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Propagation techniques and organic fertilizer supplementation on growth and tuber yield of yacon (*Smallanthus sonchifolius*)

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Abstract

Organic fertilizers in yacon (*Smallanthus sonchifolius)* cultivation promotes sustainable agriculture and advances key Sustainable Development Goals (SDGs) by improving soil fertility and yields (SDG 2), reduces synthetic inputs (SDG 12), improves soil health and biodiversity (SDGs 13 and 15), and supports smallholder farmers (SDGs 8 and 10). The study evaluated the effects of different propagation techniques and organic fertilizer supplementation on the growth, yield of Yacon. Two propagation techniques—cuttings and rhizomes—were assessed with five fertilization treatments: fullNPK (50-20-30 kg ha^{-1}), and reduced NPK (25-10-15 kg ha^{-1}) supplemented with vermichar, vermicompost, biochar, or Black Soldier Fly (BSF) frass. Measurements included plant height, branch number, marketable tuber number and weight, yield per hectare. Cuttings significantly increased plant height at 100 and 150 days after planting. While propagation had no significant effect on yield, cuttings with BSF frass consistently showed higher values across indicators. BSF frass significantly increased the marketable tuber number and weight, total yield per hectare (12.82 t ha^{-1}), indicating superior performance. Vermicompost and biochar also improved yield but were less effective than BSF frass. The interaction of propagation and fertilization revealed that the combination of cuttings and BSF frass produced the highest plant height (121.03 cm), yield (12.94 t ha^{-1}). While not statistically significant, trends indicate that organic fertilizers with reduced NPK enhance yield and quality. In conclusion, BSF frass with reduced NPK and cuttings sustainably improve yield while lowering reliance on synthetic fertilizers.

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Introduction

Yacon (*Smallanthus sonchifolius*) tastes like a cross between apple and pear and has a crisp, fresh bite like jicama. This vegetable is often eaten as an alternative to potato for its low calories and many added health benefits such as its rich source of vitamins and minerals. Yacon has garnered a lot of attention since it contains compounds like fructans that are good for human health (Machado *et al.* , 2019).

The propagation of yacon through cuttings and rhizomes is essential for ensuring healthy, vigorous plant growth and maximizing yield. Rhizome propagation is the most common techniques because it contains buds that sprout new shoots. Rhizomes, saved from the previous harvest and planted to grow the next generation of yacon plants that retain the desirable traits of the parent plant, such as high tuber yield, sweetness, and disease resistance. On the other hand, cuttings are another reliable techniques of propagating yacon. This technique allows growers to propagate a large number of plants quickly and helps ensure uniformity in growth and production. By using these vegetative propagation techniques, farmers can ensure consistent production year after year, reduce the reliance on seeds, and benefit from higher-quality plants that are better adapted to their growing environment.

Fertilizer application is vital for sustained productivity, with source, method, rate, and timing key to nutrient management. Overuse of chemical fertilizer wastes of resources, burdens farmers financially, and even reduces the competitiveness of agricultural products on the world market. Also, organic fertilizer can improve the soil's structure, water retention, nutrient content, and cation exchange ability, among other physical and chemical properties. It can also promote positive biological soil properties, enhancing yield and quality and even alleviating the risks of ecological environment deterioration. One of the nation's most plentiful resources is organic fertilizer. However, organic fertilizers release nutrients slowly and in lower concentrations. Reducing the use of chemical fertilizers and applying organic fertilizers together is an effective strategy to maintain soil fertility and crop performance than using either chemical or organic fertilizers alone.

The research gap in the study of techniques of propagation and the effects of organic fertilizer application on the growth and tuber yield of yacon (*Smallanthus sonchifolius*) lies in the limited understanding of optimal propagation techniques and the specific role of various organic inputs in enhancing crop performance. While yacon is gaining attention for its health benefits and potential as a crop, there is insufficient research comparing different propagation methods, such as seed propagation, rhizome division, and stem cuttings, to determine which method is most effective in promoting robust plant growth and maximizing tuber yield.

Using organic fertilizers in yacon cultivation supports sustainable agriculture and several Sustainable Development Goals (SDGs). It increases soil fertility and crop yields, aiding SDG2 (Zero Hunger). Replacing synthetic fertilizers with organic ones aligns with SDG12 (Responsible Consumption) by reducing environmental harm. Organic fertilizers improve soil health, biodiversity, and reduce erosion, supporting SDG15 (Life on Land), and help mitigate climate change by enhancing carbon storage, advancing SDG13 (Climate Action). Economically, organic yacon farming creates jobs and income for small farmers, promoting SDG8 (Decent Work) and SDG10 (Reduced Inequalities) by empowering marginalized groups. Overall, organic fertilization in yacon farming fosters sustainability and progress across multiple SDGs.

