were statistically non-significant. Biochar + reduced NPK (T5) significantly enhances vine branching across all varieties, outperforming full NPK and other organic combinations. BSF frass also shows promising results as an effective organic supplement. Organic inputs, especially biochar, are more effective in stimulating branching than increasing synthetic fertilizer rates.

Quantity of large, medium, and small tubers

Table 4 presents the influence of variety, fertilizer, and their interaction on tuber size distribution (large, medium, small) in sweet potatoes. While varietal and interaction effects were statistically non-significant for all tuber sizes, fertilizer treatments significantly affected the number of large tubers and medium tubers, with no significant effect on small tubers.

Main plot (Variety)

Among the varieties Bengueta (A2) had the highest mean number of large tubers (1.68), while Okinawan (A3) had more small tubers (1.59). Bintong (A1) showed a more balanced tuber distribution across sizes. These differences, although not statistically significant, suggest varietal tendencies—Bengueta for yield quality (large tubers), Okinawan for potential overall productivity (due to small tuber proliferation), and Bintong for uniform development.

Sub-plot (Fertilizer)

Fertilizer treatments had notable and significant effects on the number of large and medium tubers. For large tubers, BSF frass (T6) produced the highest number of large tubers (1.86) and was significantly superior to biochar (T5: 1.39). Vermichar (T3: 1.66) and vermicompost (T4: 1.56) showed intermediate performance. The lowest was observed in biochar-amended plots, possibly due to nutrient immobilization or its slow nutrient release properties.

For medium tubers, Biochar (T5: 1.87) and vermicompost (T4: 1.85) treatments significantly increased medium tuber production. BSF frass (T6: 1.78) and vermicompost also ranked high, demonstrating that organic amendments complement reduced NPK in enhancing medium-size tuber formation.

For small tubers: Differences across treatments were non-significant, though biochar and Okinawan combinations trended higher, suggesting a tendency toward smaller tuber formation, possibly linked to excessive vine growth or less effective tuber bulking.

Variety x Fertilizer

While interactions were non-significant, certain combinations reveal valuable insights. Bengueta × BSF frass (A2T6) yielded the highest number of large tubers (1.97) and relatively high medium tubers (1.90), indicating that BSF frass is highly effective when paired with Bengueta. Okinawan × biochar (A3T5) produced the smallest tubers (1.83) and strong medium tubers (1.83), showing biochar's potential to favor total tuber count over size. Bintong × vermicompost (A1T4) and Bintong × BSF frass (A1T6) also yielded well-balanced tuber profiles, demonstrating their compatibility with organic inputs.

BSF frass consistently improved large tuber formation, likely due to its high nitrogen and potassium content, essential for tuber bulking (Beesigamukama *et al.,* 2020). Biochar and vermicompost excelled in medium tuber production, suggesting their roles in promoting sustained nutrient release and soil moisture conservation (Lehmann and Joseph, 2015). No increase in small tubers was statistically significant, though biochar's trend of increasing small tubers may suggest a need for adjusted nutrient synchronization or planting density when using it. BSF frass is the most effective organic amendment for increasing large tuber count, especially when paired with Bengueta. Biochar and vermicompost enhance medium tuber development, contributing to overall yield bulk. Varietal response is secondary to fertilizer treatment in tuber size distribution, but pairing the right variety with the most compatible organic input (e.g., Bengueta + BSF frass) enhances productivity.

Weight of large, medium and small tubers

Table 5 presents the effects of sweet potato variety, fertilizer treatments, and their interaction on the weight of tubers classified into large, medium, and small categories. Statistically, significant differences were observed in the weight of medium tubers by variety and both large and medium tubers by fertilizer treatments, while no significant differences were recorded for small tuber weights or any of the interaction effects.

Main plot (Variety)

Large tubers: All three varieties showed comparable weights, ranging from 336.71 g (Bintong) to 349.04 g (Bengueta). The differences were statistically non-significant, indicating that tuber enlargement is not strongly influenced by variety alone.

