



Response of the sweet potato crop (*Ipomoea batatas*) to the application of edaphic bioinputs

Respuesta del cultivo de camote (*Ipomoea batatas*) a la aplicación de bioinsumos edáficos

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Abstract

This study focused on evaluating the agronomic and productive response of sweet potato (*Ipomoea batatas*) variety INIAP-Toquecita to the application of various soil bioinputs. The study took place at INIAP's Portoviejo Experimental Station in Ecuador, from July to December 2022. The effects of several bioinputs, including diatoms, efficient microorganisms, biochar, earthworm humus, and organic matter, on various agronomic parameters were analyzed. The findings revealed statistically significant effects of these bioinputs on variables such as rooting rate, foliage cover, root biomass, root proliferation, aboveground biomass yield, commercial tuberous root production, leaf chlorophyll content, and nutrient concentrations in both soil and plant tissue. Biochar proved particularly effective in promoting vegetative growth, increasing vine proliferation per plant (9 vs. 6 vines·plant⁻¹ in other treatments) and aboveground biomass production (24.17 t·ha⁻¹). Vermicompost achieved the best initial establishment (100%) and the highest yield of commercial tuberous roots (24.90 t·ha⁻¹). The addition of plant residues generated the highest concentration of foliar chlorophyll (range 41.86-45.93). At the end of the cycle, all treatments maintained adequate nutritional status, with significant absorption of phosphorus and iron. The results suggest that these bioinputs are an effective alternative to conventional chemical fertilization in sweet potato cultivation, with specific benefits for each, depending on the production objective.

Keywords: *Ipomoea batatas*, INIAP Toquecita, bioinputs, soil fertility.

Resumen

El presente estudio se centró en evaluar la respuesta agronómica y productiva del camote (*Ipomoea batatas*) variedad INIAP-Toquecita a la aplicación de diversos bioinsumos edáficos. El estudio tuvo lugar en la Estación Experimental Portoviejo del INIAP, en Ecuador, durante el periodo de julio a diciembre de 2022. Se analizaron los efectos de varios bioinsumos, incluyendo diatomeas, microorganismos eficientes, biocarbón, humus de lombriz y materia orgánica, sobre diversos parámetros agronómicos. Los hallazgos revelaron efectos estadísticamente significativos de estos bioinsumos en variables como la tasa de enraizamiento de las guías, la cobertura del follaje, la biomasa de las guías, la proliferación de guías, el rendimiento de biomasa aérea, la producción de raíces tuberosas comerciales, el contenido de clorofila en las hojas y la concentración de nutrientes tanto en el suelo como en el tejido vegetal. El biochar demostró ser particularmente eficaz en la promoción del desarrollo vegetativo, incrementando la proliferación de guías por planta (9 vs. 6 guías·planta⁻¹ en otros tratamientos) y la producción de biomasa aérea (24,17 t·ha⁻¹). El vermicompost logró el mejor establecimiento inicial (100%) y el máximo rendimiento de raíces tuberosas comerciales (24,90 t·ha⁻¹). La adición de residuos vegetales generó la mayor concentración de clorofila foliar (rango 41,86-45,93). Al final del ciclo, todos los tratamientos lograron mantener un estado nutricional adecuado, con una notable absorción de fósforo y hierro. Los resultados sugieren que estos bioinsumos son una alternativa efectiva para sustituir la fertilización química convencional en el cultivo de camote, con beneficios particulares para cada uno, dependiendo del objetivo de producción.

Palabras clave: *Ipomoea batatas*, INIAP Toquecita, bioinsumos, fertilidad del suelo.

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Introduction

Sweet potato, also known as batata, is currently cultivated in 114 countries worldwide, standing out for its versatility of use and the low costs associated with its production (Glato et al., 2017). Its nutritional importance is considerable, as it helps meet the food needs of more than two billion people around the globe (FAO, 2019). This tuberous root has great potential as an economic and productive alternative, with diverse applications: it can be used for direct human consumption, as forage in animal feed, or as a raw material in industry for the production of processed foods, additives, starches (Sunanta et al., 2019), and biofuels (Cantos et al., 2018; Weber et al., 2020).

