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# Cassava yield indicators and total organic carbon in tropical soils under different fertilization treatments

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**Abstract**

Cassava is a crop of major socioeconomic importance in Brazil because of its versatility and high yield in nutrient-poor soils. Fertilization can improve soil quality and further increase cassava yield. This study aimed to investigate the effects of different fertilizer sources on soil total organic carbon (TOC) and cassava yield indicators. The experiment was conducted on a family farm in Santarém, Brazil, in a randomized block design, with four treatments and five replications. Treatments were as follows: T1, unfertilized soil (control); T2, NPK fertilizer; T3, poultry manure; and T4, cattle manure. The variables analyzed were soil TOC, shoot fresh weight, plant height, marketable stem diameter, marketable root yield, and yield. Data were subjected to analysis of variance, Tukey's test ($p < 0.05$), hierarchical clustering, and principal component analysis. Application of organic fertilizers (T3 and T4) increased soil TOC levels. Chemical fertilizer treatment (T2) resulted in the highest shoot fresh weight, yield, and marketable root yield. Marketable stem diameter was positively influenced by T2 and T4. There were no significant treatment effects on plant height. Hierarchical clustering isolated organic fertilizers (T3 and T4) from other treatments. Principal component analysis revealed two principal components, which together explained 87.77% of the total variance. Organic fertilizer application provided the highest TOC accumulation during the experimental period, whereas NPK fertilization was the most effective in increasing cassava yield in the first year of cultivation.

**Keywords:** organic fertilizer; cattle manure; organic matter; *Manihot esculenta*; crop yield.

## Introduction

Cassava (*Manihot esculenta* Crantz) is a root crop belonging to the family Euphorbiaceae and characterized by a variable number of roots containing glycosides and latex (Alves, 2002). The crop has great economic and social importance because of its carbohydrate-rich roots, which serve as a staple food for millions of people worldwide (Guimarães et al., 2017; Utsumi et al., 2019).

Cassava shows high adaptability to different climates and is cultivated and consumed in several countries, particularly in low- and middle-income countries of Africa, Asia, and Latin America (Vieira et al., 2013; Pacheco et al., 2020). Cassava plants are also used as animal feed (Souza et al., 2019) and are considered one of the five most important commodities in bioethanol, biogas, and biodiesel production (Bezerra et al., 2019).

In Brazil, cassava is mostly produced on small family farms (Tironi et al., 2015) and holds great agronomic, sociocultural, and economic relevance throughout the country, particularly in the Amazon region. Family farming is estimated to account for 87% of the national production of cassava, meeting most of the local demand (FAO, 2016).

In 2018, global cassava production reached 277.8 million tonnes and a harvested area of 24.6 million hectares. In 2019, Brazil was the fifth largest producer, with 17.49 million tonnes and 1.25 million hectares harvested (FAO, 2020; IBGE, 2020). Although Pará State is the largest national producer, it has fallen behind in crop yield as a result of inadequate management and inherently poor soil conditions, such as low soil pH and reduced nutrient availability. These limitations can be easily mitigated by application of organic or chemical fertilizers during the crop cycle (Pimentel et al., 2020).

Organic fertilizers not only supply nutrients but also increase carbon stocks in the soil profile, offering an advantage over chemical fertilizers (Malta et al., 2019); that is, organic fertilizer application can contribute to both crop and soil quality (Leite et al., 2003). Few studies have sought to identify associations between fertilizer sources, soil organic carbon, and cassava crop indicators.

The quality, quantity, and dynamics of soil organic carbon influence several plant functions (Lal, 2016). Therefore, understanding and monitoring the availability of soil organic carbon is crucial to improve soil management and increase crop yields. Such information is even more critical in tropical regions subject to rapid organic matter degradation and leaching loss (Senesi et al., 2016).

This study aimed to assess the effects of different fertilizer sources on soil total organic carbon (TOC) and agronomic characteristics of cassava grown on a family farm.

## Results and discussion

### *TOC analysis*

Soil TOC contents at the 0.0–0.2 m depth differed according to fertilization regime. Unfertilized soil (T1) differed in TOC level from soil treated with chemical or organic fertilizers (T2, T3, and T4), which did not differ from each other (Fig. 3). Biratu et al. (2019) studied the effects of chemical and organic fertilization on cassava cultivation and obtained similar results to those reported here: soil TOC content was found to be influenced by the use of organic fertilizers.