Medium tubers: A significant difference was observed ($p < 0.01$). Bintong (225.27 g) and Bengueta (228.69 g) produced significantly heavier medium tubers than Okinawan (169.16 g). This suggests that these two varieties may have better bulking potential in the medium size class, which is often favored in local markets for uniformity and marketability.

Table 5. Weight of sweet potato varieties' large, medium, and small tubers (g) in supplementation of organic fertilizers

Treatments	Weight of tubers (g)		
	Large	Medium	Small
Main plot (Variety)			
A_1 – Bintong	336.71	225.27^{a}	108.46
A_2 – Bengueta	349.04	228.69^{a}	70.11
A_3 – Okinawan	347.47	169.16^{b}	115.63
Result	ns	**	ns
Sub plot (Fertilizer)			
T_1 – 50-60-30kg NPK ha-1	348.74^{ab}	175.88^{bc}	96.11
T_2 – 25-30-15kg NPK ha^{-1}	336.14^{ab}	168.09^{c}	96.23
T_3 – 25-30-15kg NPK ha^{-1} + Vermichar	350.44^{ab}	204.14^{ab}	88.76
T_4 – 25-30-15kg NPK ha^{-1} + Vermicompost	339.90^{ab}	238.05^{a}	108.20
T_5 – 25-30-15kg NPK ha^{-1} + Biochar	320.52^{b}	234.08^{a}	107.04
T_6 – 25-30-15kg NPK ha^{-1} + BSF Frass	370.69^{a}	226.00^{a}	92.04
Result	**	**	ns
Variety × Fertilizer			
A_1 – Bintong x T_1 – 50-60-30kg NPK ha^{-1}	332.83	180.80	113.27
A_1 – Bintong x T_2 – 25-30–15kg NPK ha^{-1}	322.53	185.80	105.80
A_1 – Bintong x T_3 – 25-30–15kg NPK ha^{-1}+ Vermichar	341.00	224.07	95.67
A_1 – Bintong x T_4 – 25-30–15kg NPK ha^{-1}+ Vermicompost	348.27	268.90	123.67
A_1 – Bintong x T_5 – 25-30–15kg NPK ha^{-1}+ Biochar	315.33	253.23	106.73
A_1 – Bintong x T_6 – 25-30–15kg NPK ha^{-1}+ BSF Frass	360.30	238.83	105.63
A_2 – Bengueta x T_1 – 50-60-30kg NPK ha^{-1}	345.23	195.60	80.67
A_2 – Bengueta x T_2 – 25-30–15kg NPK ha^{-1}	339.63	178.27	80.27
A_2 – Bengueta x T_3 – 25-30–15kg NPK ha^{-1}+ Vermichar	357.33	228.97	61.80
A_2 – Bengueta x T_4 – 25-30–15kg NPK ha^{-1}+ Vermicompost	359.53	256.93	61.27
A_2 – Bengueta x T_5 – 25-30–15kg NPK ha^{-1}+ Biochar	313.73	243.83	82.47
A_2 – Bengueta xT_6 – 25-30–15kg NPK ha^{-1}+ BSF Frass	378.67	268.53	54.17
A_3 – Okinawan x T_1 – 50-60-30kg NPK ha^{-1}	368.17	151.23	94.40
A_3 – Okinawan x T_2 – 25-30–15kg NPK ha^{-1}	346.27	140.20	102.63
A_3 – Okinawan x T_3 – 25-30–15kg NPK ha^{-1}+ Vermichar	353.00	159.37	108.80
A_3 – Okinawan x T_4 – 25-30–15kg NPK ha^{-1}+ Vermicompost	311.90	188.33	139.67
A_3 – Okinawan x T_5 – 25-30–15kg NPK ha^{-1}+ Biochar	332.50	205.17	131.93
A_3 – Okinawan x T_6 – 25-30–15kg NPK ha^{-1}+ BSF Frass	373.00	170.63	116.33
Result	ns	ns	ns

Note: According to the Honestly Significant Difference test, means with similar letters do not differ significantly from one another. At the five percent level, *-significant, At the one percent level, **-significant, Not significant (ns)

Small tubers: No significant differences were found, though Okinawan (115.63 g) had a slight advantage in terms of weight, aligning with its trend of producing more small tubers (as seen in Table 6).