Globally, there has been growing interest in improving dietary habits as part of health care efforts. In this context, organic products have emerged as a response to this demand, characterized by their freshness and the absence of chemical residues in their production (Murillo and Rodríguez, 2018).

Current consumption trends are shifting toward foods that promote well-being, focusing primarily on organic products free of agrochemicals (FAO, 2019). This change in dietary preferences drives the need to increase agricultural productivity through the use of organic amendments, which are essential for improving soil health, nutritional status, and crop productivity (Afrad et al., 2021). Fertilizers are fundamental for plant nutrition, being as important as water and sunlight. There are various types of soil amendments (organic and synthetic), each with its own advantages and disadvantages. Organic fertilizers, also known as compost or manure, can be of animal or plant origin and are valued for improving soil conditions by enhancing water and nutrient retention—an essential factor in ecological farming systems. However, one of their main drawbacks is the lower solubility of the nutrients they contain, which means it takes longer for plants to absorb them.

Regarding the nutritional management of sweet potato, as with other crops, it is essential to implement a strategy that considers the plant's phenological stages and specific nutritional needs. Based on soil analysis interpretation, the nutrient requirements of sweet potato are classified as low at 80-80-120 kg·ha⁻¹ of N-P-K; medium at 60-40-60 kg·ha⁻¹; and high at 40-40-60 kg·ha⁻¹, respectively. The success of fertilization depends on the accurate interpretation of soil analyses, which ensures that nutrients are available at appropriate levels throughout all stages of crop development, guaranteeing continuous availability during both the vegetative and reproductive phases of sweet potato growth (Padilla, 1979).

Among the key factors influencing crop productivity, nutrition stands out as a crucial element, involving the proper selection

of fertilizer sources, the appropriate timing of application, and correct dosage. Both macro- and micronutrients must be supplied in a balanced manner to ensure adequate crop nutrition; otherwise, plant development and yield may be adversely affected (Atuna et al., 2018). Crops that develop underground storage organs, such as roots and tubers, require higher amounts of potassium, an element essential for the formation and development of these structures (Hasan, 2020). Phosphorus is necessary for metabolic processes, flowering, and the proper development of tuberous roots (Kareem, 2013). Organic fertilizers have the potential to enhance agricultural productivity (Li et al., 2018), making it a priority to identify organic products that can help improve yields while maintaining soil fertility.

Diatoms are an organic amendment composed of fossilized skeletons of unicellular microalgae known as diatomites. These materials act as soil conditioners and sources of plant nutrition, providing microelements that support plant development, aid in the recovery of degraded soils, and enhance soil fertility levels (Muñoz et al., 2019). In a study conducted by Jaramillo (2021), the effect of diatom application on banana cultivation was evaluated, revealing that their complementary use with other fertilizers improved parameters such as plant height (3.73 m), bunch biomass (19.12 kg), and number of fruits per bunch (84.58), using a dose of 12 g of diatoms per plant. Similarly, Raya et al. (2022) reported positive results in sunflower cultivation through foliar application of diatoms, achieving increased seed yields of up to 2,047 kg·ha⁻¹.

According to research by Nagy et al. (2023), beneficial microbial consortia—formed from specific combinations of bacteria and fungi—show great potential for application in sweet potato production. Studies by White et al. (2019) indicate that these microorganisms help solubilize soil nutrients, thereby improving their availability and absorption by plants, which leads to better crop growth and development. Additionally, these microorganisms have a protective effect against pathogens, act as natural herbivore repellents, and can inhibit the growth of competing plants.

Biochar, also known as biocarbon, is a fine-grained, dark-colored material with high carbon content, produced through the pyrolysis of plant biomass. It functions as a soil conditioner that improves soil properties (Marousek et al., 2019). Studies conducted by Indawan et al. (2018) documented that the application of biochar derived from tobacco residues in sweet potato cultivation increased various productive parameters, including fresh and dry tuberous root biomass, total dry biomass, and estimated yield of

marketable roots. Additional research on sweet potato has shown that combining 30 t·ha⁻¹ of biochar with 10 t·ha⁻¹ of poultry manure improved the soil's physical properties (reduced bulk density, increased porosity, and enhanced moisture retention) as well as its chemical properties (optimized pH, organic carbon, nitrogen, phosphorus, potassium, calcium, and magnesium), all of which contribute to enhanced crop yield (Agbede and Oyewumi, 2022).

