



Research Article

Assessing the Potential of Irrigating Against Rainfed *Manihot Esculenta* Crantz Under Different Levels of NPK Fertilizers on Storage Root Yields in Tanzania Lake Victoria Zone

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Abstract

Objective: To assess the response of new registered Kiroba cassava variety on different rates of fertilizer under rainfed and irrigated regimes on the low fertility land of Tanzania Agricultural Research Institute of Tanzania (TARI), Ukiriguru, Mwanza, Tanzania.

Methods: The experiment was laid in a randomized complete block design in a split-plot design with irrigation and rainfed regimes being the site-main plot and fertilizer-subplots replicated three times. The treatments were absolute control and three rates i.e., 150:40:180, 75:20:90 and 300:80:360 kg ha⁻¹ of N, P, and K respectively, under the rainfed and irrigated regimes.

Results: Half rate of fertilizer blend N₇₅P₂₀K₉₀ under irrigation regime had significantly high root storage yields ranging from 24.76 to 25.21t ha⁻¹, to both cropping seasons. However, even though the root storage yields were slightly low (24.59 to 24.14t ha⁻¹) in the same treatment, it did not differ with the rainfed treatment. The high root storage yields were attributed to the narrow gap between the small and large storage root size and adequate moisture levels.

Conclusion: Cassava crop requires less fertilizer nutrients, but with appropriate proportion on soil moisture for increased root storage yield. Therefore, the study recommends further research to determine the potential yields using fertilizer blend within N₅₀P₁₀K₇₀ and N₁₀₀P₃₀K₁₂₀.

Keywords: Kiroba variety, small and large storage roots, soil nutrients, soil health

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1 INTRODUCTION

The agriculture sector is the back bone of the Tanzanian economy accounting for 30% of agricultural produce export^[1]. The food crops in the country are growing at 3.5% per annum^[2]. The most common food and cash crops in Tanzania are maize, cassava, sweet potatoes, bananas, sorghum, and sugar cane^[3,4]. It is estimated that about 82% of Tanzanian farmers grow maize, and 24% grow cassava in an estimated 655,700 ha of land and annual production of 1,786,400 ton^[3]. Recently, the cassava crop has become the most widely used food crop in Tanzania, with minimal post-harvest losses^[5].

Cassava (*Manihot esculenta* Crantz) is a perennial crop growing up to 2.4m tall^[6]; it is a starchy storage root crop that also serves as a local food crop that strengthens food security in developing countries^[7,8]. About one billion smallholder households in sub-Saharan Africa depend on cassava as a staple food crop^[9]. The preference of the crop to sub-Saharan Africa is a result of the crop's ability to grow on low fertility soils^[5,10]. For example, in Tanzania, the cassava crop is grown to the soil fertility constraints surrounding Lake Victoria in Mara, Mwanza, Simiyu, Geita and Kagera regions^[11,12].

Despite the cassava crop resilience and ability to grow on low soil fertility areas^[5,7,8,10], it requires fertility as when cultivated continuously, its storage root yields may decrease^[13]. Nitrogen (N), phosphorus (P) and potassium (K) are major nutrients required by cassava crops. Applying these nutrients in splitting has proven to be effective in increasing cassava root yields^[14,15]. The crop is efficient in N, P and K uptake^[16,17]. However, the crop removes a large quantity of K compared to other nutrients because of its involvement in the synthesis and accumulation of starch in storage roots^[16,18]. The high uptake of K increases the concentration of N and S by 2-3-fold because K is involved in N metabolism^[19]. Like other plants, cassava could naturally obtain nutrients such as N and P by forming beneficial relationships with microbes^[20]. A recent study revealed the role of microbes such as arbuscular mycorrhizal fungi (AMF) in contributing to the P nutrients availability to the cassava rhizosphere for increasing storage root yield^[21]. In fact, the crop is highly dependent on AMF for P uptake from the soils, which contributes to the increase in cassava storage root yield^[17].