Lack of soil nutrient replacement, associated with inadequate crop management, may result in biomass loss, reduction of organic matter input, and, consequently, TOC loss. Denardin et al. (2014) observed that inadequate soil management and changes to cover crops may lead, in a short time, to losses of soil carbon stocks. The soil plays a key role in carbon sequestration; thus, such alterations can enhance soil carbon emission, thereby increasing the environmental impacts of greenhouse gases (Vieira et al., 2015).

Cattle manure (T4) was the most effective in increasing carbon input to soil compared with the control. Such a result is likely related to the high cellulose and lignin contents of cattle manure, which hinder microbial decomposition of organic matter. Ramos et al. (2016) reported that lignin and cellulose, unlike hemicellulose, have a low decomposition rate, resulting in a greater accumulation of organic matter in soil pores. Organic matter accumulation is mainly observed in clay soils, characterized by a high concentration of micropores.

According to Wiesmeier et al. (2019), soil texture (sand, silt, and clay proportions) is one of the most important factors for carbon accumulation in soil. The soil of the study area had a very clayey texture. An important effect of clay is the physical protection it confers to carbon, promoted by adsorption of organic compounds within pores, preventing microbial decomposition (Kravchenko and Guber, 2017). Because manure organic matter is not easily degraded by microorganisms, much of its carbon is retained and accumulates in clay micropores.

Carbon stabilization in soil is a result of the entry and exit of organic material (Chenu et al., 2019). A net gain or loss of soil carbon, in turn, is associated with the balance between microbial decomposition of carbon inputs and protection of this organic residue in the form of plant compounds or microbially processed carbon (Barré et al., 2018). The decomposition rate of organic carbon depends on the mechanisms of organic matter protection, which, according to Lützow et al. (2006), include recalcitrance, associated with the molecular weight of the residue; physical protection, determined by the spatial inaccessibility of microorganisms to organic matter; and complexation, that is, organomineral interactions with soil mineral surfaces. Therefore, carbon accumulation from organic fertilization is closely related to mechanisms of organic matter protection.

Compared with T1, T4 afforded a gain in soil TOC of 2.13 g kg$^{-1}$ in only one crop cycle, corresponding to a TOC increase of 9.70%. Cattle manure (T4) efficiently increased soil carbon content in a short period. Cattle manure fertilization may be particularly important in tropical climate regions, where organic matter decomposition rates are high (Barbieri et al., 2013).

Soil treated with poultry manure (T3) did not differ in TOC content from soil treated with cattle manure (T4); however, T3 values were numerically lower than those of T4 and similar to those of T1. Poultry manure contains large amounts of easily degradable compounds (sugars, amino acids, proteins), contributing to the rate of organic matter mineralization and, thereby, reducing carbon accumulation (Shah et al., 2013).

Overall, the results showed that fertilization, whether organic or chemical, positively influenced soil TOC levels. We highlight, however, that organic sources are low cost and highly efficient in increasing soil organic matter. According to Ghosh et al. (2018), organic fertilizers can improve soil structure because of the aggregation power of organic matter.

### *Agronomic characteristics*

Cassava shoots fresh weight, encompassing leaves, stem, and branches, differed significantly between treatments. The parameter was highest for plants treated with chemical fertilizer (Fig. 4A). The use of nitrogen, phosphorus, and potassium (NPK) fertilizer (T2) resulted in a shoot fresh weight of 21.73 kg ha$^{-1}$, whereas lack of fertilization resulted in a shoot fresh weight of 16.53 kg ha$^{-1}$.

Such a result can be attributed to high nutrient availability, given that chemical fertilizers are readily available in soil, increasing nutrient absorption by plants. As discussed by Pereira et al. (2012), high cassava shoot development is associated with high macronutrient availability, particularly that of phosphorus. Phosphorus is of extreme importance for biochemical reactions, and its deficit impairs plant functions. High shoot fresh weight also indicates a higher leaf area index, which contributes to the production of photoassimilates and their translocation to plant organs.

Similar results were obtained by Alves et al. (2012) regarding NPK fertilization. The authors tested different NPK doses on cassava grown in Mojú, Pará State, Brazil, and observed that, when applying 600 kg ha$^{-1}$ NPK, the shoot fresh weight was 20.11 kg ha$^{-1}$; lack of fertilization resulted in a shoot fresh weight of only 13.08 kg ha$^{-1}$. In the current study, a higher shoot fresh weight was obtained, both with and without NPK fertilization.