Sub-plot (Fertilizer)

Large Tubers: BSF Frass (T6: 370.69 g) produced the heaviest large tubers, significantly outperforming biochar (T5: 320.52 g). This reaffirms BSF frass's effect on tuber bulking due to its rich nitrogen and potassium content (as shown in Table 1). Vermichar (T3: 350.44 g) and vermicompost (T4: 339.90 g) also supported good tuber bulking, although statistically comparable to other treatments except T6.

Medium tubers: Highest weights were observed in vermicompost (T4: 238.05 g) and biochar (T5: 234.08 g), both significantly heavier than the control and reduced NPK treatments. These results suggest that organic matter-rich inputs, particularly vermicompost and biochar, support medium tuber growth, likely due to improved soil moisture retention and microbial activity.

Small tubers: No significant differences were detected among fertilizer treatments. However, the trend shows higher small tuber weights under Okinawan x biochar/BSF frass combinations, supporting the tendency for Okinawan to allocate biomass more evenly across tuber sizes.

Variety x Fertilizer

Though not statistically significant, noteworthy combinations include Bengueta x BSF Frass (A2T6) yielded the heaviest large tubers (378.67 g) and medium tubers (268.53 g), indicating strong synergy between this variety and BSF frass. Bintong x Vermicompost (A1T4) also performed well, with medium tuber weight reaching 268.90 g, reflecting this variety's responsiveness to compost-based inputs. Okinawan x Biochar (A3T5) and x Vermicompost (A3T4) resulted in high small tuber weights (>130 g), consistent with the observed trend of Okinawan favoring smaller but heavier tubers.

BSF Frass is highly effective in increasing large tuber weight, making it suitable for markets prioritizing bulk yield. Its impact supports findings from Beesigamukama *et al.* (2020) on the nutrient richness and productivity-enhancing nature of frass. Vermicompost and biochar are ideal for enhancing medium tuber weight, likely due to improved soil physical structure, slow nutrient release, and microbial activation (Domínguez and Edwards, 2011; Lehmann and Joseph, 2015). Small tuber weights were less influenced by either variety or fertilizer, suggesting these are more genetically controlled or influenced by plant spacing and density. Bengueta and Bintong varieties excel in medium tuber development, while BSF frass and vermicompost are optimal for maximizing tuber weight in key marketable categories. BSF Frass is superior in bulking large tubers, while vermicompost and biochar improve medium tuber weights. For commercial cultivation targeting larger or more uniform tubers, integrating organic inputs with reduced NPK is a productive and sustainable strategy.

Weight of tubers per 12 m² Plot (kg)

Table 6 summarizes the total yield performance (in kilograms per 12 m² plot) of sweet potato varieties under different fertilizer treatments. While variety and interaction effects were statistically non-significant, the fertilizer treatment showed a highly significant effect on total tuber yield, underscoring the critical role of nutrient management in productivity enhancement.

Main plot (Variety)

Though statistically non-significant, the varietal trend suggests, Bengueta (A2) recorded the highest mean yield (18.52 kg/plot), Followed by Bintong (A1: 18.16 kg), While Okinawan (A3: 16.74 kg) trailed behind. These findings indicate that Bengueta may have a slight yield advantage under identical management, consistent with earlier results (Tables 4 and 5) showing its strong performance in producing large and medium tubers.

Sub plot (Fertilizer)

Fertilizer treatment significantly influenced the total yield per plot, BSF Frass (T6) led with the highest tuber yield (19.13 kg/plot), statistically superior to reduced NPK alone (T2: 16.48 kg) and the full NPK rate (T1: 16.83 kg). Vermicompost (T4: 18.80 kg) also produced a significantly higher yield than T1 and T2, likely due to its effect on improving soil structure, moisture retention, and microbial activity. Biochar (T5: 17.79 kg) and

Vermichar (T3: 17.79 kg) provided intermediate results, showing benefits over reduced NPK alone but not as strong as BSF frass or vermicompost. These findings support the growing body of literature advocating the use of organic amendments with reduced synthetic inputs for enhancing yield sustainably (Lehmann and Joseph, 2015; Beesigamukama *et al.,* 2020).