Although, cassava is a drought tolerant crop, recent persistence of drought for an extended period, has been observed to reduce the storage root yield^[22,23]. Drought can hinder nutrient uptake where fertilizers are applied hence reducing cassava yield potential. Thus, irrigation could be an option for increasing cassava storage root yield under climate change in the sub-Saharan countries by increasing moisture availability and nutrient solubility uptake. Based on the importance of the cassava crop in Tanzania, a need

to research on irrigating cassava applied with different NPK fertilizers throughout the year was initiated. Although, in Tanzania, only 1.8% of all cropped land is irrigated^[24], research for irrigated cassava crops is rarely studied. Therefore, the current study aimed to assess cassava biomass yields under rainfed and irrigated regimes with different NPK fertilizer blends using Kiroba, a newly released improved cassava variety in Lake Victoria zone, Tanzania.

2 MATERIALS AND METHODS

2.1 Site Description and Experimentations

Field experiments were conducted at TARI Ukiriguru site during two cropping seasons (2019-20 and 2020-21). The site is located at 2° 42'S and 33° 01'E at an altitude of 1,198 meters above sea level. Rainfall and temperature collected during the two cropping seasons are indicated in Table 1.

A randomized complete block design in split-plot arrangement with treatments being fertilizer rates-main plot and moisture regimes (irrigation vs rainfed)-subplot replicated three times was used in the experiment. The main plot treatments involved an improved cassava variety at three different application rates of NPK fertilizer; half rate (75:20:90), full rate (150:40:180), double rate (300:80:360) kg ha⁻¹, checked against a control with no fertilizer application (Table 2).

The subplot treatments involved an improved cassava variety (fertilized and control) with rainfed versus irrigated regimes. A recommended cassava variety of Kiroba was used as a test crop and was obtained from the TARI of Ukiriguru, Mwanza. Crop cuttings were planted (one per hill) in December at a spacing of 1m between the cuttings as well as between ridges in a plot size of 8m x 8m. Inter-plot separation was 2m, while the inter-block separation was 4m. Cassava was irrigated (10L plant⁻¹) twice a week during the dry season when the sum of rainfall for the three consecutive days was less than 10mm. The irrigation application was done either in the morning or evening to minimize evaporation.

The N, P and K were applied as Urea, triple superphosphate (TSP) and muriate of potash (MOP), respectively. Basal application (100%) of TSP was done at the time of planting. Urea and MOP were applied in 3 splits 30:35:35 at 4, 10 and 12 weeks after planting about 10-15cm away from each cutting. Weeding and earthing-up of ridges were observed throughout the experimental period, and the cassava crop was harvested after 12 months (in January) for each cropping season.

2.2 Physical and Chemical Properties of the Soil from the Experimental Site

Some physical and chemical properties of the soil from the experimental site were analyzed (Table 3). The physical analysis included soil constituents and textural

Table 1. Rainfall and Temperature of the Study Site During the 2019-20 and 2020-21 Cropping Seasons

Month	Cropping Season 2019-20		Cropping Season 2020-21	
	Rain (mm)	Temp (°C)	Rain (mm)	Temp (°C)
Oct	105.1	29.8	101.4	30.5
Nov	133.9	29.4	171.1	29.5
Dec	226.7	27.8	178.5	28.3
Jan	197.3	30.2	174.1	28.2
Feb	30.6	31.2	91.8	30.2
Mar	55.4	31.8	65.2	29.4
Apr	146.8	30.6	133.3	28.9
May	23.8	30.7	45.8	29.9
Jun	31.8	29.7	1.8	30.2
Jul	3.1	30.9	0.2	30.4
Aug	71.6	30.7	12.4	31.5
Sep	46.3	31.4	59.8	31.7

Table 2. Treatment Description and Rates

Treatment	Blend	N	P	K	Urea	TSP	MOP	Urea	TSP	MOP
		kg ha ⁻¹			kg ha ⁻¹			g plot ⁻¹		
T1	CON	0	0	0	0	0	0	0.0	0.0	0.0
T2	HALF	75	20	90	163	100	180	1956.5	1194.8	2160.0
T3	FULL	150	40	180	326	199	360	3913.0	2389.6	4320.0
T4	DBLE	300	80	360	652	398	720	7826.1	4779.1	8640.0

Notes: Key: CON=Control; HALF=Half NPK fertilizer blend; FULL=Full fertilizer blend; DBLE=Double fertilizer blend.

