Journal of
Current Opinion in Crop Science
Journal homepage: www.jcocs.com; ISSN(O):2583-0392

RESEARCH ARTICLE

Effect of fertilizer, planting density and variety on growth and yield of stem cuttings of cassava

Yassin Y. Mashuubu[1*], Sixbert K. Mourice[2], Abdul Kudra[2] and Freddy Baijukya[3]

[1]Tanzania Agricultural Research Institute - Ilonga Agricultural Research Center, Kilosa - Morogoro, Tanzania.
[2]Department of Crop Science and Horticulture, Sokoine University of Agriculture, Morogoro, Tanzania.
[3]International Institute of Tropical Agriculture, Dar es Salaam, Tanzania.

Edited by:

Dr. M. Murugan, KAU, CRS-Pampadumpara, Kerala, India.

Reviewed by:

Dr. Enrique E. Biñas Jr, West Visayas State University, Philippines.

Dr. M. Mobarak Hossain, IRRI Bangladesh, Dhaka 1213, Bangladesh.

Article history:

Received: January 15, 2024
Accepted: March 12, 2024
Published: March 27, 2024

Citation:

Mashuubu, Y. Y., Mourice S. K., Kudra, A., & Baijukya, F. (2024). Effect of fertilizer, planting density and variety on growth and yield of stem cuttings of cassava. *Journal of Current Opinion in Crop Science, 5*(1), 27-40.

https://doi.org/10.62773/jcocs.v5i1.226

*Corresponding author's e-mail address: yassin.mashuubu@gmail.com (Yassin Y. Mashuubu).

ABSTRACT

The shortage of cassava stem cuttings presents a significant constraint to cassava production in Kilosa district, Tanzania. To address this issue, a field experiment was conducted within the research plots of TARI Ilonga, Kilosa, to evaluate the impact of fertilizer application, planting density, and variety on cassava stem cutting yield. Employing a split-split plot design in a randomized complete block design (RCBD), the experiment featured variety, planting density, and rates of fertilizer combinations as main, sub, and sub-sub factors, respectively. The study focused on three improved varieties of cassava (Kiroba, Chereko, and Mkuranga 1), with planting densities of 10,000, 13,000, and 20,000 plants per hectare, and ten fertilizer treatment rates. Data collected encompassed soil physico-chemical characteristics of the site, total plant height, stem height, stem diameter, number of stem cuttings, and nodes per stem cutting. Analysis of the plant data involved variance analysis, with significant treatments distinguished using Tukey's honesty significance test ($p<0.05$). Notably, the application of 150 kg N ha^{-1} resulted in statistically higher total plant height and stem height, while a planting density of 20,000 plants ha^{-1} combined with the Kiroba variety exhibited statistically higher numbers of stem cuttings ha^{-1}. The study concludes that for effective stem multiplication, a planting density of 20,000 plants ha^{-1} and the application of N fertilizers at a rate of 150 kg N ha^{-1} are recommended.

Keywords: cassava, fertilizer combinations, growth, planting density, yield.

INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is a perennial shrub propagated vegetatively through matured stem cuttings (Tokunaga et al., 2020). Cultivated extensively across tropical and subtropical regions in Latin America, Asia, and Africa, cassava is valued for its starchy thickened roots, as highlighted by Malik et al. (2020). Renowned for its adaptability, cassava thrives in soils characterized by low fertility and acidity, demonstrating resilience to drought conditions (Kintché et al., 2017). Global production of cassava showed a total production of about 303.6 million MT in 2019 out of which Africa contributed about 61%. Tanzania is among the 10 major cassava producers with production of 8.2 MT, which is equivalent to 4.3% of the total production in Africa, and is the first in East Africa (FAOSTAT, 2021). The crop ranks the second most-produced agricultural commodity in Tanzania after maize (Masamba et al., 2022; Mtunguja et al., 2019).

The crop is commonly vegetative propagated through stem cuttings (Legg et al., 2015), from fresh stems of mature plants aged 8 to 18 months (Tokunaga et al., 2020). In Kilosa district, about 97% of cassava farmers are using stem cuttings from cassava local varieties (KDC, 2020/21). However, cassava landraces are low-yielding and are not able to tolerate major pests and diseases (Nweke et al., 2019), hence local varieties are not suitable for the production of healthy stem cuttings. On the other hand, improved varieties are high-yielders, and are tolerant to major pests and diseases of cassava. Such diseases include cassava mosaic virus (CMV), cassava brown streak disease (CBSD) and cassava witches broom (CWB). These diseases can cause yield reduction of up to 90% and equally affect starch content and quality (Nzuki et al., 2017). On the other hand, the common major pests of cassava in Tanzania include cassava stem borers (*Chilomina clarkei*), cassava mealybug (*Phenacoccus manihoti)* and African cassava red mites (*Eutetranychus africanus* Tucker). Other pests of cassava are cassava green mites (*Mononychellus tanajoa*), white fly (*Bemisia tabaci*) and cassava mosaic gemini viruses (CMGs) (Graziosi et al., 2016).

Currently, the main improved cassava varieties in Tanzania include *Kizimbani, Mkumba, Chereko*, *Kiroba*, *Kipusa*, *Mkumbozi* and *Mkuranga* 1*.* The stem cuttings from these varieties are highly demanded by farmers but their production does not satisfy the demands of the farmers. To improve the productivity of cassava in the Kilosa district, the rapid multiplication of stem cuttings of these varieties is important.