In studies on sweet potato, Rahmawati et al. (2022) reported that the incorporation of vermicompost (worm humus) at a dose of 10 t·ha⁻¹ led to an increase in both biomass and the number of tuberous roots per plant, compared to the untreated control. The authors also noted that this treatment promoted a higher proportion of first-grade tuberous roots (Grade A, with a biomass greater than 200 g per root).

The objective of this study was to evaluate the productive and agronomic characteristics of the INIAP-Toquecita sweet potato variety in response to the application of soil bio-inputs.

Materials and methods

The research was carried out during the dry season (July-December 2022) at the Portoviejo Experimental Station of INIAP, located in the Colón parish, Manabí province, Ecuador. The geographic coordinates of the experimental site are 1°07'2.64" S and 80°23'18.3" W, at an elevation of 44 meters above sea level. During the study period, climatic conditions included temperatures ranging from 21 to 31°C, an average relative humidity of 82%, and an annual mean precipitation of 672.7 mm. The land had flat topography, and according to analysis conducted at the Pichilingue Tropical Experimental Station, the soil has a silty texture. The evaluated factors included five soil bio-inputs: diatoms, a consortium of beneficial microorganisms, biochar, vermicompost (in pellet form), and processed plant-based organic material (peanut shells). The details of the treatments are presented in table 1.

Table 1. Description of treatments with organic soil fertilizers in INIAP-Toquecita sweet potato cultivation.

Nº	Variety	Soil bio-inputs	Dosage·ha ⁻¹
T1	INIAP-Toquecita	Diatoms	2 kg
T2	INIAP -Toquecita	Beneficial microorganisms	10 L
T3	INIAP -Toquecita	Biochar	20 kg
T4	INIAP -Toquecita	Vermicompost	1 t
T5	INIAP -Toquecita	Plant-based organic material	1 t
T6	INIAP -Toquecita	No application	

A randomized complete block design (RCBD) was implemented with six treatments and three replications, resulting in a total of 18 experimental units. Each experimental plot consisted

of three furrows, each 5.1 meters long and spaced 0.8 meters apart. For evaluations, 10 plants were randomly selected from the central furrow, which was considered the useful plot area. The propagation material consisted of cuttings from the INIAP-Toquecita variety, taken from three-month-old plants that showed vigor, were free of pests and diseases, and were re-collected from the apical section. Statistical processing included descriptive analyses, complemented by analysis of variance (ANOVA) and Tukey's multiple comparison test at a 95% confidence level.

The trial was established on land previously prepared through mechanized operations, including one deep plowing, two harrowings, and furrowing, ensuring a well-loosened and clod-free soil. Prior to planting, a chemical soil analysis was conducted to establish the baseline nutritional conditions. Planting was carried out by digging lateral furrows 10 cm deep using a hoe, where 40 cm long cuttings were placed horizontally, spaced 30 cm between plants and 80 cm between rows, resulting in a planting density of 41,666 plants·ha⁻¹. The cuttings were partially covered, leaving approximately one-quarter exposed. Irrigation was applied by gravity, on a weekly basis during the first month and biweekly from the second month until 90 days after planting. Soil bio-inputs were applied at two stages: at planting and 20 days later. Additional agronomic practices were conducted following the recommendations of the Sweet Potato Technical Manual (Cobena et al., 2017).

At 15 days after planting (DAP), the percentage of cutting establishment was evaluated. Vegetative vigor was assessed at 45 DAP using a qualitative scale with three categories: poor (P), intermediate (I), and vigorous (V). At 60 DAP, multiple parameters were measured: soil cover, assessed using a categorical scale—low (<50%), medium (50-74%), high (75-90%), and total (>90%)—based on the methodology proposed by Huamán (1991); biomass of 100 cuttings, selecting segments 40 cm in length and expressing the result in kilograms; number of cuttings per plant, counting only those longer than 40 cm; and cutting length, measured from the base to the apex of the main vine and expressed in centimeters.