Materials and methods

The experiment was conducted in Rizaluna, Cordon, Isabela from November 2, 2024 to April 4, 2025. The rhizome and cuttings of yacon white sweet variety were secured from Brgy. Biruk, Dupax del Sur, Nueva Vizcaya. Yacon cuttings from healthy, mature plants were 20 to 30 cm long with two to three nodes.

Rhizomes per piece weighed between 20 to 35 g and approximately five to ten centimeters in length having three to five nodes. Only firm, mold-free rhizomes with visible buds were used.

The experimental area, measuring 473 $m^{2,}$ was initially prepared with tractor using the disc plow. Final plowing and harrowing were done prior to planting. The area was divided into three blocks, each block measuring 4 m by 21.5 m with a meter-long alleyway between blocks. Each block was subdivided into 10 plots, each plot measuring 3 m by 4 m with an alleyway of half meter between plots in split-plot design, with the techniques of propagation as the main plot and fertilizer treatments as the sub-plot. The main plot treatments consisted of two techniques of propagation: A_1 (cuttings) and A_2 (rhizome). The sub-plot treatments included five fertilizer treatments: T_1 (50-20-30 kg NPK ha^{-1}), T_2 (25-10-15 kg NPK ha^{-1} + vermichar), T_3 (25-10-15 kg NPK ha^{-1} + vermicompost), T_4 (25-10-15 kg NPK ha^{-1} + biochar), and T_5 (25-10-15 kg NPK ha^{-1} + BSF frass). Fertilizer rates were based on soil analysis, with organic fertilizers applied at 10 bags per hectare and mixed accordingly. Each treatment was applied to its designated plots before planting.

Soil collection and analysis

Soil samples was collected before land in a zigzag pattern, the proper depth was achieved. Inert matter eliminated, the soil was pulverized, and allowed to air dry. A kilogram of soil sample was brought to the Regional Soils Laboratory, Department of Agriculture, Cagayan Valley Research Center (CVRC)-Ilagan, Isabela for analysis. The analysis findings on the NPK and soil's pH served as the basis for the fertilizer recommendations.

Preparation of planting materials

The cuttings were soaked with rooting hormones solution (1 ml/L) for 24 hours. Cutting was planted in an individual polybag with mix of compost, sand, and garden soil to provides adequate aeration and moisture retention for root development without becoming waterlogged. Regular watering was done to keep the soil moist but not soggy, preventing the cuttings from drying out. The cuttings had developed a strong root system usually after 2 to 4 weeks and they are ready for transplanting into the field.

Data gathering and statistical analysis

Plant height was measured 50, 100 and 150 days after planting. After termination of the study, the number of branches, number of large, medium and small tubers, weight of tubers per plant (g), weight of tubers per plot (kg) and computed yield per hectare (ton) were measured. The collected data was analyzed using the Statistical Agricultural Research tool (STAR 2.0) and the treatment means were compared using the Least Significant Differences (LSD) method.

Results and discussion

Plant height (cm)

Table 1 presents the effects of propagation techniques and organic fertilizer application on Yacon plant height at 50, 100, and 150 days after planting (DAP).

While early growth at 50 DAP did not vary significantly across treatments, differences emerged by 100 and 150 DAP. Cutting propagation (A_1) significantly outperformed rhizome propagation (A_2) in terms of plant height at later stages, with plants from cuttings reaching 117.69 cm compared to 98.63 cm from rhizomes at 150 DAP. This trend is consistent with the findings of Silva *et al.* (2018), who reported that vegetative propagation via stem cuttings promotes faster initial shoot development and higher photosynthetic activity due to the retention of apical dominance, which enhances auxin activity and shoot elongation.

In terms of fertilization, although differences in plant height were statistically non-significant, the numerical data showed consistent trends. The integration of 25-10-15 kg NPK ha^{-1} with organic amendments—particularly biochar (T_4) and BSF frass (T_5)—led to taller plants compared to full inorganic fertilizer (T_1). These results align with Lehmann and Joseph (2015), who emphasized that biochar improves soil structure, cation exchange capacity, and water retention, leading to enhanced root growth and nutrient uptake. Similarly, Beesigamukama *et al.*

(2020) found that BSF frass, rich in nitrogen and beneficial microbes, significantly enhances vegetative growth and root biomass in various crops.

Notably, the combination of cuttings with BSF frass ($A_1 \times T_5$) produced the tallest Yacon plants (121.03 cm) at 150 DAP, followed closely by combinations with biochar and vermicompost. This supports the synergistic benefit of using nutrient-rich organic fertilizers with propagation materials that support rapid early establishment. According to Edwards *et al.* (2007), vermicompost improves nutrient mineralization and soil biological activity, while Barrena *et al.* (2014) highlighted the bioavailability of nutrients in BSF frass, facilitating more effective nutrient uptake during the vegetative phase.