Improper planting density, resulting in fields with excessively high or low planting density, is prevalent in Tanzania. Excessive planting density results in subterranean competition for essential nutrients and moisture, whilst insufficient planting density results in certain areas of the fields remaining uncultivated, thus resulting in diminished cassava yields. Nevertheless, a study conducted in Brazil by Abrell et al. (2017) demonstrated that increased planting density can lead to improved cassava yields. The suggested planting density for cassava in many countries is 10,000 plants ha^{-1}. However, it has been noted that higher planting densities, particularly for non-branching varieties, can significantly enhance cassava yields (Ekeleme, 2016). Rojas et al. (2007) conducted a study on the spacing of cassava plants, both within and between rows. They found that the spacing within rows had an impact on various plant characteristics, including plant height, stem and canopy diameter, number of leaves, and root output.

The decrease in soil fertility, specifically in the elements Nitrogen, Phosphorus, and Potassium, is a significant constraint on crop output in Sub-Saharan Africa, notably in regions where cassava is cultivated in Tanzania. According to Howeler (2014), cassava has been observed to thrive in soils characterised by poor fertility. However, Biratu et al. (2018) have documented that the crop exhibits a significant degree of responsiveness to the use of fertilisers. The researchers additionally documented a notable augmentation in the height of cassava stems, measuring 163.9 cm, and a diameter of 2.32 cm, as a result of the utilisation of compound fertilisers (150N-33P-124K). In a study conducted by Macalou (2018), it was observed that the application of 300 kg NPK ha^{-1} resulted in a notable augmentation in stem height by 126 cm and an average of 2.05 branches per plant. The findings of this study indicate that the use of fertiliser plays a significant role in enhancing the productivity of cassava, particularly stem cuttings. Therefore, in order to enhance cassava production, the utilisation of compound fertilisers is suggested; however, the optimal rate(s) of fertiliser application have not yet been determined. Hence, the purpose of this study was to gather data regarding the most effective fertiliser rates, planting density, and enhanced varieties for the extensive propagation of cassava stem cuttings in Kilosa District, Tanzania.

MATERIALS AND METHODS

Description of the experimental site and site characterization

The field experiment was established in the research plots of Tanzania Agricultural Research Institute (TARI), Ilonga located in Kilosa District (Figure 1) at 37°04' E and 6°79' S and elevated to 476.7 m.a.s.l. The experiment was established on 05th November 2019 and ended on 24th October 2020. The rainfall pattern is bimodal with the short rainy season falling from mid-October ending in late December and the main long rainy season starting in mid-February to mid-May, with April receiving higher rains than other months. Before setting up the experiment, soil samples were gathered in a zigzag pattern using a soil auger from depths of 0 to 20 cm and 20 to 50 cm. These samples were meticulously combined to create a single composite sample. The composite soil sample was then reduced to one kilogram using the quartering method, followed by air drying, grinding, and sieving to ensure passage through a 2 mm sieve. Properly labeled, the composite soil samples were packed and dispatched to the Soil Analytical Laboratory at the International Institute for Tropical Agriculture (IITA) for the analysis of various soil chemical and physical characteristics at the experimental site.

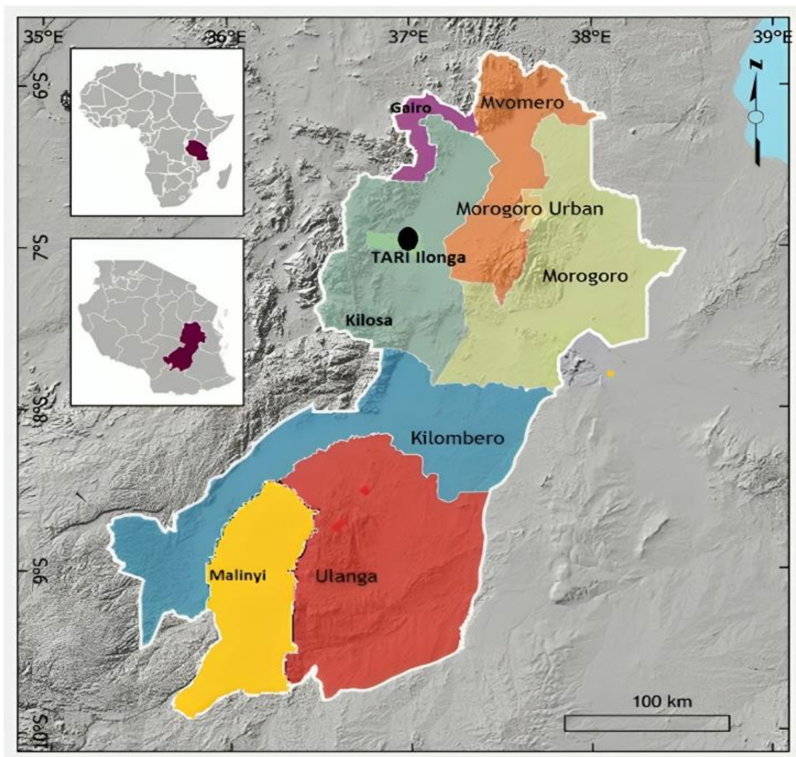

Figure 1. Location of the experimental site at TARI Ilonga in Kilosa District – Tanzania.

