



# Effects of Cassava Tails and Stalk and Superabsorbent Polymer on Soil Properties, Growth, and Yield of Cassava in Sandy Loam and Clay Loam Soils

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**Abstract:** The objective of this study was to evaluate the effects of cassava tails and stalk (CTS) and superabsorbent polymer (SAP) on soil properties, as well as on cassava growth and yield in sandy loam and clay loam soils. The research employed a randomized complete block design with three treatments, including unamended soil (control, T1), 8,000 kg/rai of fresh weight CTS (T2), and 0.25% (w/w) of SAP (T3) with four replications. In sandy loam soil, the SAP application showed a significant decrease in soil bulk density (BD) and increase in soil particle density (PD) and soil porosity (PO). Both soil amendment treatments increased organic matter (OM) (0.58%) compared with the control (0.51%). The SAP application showed the highest content of P and K (9 and 69 ppm, respectively), while CTS showed the highest content of Ca (411 ppm). In clay loam soil, the SAP application resulted in the lowest BD (1.36 g/cm<sup>3</sup>), while the CTS application resulted in the highest soil PO (50.11%). Both treatments increased OM (~1.00%) and the content of Ca and Mg (~2,000 ppm and ~220 ppm, respectively) compared with the control (0.73%, 1,559 ppm, and 182 ppm, respectively). The SAP application showed a better leaf water potential and stomatal conductance, which led to the highest plant height, leaf area, and stem diameter of cassava. In addition, the SAP application resulted in the highest cassava yield (7.83 and 6.20 tons/rai) in both soils and starch content (21.44%) in sandy loam soil. Therefore, both SAP and CTS applications improved soil properties and promoted cassava growth, resulting in higher yields; however, their effectiveness was strongly dependent on soil texture.

**Keywords:** *Manihot esculenta*; organic amendments; synthetic polymers; bulk density

## 1. Introduction

Cassava (*Manihot esculenta* (L.) Crantz) is an important economic crop in Thailand. In 2024, Thailand exported cassava products valued at 3,133.4 million USD (110,276 million baht) to major markets such as China, Japan, Indonesia, Taiwan, and Malaysia [1]. However, cassava production still faces limitations related to soil properties and moisture, especially in the Northeast, a major cassava-producing region of the country. The soils in this area are mostly coarse-textured, such as sandy soil, sandy loam, and loamy sand, with poor soil structure, high water permeability, and low water retention capacity [2]. These problems are exacerbated by climate change, continuous monoculture, herbicide use, and improper soil management, leading to soil degradation and reduced fertility, which in turn affect cassava production [3]. Physical and chemical soil

properties such as soil porosity (PO), bulk density (BD), organic matter content (OM), and nutrient fertility directly influence cassava growth and yield. It has been found that OM, phosphorus (P), and calcium (Ca) are key factors determining the variability of cassava tuber yield.

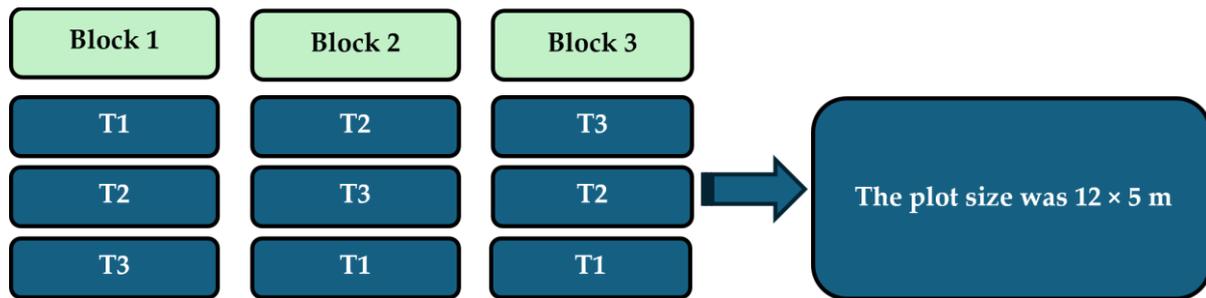
The application of organic soil amendments, such as cow manure, chicken manure, cassava pulp, and cassava processing plant residues, has been reported to significantly increase cassava root yield and starch content [4-5]. When applied at appropriate rates in combination with chemical fertilizers, these amendments result in high cassava yields. They also increase OM, P, K, Ca, and Mg, contributing to long-term soil fertility and nutrient balance [6]. Beyond improving soil fertility, these amendments enhance soil structure and physical properties, including PO, BD, aggregate stability, and water holding capacity [7-9]. Research showed that combining a sugarcane filter with biochar enhances PO and pore size distribution. It reduces large pores in sandy soils while increasing small pores, thereby reducing water loss [10]. Integrating green manure, chicken manure, and biofertilizers with chemical fertilizers promotes plant growth and yield. Green manure increases soil organic matter, pore space, and N and P levels compared with unfertilized conditions [11]. Cassava tails and stalk (CTS) are an agricultural by-product produced during the initial stage of cassava starch processing. It contains soil particles, root fragments, and other impurities removed through mechanical shaking [12]. Approximately 100-200 kg of CTS is generated per ton of fresh cassava processed [13]. Previous studies have shown that the combined application of CTS and chicken manure increases plant nutrient accumulation in plant tissues and enhances fresh root yield [14]. Moreover, CTS combined with bentonite at a rate of 25+5 tons/ha significantly increased fresh tuber yield and starch content compared with untreated soil [14]. Superabsorbent polymers (SAP) can absorb water up to approximately 1,000 times their own weight and gradually release it, thereby maintaining soil moisture and supporting crop growth under water-limited conditions [15]. Their swelling-shrinking behavior also improves soil pore distribution and aggregate stability [16], promoting root development and more efficient water uptake. This is essential for cassava growth, as it allows for better root development and water uptake. In addition to SAP, soil amendments play a crucial role in enhancing soil properties and improving cassava yield. The application of these amendments can increase production efficiency and ensure long-term food security. Effective soil management practices, including the management of macro and micronutrients, as well as efficient water use, are crucial for enhancing cassava productivity. By evaluating the effects of soil amendments and SAP on soil properties, cassava growth, and yield, sustainable soil management strategies can be identified. This can help improve cassava production, ensuring food security and reducing the environmental impact of farming practices. Overall, the use of SAP and soil amendments has the potential to significantly improve cassava yield, particularly in regions with limited water availability. The objective of this study was to evaluate the effects of CTS and SAP on soil properties, as well as on cassava growth and yield in sandy loam and clay loam soils.