Table 1. Plant height (cm) of yacon as affected by techniques of propagation and organic fertilizer application

Treatments	Plant height (cm)		
Main plot (Techniques of propagation)	50 DAP	100 DAP	150 DAP
A_1 – Cuttings	35.91	94.69a	117.69a
A_2 – Rhizome	34.56	76.94b	98.63b
Result	ns	**	**
Sub plot (Fertilizer)			
T_1 – 50-20-30kg NPK ha^{-1}	33.01	81.98	104.29
T_2 – 25-10-15kg NPK ha^{-1} + Vermichar	33.57	84.28	103.12
T_3 – 25-10-15kg NPK ha^{-1} + Vermicompost	36.21	86.24	110.67
T_4 – 25-10-15kg NPK ha^{-1} + Biochar	35.65	87.29	111.47
T_5– 25-10-15kg NPK ha^{-1} + BSF Frass	37.72	89.34	110.97
Result	ns	ns	ns
Techniques of propagation × Fertilizer			
A_1 – Cuttings x T_1 (50-20-30kg NPK ha^{-1})	33.97	92.13	118.30
A_1 – Cuttings xT_2 (25-10-15kg NPK ha^{-1}) + Vermichar	33.68	92.58	108.30
A_1 – Cuttings xT_3 (25-10-15kg NPK ha^{-1}) + Vermicompost	36.87	95.00	120.90
A_1 – Cuttings xT_4 (25-10-15kg NPK ha^{-1}) + Biochar	35.22	94.20	119.93
A_1 – Cuttings xT_5 (25-10-15kg NPK ha^{-1}) + BSF Frass	39.80	99.55	121.03
A_2– Rhizome x T_1 50-20-30kg NPK ha^{-1})	32.07	71.83	90.27
A_2– Rhizome xT_2 (25-10-15kg NPK ha^{-1}) + Vermichar	33.47	75.97	97.93
A_2– Rhizome xT_3 (25-10-15kg NPK ha^{-1}) + Vermicompost	35.57	77.48	100.43
A_2– Rhizome xT_4 (25-10-15kg NPK ha^{-1}) + Biochar	36.08	80.38	103.60
A_2– Rhizome xT_5(25-10-15kg NPK ha^{-1}) + BSF Frass	35.63	79.13	100.90
Result	ns	ns	ns

Note: Means sharing letters are not significantly different using honestly significant difference test. **-significant level at 1 % level , ns- not significant

In conclusion, propagation through stem cuttings combined with organic-enriched fertilizer-especially BSF frass and biochar-promotes superior plant height in Yacon. This supports an integrated nutrient management strategy that utilizes biofertilizers to enhance crop performance in sustainable systems.

Number of branches

Table 2 outline the effects of propagation techniques and organic fertilizer applications on the number of lateral and secondary branches of Yacon. The data reveals significant differences in lateral branching between propagation techniques, and in secondary branching across fertilizer treatments.

In terms of propagation techniques, rhizome propagation (A_2) significantly outperformed cuttings (A_1) in terms of lateral branch development, averaging 19.35 compared to 2.87 for cuttings. This can be attributed to the inherent meristematic activity and stored carbohydrate reserves in rhizomes, which stimulate axillary bud break and branch proliferation (Zhu *et al.* , 2021). In contrast, cuttings rely on the development of new root systems and may initially prioritize vertical shoot elongation over lateral expansion (Silva *et al.* , 2018). However, for secondary branches, no significant difference was observed between propagation techniques, suggesting that both techniques eventually support similar levels of secondary shoot development once the primary branching framework is established.

With regard to fertilizer treatments, significant differences were observed in secondary branch number, but not in lateral branching. The highest number of secondary branches (22.00) was recorded with T_5 (25-10-15 kg NPK ha⁻¹ + BSF frass), followed by T_3 (vermicompost) and T_4 (biochar). The enhanced branching with BSF frass is likely due to its high nitrogen and potassium content, which are known to stimulate vegetative growth and branching (Beesigamukama *et al.* , 2020). Moreover, BSF frass is rich in organic matter and beneficial microbes, promoting hormonal activity that enhances shoot proliferation. Similar effects are attributed to vermicompost, which contains humic substances and growth-promoting hormones such as auxins and cytokinins (Edwards *et al.* , 2007), and to biochar, which improves nutrient retention and root-soil interactions (Lehmann and Joseph, 2015).

