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Effect of Plant Spacing on Growth Development and Yield of Cassava (*Manihot esculenta* Crantz) in Tropical Soil

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ABSTRACT

Cassava (Manihot esculenta Crantz) is an important food crop widely cultivated worldwide and critical in addressing food security. Optimising plant spacing is essential for improving yield and agronomic performance in tropical soils. This study evaluated the effect of different plant spacings on growth and yields using the Markona variety. The experiment consisted of five spacings: T1 (0.50×1.50 m), T2 (0.75×1.50 m), T3 (1.00×1.50 m), T4 (1.25×1.50 m) and T5 (1.50×1.50 m), corresponding to plant densities of 13 333 plants ha^{-1}, 8 888 plants ha^{-1}, 6 666 plants ha^{-1}, 5 333 plants ha^{-1} and 4 444 plants ha^{-1}, respectively. Growth parameters measured included plant height, girth circumference, leaves number per plant, chlorophyll content (SPAD unit) and root fresh weight yield. Results showed that plant spacing did not significantly affect plant height, girth circumference, leaves number per plant, and chlorophyll content. Root yield was greater at plant spacings between 0.75 m and 1.25 m, while yield was lower at 0.50 m and 1.50 m. The highest yield at 14.59 t/ha was obtained at the 1.25 m spacing and was significantly higher than T1 and T5. These findings highlight the importance of appropriate plant spacing in maximising cassava productivity under land constraint and provide useful agronomic guidance that may be applied to other cassava varieties.

Key words: Girth circumference, plant spacing, soil, root tuber, yield

INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is an important food crop widely cultivated in tropical and subtropical regions. The crop is well known for its ability to tolerate low fertility, acidic soil and poor growing conditions, as well as its resilience to drought conditions (Kintché *et al*., 2017). Depending on the environment, cassava can be harvested between 6 to 24 months after planting. Whereas under less favourable conditions such as dry and cold climates, the crop may require up to 18 months or more to mature (Otálora *et al*., 2024). The crop is cultivated mainly for its starch roots, which serve as a staple food and an important source of carbohydrates in many tropical countries. A unique characteristic of cassava is that its roots can remain in the soil for a long period without harvesting, making it a valuable crop and contributing to food security (Benti *et al*., 2022). Besides the use of roots for food and livestock feed, cassava leaves can be processed as hay and silage for animal feed (Malik *et al*., 2020). Apart from the use for food, cassava is widely used as an industrial raw material in textile, chemical, pharmaceutical, paper and cardboard manufacturing (Streck *et al*, 2014). Globally, cassava production reached approximately 333.7 million metric tonnes (MT) in 2023 (Rawaida *et al*., 2024). In Malaysia, cassava production was recorded at about 45,266.1 MT in the same year, making it the second most produced agricultural commodity after sweet corn (Department of Statistics, 2023).

Despite its adaptability, cassava yield is influenced by several agronomic factors including planting time, plant spacing, quality of planting material, fertilisation and pest and disease management (Cock, 1985). Among these factors, plant spacing plays a critical role in determining productivity. Plant spacing should be adjusted according to soil fertility to ensure efficient use of available resources. High plant density can lead to competition for nutrients, water, and light, reducing root yield, while low density leaves parts of the field underutilized, thereby reducing yield productivity. Therefore, optimizing plant spacing is essential to maximize cassava productivity. Although a standard planting density of 10,000 plants per hectare is widely recommended for cassava cultivation (MARDI, 2005; Nurul Nahar *et al.*, 2024), previous studies have indicated that closer spacing may increase cassava yields by increasing plant population per unit area (Abrell *et al*., 2022). Plant spacing has been reported to influence the growth characteristics of cassava such as plant height, plant canopy, leaf number, and storage root development (Mashuubu *et al*., 2024). Hidoto and Loha (2013) further reported that cassava planted at intra- and inter-row spacing of 80–120 × 60–100 cm required about three to four months to develop a full plant canopy, potentially delaying crop maturity and harvesting time of cassava.