At 120 days after planting (DAP), the final evaluation was carried out, including: fresh aerial biomass yield (leaves and stems), expressed in t·ha⁻¹; count of marketable tuberous roots, excluding those damaged or weighing less than 100 g, expressed as units per hectare; and yield of marketable roots, expressed in t·ha⁻¹. Additionally, the greenness index was determined using the SPAD 502 Konica Minolta meter (León et al., 2021), with readings taken from leaves located in the middle section of the cuttings. At the end of the production cycle, soil and plant tissue samples were re-collected from each treatment to perform macro- and micronutrient analyses at the specialized laboratory of the Santa Catalina Experimental Station, Pichincha, Ecuador.

Results and discussion

Establishment and vigor

Regarding the establishment variable, data analysis (table 2) revealed that all treatments achieved high establishment



percentages, ranging from 96% to 100%. This favorable outcome was attributed to the quality of the propagation material used, consisting of cuttings selected from healthy and vigorous plants, three months old and approximately 40 cm in length. The values obtained exceeded those reported by Quispe (2017), who documented an average establishment rate of 91.53% in his study on sweet potato. As for vigor, table 2 shows that all treatments exhibited a vigorous level, a condition likely influenced by the appropriate moisture regime maintained during the initial stage of the crop. The gravity irrigation system implemented allowed soil moisture to be preserved for periods exceeding seven days. This observation is consistent with findings by Quispe (2017), who associated adequate plant vigor with favorable water conditions during the early development stage.

Table 2. Establishment and vigor of sweet potato.

Treatment	Establishment (%)	Vigor*
Diatoms	99	V
Beneficial microorganisms	96	V
Biochar	96	V
Vermicompost	100	V
Plant-based organic matter	98	V
No application (T)	99	V

*P scale = low vigor ; I= intermediate; V= vigorous.

Soil cover

With regard to soil cover, variability was observed among the different treatments evaluated. As shown in table 3, the control treatment (without bio-input application) achieved the highest soil coverage at 87%, followed by the vermicompost treatment, which reached 83%. These results are higher than those reported by Quispe (2017), who recorded an intermediate level of foliar cover in his study. Although classified within this range, the author emphasized the invasive nature of sweet potato and the rapid expansion of its foliar canopy.

Cutting biomass

Regarding the biomass of 100 cuttings, the results showed differences among treatments, with values ranging from 1.3 to 1.9 kg for 40 cm-long segments. The observed differences suggested that the applied bio-inputs influenced biomass accumulation in the cuttings at 60 days. In this case, the biochar treatment stood out by achieving the highest biomass, reaching 1.9 kg per 100 sampled cuttings.

Table 3. Results of soil cover (%) and the biomass from 100 cuttings (kg) in the different treatments.

Treatments	Soil cover (%)	Biomass from 100 cuttings (kg)
Diatoms	80	1.7
Beneficial microorganisms	57	1.5
Biochar	70	1.9
Vermicompost	83	1.3
Plant-based organic matter	70	1.6
No application (T)	87	1.5

Number of cuttings per plant and foliage yield

When analyzing the variable number of cuttings per plant, it was found that five out of the six treatments showed similar values, averaging six cuttings per plant. The exception was the biochar treatment, which exhibited superior vegetative development with nine cuttings per plant. This difference in vegetative proliferation was directly reflected in aerial biomass yield, where the same treatment achieved the highest production with 24.17 t·ha⁻¹ (Table 4). These findings are consistent with those reported by Andika et al. (2019), who documented that the incorporation of 10 t·ha⁻¹ of biochar derived from rice straw resulted in a significant increase in biomass, reaching 1227.81 g per plant.