## 2. Materials and Methods

The study on the effects of CTS and SAP on soil properties, cassava growth, and yield used the Rayong 72 cassava variety. The CTS was sourced from a cassava starch manufacturing plant in Nakhonratchasima, which still contained moisture, and SAP was obtained from a commercial supplier in Thailand. The experiment took place from June 2024 to May 2025 at Suranaree University of Technology in Nakhon Ratchasima, Thailand.

### 2.1 Experimental design

The experiment was conducted on two soil textures: sandy loam and clay loam. The research employed a randomized complete block design with three treatments: unamended soil (control, T1), soil amended with 8,000 kg/rai of fresh weight CTS (T2), and soil amended with 0.25% (w/w) SAP (T3), across four replications. Each sampling plot size measured 60 m<sup>2</sup> with a spacing of 1.2 x 0.8 m (Figure 1). CTS was broadcast over the field and incorporated into the soil, whereas SAP was applied along the ridge line at a depth of 30 cm.



**Figure 1.** Experimental layouts of the study.

## 2.2 Preparation, cultivation, and management of cassava

The cassava planting area was prepared using a moldboard plow, followed by disk plow tillage and ridge creation. The stems of Rayong 72 cassava were cut into stakes, soaked in thiamethoxam to prevent mealybugs, and planted along the ridges. Fertilizer application was based on soil analysis results, with N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O fertilizers at a 20-10-24 formulation at 48 kg/rai for sandy loam soil and a 12-10-8 formulation at 26 kg/rai for clay loam soil, applied at 1 and 3 months after planting (MAP). Weed control included the application of a pre-emergent herbicide (alachlor 48% w/v EC at 500 mL/80 L of water), followed by manual weeding at 3 MAP. Cassava was grown under rainfed conditions throughout the experiment.

## 2.3 Data collection and analysis

**2.3.1 Soil properties:** The soil samples collected to measure soil physical properties, including soil bulk density (BD), were determined using the core method by dividing the mass of oven-dried soil by its total volume, typically expressed in g/cm<sup>3</sup>. The equation is as follows [17]:

$$BD = \text{Mass of dry soil} / \text{The total soil volume} \quad (1)$$

Soil particle density (PD) is defined as mass per unit of solid soil components, which were divided into OM and mineral substance, typically expressed in g/cm<sup>3</sup>. The equation is as follows [18]:

$$PD = \text{Mass of solid soil components} / \text{Volume of solid soil components} \quad (2)$$

Soil porosity (PO) can be calculated from BD and PD values, typically expressed as a percentage. The equation is as follows [19]:

$$PO = [1 - (BD/PD)] \times 100 \quad (3)$$

Soil chemical properties were determined from samples collected at 0-30 cm depth, which were air-dried and passed through a 2-mm sieve before analysis. Soil pH was determined electrometrically in a 1:1 (soil: H<sub>2</sub>O) suspension using a pH meter (Model Eutech instrument, PC700). Electrical conductivity (EC) was determined by weighing soil and water at a 1:5 ratio and measuring it with an Electrical Conductivity Meter (Model Eutech instrument, PC700). Soil organic matter was determined in air-dried soil samples, after screening through a 0.5 mm mesh sieve, by the wet combustion method, employing potassium dichromate (K<sub>2</sub>Cr<sub>2</sub>O<sub>7</sub>) as the oxidizing agent [20]. Available phosphorus (P) was extracted with Bray-2 solution [21] and determined by the color developing by the molybdenum blue method using a spectrophotometer (Model Thermo Fisher Scientific, Genesys) at an absorbance of 820 nm. Soil exchangeable basic cations (K, Ca, and Mg) were extracted by ammonium saturation with the 1 M NH<sub>4</sub>OAc extraction method at pH 7.0 [22]. The levels of K<sup>+</sup>, Ca<sup>2+</sup>, and Mg<sup>2+</sup> were determined in the soil extract using an atomic absorption spectrophotometer (Model PinAAcle 900H). All measurements were conducted both before and after the experiment at 11 MAP.