Given the importance of cassava as a staple food particularly in tropical regions, determining the optimum plant spacing is crucial for agronomic consideration. Previous studies have mainly focused on the effect of spacing on tuber yield (Aguiar *et al*., 2011), while fewer studies have focused on its influence on growth development under tropical soils conditions. Therefore, this study was conducted to evaluate the effect of different plant spacings on the growth and root yield of cassava grown under tropical soil conditions in Malaysia.

MATERIALS AND METHODS

Experiment design and field management

The field experiment was established in the research plots of the Malaysian Agricultural Research & Development Institute (MARDI), Serdang, Selangor, Malaysia. The land was cleared, followed by ploughing and harrowing. The plot size was 6.0 m × 4.5 m and each plot was separated by 1.0 m and replications were separated by 1.5 m. The field experiment was set up in a randomised complete block design (RCBD). The treatments consisted of five plant spacings: T1) 0.5 m × 1.5 m, T2) 0.75 m ×1.5 m, T3) 1.0 m×1.5 m, T4) 1.25 m × 1.50 m and T5) 1.50 m × 1.50 m, corresponding to densities 13 333 plants ha^{-1}, 8 888 plants ha^{-1}, 6 666 plants ha^{-1}, 5 333 plants ha^{-1}, and 4 444 plants ha^{-1}, respectively. Markona stem cuttings were selected in this study. The stem cuttings used were about 25 cm and were planted at an approximately depth of 10 to 15 cm according to MARDI recommendation (MARDI, 2005). The sources of N were urea (46% N), while P was from triple super phosphate (21% P_2O_5) and K was from muriate of potash (60% K_2O). The fertiliser application was applied at 21 days after planting as per recommendations (MARDI, 2005; Nurul Nahar *et al.*, 2024). Supplemental irrigation was applied once daily in the morning about 10 to 15 min during the first five months of growth. Pest and disease control measures were applied whenever signs of disease and insect intensification were observed in the field as following recommendation guidelines by MARDI (MARDI, 2005).

Physico-chemical properties of soil

Soil samples were collected from the study site at a depth of 0–10 cm, two weeks before planting and at harvest. A total of 10 sub-sampling points were randomly selected within the experimental plot, and the soil was collected into clean plastic bags. The subsamples were homogenised to form a composite sample. Approximately 1 kg of composite soil was kept for laboratory analysis. Soil samples were air-dried, ground, and sieved through a 2 mm mesh for physico-chemical analysis. The parameters measured included pH value, total nitrogen (N), phosphorus (P), potassium (K), calcium (Ca) and cation exchange capacity (CEC). Soil pH value was determined using a glass electrode pH meter in a 1:2.5 (soil: water) suspension. Available P was analysed accordingly following the Bray and Kurtz No. 2 method (Bray & Kurtz, 1945) and measured by a UV-Visible Spectrophotometer. Total N was analysed using the Kjeldahl method (Kjeldahl, 1883). Exchangeable bases and CEC were determined by leaching the soil with 1.0 M ammonium acetate (NH4 OA) solution buffered at pH 7 following the method described by Lavkulich (1981). The concentration of exchangeable bases was measured using an inductively coupled plasma mass spectrometry (ICP-MS).

Data collection and measurements

Plants were randomly selected and tagged in each plot to measure the growth performance every month until ninth month. Plant height was taken from the base to top by using a measuring tape. Plant girth was measured at the base of the cassava using a digital vernier caliper. Leaf count per plant was manually counted before harvest. The cassava plants were harvested at the center of each plot by using 6.0 m × 1.5 m quadrat. The fresh weight of the cassava was determined using a weighing machine. The total yield from the quadrat sample was calculated in kg per hectare.

Data analysis

The experimental data were analysed using SAS software. Treatments means were separated using Least Significant Difference (LSD) test at the 1% probability level.

RESULTS AND DISCUSSION

Chemical characteristics of soil

The soil before and after treatment was compared with the optimum range as shown in **Table 1**. The initial soil pH was acidic (pH 4.83), which is typical of many tropical soils in Malaysia that are prone to acidity-related nutrient limitations. After harvest, all treatments significantly increased soil pH to values between 6.51 and 6.70. Treatment 2 recorded the highest pH, while the lowest values were observed in T4 and T5. The increase in soil pH compared to initial conditions was attributed to early fertilisation, which can enhance nutrient availability throughout cassava's growth cycle.