Table 4. Number of cuttings per plant and foliage yield

Treatment	Cuttings·planta ⁻¹	Foliage yield (t·ha ⁻¹)
Diatoms	6	21.25
Beneficial microorganisms	6	17.78
Biochar	9	24.17
Vermicompost	6	16.53
Plant-based organic matter	6	17.08
No application (T)	6	19.44
CV (%)	46.92	42.09
Tukey 0.05	ns	ns

Quantit and yield of marketable roots

Regarding storage organ yield, statistical analysis of the number of marketable roots (table 5) did not detect significant differences among treatments. However, notable numerical variations were observed, with the vermicompost treatment standing out by recording the highest number of marketable roots per hectare (170,835 units) and the highest yield at 24.90 t·ha⁻¹. These results are consistent with those reported by Rahmawati et al. (2022), who indicated that the application of 10 t·ha⁻¹ of vermicompost increased both biomass and the number of tubers

per plant compared to the untreated control. Additionally, those researchers observed a higher proportion of premium-grade fresh tuberous roots (Grade A, with a biomass greater than 200 g per root) in the plots treated with this bio-input.

Table 5. Quantity and yield of marketable roots.

Treatments	Quantity of marketable roots·ha ⁻¹	Yield of marketable roots (t·ha ⁻¹)
Diatoms	162,501	24.13
Beneficial microorganisms	158,334	21.01
Biochar	115,279	16,13
Vermicompost	170,835	24.90
Plant-based organic matter	168,057	22.70
(T)	154,168	19.71
CV (%)	30.07	24.76
Tukey 0.05	ns	ns

Greenness index (SPAD)

The greenness index—a parameter related to the concentration of photosynthetic pigments that enables plants to capture light energy and convert it into chemical energy during photosynthesis—showed an increasing trend over time. As illustrated in figure 1, SPAD values progressively increased throughout the phenological cycle, from early August to late November. The treatment with plant-based organic matter consistently recorded the highest readings, with values ranging from 41.86 to 45.93 SPAD units. These results differed from those reported by Pepo (2018), who documented a decreasing trend in SPAD readings toward the end of the vegetative cycle.

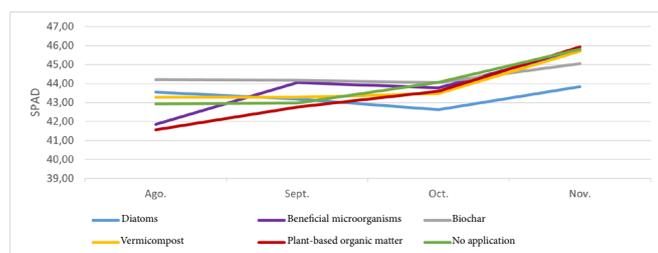


Figure 1. Greenness units shown in SPAD in sweet potato plants (*Ipomoea batatas*).

Macro and micro analysis of elements in soil

Soil analyses (Table 6) indicated that certain mineral elements initially present in the soil—such as phosphorus, sulfur, boron, zinc, iron, and manganese—showed a reduction in their concentrations by the end of the production cycle, revealing active uptake of these nutrients by the crop during its development.

Table 6. Macro and micro elements present in the soil pre and post-harvest, EEP, 2023.

Treatments	Macro and micro elements												
	ppm			Meq/100 g			ppm			%			
	N	P	K	Ca	Mg	S	B	Zn	Cu	Fe	Mn	MO	pH
Diatoms	6.7	16.1	1.8	27.9	5.4	12.6	0.8	1.4	8.4	16.0	1.9	0.9	8.2
Beneficial microorganisms	9.3	17.6	1.9	28.3	5.0	15.0	0.7	1.3	8.0	15.0	2.2	0.9	8.3
Biochar	32.6	18.0	1.9	28.6	5.3	13.1	0.7	1.1	8.2	19.0	2.1	0.9	8.5
Vermicompost	15.6	13.2	1.8	29.4	5.6	16.7	0.7	1.4	8.1	17.0	1.9	0.8	8.5
Plant-based organic matter	15.1	17.1	1.8	25.5	5.1	10.5	0.7	1.5	7.6	18.0	2.0	0.7	8.7
No application (T)	15.3	14.6	1.9	24.8	4.7	14.3	0.8	1.2	7.7	12.0	2.3	0.9	8.5
Initial soil analysis	6.0	50.0	1.3	12.0	4.3	24.0	1.3	4.1	3.6	100.0	7.0	1.0	8.1