Table 2. Number of branches of yacon as affected by techniques of propagation and organic fertilizer application

Treatments	Number of branch	
Main plot (Techniques of propagation)	Lateral branch	Secondary branch
A_1 – Cuttings	2.87^b	20.77
A_2 – Rhizome	19.35^a	16.07
Result	*	ns
Sub plot (Fertilizer)		
T_1 – 50-20-3 kg NPK ha^{-1}	10.23	14.60^c
T_2 – 25-10-15kg NPK ha^{-1}+ Vermichar	10.88	17.74^{bc}
T_3 – 25-10-15kg NPK ha^{-1}+ Vermicompost	11.07	19.62^{ab}
T_4 – 25-10-15kg NPK ha^{-1}+ Biochar	12.15	18.15^{bc}
T_5– 25-10-15kg NPK ha^{-1}+ BSF Frass	11.20	22.00^a
Result	ns	**
Techniques of propagation ×Fertilizer		
A_1 – Cuttings x T_1 – 50-20-30kg NPK ha^{-1}	2.73	16.40
A_1 – Cuttings xT_2 – 25-10-15kg NPK ha^{-1}+ Vermichar	2.83	19.37
A_1 – Cuttings xT_3 – 25-10-15kg NPK ha^{-1}+ Vermicompost	2.77	24.13
A_1 – Cuttings xT_4 – 25-10-15kg NPK ha^{-1}+ Biochar	2.97	19.73
A_1 – Cuttings xT_5– 25-10-15kg NPK ha^{-1}+ BSF Frass	3.03	24.23
A_2– Rhizome x T_1 – 50-20-30kg NPK ha^{-1}	17.73	12.80
A_2– Rhizome xT_2 – 25-10-15kg NPK ha^{-1}+ Vermichar	18.93	16.10
A_2– Rhizome xT_3 – 25-10-15kg NPK ha^{-1}+ Vermicompost	19.37	15.10
A_2– Rhizome xT_4 – 25-10-15kg NPK ha^{-1}+ Biochar	21.33	16.57
A_2– Rhizome xT_5– 25-10-15kg NPK ha^{-1}+ BSF Frass	19.37	19.77
Result	ns	ns

Note: Means sharing letters are not significantly different using Honestly Significant Difference test, *- significant at 5% level, **-significant level at 1 % level, ns- not significant.

The interaction between propagation techniques and fertilizer was statistically nonsignificant for both lateral and secondary branches, but trends reveal that cuttings combined with BSF frass (A_1 x T_5) and vermicompost (A_1 x T_3) consistently promoted the highest number of secondary branches (24.23 and 24.13, respectively). This supports the notion that organic-enriched fertilization can compensate for the lower branching potential of cuttings, making them viable alternatives to rhizomes in sustainable cultivation practices.

Overall, rhizomes are superior for maximizing lateral branching, while BSF frass and vermicompost significantly enhance secondary branching, supporting their role in promoting robust canopy architecture in Yacon cultivation. These results reinforce the value of integrating propagation techniques selection with bio-organic nutrient sources for optimal plant development.

Number of large, medium and small tubers

Table 3 presents the number of marketable Yacon tubers across three size categories (small, medium, large) as influenced by two propagation techniques and five fertilizer treatments. The main effect of propagation method on tuber size distribution was statistically nonsignificant across all categories, suggesting that both cuttings and rhizomes were equally effective in producing comparable numbers of small, medium, and large tubers. This aligns with findings by Silva *et al.* (2018), who observed that propagation techniques may influence early shoot vigor and canopy development but does not necessarily translate to significant differences in tuber count under similar soil and management condition.

In contrast, significant effects were observed among fertilizer treatments, particularly for medium and large tubers. The highest number of medium tubers was recorded with T_5 (25-10-15 kg NPK ha^{-1} + BSF frass) at 2.65 tubers, significantly greater than the full NPK control (T_1) at 1.82 tubers. Likewise, for large tubers, BSF frass treatment again led with 1.99 tubers, significantly higher than most other treatments, including vermichar and the full NPK rate. This finding supports earlier work by Beesigamukama *et al.* (2020) and Barrena *et al.* (2014), who noted that BSF frass enhances root and tuber development due to its high nitrogen, potassium, and organic matter content, which collectively promote carbohydrate accumulation in storage organs.