Long *et al*. (2017) highlighted that a low pH value can lead to poor crop growth and yield due to deficiencies in macronutrients and micronutrients such as P, Ca, Mg, and K. Conversely, Guo *et al*. (2020) reported that a high pH value reduces root activity, thereby limiting water and nutrient absorption. Meanwhile, EC values ranged from 29.81 to 33.41 µs/cm across treatments, remaining within the optimum range for cassava production. Compared with the initial soil, EC showed a slight decline possibly due to the stabilization of soluble salts and nutrient uptake by the crop. A similar trend was observed in the CEC where values ranged from 0.10 to 0.42 meq/100g soil. The reduction in CEC values may be associated with nutrient removal by cassava plants during the growth cycle.

Total N increased in all treatments compared with the initial soil, although no significant difference was observed among treatments. Similarly, organic C increased to a range of 8.10% to 9.82%, which is higher than the initial soil condition. This increase may be attributed to the accumulation of fallen leaves and the incorporation of crop residues into the soil during the growth cycle. Higher levels of organic matter can enhance microbial activity in the soil, thereby promoting a healthier root environment (Radhakrishnan *et al*., 2022).

In contrast, available P decreased from an initial 34.25 mg/kg to a range of 1.52–1.86 mg/kg across all treatments. The depletion highlights the high P demand by cassava during tuberous root development. Howeler (2002) reported that harvesting cassava roots can remove approximately 0.30-11.2 kg/ha of P from the soil. The results suggest that the application of phosphate fertiliser is essential for sustainable cassava production, particularly when soil P levels fall below the optimum range.

Meanwhile, exchangeable K and Mg were higher in T4 although no significant differences were observed among treatments. This is possibly due to greater nutrient uptake associated with plant growth and biomass accumulation under different planting densities. However, based on the status of exchangeable K across the treatments, there is a risk of declining exchangeable K levels if continuous cropping is practised without replenishment through K containing fertiliser. Basri *et al*. (2024) stated that increased levels of Ca and Mg, along sufficient P availability, are essential factors for enhancing plant development. Furthermore, the presence of Ca and Mg can help to promote favorable soil structure and chlorophyll formation (Shafar *et al*., 2013). Based on the soil conditions described above, although cassava can tolerate soils with low fertility, fertiliser application remains vital to support plant growth and tuberous root production. Without balanced fertilisation, continuous cultivation leads to a decline in soil fertility due to nutrient removal during harvest (Noorsuhaila *et al*., 2024), potentially lowering crop yield in subsequent cycles.

Table 1: Physico-chemical properties of soil before and after experiment and soil fertility range for cassava production

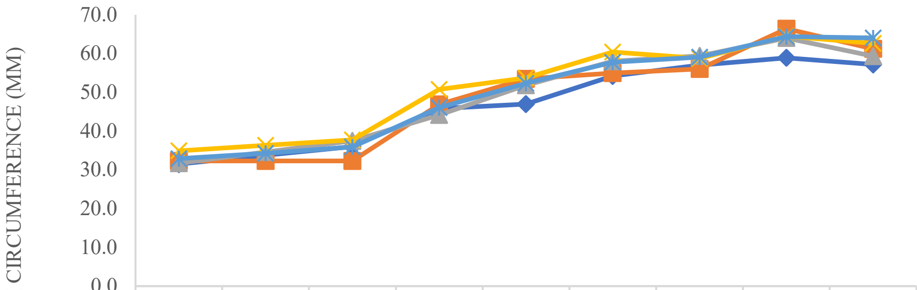
Parameters	Soil before experiment	Optimum requirement	T1	T2	T3	T4	T5
pH	4.83	4.5 - 8.0	6.65^{ab}	6.70^{a}	6.55^{bc}	6.51^{c}	6.51^{c}
EC (µs/cm)	36.03	10 – 1700	29.81^{a}	30.98^{a}	33.41^{a}	32.10^{a}	32.52^{a}
CEC (meq/100g soil)	9.47	4.2 – 10.7	0.23^{a}	0.42^{a}	0.10^{a}	0.40^{a}	0.28^{a}
Total N (%)	0.14	0.20 - 0.50	1.90^{a}	3.31^{a}	1.00^{a}	3.11^{a}	2.30^{a}
Organic C (%)	1.62	4.0 – 10.0	9.01^{a}	9.82^{a}	8.41^{a}	8.63^{a}	8.10^{a}
Av. P (µg/g)	34.25	4.2 – 1.0	1.70^{a}	1.86^{a}	1.58^{a}	1.62^{a}	1.52^{a}
Ex. K (ppm)	3.51	0.15 - 0.25	4.13^{ab}	4.92^{a}	4.35^{ab}	3.41^{b}	4.30^{ab}
Ex. Mg (ppm)	0.91	0.40 - 1.00	9.88^{ab}	11.33^{a}	11.33^{a}	9.44^{b}	10.10^{ab}
Ex. Ca (ppm)	11.91	1.0 – 5.0	3.18^{a}	4.15^{a}	4.18^{a}	3.13^{a}	3.33^{a}