The initial physical and chemical properties of the studied soils are summarized in Table 1. In sandy loam soil were characterized by a BD of 1.47 g/cm<sup>3</sup>, PD of 2.79 g/cm<sup>3</sup>, PO of 46.24% while soil chemical

properties was pH of 6.43, EC of 0.02 dS/m, and OM of 0.48%, with available P, exchangeable K, Ca, and Mg content of 6, 23, 23, and 46 ppm, respectively. For clay loam soil, the initial physical properties were BD of 1.52 g/cm<sup>3</sup>, PD of 2.69 g/cm<sup>3</sup>, and PO of 43.29%. The soil chemical properties of the clay loam soil were pH of 7.27, EC of 0.07 dS/m, an OM content of 1.55%, and available P, exchangeable K, Ca, and Mg contents of 5, 226, 1,613, and 226 ppm, respectively.

**Table 1.** Initial soil properties in sandy loam and clay loam soils.

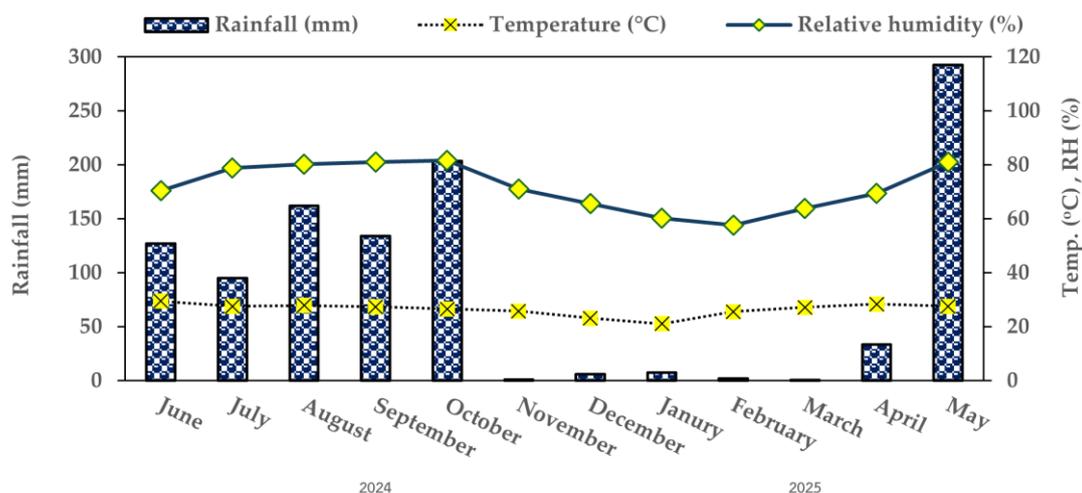
Soil properties	Sandy loam	Clay loam
Bulk density (g/cm <sup>3</sup> )	1.47	1.52
Particle density (g/cm <sup>3</sup> )	2.79	2.69
Soil porosity (%)	46.24	43.29
pH	6.43	6.81
EC (dS/m)	0.02	0.07
OM (%)	0.48	1.55
P (ppm)	6	5
K (ppm)	23	226
Ca (ppm)	23	1,613
Mg (ppm)	46	226

**2.3.2 Cassava physiology:** Predawn leaf water potential (LWP) was measured using a pressure bomb from 4:00 to 5:00 a.m., at 3, 4, 5, 6, and 7 MAP [23]. Stomatal conductance (g<sub>s</sub>) was measured using the brand LICOR, model LI-6800P, from 8:30 to 11:00 a.m., at 3, 4, 5, and 6 MAP [24]. Five plants per replication were randomly selected, and the fifth fully expanded leaf from the apex was measured. Leaf Greenness (SPAD) was measured using a Chlorophyll Meter SPAD-502 Plus from 8:30 to 12:00 p.m. on the third fully expanded leaf. Three measurement points per leaf were recorded and averaged to obtain a final value per plant. Measurements were conducted at 3, 5, and 7 MAP [25], with five plants randomly sampled per replication.

**2.3.3 Cassava growth:** plant height, measured from the base of the stem to the apex using ten randomly selected plants per replication. Stem diameter was measured at the midpoint of the main stem from the same number of sampled plants. Leaf area was determined by randomly selecting ten plants per replication, harvesting all leaves from each plant, and measuring total leaf area using a Li-Cor leaf area meter [26]. All parameters were measured at 3, 5, and 7 MAP.

**2.3.4 Tuber weight and starch content:** At 11 MAP, cassava yield was determined by harvesting a random sample of 60 m<sup>2</sup> per treatment. Fresh tuber weight from each area was recorded and averaged, and the mean value was converted to tons per rai. Starch content (%) was measured using a Reimann scale balance [27], with samples collected randomly from 10 plants per replication.

**2.3.5 Climatic recording:** Climate data collected from the meteorological station at Suranaree University of Technology provided monthly patterns of rainfall, temperature, and relative humidity during the experiment period. Daily records of temperature (°C), rainfall (mm), and relative humidity (%RH) were collected throughout the experiment. From June 2024 to May 2025, daily temperatures ranged from 21.10 to 29.9 °C, while relative humidity ranged from 57.6% to 81.6% (Figure 2). The highest rainfall occurred between June and October 2024, followed by a decline from November 2024 to March 2025. This data is crucial for interpreting variations in soil moisture and their potential effects on cassava growth and yield.