Table 3. Initial Physical and Chemical Characteristics of the Ukiriguru Experimental Soil

Soil Constituents	Depth		Rating*
	1-15cm	15-30cm	
Sand (%)	73	71	N/A
Silt (%)	11	12	N/A
Clay (%)	16	17	N/A
Textural class	Sandy loam	Sandy loam	N/A
pH (H ₂ O)	6.55	6.71	Slightly acidic to neutral
Total N (%)	0.04	0.03	Very low
Organic C (%)	0.46	0.32	Very low
Bray IP (mg kg ⁻¹)	8.00	9.00	Medium
Exchangeable K (cmol kg ⁻¹)	0.12	0.07	Very low
Exchangeable Ca (cmol kg ⁻¹)	1.84	1.54	Medium
Exchangeable Mg (cmol kg ⁻¹)	0.64	0.54	Medium

Notes: * Source: Landon^[25].

class determination, while chemical analysis involved exchangeable Ca, K and Mg, available P, total N, OC and soil pH.

2.3 Soil Data Collection

Before starting the experiment, each composite soil sample from 0-15 and 15-30cm depth were collected from the experimental site for determining the soil texture, pH,

OC, Total N, extractable P, exchangeable Ca, Mg and K. Soil texture was determined using the Bouyoucos hydrometer method as described by^[26].

The pH measurements were done potentiometrically in water and in 1M KCl both at a ratio of 1:2.5, soil: water and soil: 1M KCl suspensions, respectively^[27], and the pH meter was used to read the pH, soil samples were ground

to pass through a 0.25mm sieve, then procedure by the Walkley and Black wet digestion method^[28], was used to determine the organic carbon (OC). For the determination of total N, about 1g of soil samples was hydrolyzed with 15mL concentrated sulfuric acid (H₂SO₄)-hydrogen peroxide method for 2h. Then, total N was determined using the micro-Kjeldahl procedure^[29]. Available P was determined by Bray and Kurtz method^[30]. Exchangeable Ca and Mg in 1M neutral ammonium acetate (NH₄OAc) filtrates were determined by atomic absorption spectrophotometer (AAS) and exchangeable K by flame photometer^[31].

2.4 Plant Data Collection, Harvesting of Cassava Storage Roots

Five plants from each plot were selected randomly for plant data collection. Data on cassava parameters included plant height (PH) ‘measurement of the plant from the ground to the top-most portion of the plant at maturity’, stem diameter (SD) ‘measurement of stem base girth’, canopy length (CL) ‘measurement of the longest part of the canopy diameter’, canopy width (CW) ‘measurement of the shortest part of the canopy diameter’, canopy height (CH) ‘measurement from the lowest node of the stem or branch that had a green leaf to the highest leaf of the plant’, canopy volume (CV) ‘calculated from the CL, CW and CH parameters’, and weight of small and large roots. At cassava maturity (12 months after planting), CL, CH and CW were measured using a measuring tape, PH was measured from the soil surface (at the root collar of the plant) to the plant apex by a calibrated measuring tape. Stem diameter (SD) was measured using a vernier caliper. Finally, the weight of small and large storage roots was determined at 12.5% moisture content by weighing the roots on a digital scale after removing soil particles adhered to the roots.

2.5 Statistical Analyses

Data were analyzed using STATISTICA 8th Edition, StatSoft, Inc., Tulsa, OK, USA. Cassava storage root weights were evaluated based on the interactions among the treatments. One-way ANOVA statistical analyses were performed through the split-plot design with treatments being fertilizer rates, rainfed, or irrigated regime. A Fisher’s comparison test was used, and the significance threshold was set at $P=0.05$ and $P=0.001$ for high significance. The treatment means were compared to the standard error of the difference of the mean.

2.5.1 Regression and Correlation Assessment

Multiple linear regression was used to determine the parameter(s) that contribute significantly to root yields. Thus, total root yield as a response parameter (Y) was regressed against CH, CW, CL, CV, PH and SD in the following model:

$$Y = x_1 W_i + x_2 W_{ii} + x_3 W_{iii} + x_4 W_{iv} + x_5 W_v + x_6 W_{vi} + x_7 W_{vii} + C \quad (1)$$

Where Y is the total root yield, W_i to W_{vii} stand for parameters CH, CW, CL, CV, PH and SD, x_1 to x_7 represent coefficients of the parameters and C is the constant. A diagnostic test of coefficient of determination (R^2) was used to predict the results perfectly.

Correlations of total root yield against CH, CW, CL, CV, PH and SD were carried out to determine the association impact of total root yield.