Note: Means with the same letters in the same row were not significant at p≥0.05. EC – electrical conductivity; CEC – cation exchange capacity; N – nitrogen; C – carbon; Av. – available; P – phosphorus; Ex. – exchangeable; K – potassium; Mg – magnesium; Ca – calcium. Source: Howeler, 2002; Imakumbili *et al*., 2021; Landon, 2014; Lelago and Buraka, 2019; Lindsay and Norvell, 1978; Motsara and Roy, 200); Ocaña-Reyes *et al*., 2024; Vinhal-Freitas *et al*.,2017.

Growth characteristics

Stem girth

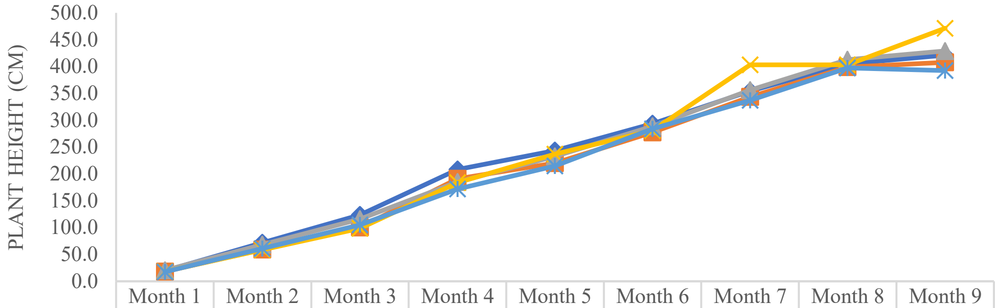
Stem girth development followed a uniform growth pattern across all planting distances from the first to the eighth month, with a slight decline observed in the ninth month (**Figure 1**). During the initiation phase, stem girth ranged between 31.5 and 37.7 mm, with no significant difference among treatments. An increase in girth was observed between the fourth and sixth months during the secondary thickening phase, where T3 and T4 showed slightly greater expansion compared to the narrowest spacing (T1) and the widest spacing (T5). By the sixth month, T4 recorded the highest girth (60.4 mm), indicating that this wider spacing provided more available nutrients for plant uptake. From the seventh to the ninth month, stem girth continued to increase gradually, reaching peak values of 58.9 and 66.4 mm across treatments. Treatment 2 and T5 recorded the highest girth values at the eighth (66.4 mm) and ninth (64.0 mm) months, respectively, while T1 recorded the smallest girth circumference, however no significant differences were observed among the treatments. These results align with Oliveira *et al*. (2019), who reported that reduced plant density increased stem diameter and the production of marketable cassava. The slight decline observed in the ninth month likely reflects physiological transition from the root bulking to the maturity phase, when assimilate translocations become saturated for tuber development.