**Figure 2.** Total monthly rainfall, temperature, and relative humidity in field sites from June 2024 to May 2025

### 2.3.6 Statistical analysis

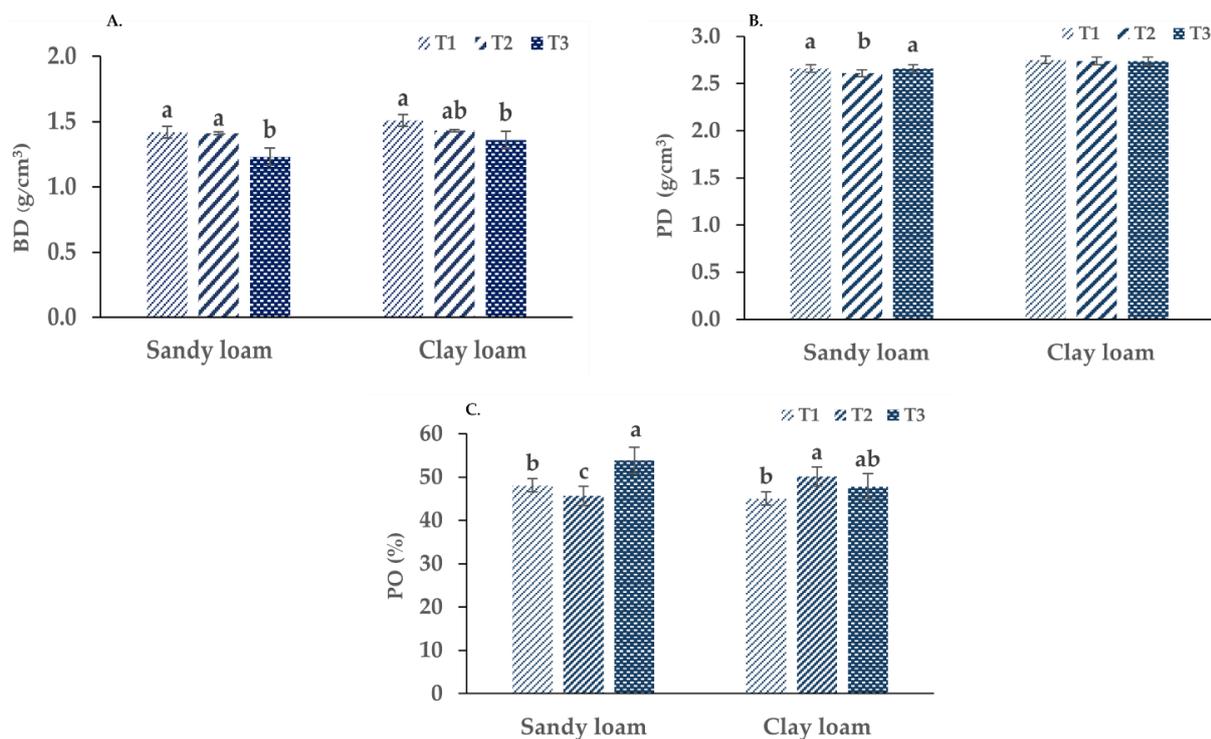
The experimental results were analysed using Analysis of Variance (ANOVA) by SPSS v.16, and mean comparisons among treatments were performed using Duncan's New Multiple Range Test (DMRT) at a 95% confidence level.

## 3. Results and Discussion

### 3.1. Soil properties

#### 3.1.1. Soil physical properties

The soil's physical properties were affected by the treatments, as shown in Figure 3. At 11 MAP, in sandy loam soil, the SAP application resulted in the lowest BD and PD values (1.31 g/cm<sup>3</sup> and 2.61 g/cm<sup>3</sup>, respectively) and the highest PO value of 53.85%. In clay loam soil, the SAP application yielded the lowest BD value of 1.43 g/cm<sup>3</sup>, while the CTS application yielded the highest PO value of 47.86%. The results of the SAP application, with numerous studies showing that it reduced soil BD and improved PO. For example, Cao et al. [25] found that the SAP application (approximately 45 kg/ha) significantly enhanced soil-water retention, increased moisture content by up to 33.5%, and improved soil structure while reducing BD. Similarly, Zheng et al. [26] conducted a meta-analysis of 1,504 paired data points from 310 papers published before July 2022 to evaluate the effects of SAP on crop yield and water productivity, accounting for SAP attributes, initial soil properties, and experimental conditions. They found that the SAP application significantly increased water stable aggregates (WSA) (18.9%) and PO (18.01%). In addition, previous studies reported that SAP could improve soil PO and soil aggregates by affecting the degree of agglutination with soil particles and the process of shrinking and swelling [27-28]. Incorporating CTS into soil as an organic amendment significantly improves physical properties, primarily by forming stable aggregates that enhance soil structure, buffer the soil, improve aggregate stability, increase the population of soil microorganisms, and enhance water retention capacity [29-32]. These organic amendments increase OM, leading to reduced BD and improved water-holding capacity. Similarly, Cassava peels applied at rates up to 25 tons/ha significantly enhance Ultisol fertility by improving soil physical properties, reducing BD (from 0.92 to 0.79 g/cm<sup>3</sup>), and increasing moisture content to 23.49% [32]. These changes suggest that CTS enhances soil aggregation and pore development, thereby improving soil aeration, water retention, and root proliferation, particularly in structurally constrained sandy loam and clay loam soils. Consistent with these findings, CTS has been reported to increase soil pore space, enhance aeration, and improve moisture storage [9, 28].



T1 = unamended soil (control), T2 = cassava tails and stalk (CTS), and T3 = superabsorbent polymer (SAP)

**Figure 3.** Effects of soil amendments on soil properties at 11 months after planting (MAP) in sandy loam and clay loam soils: (A) soil bulk density (BD), (B) soil particle density (PD), and (C) soil porosity (PO). The different letters indicate a significant difference at the 95% confidence level using Duncan's New Multiple Range Test (DMRT). Vertical bars represent standard error of the means (n = 4).