Soares et al. (2019) argued that NPK fertilization can increase the shoot fresh weight of cassava, with the added benefit of minimizing losses related to weeds because of the higher soil coverage. Otsubo et al. (2012) underscored the importance of rapid cassava shoot development, which allows obtaining propagative material and animal feed in a short period.

Plant height did not differ significantly between treatments, although the variable was numerically higher in plants fertilized with cattle manure (3.03 m) and NPK (2.98 m); the lowest height was observed in unfertilized plants (2.61 m) and plants fertilized with poultry manure (2.60 m) (Fig. 4B). These results are in line with those described by Suárez and Mederos (2011), who reported that cassava plant height can range from 1 to 5 m but typically does not exceed 3 m.

Plant height is an important factor, particularly for strong plants, as strong winds can lead to lodging. Rós et al. (2013) argued that cassava plant height must be considered when choosing crops for intercropping.

The diameter of marketable stems differed significantly between treatments (Fig. 4C). NPK and cattle manure treatments did not differ from each other and afforded higher means than the control and poultry manure fertilization. NPK

**Table 1.** Chemical and physical properties of 0–20 cm depth soil before cassava cropping.

| Attribute | 0–20 cm depth soil |
|---|---|
| pH $H_2O$ | 6.1 |
| pH $CaCl_2$ | 5.4 |
| P (mg dm$^{-3}$) | 4.0 |
| K (mg dm$^{-3}$) | 43.9 |
| Ca + Mg (cmol$_c$ kg$^{-1}$) | 4.6 |
| Ca (cmol$_c$ kg$^{-1}$) | 3.4 |
| Mg (cmol$_c$ kg$^{-1}$) | 1.2 |
| Al (cmol$_c$ kg$^{-1}$) | 0.0 |
| H (cmol$_c$ kg$^{-1}$) | 4.0 |
| Organic matter (g kg$^{-1}$) | 37.8 |
| Sum of bases (cmol$_c$ dm$^{-3}$) | 4.8 |
| Cation-exchange capacity (cmol$_c$ dm$^{-3}$) | 8.7 |
| Base saturation (%) | 54.5 |
| Al saturation (%) | 0.0 |
| Ca saturation (%) | 39.0 |
| Mg saturation (%) | 14.3 |
| K saturation (%) | 1.3 |
| H saturation (%) | 45.5 |
| Ca/Mg | 2.7 |
| Ca/K | 29.8 |
| Mg/K | 11.0 |
| Sand (g kg$^{-1}$) | 173.0 |
| Silt (g kg$^{-1}$) | 168.0 |
| Clay (g kg$^{-1}$) | 659.0 |