	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8	Month 9
T1	31.5	33.8	36.0	45.8	47.0	54.2	57.0	58.9	57.2
T2	32.3	32.3	32.3	46.9	53.5	55.0	56.0	66.4	61.2
T3	31.7	34.6	37.5	44.2	51.8	58.0	59.4	64.0	59.3
T4	34.9	36.3	37.7	50.8	53.7	60.4	58.8	64.5	62.6
T5	32.9	34.3	35.9	46.1	52.3	57.8	59.1	64.4	64.0

Figure 1: Girth circumference increments amongst the treatments

Plant height increased consistently from the first to the ninth month across all treatments, indicating normal growth development of cassava under favourable soil conditions (**Figure 2**). During the initiation phase, plant height ranged from 17.6 to 123.8 cm, with all treatments showing an upward trend. This growth pattern corresponds with the initial soil status, where soil pH, organic C, and nutrient levels were within acceptable ranges, indicating that soil chemical properties did not limit early growth. During secondary thickening phase, plant height increased more rapidly, reflecting active canopy expansion. By the sixth month, plant heights ranged between 280 to 294 cm across treatments. The similar growth trend observed among treatments during this stage indicates that planting distance did not influence vertical growth when soil fertility and nutrient availability were adequate. This observation is consistent with the finding of Mashuubu *et al*. (2024), who reported no significant differences in cassava plant height despite variations in planting density. A similar trend was also observed for stem girth, where all treatments demonstrated consistent development. By the ninth month, T4 showed the highest plant height reaching 471.4 cm followed by T3 and T1, while the lowest was observed in T5. The vigorous height performance in T4 may be attributed to the wider planting distance, which allowed more efficient utilisation of soil nutrients such as P and K, thereby promoting biomass accumulation. These findings suggest that plant height and stem girth represent indicators of development of tuberous roots yield under favourable soil conditions. Apriamti *et al*. (2022) reported that vigorous vegetative growth, particularly plant height and stem diameter plays an important role in plant metabolic processes. Their study demonstrated that plants with greater high and stem thickness were able to synthesise amino acids and proteins more effectively. This improves photosynthetic efficiency and the translocation of assimilates to various plant parts, contributing to increase the tuber weight and cassava productivity.

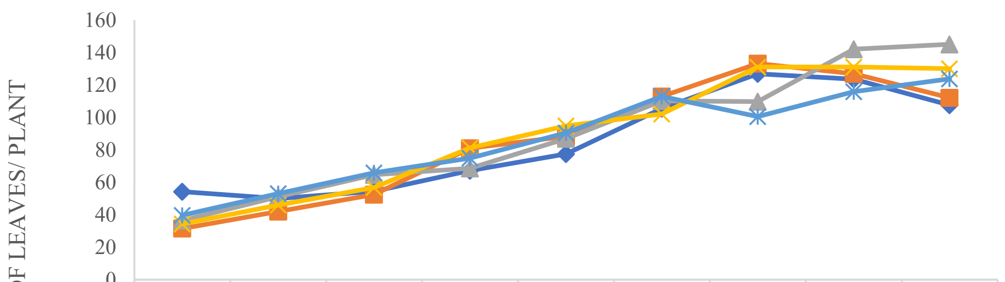


	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8	Month 9
T1	19.5	71.6	123.8	208.0	243.6	293.8	354.5	405.3	421.2
T2	18.1	59.1	100.2	191.1	220.3	277.5	343.4	399.1	407.8
T3	20.4	68.0	115.7	184.9	232.6	288.8	356.3	413.0	429.1
T4	18.3	58.4	98.5	183.9	237.0	280.8	403.4	403.4	471.4
T5	17.6	61.3	105.0	171.9	215.1	283.8	337.1	397.4	392.2

Figure 2: Plant height increment among the treatments

Number of leaves

The number of leaves per plant increased consistently from the first to the eighth month across all planting distances (**Figure 3**). During the initiation phase, the number of leaves ranged from 32 to 66 leaves per plant. No significant differences were observed among the treatments, indicating that planting distance had no effect on leaf production during this phase. An increase in leaf number was observed between the fourth and sixth months, corresponding to the active secondary thickening phase. During this period, leaf numbers increased across all treatments, reaching 102 and 113 leaves per plant by the sixth month. This trend aligns with the earlier results for stem girth and plant height, which also showed rapid growth during the same phase. By eight months, T3 recorded the highest leaf number, with a maximum of 145 leaves per plant followed by T4 and T5. In contrast, T1 showed a slight decline from the eighth to the ninth month. The reduction in leaf number during the maturity stage can be attributed to natural leaf senescence as the crop approaches maturity and assimilates translocation is increasingly allocated to tuberous root development. This observation is consistent with the findings of Apriamti *et al*. (2022) who reported that the rate of dry matter accumulation is highest in the tubers at this stage, while leaf aging begins to occur, leading to leaf senescence.