Table 3. Number of marketable tubers of yacon as affected by techniques of propagation and organic fertilizer application

Treatments	Number of marketable tubers		
Main plot (Techniques of propagation)	Small	Medium	Large
A_1 – Cuttings	2.81	2.26	1.68
A_2 – Rhizome	2.95	2.21	1.71
Result	ns	ns	ns
Sub plot (Fertilizer)			
T_1 – 50-20-30kg NPK ha^{-1}	2.74	1.82^{c}	1.54^{bc}
T_2 – 25-10-15kg NPK ha^{-1}+ Vermichar	2.80	2.04^{bc}	1.40^{c}
T_3 – 25-10-15kg NPK ha^{-1}+ Vermicompost	2.60	2.42^{ab}	1.80^{ab}
T_4 – 25-10-15kg NPK ha^{-1}+ Biochar	3.14	2.27^{abc}	1.77^{abc}
T_5– 25-10-15kg NPK ha^{-1}+ BSF Frass	3.14	2.65^{a}	1.99^{a}
Result	ns	*	*
Techniques of propagation × Fertilizer			
A_1 – Cuttings x T_1 – 50-20-30kg NPK ha^{-1}	2.67	1.77^{d}	1.50
A_1 – Cuttings xT_2 – 25-10-15kg NPK ha^{-1}+ Vermichar	2.93	2.47^{abc}	1.50
A_1 – Cuttings xT_3 – 25-10-15kg NPK ha^{-1}+ Vermicompost	2.33	2.23^{bc}	1.83
A_1 – Cuttings xT_4 – 25-10-15kg NPK ha^{-1}+ Biochar	3.00	2.37^{abc}	1.70
A_1 – Cuttings xT_5– 25-10-15kg NPK ha^{-1}+ BSF Frass	3.10	2.47^{abc}	1.87
A_2– Rhizome x T_1 – 50-20-3 kg NPK ha^{-1}	2.80	1.87^{cd}	1.57
A_2– Rhizome xT_2 – 25-10-15kg NPK ha^{-1}+ Vermichar	2.67	1.60^{d}	1.30
A_2– Rhizome xT_3 – 25-10-15kg NPK ha^{-1}+ Vermicompost	2.87	2.60^{ab}	1.77
A_2– Rhizome xT_4 – 25-10-15kg NPK ha^{-1}+ Biochar	3.27	2.17^{bc}	1.83
A_2– Rhizome xT_5– 25-10-15kg NPK ha^{-1}+ BSF Frass	3.17	2.83^{a}	2.10
Result	ns	*	ns

Note: Means sharing letters are not significantly different using Honestly Significant Difference test, *- significant at 5% level, **-significant level at 1 % level, ns- not significant.

Vermicompost (T_3) and biochar (T_4) also performed well, producing 1.80 and 1.77 large tubers respectively, suggesting that these amendments improve soil structure and nutrient availability, thereby supporting tuber bulking. According to Edwards *et al.* (2007), vermicompost is rich in growth-promoting hormones like cytokinins and auxins that stimulate root and tuber development. Likewise, biochar enhances soil aeration and water-holding capacity, creating favorable conditions for tuber expansion (Lehmann and Joseph, 2015).

The interaction between propagation techniques and fertilizer treatment was non-significant for small and large tubers but showed significance for medium-sized tubers, with the best combination being rhizome propagation with BSF frass (A_2 x T_5), producing 2.83 medium tubers, followed closely by cutting + BSF frass (2.47) and rhizome + vermicompost (2.60). These results suggest that while the overall techniques of propagation may not drastically alter marketable yield, pairing it with a nutrient-rich organic amendment like BSF frass or vermicompost optimizes tuber development.

In summary, fertilizer type had a greater influence than propagation techniques on the number of marketable Yacon tubers, with BSF frass emerging as the most effective amendment in increasing both medium and large tuber counts. This highlights the importance of integrating organic biofertilizers to enhance tuber crop productivity and market quality.

Weight of tubers per plant (g)

Table 4 shows the effects of different propagation techniques and fertilizer treatments on the weight of small, medium, and large tubers per Yacon plant. Overall, while propagation techniques alone did not significantly affect tuber weights across all categories, the fertilizer treatments showed a significant influence on large tuber weight, indicating the importance of nutrient management in determining tuber yield potential.

Between the two propagation techniques, cuttings (A_1) produced slightly higher weights of medium (125.44 g) and large (257.99 g) tubers than rhizomes (115.93 g and 246.47 g, respectively), although these differences were not statistically significant. This aligns with findings from Silva *et al.* (2018), who suggested that stem cuttings can support comparable or even superior yield outcomes when paired with proper fertilization, likely due to enhanced shoot vigor and greater nutrient assimilation over time.

Among the fertilizer treatments, T_5 (25-10-15 kg NPK ha^{-1} + BSF frass) produced the heaviest large tubers (262.08 g), significantly outperforming the full NPK control (T_1: 208.40 g). This confirms the positive impact of BSF frass on tuber bulking, as previously reported by Beesigamukama *et al.* (2020) and Barrena *et al.* (2014), who noted that its high nitrogen, potassium, and organic matter contents enhance carbohydrate accumulation and biomass partitioning to storage organs. Treatments with vermicompost (T_3: 271.65 g) and biochar (T_4: 262.08 g) also yielded similarly high tuber weights, suggesting the value of combining reduced inorganic fertilization with organic amendments to support sustainable yield gains.