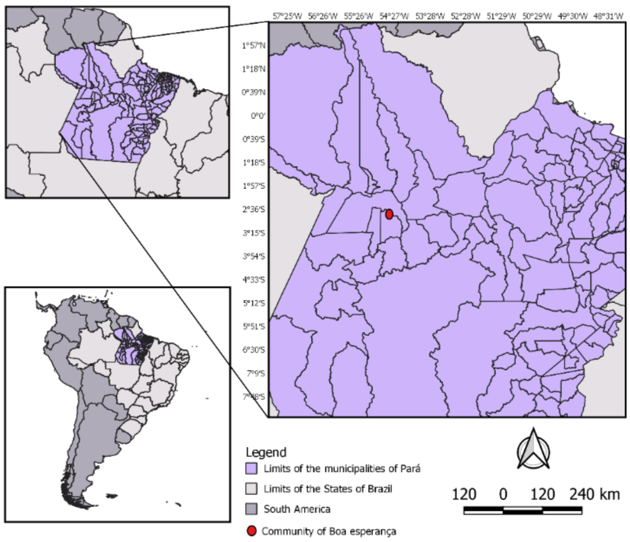


**Fig 1.** Experimental cassava cultivation on a family farm in the Boa Esperança community, Santarém, Pará, Brazil.

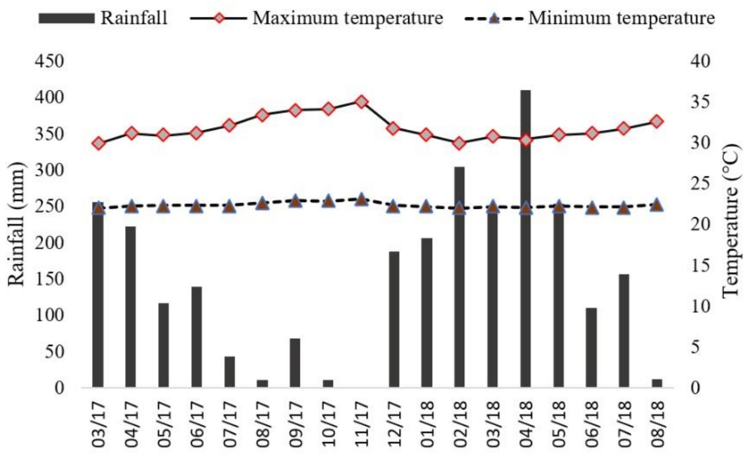


**Fig 2.** Rainfall and average maximum and minimum temperatures during the experimental period.

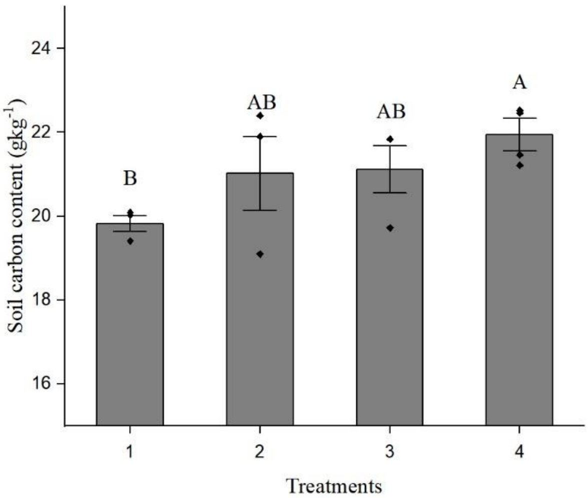


**Fig 3.** Total organic carbon (TOC) content in unfertilized soil (T1) and soils fertilized with NPK (T2), poultry manure (T3), and cattle manure (T4). Means followed by the same letter are not significantly different by Tukey's test ($p < 0.05$). ♦ Outliers.

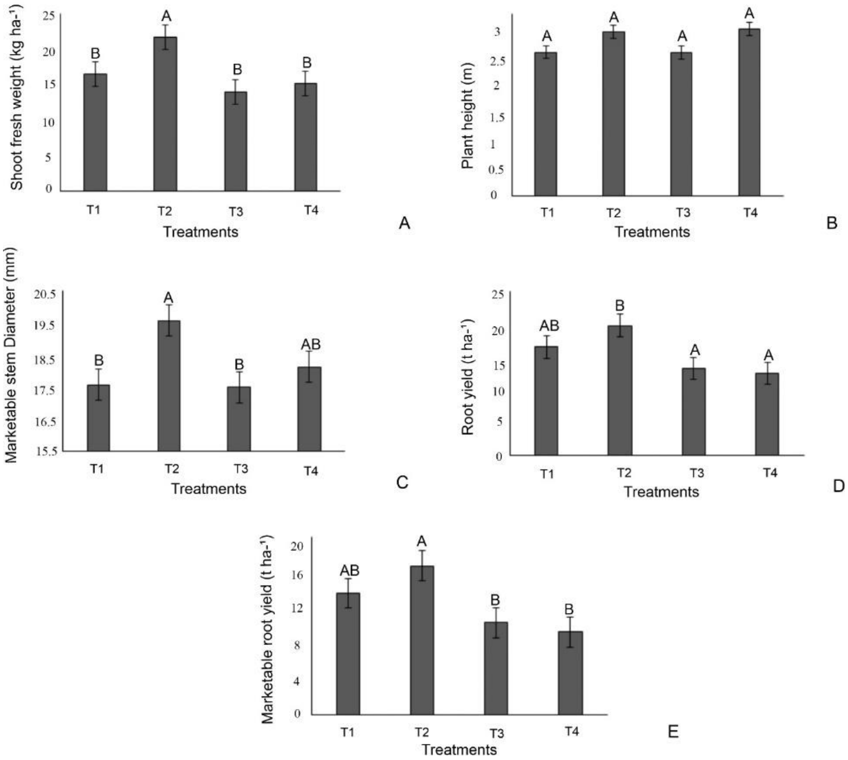


**Fig 4.** (A) Shoot fresh weight, (B) plant height, (C) marketable stem diameter, (D) root yield, and (E) marketable root yield of cassava grown on unfertilized soil (T1) and soils fertilized with NPK (T2), poultry manure (T3), and cattle manure (T4). Means followed by the same letter are not significantly different by Tukey's test ($p < 0.05$).