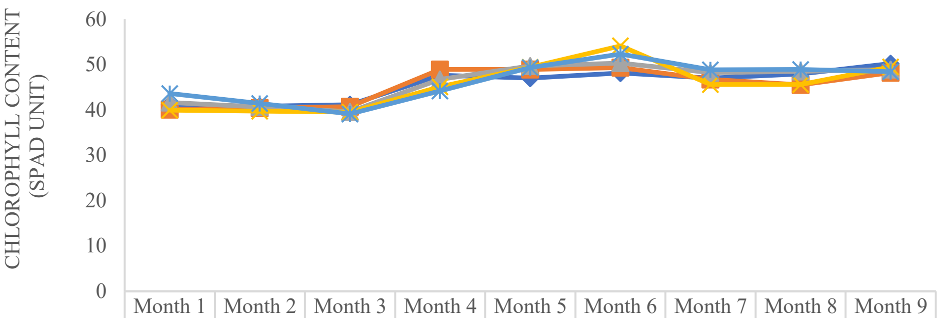


	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8	Month 9
T1	54	50	54	67	77	106	127	124	108
T2	32	42	53	81	88	113	133	127	112
T3	37	51	65	69	87	110	110	142	145
T4	34	46	57	81	95	102	131	131	130
T5	40	53	66	75	90	113	101	116	124

Figure 3: Number of leaves per plant amongst the treatments

Chlorophyll content (SPAD value)

The SPAD value, which reflects relative leaf chlorophyll content and plant N status, remained stable throughout the nine months growth period across all planting distances (**Figure 4**). During the initiation phase, SPAD values ranged between 39 and 44 units. No significant differences were observed among the treatments, indicating that planting distance had no effect on chlorophyll concentration during this phase. This observation is consistent with the earlier soil chemical analysis, where soil pH, organic carbon, and nutrient availability were within suitable ranges for cassava production, allowing for uniform early growth across the treatments. During the secondary thickening phase, SPAD values increased gradually across all treatments, reaching values between 47 and 54 units. This suggests improved photosynthetic capacity and efficient N utilisation during canopy expansion. Among treatments, T4 recorded the highest SPAD value (54.1) at the sixth month, indicating slightly higher chlorophyll content compared with other planting distances. This increase is similar to the trends observed in plant height and leaf number during the same phase, suggesting that wider spacing allow for better light interception and chlorophyll synthesis. After the sixth month, SPAD values showed slight fluctuations but remained generally stable, ranging between 45 and 50 units until the ninth month. The small decline observed at the ninth months may be associated with natural aging, though the leaves maintained sufficient photosynthetic capacity to continue providing carbon assimilated as the crop shifted energy towards tuber bulking. All treatments maintained relatively similar SPAD values, indicating that chlorophyll content and leaf N status were not significantly influenced by planting distance. This suggests that soil fertility and fertiliser application played a more important role in sustaining leaf physiological activity than planting distance alone.



	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8	Month 9
T1	41.1	40.8	41.1	47.6	47	48.1	47	47.9	50.2
T2	40.1	40.4	40.7	48.9	48.9	49.3	46.7	45.5	48.2
T3	41.6	40.6	39.6	46.7	49.7	50.3	48.2	48.5	48.9
T4	39.9	39.7	39.5	45.1	49.4	54.1	45.6	45.6	49.5
T5	43.6	41.4	39.1	44.2	49.3	52.3	48.8	48.9	48.4