3 RESULTS

3.1 Weather Data, Physical and Chemical Properties of the Soil from the Experimental Site

Precipitation and atmospheric temperature data for the first season (2019-20) were an annual average of 89.37mm and 30.35°C respectively. During the cropping season, 2020-21 recorded average rainfall (86.28mm) and temperature (29.89°C) were slightly lower than in the previous season (Table 1).

The high rates of fertilizer (Table 2) were not in favour of significantly higher cassava root yields. Ukiriguru texture soil was categorized as a sandy loam (Table 3). Soil available P content ranged from 8 to 9mg kg⁻¹, while exchangeable Ca ranged from 1.54 to 1.84cmol kg⁻¹ and Mg from 0.54 to 0.64cmol kg⁻¹, were considered as medium. Soil total N (0.03-0.04%), K (0.07-0.12cmol kg⁻¹) and OC (0.32-0.46%) were very low. Soil pH was slightly acidic to neutral, ranging from 6.55 to 6.71 at the depth of 0-15 and 15-30cm respectively.

3.2 Effect of Fertilizer Treatments on Aerial Cassava Characteristics

The effects of growing cassava crop under fertilization to both rainfed and irrigated crop regimes on aerial cassava characteristics for 2019-20 and 2020-21 crop seasons are shown in Table 4 and Table 5. The absolute control (T1), which received no fertilizer, had significantly ($P \leq 0.001$) lowest SD (6.42-6.45cm), PH (137.50-137.70cm), CL (116.22-117.10cm), CW (85.12-85.86cm), CH (24.60-24.95cm), and CV (135.22-139.18cm³) than the rest of treatments to both cropping seasons.

With exception to the absolute control treatment (T1), application of different fertilizer rates, T2 (N₁₅₀P₄₀K₁₈₀ i.e. 1,957, 1,195, 2,160g plot⁻¹ for Urea, TSP and MOP, respectively), T5 (N₃₀₀P₈₀K₃₆₀ i.e. 3,913, 2,390, 4,320g plot⁻¹ for Urea, TSP and MOP, respectively) and T6 (N₃₀₀P₈₀K₃₆₀ i.e. 7,826, 4,779, 8,640g plot⁻¹ for Urea, TSP and MOP, respectively), did not significantly ($P \leq 0.001$) affect the SD, PH, CL, CW, CH, and CV during both cropping seasons (2019-20 and 2020-21). On the other hand, the application of half fertilizer rates N₇₅P₂₀K₉₀ under rainfed (T4) had reduced stem diameter in both cropping seasons. However, the cassava plant height did not differ significantly ($P \leq 0.001$)

Table 4. Effect of Fertilizer on Cassava Above Ground Canopy for 2019-20 Cropping Season

Treatments	Cropping Season 2019-20					
	Canopy Length (cm)	Canopy Width (cm)	Canopy Height (cm)	Canopy Volume (cm ³)	Stem Diameter (mm)	Plant Height (cm)
1. Absolute control no fertilizer-Rainfed	117.10±9.30c	85.86±8.34b	24.95±2.68b	139.18±37.67b	6.45±0.20c	137.70±7.53b
2. Standard fertilizer rate N ₁₅₀ P ₄₀ K ₁₈₀ -Rainfed	190.05±19.25ab	147.30±18.41a	32.80±2.71ab	515.12±124.30a	10.25±0.22a	185.25±4.58a
3. Half fertilizer rate N ₇₅ P ₂₀ K ₉₀ -Irrigated	163.55±9.90b	124.30±9.33a	36.30±3.61a	396.15±66.05a	10.45±4.57a	174.75±8.03a
4. Half fertilizer rate N ₇₅ P ₂₀ K ₉₀ -Rainfed	161.50±9.76b	123.37±8.82a	34.65±3.69a	375.43±60.60a	9.80±0.42a	173.57±7.64a
5. Double fertilizer rate N ₃₀₀ P ₈₀ K ₃₆₀ -Irrigated	188.75±11.77ab	130.60±9.28a	36.75±3.59a	482.27±91.33a	10.35±0.22a	182.65±6.03a
6. Double fertilizer rate N ₃₀₀ P ₈₀ K ₃₆₀ -Rainfed	214.95±17.62a	138.45±2.55a	36.45±2.34a	569.08±63.59a	9.90±0.52ab	184.65 ±11.35a
F-statistics	6.15***	4.05**	2.05ns	3.74*	15.19***	5.32**