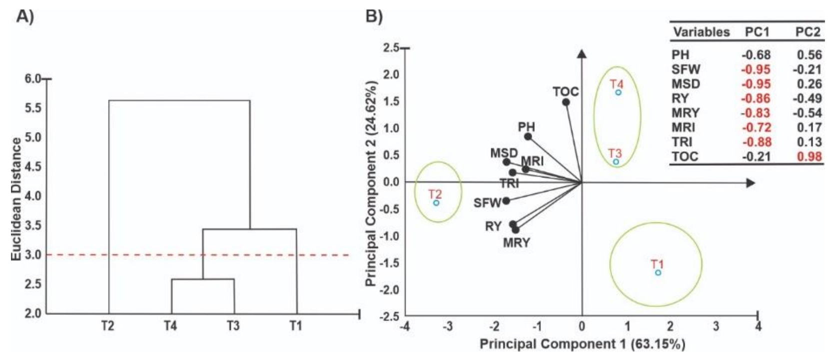


**Fig 5.** (A) Dendrogram and (B) PCA biplot of cassava plant height (PH), shoot fresh weight (SFW), marketable stem diameter (MSD), root yield (RY), marketable root yield (MRY), marketable root index (MRI), total root index (TRI), and soil total organic carbon (TOC). T1, unfertilized soil (control); T2, NPK fertilizer; T3, poultry manure; and T4, cattle manure.

fertilization increased stem diameter by 2 mm compared with the control, representing an increase of 10.2%, whereas cattle manure fertilization increased stem diameter by 0.56 mm (3.08%). The high increase in stem diameter (10.2%) promoted by NPK fertilization can be attributed to adequate potassium supply and the high vigor of cassava cuttings. Silva et al. (2017) observed an increase of 2.27 mm in stem diameter by fertilizing with 240 kg $ha^{-1}$ $K_2O$, in agreement with the findings of the current study. Overall, the results showed that NPK was effective in increasing nutrient availability, as it is a source of readily available nutrients, positively influencing shoot development, photoassimilate synthesis and conversion, and cutting yield.

NPK fertilization also significantly enhanced root yield, whereas poultry manure, cattle manure, and the control did not differ significantly from each other (Fig. 4D). Compared with the control, NPK fertilizer increased total root yield by 3.29 t $ha^{-1}$ (16.59%), from 16.53 to 19.82 t $ha^{-1}$.

Falqueto et al. (2009) argued that an increase in shoot fresh weight is indicative of an increase in photoassimilate synthesis. As plants grow, photoassimilates are translocated from the leaves to other plant organs, such as the roots. Unfertilized plots had the second-highest yield, indicating that there might have been an excessive amount of organic fertilizers. Rós et al. (2020), in studying the effects of organic fertilization on cassava, found that excessive fertilization decreased yield; yield was highest when using 8 t $ha^{-1}$ poultry manure, decreasing at higher fertilizer doses.

Cattle manure fertilization did not increase yield in the first crop cycle likely because of its low organic matter decomposition rate and, consequently, slow nutrient release. By contrast, Mathias and Kabambe (2015) found that cattle manure increased cassava yield by 26% compared with non-fertilization. Odedina et al. (2011) found that poultry manure was more effective in increasing yield than NPK fertilizer.

Marketable root yield was lower in plants treated with organic fertilizers than in unfertilized plants and plants fertilized with NPK, which did not differ from each other. This result was expected, given the results of root yield (Fig. 4E). Although differences were not significant, NPK fertilization increased marketable root yield by 18.24% (16.77 t $ha^{-1}$) compared with the control.

Cassava plants require large amounts of nutrients in the early stages of development, explaining why chemical fertilization promoted favorable conditions for crop growth and yield. According to Corrêa et al. (2016), about 80% of tuberous roots are formed in the first four weeks after planting, necessitating adequate irrigation and nutrient availability during the growth period.