Experimental design

The field experiment was set up in a split-split plot design within a randomized complete block design (RCBD), incorporating three factors: cassava variety as the main plot, planting density as the subplot factor, and fertilizer combinations as the sub-subplot factor (3 × 3 × 10). Each replication of the experiment comprised three replications, totaling 90 plots in each replication.

Planting materials and Treatment combinations

The planting materials and treatment combinations composed of main-, sub- and, sub-sub plots are shown below. The main plot was comprised of the planting materials from three selected varieties of cassava commonly grown by farmers in Tanzania, which are:

1) *Chereko, 2) Kiroba* and *3) Mkuranga* - 1*.* The subplot as planting densities tested were:1) 10 000-plants ha^{-1}, with the spacing of 1m x 1m, 2) 13 000-plants ha^{-1}, with a spacing of 1m x 0.75m, and 3) 20 000-plants ha^{-1}, with a spacing of 1m x 0.5m.

The sub-sub plot factor included ten fertilizer levels as outlined below:

F1 Control (0N-0P-0K ha^{-1})

F2 75N-0P-0K [75 kg N ha^{-1} (SA) + 0 kg P + 0 kg K]

F3 150N-0P-0K [150 kg N ha^{-1} (SA) + 0 kg P + 0 kg K]

F4 75N-0P-0K [75 kg N ha^{-1} (Urea) + 0 kg P + 0 kg K]

F5 150 kg -0P-0K [150 kg N ha^{-1} (Urea) + 0kg P + 0 kg K]

F6 0N-20P-40K [0 kg N + 20kg P ha^{-1} (TSP) + 40 kg K ha^{-1} (MoP)]

F7 75N-20P-40K [75 kg N (SA) + 20 kg P ha^{-1} (TSP) + 40 kg K ha^{-1} (MoP)]

F8 150N-20P-40K [150 kg N (SA) + 20 kg P ha^{-1} (TSP) + 40 kg K ha^{-1} (MoP)]

F9 75N-20P-40K [75 kg N (Urea) + 20 kg P ha^{-1} (TSP) + 40 kg K ha^{-1} (MoP)], and

F10 150N-20P-40K [150 kg N (Urea) + 20 kg P ha^{-1} (TSP) + 40 kg K ha^{-1} (MoP)]

The sources of N were Sulphate of Ammonia (SA 21 % N) and Urea (46 % N), while P was from Triple Super Phosphate (TSP 21 % P) and K was from Muriate of Potash (MoP 60 % K).

Land clearing and land preparation

The land was cleared to remove previous crop residues, remnants of grasses and some bushes using a machete. This was then followed by ploughing and harrowing. The experiment was laid on a flat land, using pegs, sisal rope and a tape measure. The plot size was 3 m x 4 m equivalent to 12 m^2 and each plot was separated by 1.5 m and replications were separated by 2 m.

Establishment of the experiment

The field experiment was established by planting cassava stem cuttings which were selected from healthy plants, insect pests and disease-free cassava fields found at TARI Ilonga research fields. The fresh stem cuttings used were about 25cm long with diameters ranging from 2.5 - 3.5 cm and number of nodes varied from 5 to 7. These cuttings were collected from improved varieties of *Chereko, Kiroba* and *Mkuranga* 1 which are commonly grown in Tanzania. The stem cuttings were planted on 05th November 2019 at an inclined position of about 45° and an approximate depth of 10-15 cm (Anikwe & Ikenganyia, 2018) and were gap-filled two weeks after planting.

Each plot consisted of three rows with varied numbers of plants depending on the spacing of respective planting density. The between rows spacing of 1.0 m was constant for the three planting densities but varied within row spacing (1m, 0.75 m, and 0.50 m), making a total of 12 (10 000 plants ha^{-1}), 15 (13 000 plants ha^{-1}) and 24 (20 000 plants ha^{-1}) plants $plot^{-1}$ for respective 1.0 m, 0.75 m, and 0.50 m, within row spacing.

Fertilizer application

The NPK fertilizer treatments were applied as a basal and top dressing. The basal application was done at planting by placing TSP fertilizers in small holes with a depth of 16-20cm spaced 5cm from the planted stem cuttings and covered by soil (Abass et al., 2014). The amount of fertilizers of SA, Urea and MoP required in each treatment was divided into two equal splits and were top dressed twice by banding at 10-15 cm from the stem at 2 and 4 months after planting, as described by Biratu et al. (2018).

Experimental field management

Each treatment in each replication was properly labeled. Cassava is highly susceptible to weed infestation during the first 3 to 4 months of crop growth and development (Ekeleme et al., 2016). To avoid the effects of weeds on the performance of cassava, weeding was done three times using a hand hoe. The first, second and third weeding was done at one-, two-and four-months after planting respectively. Thereafter, the cassava plants formed a canopy that could not allow the growth of more weeds in the experiment. During weeding, earthing up was also done for each cassava stand. During the execution of the trial, the experiment was also assessed for the existence of any pests and disease infestation. This is because the trial intended to provide pests and disease-free stem cuttings.

Agronomic performance and data collection

The data were collected from the soil of the experimental site as well as from the field crop data obtained during the cassava stem production trial.