Notes: a, b, and c means in the same category of evaluated interface sharing similar letter(s) do not differ significantly based on their respective standard error (SE) at 5% error rate. Values presented are means ± SE (standard error of means); * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$; ns = non-significant ($P \geq 0.05$)

Table 5. Effect of Fertilizer on Cassava Above Ground Canopy for 2020-21 Cropping Season

Treatments	Cropping Season 2020-21					
	Canopy Length (cm)	Canopy Width (cm)	Canopy Height (cm)	Canopy Volume (cm ³)	Stem Diameter (mm)	Plant Height (cm)
1. Absolute control no fertilizer-Rainfed	116.22±9.4c	85.12±8.55b	24.60±2.62b	135.22±36.65b	6.42±0.22c	137.50±7.69b
2. Standard fertilizer rate N ₁₅₀ P ₄₀ K ₁₈₀ -Rainfed	189.00±9.24ab	145.85±18.42a	32.30±2.56ab	499.55±120.35a	10.12±0.20a	184.65±4.44a
3. Half fertilizer rate N ₇₅ P ₂₀ K ₉₀ -Irrigated	162.40±10.06b	122.75±9.48a	35.77±3.69a	382.44±63.88a	10.37±0.64a	174.47±8.01a
4. Half fertilizer rate N ₇₅ P ₂₀ K ₉₀ -Rainfed	158.75±9.38b	122.22±9.42a	35.00±4.12a	370.48±64.61a	9.95±0.65a	173.20±7.52a
5. Double fertilizer rate N ₃₀₀ P ₈₀ K ₃₆₀ -Irrigated	187.72±11.79ab	129.47±9.35a	35.92±3.54a	465.96±90.35a	10.20±0.19a	182.27±6.08a
6. Double fertilizer rate N ₃₀₀ P ₈₀ K ₃₆₀ -Rainfed	212.37±17.01a	137.40±2.69a	36.07±2.34a	552.21±61.45a	9.75±0.42ab	183.97 ±11.25a
F-statistics	6.17***	3.85**	1.94ns	3.62*	11.80***	5.29**

Notes: a, b, and c means in the same category of evaluated interface sharing similar letter(s) do not differ significantly based on their respective standard error (SE) at 5% error rate. Values presented are means ± SE (standard error of means); * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$; ns = non-significant ($P \geq 0.05$).

to all fertilized treatments under the rainfed regime.

3.3 Effect of Fertilizer Treatments on Cassava Storage Root Yields

The effects of growing cassava crop under fertilization to both rainfed and irrigated crop regimes for 2019-20 and 2020-21 crop seasons on storage root yield are shown in Table 6. The lowest significant ($P \leq 0.001$) root storage yields were 11.20, and 11.09t ha⁻¹ obtained in absolute control (T1) for 2019-20 and 2020-21 cropping seasons, respectively. Application of N₁₅₀P₄₀K₁₈₀ under the rainfed regime (T2) increased root storage to 16.82 and 16.57t ha⁻¹ in 2019-20 and 2020-21 respectively. The N₇₅P₂₀K₉₀ treatment (T3) under

the irrigated regime, had significantly highest ($P \leq 0.001$) yields with 25.21 and 24.76t ha⁻¹ for the cropping seasons, respectively.

The T4 treatment (N₇₅P₂₀K₉₀) had a decreased yield, though not significant, of 24.59 and 24.14t ha⁻¹ in 2019-20 and 2020-21 cropping seasons, respectively. Doubling the fertilizer (N₃₀₀P₈₀K₃₆₀) under irrigation regime (T5) produced 20.66 to 20.75t ha⁻¹ storage yield for both cropping seasons, which did not differ significantly from those of T3 and T4. However, a similar fertilizer treatment but under a rainfed regime (T6), had a substantial increase in root storage yield (21.64-21.87t ha⁻¹) in spite of insignificant difference with T3, T4 and T5.