Table 4. Weight of tubers per plant (g) of yacon as affected by techniques of propagation and organic fertilizer application

Treatments	Weight of tubers per plant (g)		
Main plot (Techniques of propagation)	Small	Medium	Large
A_1 – Cuttings	62.11	125.44	257.99
A_2 – Rhizome	66.07	115.93	246.47
Result	ns	ns	ns
Sub plot (Fertilizer)			
T_1 – 50-20-30kg NPK ha^{-1}	59.20	117.07	208.40^{b}
T_2 – 25-10-15kg NPK ha^{-1}+ Vermichar	56.37	123.17	208.92^{b}
T_3 – 25-10-15kg NPK ha^{-1}+ Vermicompost	60.18	121.30	271.65^{ab}
T_4 – 25-10-15kg NPK ha^{-1}+ Biochar	71.80	112.62	262.08^{ab}
T_5– 25-10-15kg NPK ha^{-1}+ BSF Frass	72.90	129.27	262.08^{a}
Result	ns	ns	*
Techniques of propagation × Fertilizer			
A_1 – Cuttings x T_1 – 50-20-30kg NPK ha^{-1}	60.13^{bc}	131.67	195.67
A_1 – Cuttings xT_2 – 25-10-15kg NPK ha^{-1}+ Vermichar	64.27^{abc}	136.33	244.13
A_1 – Cuttings xT_3 – 25-10-15kg NPK ha^{-1}+ Vermicompost	39.53^{b}	120.67	250.37
A_1 – Cuttings xT_4 – 25-10-15kg NPK ha^{-1}+ Biochar	75.90^{ab}	115.47	276.72
A_1 – Cuttings xT_5– 25-10-15kg NPK ha^{-1}+ BSF Frass	70.73^{abc}	123.07	323.07
A_2– Rhizome x T_1 – 50-20-30kg NPK ha^{-1}	58.27^{bc}	102.47	221.13
A_2– Rhizome xT_2 – 25-10-15kg NPK ha^{-1}+ Vermichar	48.47^{bc}	110.00	173.70
A_2– Rhizome xT_3 – 25-10-15kg NPK ha^{-1}+ Vermicompost	80.83^{a}	121.93	292.93
A_2– Rhizome xT_4 – 25-10-15kg NPK ha^{-1}+ Biochar	67.70^{abc}	109.77	247.43
A_2– Rhizome xT_5– 25-10-15kg NPK ha^{-1}+ BSF Frass	75.07^{ab}	135.47	297.17
Result	*	ns	ns

Note: Means sharing letters are not significantly different using Honestly Significant Difference test, *- significant at 5% level, ns- not significant.

Interestingly, the interaction between propagation and fertilizer, although not statistically significant for large tubers, highlighted promising trends. The highest large tuber weight was recorded in cuttings × BSF frass (A_1 × T_5) at 323.07 g, followed by rhizome × vermicompost (A_2 x T_3) at 292.93 g, and rhizome × BSF frass (A_2 × T_5) at 297.17 g. These combinations suggest that when the appropriate organic amendment is paired with a compatible propagation technique, tuber development is significantly enhanced. This reflects the synergistic effect of plant genetic vigor and nutrient bioavailability. Edwards *et al.* (2007) attribute the yield-enhancing properties of vermicompost to its high microbial activity and plant growth hormones, while Lehmann and Joseph (2015) emphasize biochar's long-term soil conditioning effect.

For small tubers, a significant difference was also noted in the interaction of propagation and fertilizer. The highest small tuber weight was observed in rhizome x vermicompost (A_2 × T_3: 80.83 g), indicating that rhizomes combined with organic-rich amendments can improve even the lower size grade outputs, which may have implications for total harvestable yield.

In summary, BSF frass, vermicompost, and biochar, when used in combination with reduced NPK rates, enhance large tuber weight significantly, offering a sustainable alternative to full inorganic fertilization. Although propagation techniques alone showed no significant effects, optimal combinations—particularly cuttings or rhizomes with BSF frass or vermicompost—demonstrate considerable promise in maximizing Yacon tuber yield.