Soils data

Before planting, soil data were acquired from the analyzed soil samples collected at the experimental site. The analyzed soil parameters included soil texture, soil pH, total organic carbon, total nitrogen (N), available phosphorus (P), exchangeable bases, and cation exchange capacity (CEC). Standard analytical methods as outlined by Lelago and Buraka (2019) were employed for the soil analysis.

Plant sampling and data collection

At 8 months after planting (MAP), field data were gathered from a net plot area measuring 2 square meters. The number of sampled plants within the net area of each treatment varied: 2, 3, and 6 plants were sampled for planting densities of 10,000 (1.0 x 1.0) plants per hectare, 13,000 (1.0 x 0.75) plants per hectare, and 20,000 (1.0 x 0.5) plants per hectare, respectively. The collected plant data encompassed total plant height, stem height, stem diameter, number of stem cuttings, and number of nodes per stem cutting.

Total plant height and stem height were measured using a metered ruler and a tape measure, respectively. Stem diameter was assessed using a vernier caliper, while the numbers of stem cuttings and nodes per stem cutting were physically counted. Total plant height was determined from the base of the plant to the growing tip of the tallest stem, while stem height was measured from stems positioned 25 cm above the ground level to the end of the semi-lignified stem portion (Baraka, 2016 & Chiona et al., 2016).

Data analysis

The data collected from field experiments were subjected to analysis of variance (ANOVA) using the *agricolae* package of R software (v4) (R Core Team, 2021) statistical package (Lüdecke et al., 2021). Significant treatment means of values were separated using Tukey's significance test at a 5% probability level (Tsuka et al., 2019; Nanda et al., 2021).

RESULTS

Soil physical and chemical characteristics of the studied area

The soil physio-chemical characteristics of the top (0 - 20 cm) and sub-soil (20 - 50 cm) of the experimental site before the experiment are presented in Table 1. Except for total N and organic matter, which were characterized as low, the other parameters were either medium (exchangeable Na and available Zn) or high (available P and Cu, exchangeable K, Ca and Mg). The soil texture was sand clay loam (SCL). These results indicate that the soil of the experimental site was deficient in total N, suggesting that the application of N fertilizers is likely to substantially increase the stem yields.

Table 1. Some physicochemical characteristics of the experimental site

Parameter	Depths		Range suitable for cassava production	Remarks	Reference
	(0 - 20 cm)	(20 - 50 cm)			
Sand (%)	51	57	-		
Silt (%)	19	13	-	Sand Clay Loam	Vinhal-Freitas *et al* . (2017)
Clay (%)	30	30	-		
pH (H_2O)	6.04	6.17	4.5 - 7.0	Medium	Lelago and Buraka (2019)
Organic Carbon (%)	1.84	1.24	4.0 - 10.0	Low	Landon (2014)
Total N (%)	0.22	0.19	0.20 - 0.50	Low	
Available P (mg kg^{-1} P)	17.1	26.7	4.2 - 10	High	Howeler (2002)
K ($cmol_c$ K kg^{-1})	0.79	0.47	0.15 - 0.25	High	
Mg ($cmol_c$ Mg kg^{-1})	2.84	2.79	0.40 - 1.00	High	Motsara and Roy (2008)
Ca ($cmol_c$ Ca kg^{-1})	14.36	12.23	1.0 - 5.0	High	
Na ($cmol_c$ Na kg^{-1})	0.09	0.11	< 2	Medium	
Zn (mgkg^{-1}Zn)	1.27	0.61	1.0 - 3.0	Medium	Lindsay and Norvell, 1978
Cu (mgkg^{-1} Cu)	2.37	2.72	0.3 - 0.8	High	

Influence of fertilizers, cassava varieties and planting densities on total plant height and stem height

Total plant height and stem height are very important traits determining the production of stem cuttings in cassava production. Table 2 presents the influence of fertilizers, cassava varieties and planting densities on total plant height and stem height of cassava. The total plant height of cassava varieties as influenced by rates of fertilizers applied and planting densities varied from 229.0 cm to 246.7 cm. Cassava variety significantly ($p<0.012$) affected total plant height. The highest plant height (246.7 cm) was from the *Chereko* variety with the lowest (229 cm) from *the Kiroba* variety but the total plant height of *Kiroba* did not statistically ($p>0.05$) differ from that obtained from *Mkuranga* 1.

Similarly, the total plant heights of varieties *Chereko* and *Mkuranga* 1 were not statistically ($p>0.05$) different (Table 2).

The planting density of 13,000 plants ha^{-1} significantly affected total plant height ($p<0.05$) and stem height compared to the planting density of 10,000 plants ha^{-1}. The plant density of 13,000 plants ha^{-1} had slightly higher total plant height and stem height than that recorded from 20,000 plants ha^{-1}. Stem height is significantly ($p<0.05$) affected by fertilizer application. The highest stem height (198 cm) was revealed from fertilizer level F3 (150 kg N ha^{-1} SA) while the lowest (167.2 cm) was from no use of fertilizer. The results further indicated that the interaction between cassava variety x fertilizer, and planting density x fertilizer did not show a significant difference ($p>0.05$) in total plant height and stem height (Table 2). The study results implied that farmers in the study area can use any of the three improved varieties of cassava to achieve maximized total plant height. However, on stem height, the study findings implied that the improved varieties could have different yield potentials even though they were planted in a similar environment. The observation of this nature of yield variation could probably be attributed to genetic potential variations among cassava varieties. It became evident from the current study results that planting density slightly favours the total plant height and stem height of cassava. The study further implied that planting density highly impacted the stem height of the crop. It was further discovered that varying planting density in stem production influenced the stem height of the crop but no noticeable variation in total plant heights of the crop (Table 2). This could be attributed to branching habit variation among the cassava varieties under the study.