Table 6. Effect of Fertilizer on Cassava Below Ground Root Yields for 2019-20 and 2020-21 Cropping Seasons

Treatments	Crop Season 2019-20			Crop Season 2020-21		
	Large storage roots yield (t ha ⁻¹)	Small storage roots yield (t ha ⁻¹)	Overall root storage yield (t ha ⁻¹)	Large storage roots yield (t ha ⁻¹)	Small storage roots yield (t ha ⁻¹)	Overall root storage yield (t ha ⁻¹)
1. Absolute control no fertilizer-Rainfed	5.75±0.45c	5.44±0.70c	11.20±0.87c	5.66±0.41c	5.43±0.61c	11.09±0.75c
2. Standard fertilizer rate N ₁₅₀ P ₄₀ K ₁₈₀ -Rainfed	9.30±0.73abc	7.52±1.04bc	16.82±0.35bc	9.22±0.74abc	7.34±1.04bc	16.57±0.34bc
3. Half fertilizer rate N ₇₅ P ₂₀ K ₉₀ -Irrigated	13.12±2.17a	12.08±1.77a	25.21±3.24a	12.91±2.16a	11.84±1.76a	24.76±3.19a
4. Half fertilizer rate N ₇₅ P ₂₀ K ₉₀ -Rainfed	13.04±2.02a	11.54±1.86a	24.59±3.24a	12.68±2.04a	11.46±1.72a	24.14±3.02a
5. Double fertilizer rate N ₃₀₀ P ₈₀ K ₃₆₀ -Irrigated	11.67±1.15ab	9.07±0.72abc	20.75±1.31ab	11.57±1.08ab	9.08±0.64abc	20.66±1.07ab
6. Double fertilizer rate N ₃₀₀ P ₈₀ K ₃₆₀ -Rainfed	11.42±1.15ab	10.45±0.38ab	21.87±0.91ab	11.30±1.09ab	10.34±0.36ab	21.64±0.97ab
F-statistics	3.86**	4.35**	6.85***	3.74**	4.61***	7.23***

Notes: a, b, and c means in the same category of evaluated interface sharing similar letter(s) do not differ significantly based on their respective standard error (SE) at 5% error rate. Values presented are means ± SE (standard error of means); **P*<0.05, ***P*<0.01, ****P*<0.001; ns = non-significant (*P*≥0.05).

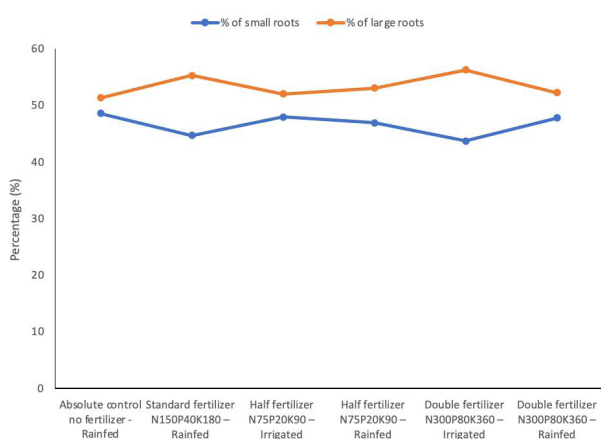


Figure 1. Small and large roots distribution size for 2019-20 cropping season.

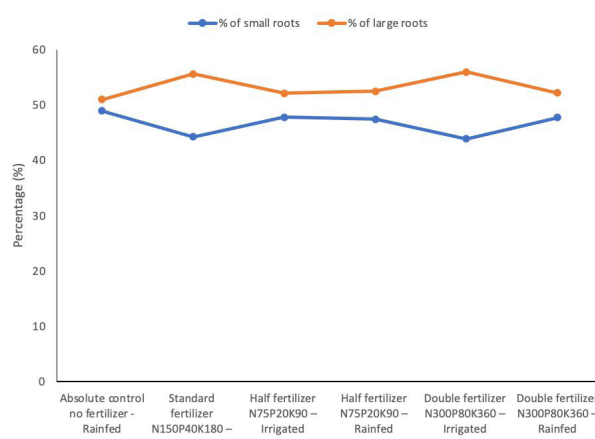


Figure 2. Small and large roots distribution size for 2020-21 cropping season.

3.4 Effect of Fertilizer on the Root Size Distributions

The effect of fertilization on the distribution percentage of root size under both rainfed and irrigated crop regimes for the 2019-20 and 2020-21 crop seasons is shown in Figure 1 and Figure 2. The absolute control under the rainfed regime (T1) had small roots ranging from 48.57 to 48.96% and large roots ranging from 51.04 to 51.34%. Applying fertilizer at N₁₅₀P₄₀K₁₈₀ (T2) resulted in a broader gap of root size due to a decrease in the small roots ranging from 44.29 to 44.70% and an increase in large roots by ranging from 55.29 to 55.64% in both cropping seasons. The N₇₅P₂₀K₉₀ fertilizer application under the irrigated regime (T3) narrowed the gap between small roots, which ranged from 47.82 to 47.92%, and large roots that ranged from 52.04 to 52.14%. However, the same fertilizer treatment rate under the rainfed regime (T4) lowered slightly the percentage of small roots distribution ranging from 46.92 to 47.47%, but

increased large roots distribution ranging from 52.53 to 53.03% in both cropping seasons compared to T3.