### 3.1.2 Soil chemical properties

The soil's chemical properties were affected by the treatments, as shown in Table 2. At 11 MAP, in sandy loam soil, both treatments increased OM (0.58%) as compared with the control (0.51%). The SAP application showed the highest content of P and K (9 and 69 ppm, respectively), while CTS showed the highest content of Ca (411 ppm). In clay loam soil, both treatments increased OM (~ 1.00%) as compared with the control (0.73%). The SAP application showed the highest Ca content (2,828 ppm), and the CTS application showed the highest Mg content in soil (229 ppm), compared with the control (1,559 ppm and 182 ppm, respectively). The high OM accumulation changed after the application of soil amendments, which may be attributed to increased WSA, improving soil structure and enhancing its stability, thus facilitating the physical protection of OM [28,33-34]. Previous studies reported that SAP has the potential to help superfluous SOM aggregate in the soil layer, thereby preventing it from being immediately decomposed or lost [33, 35]. In addition, SAP can promote the metabolism of soil microorganisms by increasing their populations [36]. It was found that OM, microbial biomass, and soil microorganisms were improved through applying SAP [28]. Both soil amendments in sandy loam increased the availability of P, K, and Ca, supporting better nutrient retention and reduced leaching [34]. Soils with more large macroaggregates have a more stable structure and better nutrient storage under SAP application conditions [28, 37].

**Table 2.** Soil properties and the effect of soil amendments on soil properties in sandy loam and clay loam soils.

Parameter	pH	EC (dS/m)	OM (%)	P (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)
Sandy loam							
T1	6.51	0.05	0.51	8	53	331	143
T2	6.43	0.06	0.58	7	63	411	122
T3	6.50	0.05	0.58	9	69	268	93
F-test	ns	ns	ns	ns	ns	ns	ns
Clay loam							
T1	6.80	0.10	0.73	117	207	1,559	182
T2	6.73	0.10	1.02	82	97	1,953	229
T3	6.78	0.11	1.00	32	135	2,828	214
F-test	ns	ns	ns	ns	ns	ns	ns

T1 = unamended soil (control), T2 = cassava tails and stalk (CTS), and T3 = superabsorbent polymer (SAP)