Table 6. Weight of sweet potato tubers per 12 m² plot (kg) as influenced by organic fertilizers

Treatments	Weight of tubers per plot (kg)
Main plot (Variety)	
A_1 – Bintong	18.16
A_2 – Bengueta	18.52
A_3 – Okinawan	16.74
Result	ns
Sub plot (Fertilizer)	
T_1 – 50-60-30kg NPK ha-1	16.83bc
T_2 – 25-30-15kg NPK ha^{-1}	16.48c
T_3 – 25-30-15kg NPK ha^{-1} + Vermichar	17.79abc
T_4 – 25-30-15kg NPK ha^{-1} + Vermicompost	18.80ab
T_5 – 25-30-15kg NPK ha^{-1} + Biochar	17.79abc
T_6 – 25-30-15kg NPK ha^{-1} + BSF Frass	19.13a
Result	**
Variety ×Fertilizer	
A_1 – Bintong x T_1 – 50-60-30kg NPK ha^{-1}	16.48
A_1 – Bintong x T_2 – 25-30–15kg NPK ha^{-1}	16.26
A_1 – Bintong x T_3 – 25-30–15kg NPK ha^{-1}+ Vermichar	18.13
A_1 – Bintong x T_4 – 25-30–15kg NPK ha^{-1}+ Vermicompost	20.60
A_1 – Bintong x T_5 – 25-30–15kg NPK ha^{-1}+ Biochar	18.24
A_1 – Bintong x T_6 – 25-30–15kg NPK ha^{-1}+ BSF Frass	19.22
A_2 – Bengueta x T_1 – 50-60-30kg NPK ha^{-1}	17.35
A_2 – Bengueta x T_2 – 25-30–15kg NPK ha^{-1}	16.61
A_2 – Bengueta x T_3 – 25-30–15kg NPK ha^{-1}+ Vermichar	18.80
A_2 – Bengueta x T_4 – 25-30–15kg NPK ha^{-1}+ Vermicompost	19.75
A_2 – Bengueta x T_5 – 25-30–15kg NPK ha^{-1}+ Biochar	17.87
A_2 – Bengueta xT_6 – 25-30–15kg NPK ha^{-1}+ BSF Frass	20.73
A_3 – Okinawan x T_1 – 50-60-30kg NPK ha^{-1}	16.66
A_3 – Okinawan x T_2 – 25-30–15kg NPK ha^{-1}	16.56
A_3 – Okinawan x T_3 – 25-30–15kg NPK ha^{-1}+ Vermichar	16.44
A_3 – Okinawan x T_4 – 25-30–15kg NPK ha^{-1}+ Vermicompost	16.06
A_3 – Okinawan x T_5 – 25-30–15kg NPK ha^{-1}+ Biochar	17.26
A_3 – Okinawan x T_6 – 25-30–15kg NPK ha^{-1}+ BSF Frass	17.45
Result	ns

Note: According to the Honestly Significant Difference test, means with similar letters do not differ significantly from one another. At the five percent level, *-significant, At the one percent level, **-significant, Not significant (ns)

Variety x Fertilizer

Although non-significant, the data show useful trends: Bengueta × BSF Frass (A2T6) produced the highest yield (20.73 kg/plot), followed closely by Bintong × Vermicompost (A1T4: 20.60 kg). Other productive combinations included Bengueta × Vermicompost (A2T4: 19.75 kg) and Bintong × BSF Frass (A1T6: 19.22 kg). Okinawan consistently produced lower yields across all treatments, with the lowest value (16.06 kg) observed in Okinawan × Vermicompost (A3T4). This suggests that while organic fertilizers are generally beneficial, variety-specific responses must be considered for yield optimization.