### *Hierarchical clustering and principal component analysis*

Hierarchical clustering, using a Euclidean distance of 3, afforded three groups (Fig. 5A): T2, isolated from T3 and T4, which were grouped together, and T1, also isolated from the other treatments. Principal component analysis was used to complement hierarchical clustering analysis. Principal component (PC) 1 and PC2 explained 87.77% of the total variance in the dataset, with PC1 (plant factors) accountable for 63.15% of the total variance and PC2 (soil carbon) accountable for 24.62% (Fig. 5B). A strong negative correlation was observed between PC1 and shoot fresh weight, marketable stem diameter, root yield, marketable root yield, total root index, and marketable root index. These variables were important to discriminate the yield indices of NPK-treated plants. PC2 was strongly and positively correlated with soil TOC, explaining the differences between organic fertilizers and other treatments. The control also differed from the other treatments, as revealed by hierarchical cluster analysis.

These results show that, although cassava is a tolerant plant able to grow on acidic soils with low nutrient availability, synthetic fertilizers can markedly increase root yield. Adiele et al. (2020) concluded that cassava yield is greater when using chemical fertilization. Similarly, Alves et al. (2012) reported that chemical fertilizers provide gains in cassava production; however, these inputs are not always available to farmers because of their high costs. Organic fertilizers did not influence yield in the first crop cycle; more time is needed to investigate their effects over a longer period. According to Nascimento et al. (2014), organic fertilizers tend to improve the chemical, physical, and biological attributes of soil.

## Material and methods

### *Experimental site*

The experiment was conducted on a family farm in the Boa Esperança community (2°44′24.7″S 54°31′33.2″W, 145 m elevation), PA-370, km 41, Santarém, Pará, Brazil (Fig. 1).

The region has a tropical climate with two well-defined seasons (Köppen classification), a rainy period from December to May and a dry period from June to November (Oliveira et al., 2018). The average annual temperature ranges from 25 to 28 °C, the average relative air humidity is about 86%, and the average annual precipitation is 2,282 mm (Souza et al., 2019), as depicted in Fig. 2.

### *Cassava cultivation in the 2017/2018 agricultural year*

The experiment was conducted between March 2017 and July 2018. Cuttings of cassava (*M. esculenta*) 'Bem-te-vi' were planted at a spacing of 1 × 1 m over an area of 980 $m^2$ on yellow Latosol of very clayey texture. Soil samples were collected before planting and analyzed for fertility (Table 1). Soil acidity was corrected by lime application, according to Cravo et al. (2007).

### *Experimental design*

A randomized block design was used, with four treatments of five blocks, totaling 20 plots of 36 $m^2$ each. Treatments were as follows: T1, unfertilized soil; T2, soil fertilized with NPK fertilizer, according to Cravo et al. (2007); T3, soil fertilized with 3.06 t $ha^{-1}$ poultry manure; and T4, soil fertilized with 4.44 t $ha^{-1}$ cattle manure.

### *TOC analysis*

For TOC determination, 20 composite samples were collected from each experimental plot using a Dutch auger at a depth of 0.0–0.20 m. Samples were air-dried, sieved through 80 mesh sieves, and analyzed by wet oxidation with potassium dichromate in acidic medium (Yeomans & Bremner, 1988).

### *Determination of cassava crop characteristics*

Crop characteristics were determined at harvest. The following morphological and agronomic descriptors were analyzed as proposed by Fukuda and Guevara (1998): shoot fresh weight, plant height, marketable stem diameter, root yield, and marketable root yield.

### *Statistical analysis*

Data were subjected to analysis of variance, and treatment means were compared at the 5% significance level by Tukey's test. After normalization to zero mean and unit standard deviation (μ = 0, σ = 1), the data were subjected to hierarchical clustering and principal component analysis. Variables with eigenvalues greater than 1.00 were retained, according to the criterion proposed by Kaiser (1958). All statistical analyses were performed using Statistica 7.0 software.

## Conclusion

Organic fertilization led to greater organic carbon accumulation in soil at the end of the crop cycle, resulting in increased TOC levels. NPK fertilizer application provided the best results for shoot fresh weight, whereas, for plant height and stem diameter, NPK and cattle manure were the most effective. Organic fertilizer treatments did not affect marketable or total root yield, but NPK application positively influenced these parameters. Multivariate analyses identified three groups, separating chemical fertilizer, organic fertilizer, and unfertilized treatments.

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