Figure 4: SPAD reading values among treatments

Root fresh weigh yield

Cassava yield was significantly affected by planting distance ($p \leq 0.01$), highlighting that plant spacing plays a crucial role in determining tuber productivity per hectare (**Figure 5**). T4 produced the highest yield at 14.59 t ha^{-1} which was significantly different from T1 and T5. The yield followed the order T4> T3>T2>T5>T1, with the lowest yield recorded in T1 at 7.66 t ha^{-1}. The lowest yield under T1 was likely due to competition for nutrients, water, and light which may have restricted canopy development and limited storage root expansion. Conversely, the widest spacing in T5 resulted in a yield reduction to 9.17 t ha^{-1}. This reduction is associated with a lower plant population per unit area, which limited total yield accumulation despite the potential for producing larger tubers per plant. As noted by Kartika (2018), wider plant spacing may reduce the efficient utilisation of sunlight and soil nutrients, as light interception falls directly onto the soil surface and nutrients may be lost through leaching and surface runoff. Their study reported that the reduction in light interception efficiency limits the total photosynthetic activity and decreases the allocation of assimilates to the tubers, thereby reducing yield. Other studies by Apriamti *et al*. (2022) support this finding, reporting that lower plant populations increase the area of exposed soil surface. Their study reported that exposed soil surfaces increase soil evaporation and cause greater nutrient losses compared to the amounts absorbed by plants. As a result, plants may experience nutrient deficiencies, which can negatively affect their growth and development. Meanwhile, plant spacing at 1.00 m (T3) and 0.75 m (T2) produced high yields at 13.65 t ha^{-1} and 10.80 t ha^{-1}, respectively, and were not significantly different from plant spacing at 1.25 m (T4). This suggests that a plant spacing between 0.75 m and 1.25 m and, with 1.5 m between rows provides an optimal balance between plant population density and nutrient availability, especially P and K for tuber development. In contrast, the narrow plant spacing in T1 resulted in the lowest yield, likely due to nutrient competition among plants, while the widest spacing in T5 reduced total yield due to the lower plant population per hectare. Tis suggets that an optimum palnting density is required to balance resouce availability and lant popuplation. Haryadi (1988) highlighted that plant density strongly influences crop growth and yield performanc. Probowati (2014) further noted that appropriate plant spacing promotes efficient resourse untilisation by ensuring adequate access to nutrients and sunlight for each plant, while also facilitating crop management and field maintenance. This study provides significant data on the effect of plant spacing on the development of cassava root yield. These findings offer useful insights that may be applicable to other cassava varieties grown under similar soil conditions. Further research is recommended to determine the optimum harvesting age for cassava, as the ideal plant density may vary with soil type and maturity.

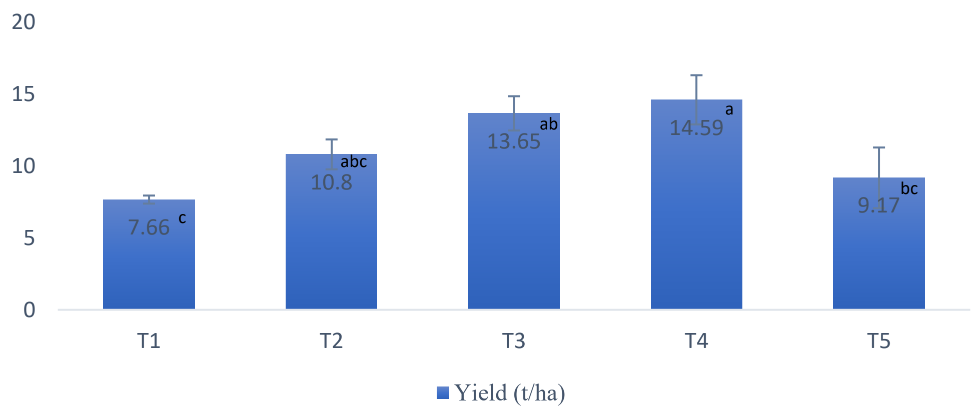


Figure 5: Comparison of fresh roots yield of cassava between treatments

CONCLUSION

Ultimately, plant spacing significantly influences cassava fresh yield and soil nutrient dynamics, while growth performance was not significantly affected by plant spacing. Based on the results presented above, a plant spacing between 0.75 m and 1.25 m (intra-row) and 1.50 m between rows (inter-row) is recommended to achieve higher yields while maintaining soil fertility in tropical acidic soils. This spacing ensures an optimal balance between plant population and nutrient availability, thereby enhancing yield and nutrient use efficiency. These findings provide practical agronomic guidance for improving cassava production by maximising field productivity. With increasing global food demand and limited agricultural land, sustainable agricultural practices are important to maintain crop productivity and soil fertility while ensuring food security.

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