The significant increase in yield with BSF frass and vermicompost suggests their potential as reliable organic alternatives to full NPK rates. BSF frass, with its high macronutrient content (especially N and K), likely enhanced tuber bulking and carbohydrate translocation. Vermicompost, being high in organic matter and microbial activity, likely improved soil health and nutrient cycling. Biochar and vermichar, while beneficial, may require longer-term integration to realize full yield benefits due to their slow nutrient release and soil-conditioning nature.

Fertilizer treatment had a significant impact on sweet potato yield, with BSF frass and vermicompost emerging as superior options. Reduced NPK combined with organic fertilizers outperformed full NPK rates, demonstrating the value of integrated nutrient management. Bengueta variety generally performed best, especially when paired with BSF frass, highlighting the importance of matching variety with appropriate fertilizer strategy.

Calculated sweet potato variety yield/ha (ton)

Table 7 presents the computed yields per hectare of sweet potato varieties under different fertilizer treatments. While varietal and interaction effects were not statistically significant, the fertilizer treatments showed a highly significant effect, reinforcing the vital role of nutrient management in optimizing sweet potato productivity.

Table 7. Computed yield per hectare (ton) of sweet potato varieties as affected by organic fertilizer

Treatments	Computed yield per hectare (ton)
Main plot (Variety)	
A_1 – Bintong	15.13
A_2 – Bengueta	15.43
A_3 – Okinawan	13.93
Result	ns
Sub plot (Fertilizer)	
T_1 – 50-60-30kg NPK ha-1	14.02^{bc}
T_2 – 25-30-15kg NPK ha^{-1}	13.73^{c}
T_3 – 25-30-15kg NPK ha^{-1} + Vermichar	14.82^{abc}
T_4 – 25-30-15kg NPK ha^{-1} + Vermicompost	15.67^{ab}
T_5 – 25-30-15kg NPK ha^{-1} + Biochar	14.78^{abc}
T_6 – 25-30-15kg NPK ha^{-1} + BSF Frass	15.94^{a}
Result	**
Variety × Fertilizer	
A_1 – Bintong x T_1 – 50-60-30kg NPK ha^{-1}	13.73
A_1 – Bintong x T_2 – 25-30-15kg NPK ha^{-1}	13.55
A_1 – Bintong x T_3 – 25-30-15kg NPK ha^{-1} + Vermichar	15.10
A_1 – Bintong x T_4 – 25-30-15kg NPK ha^{-1} + Vermicompost	17.17
A_1 – Bintong x T_5 – 25-30-15kg NPK ha^{-1} + Biochar	15.20
A_1 – Bintong x T_6 – 25-30-15kg NPK ha^{-1} + BSF Frass	16.01
A_2 – Bengueta x T_1 – 50-60-30kg NPK ha^{-1}	14.45
A_2 – Bengueta x T_2 – 25-30-15kg NPK ha^{-1}	13.84
A_2 – Bengueta x T_3 – 25-30-15kg NPK ha^{-1} + Vermichar	15.67
A_2 – Bengueta x T_4 – 25-30-15kg NPK ha^{-1} + Vermicompost	16.46
A_2 – Bengueta x T_5 – 25-30-15kg NPK ha^{-1} + Biochar	14.89
A_2 – Bengueta xT_6 – 25-30-15kg NPK ha^{-1} + BSF Frass	17.27
A_3 – Okinawan x T_1 – 50-60-30kg NPK ha^{-1}	13.89
A_3 – Okinawan x T_2 – 25-30-15kg NPK ha^{-1}	13.80
A_3 – Okinawan x T_3 – 25-30-15kg NPK ha^{-1} + Vermichar	13.70
A_3 – Okinawan x T_4 – 25-30-15kg NPK ha^{-1} + Vermicompost	13.39
A_3 – Okinawan x T_5 – 25-30-15kg NPK ha^{-1} + Biochar	14.24
A_3 – Okinawan xT_6 – 25-30-15kg NPK ha^{-1} + BSF Frass	14.54
Result	ns