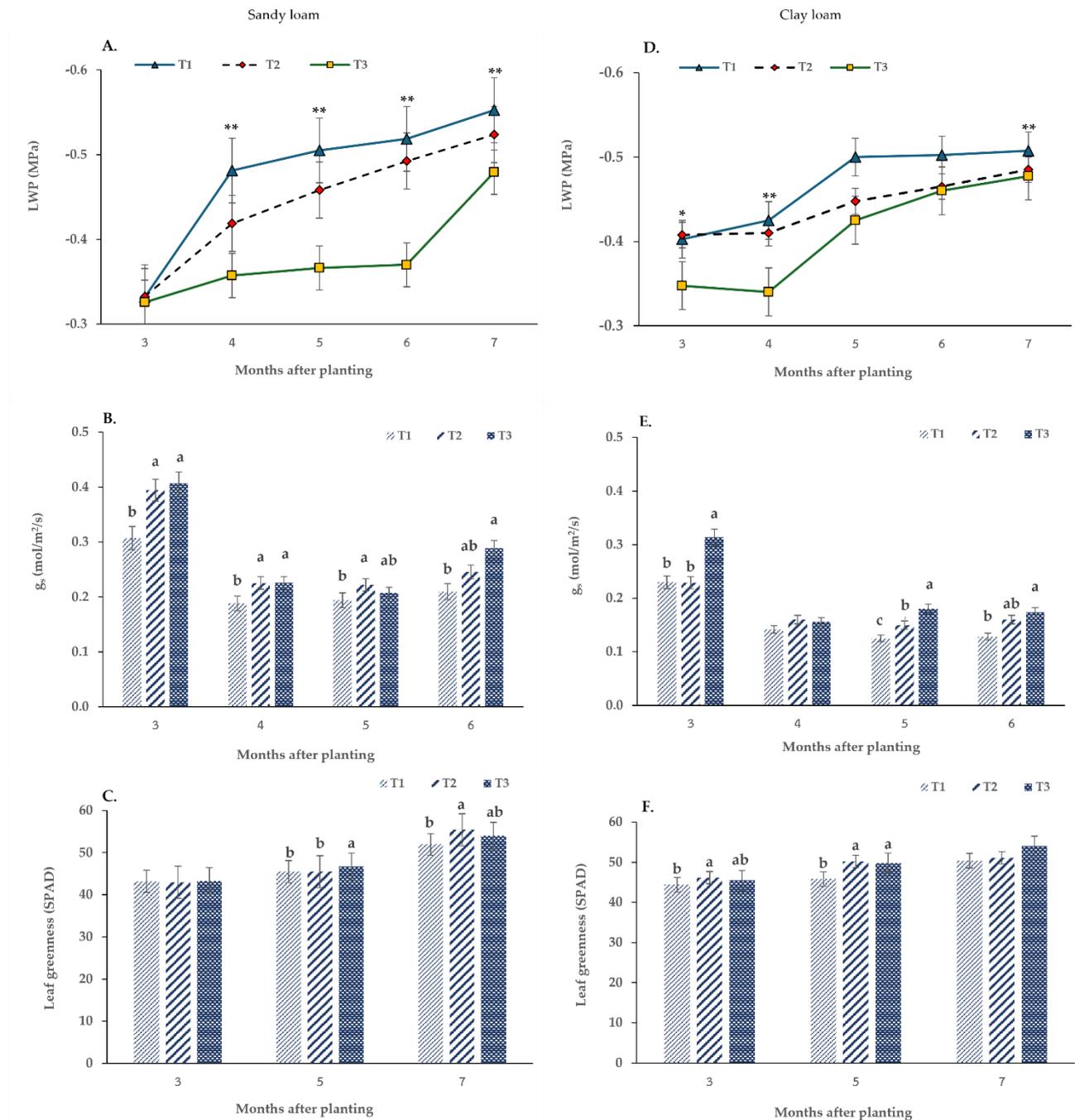
### 3.2 Cassava physiology

#### 3.2.1 Sandy loam soil

The LWP,  $g_s$ , and leaf greenness of cassava in sandy loam soil were significantly affected by both treatments (Figure 4A-C). During 4-7 MAP, all treatments exhibited increased LWP, while SAP resulted in the lowest negative value of LWP followed by CTS, indicating reduced plant water stress compared with the control (Figure. 4A). The main growth stages of cassava (3-6 MAP), both SAP and CTS applications had higher  $g_s$  than the control, indicating better stomatal conductance as compared with the control (Figure. 4B). At 5 and 7 MAP, SAP application yielded the highest leaf greenness (Figure. 4C). These results indicated that both soil amendment applications enhanced leaf chlorophyll status as compared with the control.

#### 3.2.2 Clay loam soil

The LWP,  $g_s$ , and leaf greenness were affected by the treatments in clay loam soil, as shown in Figure 4D-F. During 3-4 MAP, both SAP and CTS applications showed a slight decrease in LWP. During 4-7 MAP, SAP application showed the lowest negative value of LWP followed by CTS, indicating that lower plant stress as compared with the control (Figure. 4D). At 3, 5, 6 MAP, SAP application showed the highest  $g_s$  indicating better stomatal conductance as compared with other treatments (Figure. 4E). During 3-5 MAP, both SAP and CTS applications had higher leaf greenness than the control indicating that both soil amendment applications had higher chlorophyll content as compared with the control (Figure. 4F). The SAP application can enhance soil water retention following irrigation or rainfall and reduce irrigation frequency, thereby lowering overall water use and increasing crop water productivity [28,38-39]. Moreover, SAP has been reported to significantly decrease evapotranspiration by reducing soil evaporation losses [28, 40]. Therefore, our results confirmed that water use during the early growth period after SAP application was significantly lower than that in the control, which was attributed to reduced soil water evaporation. In addition, SAP improves soil water availability and enables plants to sustain physiological activity, including stomatal function and photosynthesis [40]. Sabeliwe and Witbooi [41] reported that SAP increases available moisture in the root zone, reduces water stress, and indirectly supports gas exchange traits such as  $g_s$  and photosynthesis. These findings support our results that both soil amendments improved soil moisture status, thereby reducing plant water stress and enhancing stomatal conductance and leaf chlorophyll content.



T1 = unamended soil (control), T2 = cassava tails and stalk (CTS), and T3 = superabsorbent polymer (SAP)

**Figure 4.** Dynamics of cassava physiology months after planting (MAP) under soil amendments in sandy loam and clay loam soils: sandy loam soil (A) leaf water potential (LWP), (B) stomatal conductance ( $g_s$ ) and (C) leaf greenness (SPAD); clay loam soil (D) leaf water potential (LWP), (E) stomatal conductance ( $g_s$ ) and (F) leaf greenness (SPAD). The different letters indicate a significant difference at the 95% confidence level using Duncan's New Multiple Range Test (DMRT). Vertical bars represent the standard error of the means (n = 10).