Table 2. Effect of varieties, planting densities and fertilizer rates on total plant height and stem height of cassava in cropping season 2019

Factor(s)	Treatments	Total plant height (cm)	Stem height (cm)
Cassava variety	*Chereko*	246.7^{a}	192.9^{a}
	Mkuranga 1	242.9^{ab}	176.4^{b}
	Kiroba	229.0^{b}	177.0^{b}
	Mean	*239.53*	*182.1*
	p value	*0.012*	*0.001*
Planting density	13 000	246.9^{a}	188.3^{ab}
	20 000	240.2^{ab}	181.4^{ab}
	10 000	231.6^{b}	176.5^{b}
	Mean	*239.57*	*182.07*
	p value	*0.051*	*0.011*
Fertilizer levels	(F3) 150 N-0P-0K [(150 kg N ha^{-1}) (SA) + 0 kg P + 0 kg K]	252.0^{a}	198.7^{a}
	(F5) 150 N-0P-0K [(150 kg N ha^{-1}) (Urea) + 0 kg P + 0 kg K]	252.0^{a}	194.7^{a}
	(F8) 150 N-20P-40K [(150 kg N ha^{-1}) (SA) + 20 kg P ha^{-1} (TSP) + 40 kg K ha^{-1} (MoP)]	245.2^{a}	192.2^{a}
	(F4) 75 N-0P-0K [(75 kg N ha^{-1}) (SA) + 0 kg P + 0 kg K]	242.8^{a}	185.0^{ab}
	(F9) 75 N-20P-40K [(75 kg N ha^{-1}) (Urea) + 20 kg P (TSP) + 40 kg K (MoP)]	252.3^{a}	183.1^{ab}
	(F10) 150 N-20P-40K [(150 kg N ha^{-1}) (Urea) + 20 kg P ha^{-1} (TSP) + 40 kg K ha^{-1} (MoP)]	238.2^{a}	182.5^{ab}
	(F7) 75 N-20P-40K [(75 kg N ha^{-1}) (SA) + 20 kg P (TSP) + 40 kg K (MoP)]	237.7^{a}	180.5^{ab}
	(F2) 75 N-0P-0K [(75 kg N ha^{-1}) (Urea) + 0 kg P + 0 kg K]	224.7^{a}	168.9^{b}
	(F6) 0 N-20P-40K [(0 kg N ha^{-1}) + 20 kg P (TSP) + 40 kg K (MoP)]	221.2^{a}	167.9^{b}
	(F1) Control (0N-0P-0K)	228.7^{a}	167.2^{b}
	Mean	*239.57*	*182.07*
	p value	*0.031*	*0 .001*

Means with the same letters in the same columns indicate no significant difference ($p>0.05$). Mean separation was conducted according to Tukey's honestly significant difference test.

Influence of fertilizers, cassava varieties and planting densities on stem diameter

Stem diameter is one of the important growth parameters among others in cassava production. The effect of fertilizer combinations on the stem diameter of cassava is presented in Table 3. Two split applications of fertilizer significantly showed variations in stem diameter in cassava stem production. The fertilizer application rate of level (F8) 150N-20P-40K [150 kg N (SA) + 20 kg P ha^{-1} (TSP) + 40 kg K ha^{-1} (MoP)] had the highest (2.78 cm) stem diameter. The lowest stem diameter was observed from the use of two split applications of 75 kg N ha^{-1} (Urea) (Table 3). Although the use of fertilizer treatment (F8) 150N-20P-40K [150 kg N (SA) + 20 kg P ha^{-1} (TSP) + 40 kg K ha^{-1} (MoP)] had outstanding performance, it did not significantly differ from the use of F3, F5, F6, F7, F9, F10 and the control (F1) (Table 3). Furthermore, the interaction between cassava variety x fertilizer and planting density did not show a significant difference in the stem diameter of cassava.

Table 3. The influence of fertilizer application, varieties and planting densities on stem diameter of cassava

Factor (s)	Treatments	Stem diameter(cm)
	(F8) 150N-20P-40K [150 kg N (SA) + 20 kg P ha-1 (TSP) + 40 kg K ha^{-1} (MoP)]	2.78^{a}
	(F3) 150N-0P-0K [15 0 kg N ha^{-1} (SA)+ 0 kg P + 0 kg K]	2.55^{ab}
	(F5) 150 kg -0P-0K [150 kg N ha^{-1} (Urea) + 0 kg P + 0 kg K]	2.54^{ab}
	(F9) 75N-20P-40K [75 kg N (Urea) + 20 kg P ha^{-1} (TSP) + 40 kg K ha^{-1} (MoP)],	2.51^{ab}
	(F7) 75N-20P-40K [75 kg N (SA) + 20 kg P ha-1 (TSP) + 40 kg K ha^{-1} (MoP)]	2.44^{ab}
	(F6) 0N-20P-40K [0kg N + 20 kg P ha^{-1} (TSP) + 40 kg K ha^{-1} (MoP)]	2.44^{ab}
	(F10) 150N-20P-40K [150 kg N (Urea) + 20 kg P ha^{-1} (TSP) + 40 kg K ha^{-1} (MoP)]	2.40^{ab}
	(F1) Control (0N-0P-0K) kg ha^{-1}	2.38^{ab}
Fertilizer	(F2) 75N-0P-0K [75 kg N ha^{-1} (SA) + 0 kg P + 0 kg K]	2.32^{b}
levels	(F4) 75N-0P-0K [75 kg N ha^{-1} (Urea)	2.31^{b}
Mean		*2.466*
p value		*0.033*

The presence of same letters in the same columns suggests that there is no statistically significant difference (p>0.05). Tukey's honestly significant difference test was employed to conduct mean separation.