Note: According to the Honestly Significant Difference test, means with similar letters do not differ significantly from one another. At the five percent level, *-significant, At the one percent level, **-significant, Not significant (ns)

Main plot (Variety)

Although non-significant, the average yields show a clear trend: Bengueta (A2) had the highest yield (15.43 tons/ha), Followed by Bintong (A1: 15.13 tons/ha), And Okinawan (A3: 13.93 tons/ha). This result aligns with earlier data (Tables 5–7), where Bengueta consistently exhibited stronger performance in tuber size and weight, suggesting it is a promising variety for higher yield potential under organic-integrated nutrient management systems.

Sub plot (Fertilizer)

Fertilizer treatments had a statistically significant effect ($p < 0.01$) on computed yield: T6 (25-30-15kg NPK + BSF Frass) recorded the highest yield (15.94 t/ha), significantly outperforming T2 (reduced NPK only: 13.73 t/ha) and T1 (full NPK: 14.02 t/ha). T4 (with vermicompost: 15.67 t/ha) also resulted in significantly higher yield than T1 and T2. T3 (with vermichar: 14.82 t/ha) and T5 (with biochar: 14.78 t/ha) showed moderate improvement, highlighting the yield-enhancing effects of organic materials when combined with reduced synthetic fertilizer. This emphasizes that integrated organic fertilization is not only a sustainable approach but also a yield-competitive strategy compared to conventional full synthetic inputs.

Variety x Fertilizer

While statistically non-significant, the interaction results provide useful insights: Bintong × Vermichar (A1T3) produced the highest yield across all combinations (17.17 t/ha), suggesting vermichar's compatibility with this variety. Bengueta × Biochar (A2T5) also performed well (17.27 t/ha), indicating a strong synergy for yield optimization. Surprisingly, Bengueta × BSF Frass (A2T6: 13.89 t/ha) and Bintong × BSF Frass (A1T6: 14.45 t/ha) yielded less than expected, suggesting varietal responses may vary despite the high average yield of T6. On the other hand, Okinawan yielded consistently lower across treatments, with marginal gains from organic inputs—indicating its limited responsiveness or suitability under the tested nutrient regimes.

BSF Frass and vermicompost are the most effective amendments for maximizing yield under reduced NPK rates, proving superior to full synthetic fertilizer application. Vermichar and biochar are also promising, though their effects appear to be more variety-dependent. While variety had no significant effect, Bengueta consistently performed better, making it a good candidate for organic-based yield enhancement. These findings are in line with sustainable agriculture principles, as reduced synthetic inputs combined with organic amendments can maintain or even improve yields while reducing environmental risks and input costs (Beesigamukama *et al.,* 2020; Lehmann and Joseph, 2015).

Fertilizer treatment significantly influenced sweet potato yield, with BSF Frass (15.94 t/ha) and vermicompost (15.67 t/ha) outperforming both reduced and full synthetic fertilizer rates. Among the varieties, Bengueta showed the best overall yield performance, especially when paired with biochar or vermicompost. Integrated nutrient management using reduced NPK + organic fertilizers are an effective, sustainable strategy to maximize sweet potato productivity.

Conclusion

Among the three varieties evaluated, Bengueta produced the highest computed yield per hectare (15.43 t/ha), followed by Bintong and Okinawan. Although the differences were statistically non-significant, Bengueta consistently performed well across multiple yield parameters such as number and weight of large and medium tubers, making it the most productive variety under the tested conditions. The application of BSF frass combined with reduced NPK significantly improved yield, with the highest recorded output of 15.94 t/ha, outperforming both full and reduced NPK alone. Vermicompost also showed high yield potential (15.67 t/ha), indicating the efficacy of integrating organic fertilizers into nutrient management.

While the statistical interaction between variety and fertilizer was not significant, notable combinations such as Bengueta × Biochar and Bintong × Vermichar showed enhanced performance in both yield and quality.

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