Macro and micro-elements of foliage in 120 days

The results of the foliar nutritional analysis at 120 days after planting (table 7) indicated that all elements analyzed across the different treatments exceeded the critical levels established by Bolle-Jones and Ismunadji (1963) and Spence and Ahmad (1967). According to these authors, the adequate nutrient levels at 105 days after planting are: N 3.7 ppm; P 0.4 ppm; K 5.9 meq/100 g; Ca 0.6 meq/100 g; Mg 0.54 meq/100 g; and S 0.41 ppm. Deficiency levels are considered to be: N 2.5 ppm; P 0.1 ppm; K 0.8 meq/100 g; Ca 0.2 meq/100 g; and Mg 0.16 meq/100 g. At 150 days after planting, the reported optimal levels are: N 2.88 ppm; P 0.2 ppm; K 1.76 meq/100 g; Ca 0.92 meq/100 g; Mg 0.22 meq/100 g; and S 0.25 ppm, with deficiency levels defined as: N 1.5 ppm; P 0.1 ppm; K 0.5 meq/100 g; Ca 0.2 meq/100 g; Mg 0.05 meq/100 g; and S 0.08 ppm.

Table 7. Macro and micro elements presents in the foliage 120 dds, EEP, 2023.

Treatments	%						mg·kg ⁻¹				
	N	P	K	Ca	Mg	S	B	Zn	Cu	Fe	Mn
Diatoms	2.13	0.39	2.99	2.62	0.47	0.29	62.11	54.30	10.18	812.85	37.54
Beneficial microorganisms	2.61	0.42	3.55	2.28	0.46	0.28	44.56	26.41	10.97	842.00	36.78
Biochar	2.24	0.40	3.17	2.24	0.48	0.26	44.61	32.78	11.67	830.38	25.75
Vermicompost	2.18	0.40	3.08	2.58	0.47	0.30	63.42	26.55	9.98	1038.10	43.94
Plant-based organic matter	2.20	0.42	3.41	2.28	0.44	0.27	53.66	29.20	12.77	940.50	38.35
No application (T)	2.89	0.40	3.72	1.72	0.43	0.27	33.15	34.31	12.31	1229.00	42.19

Regarding the dry biomass content in the foliar material evaluated at 120 days after planting, figure 2 showed values ranging between 16% and 20%. The biochar treatment stood out by achieving the highest dry biomass concentration, with 20%.



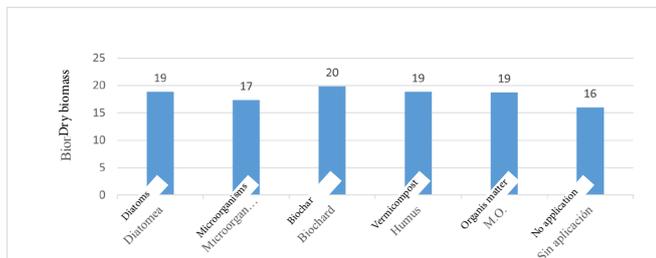


Figure 2. Dry biomass content in sweet potato leaves over a 120 day period.

Conclusion

The results of this study demonstrate that the incorporation of soil bio-inputs has significant effects on various agronomic and productive parameters in the INIAP-Toquecita sweet potato variety. This suggests that the evaluated biological inputs are viable alternatives for increasing crop yield and quality.

Biochar showed a positive effect on vegetative plant development. Plants that received this treatment exhibited greater branching (nine cuttings per plant, compared to six in the other treatments), higher biomass in the cuttings (1.9 kg per 100 cuttings), and, as a result, greater aerial biomass production (24.17 t·ha⁻¹). These results make biochar a recommended option when the goal is to optimize foliar biomass production.

Vermicompost achieved perfect cutting establishment (100% take rate), the highest density of marketable roots per hectare (170,835 units), and the highest yield of marketable tuberous roots (24.90 t·ha⁻¹). These results indicate that vermicompost may be particularly effective for increasing the production of storage organs in sweet potato.

Nutrient level analyses in both soil and foliar tissue indicated that by the end of the production cycle, none of the treatments showed macro- or micronutrient deficiencies. This suggests that all evaluated bio-inputs provided adequate nutrition for the crop. Efficient uptake of phosphorus and iron was observed, which may be related to the improvements in vegetative development and yield.

Conflict of interest

The authors declare no conflict of interest at any stage of the present publication.

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