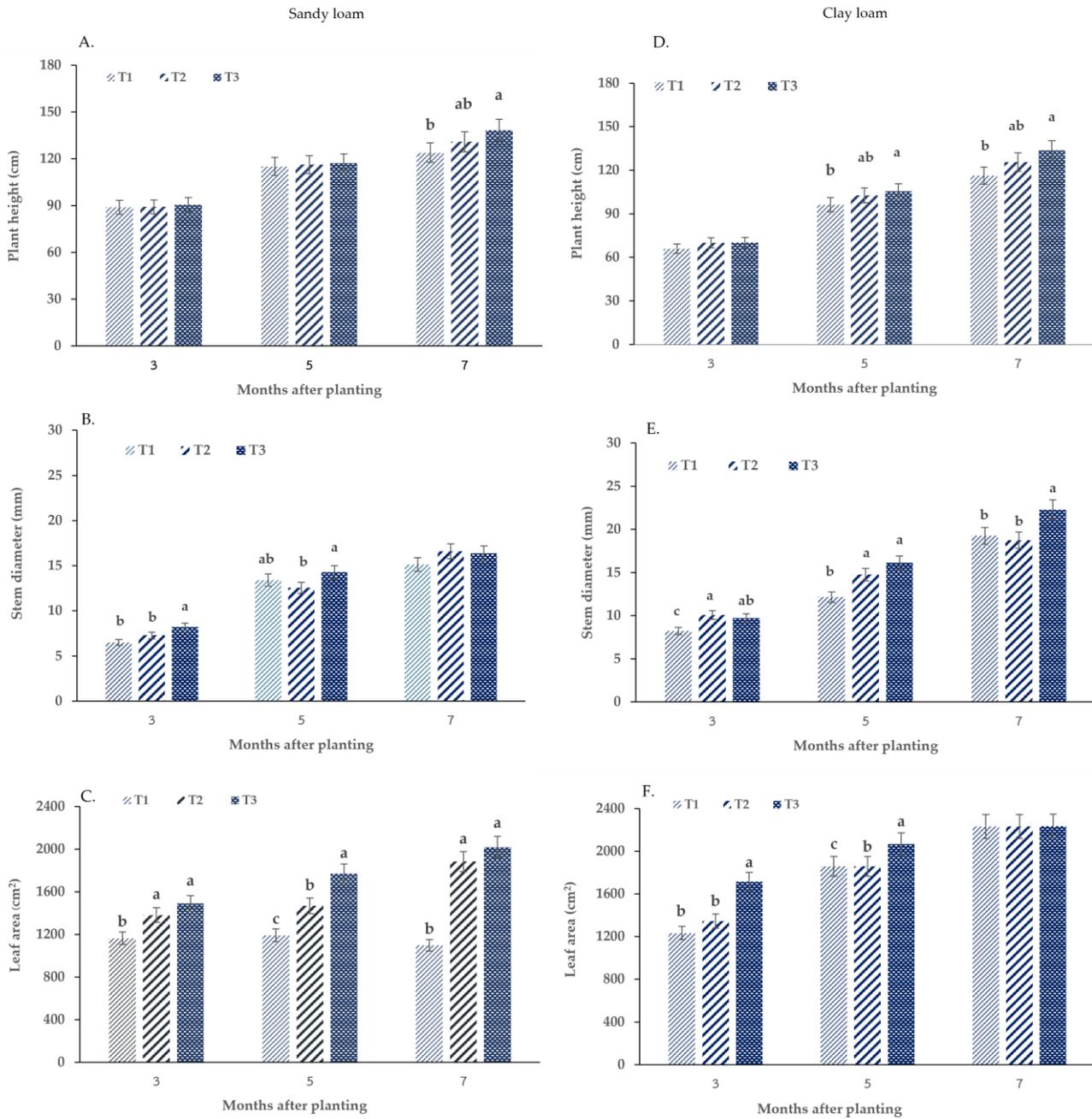
### 3.3 Cassava growth

#### 3.3.1 Sandy loam soil

Plant height, stem diameter, and leaf area in sandy loam soil were affected by the treatments, as shown in Figure 5A-C. At 7 MAP, SAP produced the tallest plants (Figure 5A). During 3-5 MAP, SAP resulted in the greatest stem diameter (Figure 5B). Throughout the growth stages of cassava (during 3-7 MAP), both SAP and CTS applications exhibited higher leaf area than the control (Figure 5C).

#### 3.3.2 Clay loam soil

The plant height, stem diameter, and leaf area in clay loam soil were affected by the treatments as shown in Figure 5D-F. At later growth stages (5-7 MAP), SAP produced the tallest plants (Figure 5D). At the beginning growth stages of cassava (3 MAP), CTS resulted in the greatest stem diameter, whereas at the intermediate growth stages (5 MAP), both SAP and CTS applications exhibited higher stem diameters than the control. At the late stage (7 MAP), SAP produced the greatest stem diameter (Figure 5E). During 5-7 MAP, SAP also had the largest leaf area (Figure 5F). Both CTS and SAP significantly enhanced cassava growth and played key roles in promoting plant development, particularly by increasing plant height, stem diameter, and leaf area. The CTS contained various plant nutrients and was gradually released during early growth stages [34, 41]. Moreover, the considerable amount of OM in the CTS additionally contributes to the activity of vesicular arbuscular mycorrhizae, which have been reported as important for cassava [34]. These findings align with those of Pereira et al. [42], who reported that OM enrichment improves cassava growth, especially in low-fertility soils. Soil amendments also improve soil structure, nutrient availability, and root-zone aeration, thereby stimulating leaf expansion, stem elongation, and root development [43]. Similarly, Ndunge et al. [44] demonstrated that the SAP application significantly enhanced plant growth and yield compared with the control. Their optimal treatment, 1 g SAP per kg of soil combined with a 5-day irrigation interval, increased plant height by 24.0%, leaf area by 11.7%, the number of mature leaves by 11.1%, and dry weight per plant by 85.9% in cowpea. SAP can also serve as a slow-release carrier for nutrients such as K and N, enabling a sustained nutrient supply over time. However, contrasting results were reported by Alotaibi et al. [45], who found that the SAP application, combined with a 50% reduction in irrigation, significantly reduced several growth and yield parameters, including leaf fresh weight, leaf area, total chlorophyll content, leaf water content, fresh weight per plant, and overall yield. This suggests that while SAP can enhance growth under moderate water deficit conditions, excessive reductions in irrigation may limit its effectiveness.