Table 4. The effect of variety, planting density and fertilizer rates on the number of cassava stem cuttings ha^{-1} and number of nodes per stem cutting

Factor(s)	Treatments	Number of stem cuttings ha^{-1}	Number of nodes per stem
Cassava variety	*Chereko*	248 339a	12^{a}
	Kiroba	259 314a	11^{b}
	Mkuranga 1	217 911b	11^{b}
	Mean	*241 855*	*12*
	p value	*0.001*	*0.001*
Density	10, 000 plants ha^{-1}	175 773^{b}	12^{a}
	13 000 plants ha^{-1}	226 533^{b}	11^{b}
	20, 000 plants ha^{-1}	323 258^{a}	11^{b}
	Mean	241 855	12
	p value	*0.001*	*0.001*

The presence of same letters in the same columns suggests that there is no statistically significant difference (p>0.05). Tukey's honestly significant difference test was employed to conduct mean separation.

The influence of fertilizer application, cassava varieties and planting densities on total stem cuttings and number of nodes

An interaction between fertilizer combination, cassava varieties and planting densities was determined under field experimentation for total stem cuttings and number of nodes stem^{-1} and results were presented in Table 4. The higher number of stem cuttings ha^{-1} was recorded from *Kiroba* cassava variety but this was not significantly different from *Chereko*. Varieties *Chereko* and *Kiroba* had significantly ($p<0.05$) higher number of stem cuttings ha^{-1} compared to *Mkuranga* 1 variety. The number of nodes per stem cuttings varied significantly with cassava varieties. *Chereko* showed a significantly higher number of nodes (12) per stem cuttings compared to varieties *Kiroba* and *Mkuranga* 1. The planting density of 20, 000 plants ha^{-1} gave higher stem cuttings but a statistically lower number of nodes per stem cuttings. The planting density of 10, 000 plants ha^{-1} showed a significantly higher number of nodes per stem cutting than the other two planting densities (13,000 and 20,000 plants ha^{-1}). The rapid multiplication of stem cuttings projected to be from higher density implies that 20 000 ha^{-1} can be suitable agronomic practice for massive multiplication of cassava stem cuttings in the study area and other places with homologous characteristics. The interaction between cassava variety x fertilizer, planting density x fertilizer as well as the interaction between fertilizer x planting density x cassava varieties did not have a significant difference in cassava stem cuttings and number of nodes per stem cuttings (Table 4).

The effect of interaction between Variety x planting density on total stem cuttings and number of nodes in cassava stem production

The number of stem cuttings is one of the important quantitative parameters for determining yields of cassava stems vegetative planting materials. An interaction between variety and planting density treatment was determined for total stem cuttings and the number of nodes in cassava stem cuttings ha^{-1} (Table 5).

The interaction between the three selected varieties (Chereko, Kiroba, and Mkuranga 1) and planting densities (10,000, 13,000, and 20,000 plants ha^{-1}) had a significant ($p<0.05$) impact on the number of stem cuttings per hectare. The highest yield of stem cuttings (339 644 stem cuttings ha^{-1}) was from the interaction between [*Kiroba* variety x density (3) 20,000 plants ha^{-1}], while the lowest stem cuttings yield (137 364 stem cuttings ha^{-1}) was from the interaction between [*Mkuranga* 1 var x planting density (1) 10,000 plants ha^{-1}]. The lowest stem cuttings producers based on means separation were from the interaction between *Chereko* x planting density (1) 10,000 plants ha^{-1} (170 191e) and *Mkuranga* 1 x density (1) 10,000 plants ha^{-1} (137 364e) according to Turkeys Honest significance ($p<0.05$) (Table 5). Stem yielding performance between *Kiroba* and *Chereko* varieties did not significantly ($p>0.05$) differ where planted using the similar density of 20,000 plants ha^{-1}.

Table 5. The interaction effect between cassava variety x planting density on number of stem cuttings ha^{-1}

Factors	Treatments	Number of cassava stem cuttings
Cassava variety x Planting density	*Kiroba* * Density 3	339 644^{a}
	Chereko * Density 3	333 178^{a}
	Mkuranga 1 * Density 3	296 951^{ab}
	Chereko * Density 2	241 647^{bc}
	Kiroba * Density 1	219 764^{cd}
	Mkuranga 1 * Density 2	219 417^{cd}
	Kiroba * Density 2	218 534^{cd}
	Chereko * Density 1	170 191^{e}
	Mkuranga 1 * Density 1	137 364^{e}
	Mean	*241 854*
	p value	*0.016*

Means that same letters in the same columns are not significantly different ($p>0.05$). Tukey's honest significance test was used to determine the mean separation. The numerical values assigned to Density 1 are 10,000 plants ha^{-1}, 13,000 plants ha^{-1}, and 20,000 plants ha^{-1}, respectively.