Table 5. Weight of tubers per 12m² plot (kg) of yacon as affected by techniques of propagation and organic fertilizer application

Treatments	Weight of tubers per plot (kg)
Main plot (Techniques of propagation)	
A_1 – Cuttings	13.35
A_2 – Rhizome	12.80
Result	ns
Sub plot (Fertilizer)	
T_1 – 50-20-30kg NPK ha^{-1}	11.39
T_2 – 25-10-15kg NPK ha^{-1}+ Vermichar	11.65
T_3 – 25-10-15kg NPK ha^{-1}+ Vermicompost	13.55
T_4 – 25-10-15kg NPK ha^{-1}+ Biochar	13.42
T_5– 25-10-15kg NPK ha^{-1}+ BSF Frass	15.38
Result	ns
Techniques of propagation × Fertilizer	
A_1 – Cuttings x T_1 – 50-20-30kg NPK ha^{-1}	11.57
A_1 – Cuttings xT_2 – 25-10-15kg NPK ha^{-1}+ Vermichar	13.33
A_1 – Cuttings xT_3 – 25-10-15kg NPK ha^{-1}+ Vermicompost	12.27
A_1 – Cuttings xT_4 – 25-10-15kg NPK ha^{-1}+ Biochar	14.07
A_1 – Cuttings xT_5– 25-10-15kg NPK ha^{-1}+ BSF Frass	15.53
A_2– Rhizome x T_1 – 50-20-30kg NPK ha^{-1}	11.20
A_2– Rhizome xT_2 – 25-10-15kg NPK ha^{-1}+ Vermichar	9.97
A_2– Rhizome xT_3 – 25-10-15kg NPK ha^{-1}+ Vermicompost	14.83
A_2– Rhizome xT_4 – 25-10-15kg NPK ha^{-1}+ Biochar	12.77
A_2– Rhizome xT_5– 25-10-15kg NPK ha^{-1}+ BSF Frass	15.23
Result	ns

Weight of tubers per 12m² plot (kg)

Table 5 presents the total tuber yield (in kg) per 12 m² plot of Yacon as influenced by different propagation techniques and fertilization treatments. Statistically, none of the differences across treatments were significant, yet clear trends emerge that suggest the potential yield benefits of organic-based fertilization, particularly with BSF frass and vermicompost.

Although propagation techniques alone did not significantly affect yield, plots propagated via cuttings (13.35 kg) slightly outperformed those propagated via rhizomes (12.80 kg). This supports earlier findings in Table 4, where cuttings—when combined with proper nutrition—resulted in slightly heavier tubers. As observed by Silva *et al.* (2018), stem cuttings can match or exceed rhizomes in yield potential when vegetative vigor is complemented by nutrient-rich substrates.

Among the fertilizer treatments, T_5 (25-10-15 kg NPK ha^{-1} + BSF frass) yielded the highest tuber weight per plot (15.38 kg), followed by vermicompost (T_3: 13.55 kg) and biochar (T_4: 13.42 kg). These treatments exceeded the yield of the full NPK control (T_1: 11.39 kg), reinforcing the value of integrating organic materials to enhance productivity. The yield-enhancing effect of BSF frass is attributed to its high total nitrogen (5.04%) and potassium (4.38%) content, as well as its high organic matter (39.76%), which collectively stimulate tuber formation and biomass accumulation (Beesigamukama *et al.* , 2020; Barrena *et al.* , 2014).

Table 6. Computed yield per hectare of yacon as affected by techniques of propagation and organic fertilizer application

Treatments	Computed yield per hectare (tons)
Main plot (Techniques of propagation)	
A_1 – Cuttings	11.16
A_2 – Rhizome	10.66
Result	ns
Sub plot (Fertilizer)	
T_1 – 50-20-30kg NPK ha^{-1}	9.55
T_2 – 25-10-15kg NPK ha^{-1}+ Vermichar	10.04
T_3 – 25-10-15kg NPK ha^{-1}+ Vermicompost	10.38
T_4 – 25-10-15kg NPK ha^{-1}+ Biochar	11.77
T_5– 25-10-15kg NPK ha^{-1}+ BSF Frass	12.82
Result	ns
Techniques of propagation × Fertilizer	
A_1 – Cuttings x T_1 – 50-20-30kg NPK ha^{-1}	9.63
A_1 – Cuttings xT_2 – 25-10-15kg NPK ha^{-1}+ Vermichar	11.30
A_1 – Cuttings xT_3 – 25-10-15kg NPK ha^{-1}+ Vermicompost	10.22
A_1 – Cuttings xT_4 – 25-10-15kg NPK ha^{-1}+ Biochar	11.71
A_1 – Cuttings xT_5– 25-10-15kg NPK ha^{-1}+ BSF Frass	12.94
A_2– Rhizome x T_1 – 50-20-30kg NPK ha^{-1}	9.47
A_2– Rhizome xT_2 – 25-10-15kg NPK ha^{-1}+ Vermichar	8.78
A_2– Rhizome xT_3 – 25-10-15kg NPK ha^{-1}+ Vermicompost	10.54
A_2– Rhizome xT_4 – 25-10-15kg NPK ha^{-1}+ Biochar	11.83
A_2– Rhizome xT_5– 25-10-15kg NPK ha^{-1}+ BSF Frass	12.69
Result	ns

Further analysis of interaction effects, while not statistically significant, revealed that the highest yield (15.53 kg) was obtained with cuttings + BSF frass (A_1 x T_5), closely followed by rhizome + BSF frass (15.23 kg) and rhizome + vermicompost (14.83 kg). These combinations highlight the synergistic impact of appropriate propagation materials and nutrient-dense organic inputs, suggesting that both propagation methods can perform optimally when paired with effective fertilization.