T1 = unamended soil (control), T2 = cassava tails and stalk (CTS), and T3 = superabsorbent polymer (SAP)

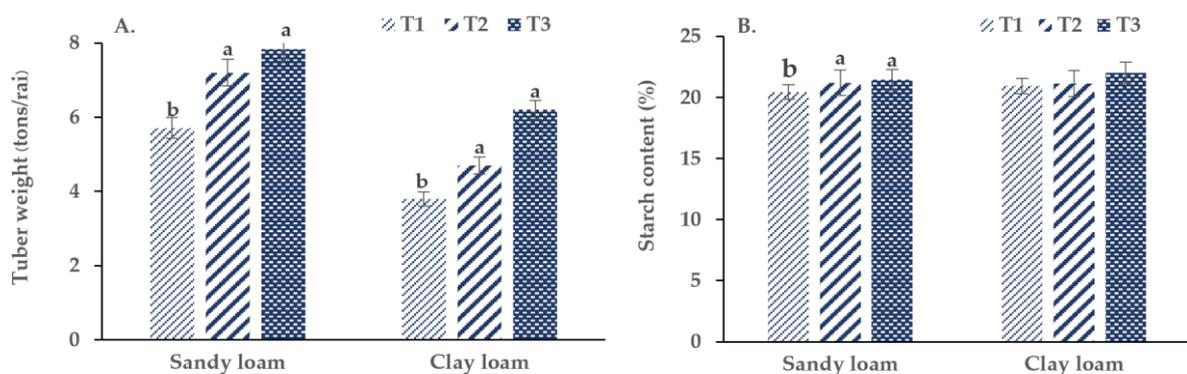
**Figure 5.** Dynamics of cassava growth under soil amendments in sandy loam and clay loam soils: sandy loam soil (A) plant height, (B) stem diameter, and (C) leaf area; clay loam soil (D) plant height, (E) stem diameter, and (F) leaf area. The different letters indicate a significant difference at the 95% confidence level using Duncan's New Multiple Range Test (DMRT). Vertical bars represent the standard error of the means (n = 10).

### 3.4 Tuber weight and starch content

Tuber weight was affected by the treatments, as shown in Figure 6A. In both soil textures, SAP and CTS applications produced significantly higher yields than the control. In sandy loam soil, SAP and CTS produced the highest tuber yields (7.83 and 7.20 tons/rai, respectively), corresponding to increases of 26.09-37.13% compared with the control (5.71 tons/rai). Similarly, in clay loam soil, SAP and CTS applications

produced the highest yields (6.20 and 4.71 tons/rai, respectively), meaning improvements of 23.29–62.30% over the control (3.82 tons/rai). Overall, these results indicated that soil amendments significantly enhanced cassava tuber production in both sandy loam and clay loam soils. Starch content was also affected by the treatments, as shown in Figure 6B. In sandy loam soil, both soil amendments increased starch content compared with the control. SAP yielded the highest starch content (21.44%), followed by CTS (21.20%), whereas the control exhibited the lowest (20.43%). These findings indicate that soil amendment application enhanced starch accumulation relative to unamended soil.

Across soil textures, SAP produced the greatest improvements in cassava yield and starch content, likely owing to its superior capacity to retain water and nutrients [46–47]. Previous studies have suggested that yield enhancement following SAP application is associated with increases in water-stable aggregates and soil OM [33, 37, 48]. By maintaining soil moisture in the root zone, SAP reduces plant water stress and supports crop development during dry periods. Moreover, SAP can extend the time required for soil to reach the permanent wilting point (PWP), thereby enabling crops to withstand prolonged drought. For example, the application of natural superabsorbent hydrogel at rates of 0.3–1.0% increased the time needed to reach PWP in loamy sand soils by more than threefold compared with untreated soil [48]. Moreover, SAP acts as a slow-release carrier for fertilizers due to its three-dimensional polymer network, which can absorb water several hundred times its own weight. As soil dries, water and dissolved nutrients are gradually released through diffusion-controlled processes, with release rates governed by polymer concentration and the volume of water stored within the matrix [49]. The CTS application also improved cassava productivity, particularly in coarse-textured soils, by increasing soil organic matter and major nutrient contents. Previous work has shown that CTS applied alone or in combination with bentonite substantially enhanced tuber yield and starch concentration. This finding was reported by Ketkhaio et al. [34], who found that amending the soil with CTS at both rates (6.25 and 12.5 tons/ha, respectively) undoubtedly increased cassava yields in both growing seasons. The CTS application played a part in cassava yield improvement by providing secondary and micronutrients, in addition to improving the nutrient retention in soil, which in turn increased nutrient use efficiency, held plant nutrients against leaching, and retained soil moisture [34].



T1 = unamended soil (control), T2 = cassava tails and stalk (CTS), and T3 = superabsorbent polymer (SAP)

**Figure 6.** Effect of soil amendments on tuber weight at 11 months after planting (MAP) in sandy loam and clay loam soils: (A) tuber weight, (B) starch content. The different letters indicate a significant difference at the 95% confidence level using Duncan's New Multiple Range Test (DMRT). Vertical bars represent standard error of the means (n = 4).

#### 4. Conclusions

The application of CTS and SAP has been proven to be highly effective in enhancing both the physical and chemical properties of soil. These amendments reduce BD and PD, increase PO, and increase nutrient availability in both sandy loam and clay loam soils, which are important requirements for plant growth. They also induce physiological responses and cassava plant growth. Applying SAP can enhance LWP, gs, leaf

greenness, plant height, as well as fresh tuber yield and cassava starch content, particularly in sandy loam soil. The present research also provides evidence that using CTS and SAP is an effective way to improve soil properties and physiological processes of the vegetative community, as well as to enhance cassava growth. Such practices can increase yields and provide a sustainable, appropriate soil management strategy for cassava production systems, especially in areas with soil and water limitations. However, this study was conducted over a single growing season and involved only one cassava cultivar. Future research should therefore investigate the long-term and multi-season effects of CTS and SAP applications across different cultivars and environments to assess soil properties and cassava yield comprehensively.

## 5. Acknowledgements

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