DISCUSSION

Soil physical and chemical characteristics of the experimental area

The cassava production at the analysed location is facilitated by the presence of somewhat acidic soils (Nanganoa et al., 2020). This is evident in the observed effects on sprouting, sprout height, fresh and dried biomass, as well as the significant proliferation of stem cuttings. The observed mild acidity of the soil in the study area can be primarily due to the significant intensity of rainfall, resulting in the leaching of basic cations. According to Eze's (2016) research findings, soils with somewhat acidic and acidic (mid to low pH) characteristics can be attributed to many factors such as prolonged agriculture, erosion, nutrient leaching, or a combination thereof. The site for the study area (TARI Ilonga) is always under continuous cultivation for research purposes. Due to this, mobilization of organic matter through fallow is relatively minimal in the study area. Leaching is always high on continuously cultivated land due to reduced vegetation cover leading to soil erosion.

The low level of organic carbon (OC) at the experimental site requires purposeful management practices that will contribute to improving and maintaining soil organic matter levels in the soil. Increased level of soil organic matter enhances soil structure, nutrient availability and water retention benefiting cassava yields. A high level of organic matter mostly improves microbial activity, fostering a healthier root environment for cassava plants (Radhakrishnan et al., 2022).

The presence of low organic matter in soil can impact the speed of microbial activities and physical characteristics (Wang et al., 2015; Paul et al., 2016). This, in turn, affects the penetration, growth, and expansion of cassava roots, ultimately leading to a decrease in cassava output in the region. The enhancement of organic carbon levels among farmers in Kilosa can be achieved by the avoidance of continual burning of crop leftovers and the use of mono-cropping practices. The insufficient organic matter contents of the soil at the experimental site may be responsible for the low total nitrogen concentration. Landon (2014) states that the critical nitrogen (N) concentration required for cassava production falls within the range of 0.20 to 0.50%, surpassing the existing nitrogen stocks. This implies that the utilisation of nitrogen-containing fertilisers is vital as it will enhance the overall plant height, stem height, stem diameter, and consequently, the number of stem cuttings in cassava. The diminished nitrogen levels in the soils may also be attributed to persistent and intensive agricultural techniques lacking the use of fertilisers, resulting in the accumulation of soil nutrient reserves (Purwanto and Alam, 2020). According to Biratu et al. (2018), the utilisation of nitrogen-containing fertilisers on cassava crops grown on soils with low nitrogen content resulted in a notable enhancement in the various components of cassava yield. The workers conducted two fertiliser trials in two villages (Mansa and Kabagwe) that had a nitrogen deficiency ranging from 0.05% to 0.06%. They observed a notable enhancement in the various components of cassava yield compared to the control treatment. Munyahali et al. (2023) found that the application of nitrogen, along with phosphorus and potassium, in a long-term experiment resulted in a considerable increase in cassava yields. The experimental site had a P status that exceeded the predetermined critical levels for cassava production. The observed phenomenon might likely be linked to the regular application of fertilizers containing phosphorus (P) to the experimental plots within the TARI Ilonga Centre. Therefore, the site possessed sufficient quantities of accessible phosphorus for cassava cultivation, which promoted extensive proliferation of cassava stems. The results presented in this study contradict the conclusions of Chianu et al. (2012), who suggested that the application of phosphate fertiliser may be necessary for sustainable cassava production when considering the critical value for phosphorus (P) in soils across different land use types.

According to Kintché et al. (2017), the exchangeable K of the site is rated as high because it was above the established critical limits for cassava production. Based on the status of the exchangeable K, the site had a high K level which is adequate for cassava production, hence stem cuttings. Even though cassava extracts more K than any other nutrients from the soil (Sanginga, 2022). Therefore, there are chances of declining exchangeable K levels if continuous cropping with cassava is practiced without replenishing with K-containing fertilizers.

The effect of variety, planting density and fertilizer application on total plant height and stem height

The significant difference attained from cassava varieties in total plant height and stem height could probably be attributed to the individual responsiveness of each cassava variety to applied fertilizer on the growth and development of cassava.

Alternatively, the observed variations in growth responses of the three selected varieties could also be attributed to their respective variation toward a variation within row plant spacing. Following the findings in this study, it is often thought that different cassava varieties can have equal potential on stem production following fertilizer use which is not necessarily to be like that.

The observed increase in stem height (198.7cm) compared to (167.2 cm) of the control treatment following the split application of 150 kg N ha^{-1} (SA) showed the effectiveness of N on cassava growth. This increase in stem height due to fertilizer statistically outweighed the performance of the control treatment. This change in the height of the stem implies that fertilizer use is necessary for stem elongation hence cassava stem massive multiplication in Kilosa. Other studies conducted in the Democratic Republic of Congo (DRC) also reported similar results. Munyahali et al. (2017) observed stem diameter and stem height significantly ($p<0.05$) increased by NPK fertilizer use.