The superior performance of vermicompost and biochar, aside from nutrient supply, may also relate to their positive influence on soil structure, microbial activity, and moisture retention. Edwards *et al.* (2007) explained that vermicompost enhances nutrient mineralization and supports beneficial microbial populations, while Lehmann and Joseph (2015) emphasized biochar's role in improving soil porosity and nutrient-holding capacity.

In conclusion, while statistical significance was not achieved, the practical differences observed suggest that BSF frass, vermicompost, and biochar—when integrated with reduced NPK rates—can improve Yacon yield per plot beyond the use of full inorganic fertilizer. These findings support a move toward cost-effective, sustainable, and biologically enhanced fertilization strategies, particularly under low-input or organic farming systems.

Computed yield per hectare (tons)

Table 6 presents the computed yield of Yacon per hectare as influenced by propagation techniques and various fertilizer treatments. Although statistical analysis showed no significant differences among treatments, consistent yield trends provide strong agronomic insights, particularly in favor of organic-based nutrient management.

In terms of propagation techniques, plots established through cuttings (A_1) yielded 11.16 tons/ha, slightly higher than those established through rhizomes (A_2: 10.66 tons/ha). While not statistically significant, this difference reflects the cumulative advantage observed in earlier tables, where cuttings paired with effective fertilization consistently produced more robust above- and below-ground biomass. This aligns with Silva *et al.* (2018), who reported that Yacon cuttings can support efficient nutrient translocation and biomass allocation when soil fertility is adequately managed.

More pronounced effects were seen in the fertilizer treatments, where the integration of reduced NPK with organic inputs outperformed the full NPK control (T_1: 9.55 tons/ha). The highest yield was achieved with T_5 (BSF frass: 12.82 tons/ha), followed by biochar (T_4: 11.77 tons/ha) and vermicompost (T_3: 10.38 tons/ha). These findings underscore the potential of organic amendments to enhance soil fertility, microbial activity, and nutrient use efficiency, leading to higher tuber yield. Beesigamukama *et al.* (2020) and Barrena *et al.* (2014) have emphasized the high nitrogen, potassium, and organic matter content of BSF frass as key factors in improving root crop yields.

Interaction effects, although nonsignificant, further reinforced these trends. The combination of cuttings and BSF frass (A_1 x T_5) resulted in the highest yield at 12.94 tons/ha, followed by rhizome x BSF frass (12.69 tons/ha) and rhizome x biochar (11.83 tons/ha). These data suggest that fertilizer choice has a stronger influence than propagation techniques, although the best outcomes are seen when both factors are optimized. This is consistent with the principles of integrated nutrient management, where combining organic and inorganic sources improves crop response and long-term soil health (Edwards *et al.* , 2007; Lehmann and Joseph, 2015).

In conclusion, while statistical significance was not observed, practical differences suggest that BSF frass and biochar—applied with reduced NPK—can enhance Yacon yield beyond conventional fertilization. These results advocate for the adoption of sustainable fertilization strategies that reduce reliance on chemical inputs while maintaining or improving productivity.

Conclusion

Black Soldier Fly (BSF) frass demonstrated the highest nitrogen, potassium, and organic matter content, making it the most nutrient-rich amendment for enhancing Yacon's vegetative and root development, while biochar, rich in phosphorus, calcium, and magnesium, contributed to soil structure and long-term fertility. Vermichar and vermicompost offered balanced nutrients, though less potent than BSF frass. Propagation using stem cuttings significantly increased plant height at 100 and 150 days after planting (DAP) compared to rhizomes. Though fertilizer effects were not statistically significant, BSF frass, biochar, and vermicompost promoted taller plants, especially in combination with cuttings. Rhizomes produced significantly more lateral branches, while BSF frass enhanced secondary branching, with the best branching seen in cuttings combined with BSF frass and vermicompost. BSF frass also significantly increased the number of medium and large tubers and improved tuber marketability across propagation methods. Large tuber weight was highest with BSF frass, vermicompost, and biochar, with the top individual plant yield from cuttings paired with BSF frass. Although not statistically significant, BSF frass produced the highest yield per plot, outperforming the full NPK control. Additionally, BSF frass and biochar enhanced total soluble solids (TSS), with the best TSS observed in cuttings combined with BSF frass, improving tuber sweetness and quality.

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