Further research on the effectiveness of fertilizer has indicated that N application can significantly increase yields of cassava (Senkoro et al. 2018; Byju and Haripriya Anand, 2009; Shekiffu, 2011). Stem elongation was also clarified by Senkoro et al. (2018) who reported that application of 90 kg N ha^{-1} significantly increased stem elongation by 2-4 m and cassava yields.

Similarly, Shekiffu (2011) conducted research on cassava-based cropping systems in the Coastal region of Tanzania and reported a significant increase in cassava tuber yield from treatments that received all tested nutrients (N, P, K, S, and Zn) compared to the absolute control by 97% and 110% at Bungu and Soga sites. However, these findings contrast with those of other researchers. For example, studies by Kaweewong et al. (2013), Chianu et al. (2012), and Omondi et al. (2019) in Sub-Saharan Africa revealed that excessive use of N decreased cassava yields to levels comparable to the control, as it promoted shoot development over root growth, rendering N application ineffective. Similarly, Nguyen et al. (2002) observed a yield decline at 160 kg N ha^{-1}, while Kaweewong et al. (2013) reported optimal root yields at N applications as high as 250 kg N ha^{-1}. Conversely, in Oyo State, Nigeria, Uwah et al. (2013) demonstrated no yield responses to the application of N at rates ranging from 80 to 120 kg N ha-1.

Influence of compound fertilizers, cassava varieties and planting densities on stem diameter

Cassava stem diameter is one of the most important characteristics used by farmers where the selection of quality cassava stem cuttings for planting is considered. Commonly the mean range between 2.5-3.5 cm of stem cutting diameter is ideal and recommended for use in cassava production. The findings of the current study further imply that for better quality cassava stems (stem diameter included), following low levels of soil fertility in most of cassava fields, the use of fertilizer on stem mother plants is inevitable. Following the findings of the current study, the observed higher stem diameter (2.78 cm) performance due to fertilizing stem mother plants with fertilizer combination (150N-20P-40K) kg ha^{-1} has significant implications on future massive multiplication of quality stems in the study area. Similar results to current findings were also reported by other workers globally. In Zambia, Biratu et al. (2018) reported higher responses of cassava varieties on stem diameter due to applied fertilizers. In DRC, Munyahali et al. (2017) applied 150N-33P-124.5K kg ha^{-1} on cassava planted on N deficient soils (0.06 % N) in the Kibangwe site and South Kivu province. Their findings revealed higher and significant stem diameter compared to control plots in both sites. The use of fertilizer nutrients combination (N + P + K) is necessary on soil with a nutrient deficiency if a massive multiplication of stems with standard range diameters (2.5 -3.5 cm) is needed.

Influence of fertilizer application, variety and planting density on stem cuttings and number of nodes

The yield of economic performance in our study is the number of stem cuttings, the higher the number of stem cuttings per hectare justifies the proficiency of employed stem production agronomic packages. Following the findings in our study, the cassava variety that out performance others was *Chereko* planted using 20,000 plants ha^{-1}. The study findings imply that for an improved variety of cassava to produce massive stem cuttings, proper selection of planting density and fertilizer rates become very important.

Similarly, the findings of this study align with research conducted in Nigeria by Akpan and Ikeh (2018), demonstrating that the stem yield responses, measured by the number of stems per stand at 6 months after planting (MAP) and influenced by cassava varieties, showed no significant difference. However, the varierty TME 419 exhibited the highest number of stems per stand at 2.18, followed by TMS 0505 at 2.04. Variety TMS 30572 produced the least number of stems per stand (1.86).

Katuromunda et al. (2021) also found that fertiliser boosted stem numbers. The study found that applying NPK fertiliser led to a substantial increase in stems for both types compared to the control. Higher fertiliser rates did not enhance stem numbers. The branching features of the enhanced cultivars Chereko, Kiroba, and Mkuranga 1 in this study may also affect enormous stem-cutting multiplication. In other studies, Rojas et al. (2007) worked with within- and between-row spacing of cassava and observed that within-row spacing influenced plant height and stem diameter. Guerra et al. (2021) and Rojas et al. (2007) also reported higher cassava yields including stem cuttings at higher planting densities in mono-cropping. Thus, for stem cuttings' massive multiplication in Kilosa District, planting density agronomic practice of 20,000 plants ha^{-1} was found to be a better option.

CONCLUSION

Based on the study findings, sustainable production of cassava stem cuttings of improved varieties can be achieved through interaction on the split application of nitrogen fertilizer (150 kg N ha^{-1}) which appeared to give statistically higher total plant height contributing to the highest number` of cassava stem cuttings at planting density 20 000 plants ha^{-1}. Thus, for the production of quality stems with suitable diameters, farmers can use fertilizer combinations at (150N-20P-40K) kg ha^{-1}. Furthermore, all the improved varieties of *Kiroba*, *Chereko* and *Mkuranga* 1 can be planted to produce stem cuttings using a plant density of 20,000 plants ha^{-1}, hence they are suitable for use in massive multiplication of stem cuttings for distribution in Kilosa District.

CONFLICT OF INTERESTS

The authors declare no conflict of interest.

AUTHORS' CONTRIBUTIONS

YM was responsible for conceptualizing and designing the work, collecting and analyzing data, and interpreting the findings. They also played a significant role in drafting the manuscript. SM, AK, and FB conducted a thorough review of the article, offering critical insights on the discussion of results, conclusions, and recommendations. All authors reviewed and approved the final version of the manuscript.

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