Applying N₃₀₀P₈₀K₃₆₀ fertilizer under the irrigated regime (T5) significantly widened the distribution gap between small and large roots. This treatment had the lowest small roots distribution compared to the rest of the treatments by ranging from 43.71 to 43.94%, and the highest large roots distribution ranging from 56.00 to 56.24% for both cropping seasons. On the other hand, the treatment (T6), which had a similar application rate as T5 but under the rainfed regime, had an increased small roots distribution by 47% compared with T5, but decreased large roots distribution by 52.22%.

3.5 Association between Total Root Storage Yield and Leaf Canopy, Stem Diameter and Plant Height

Multiple linear regression results (Table 7) generated

Table 7. Multiple Linear Regression Analysis of Root Yield Versus Canopy, Stem Diameter and Plant Height

Parameter	Estimate	Standard Error	T-statistics	P-value
Constant (C)	-18.91	13.37	-1.41	0.17
Canopy width (CW)	-0.03	0.09	-0.32	0.75
Canopy length (CL)	-0.03	0.07	-0.40	0.69
Canopy height (CH)	0.10	0.25	0.39	0.69
Canopy volume (CV)	-0.01	0.02	-0.67	0.51
Stem diameter (SD)	2.36	1.03	2.30	0.03
Plant height (PH)	0.16	0.08	1.90	0.07

Model: Total Root Yield (Y)=2.36SD+0.16PH+0.10CH-0.03CW-0.03CL-0.01CV-18.91

Table 8. Correlations between Total Root Yields and Leaf Canopy, Stem Diameter and Plant Height

		Measured Variables and Their Correlations						
		1	2	3	4	5	6	7
1	Total root yield	1						
2	Canopy width (CW)	0.14	1					
3	Canopy length (CL)	0.16	0.85	1				
4	Canopy height (CH)	0.35	0.49	0.53	1			
5	Canopy volume (CV)	0.17	0.89	0.91	0.73	1		
6	Stem diameter (SD)	0.70	0.63	0.59	0.60	0.64	1	
7	Plant height (PH)	0.63	0.64	0.73	0.59	0.71	0.83	1

based on a regression model with total root storage yield as a response variable (Y) and the fitted constants CV, CL, CW, CH, PH and SD such that:

$$Y=2.63SD+0.16PH+0.10CH-0.03CW-0.03CL-0.01CV-18.91 \quad (2)$$

The coefficient of determination (R^2) was 0.85. The model indicated that for every unit increase of SD, PH and CH, total root yield increased by 2.36, 0.16 and 0.1% respectively. But, with the same unit increase in CW, CL and CV the amount of total root yield would decrease by 0.03, 0.03 and 0.01% respectively.

The correlation analysis (Table 8) indicates that SD ($r=0.70$), and PH ($r=0.63$) had a positive and significant relationship with total root yields. In addition, there was positive relationship between CV and CL ($r=0.91$), SD and PH ($r=0.83$).

4 DISCUSSIONS

The soil of Ukiriguru site was slightly acidic to the depth of 0-15cm to neutral from 15 to 30cm and had sandy loam texture which is categorized as Arenosols^[32,33]. The soil had the low OC (Table 3) reflecting low organic matter resulting from high temperature (Table 1) that enhances rapid decomposition of organic matter and hence leaching of minerals^[32]. As a result, the N and K levels are low while P and Ca are at medium range.

With exception to absolute control treatment, Kiroba

cassava variety, aerial vegetative parts did not differ significantly, and were better in 2019-20 cropping season compared to 2020-21 cropping season as a result of favourable precipitation and atmospheric temperature (Table 1). Higher fertilizer rates (Table 2) favoured but not significant the PH, CH and CW indicating that varying fertilizer did not influence significant change of these vegetative characteristics for Kiroba variety used in this study. These results suggest that aerial parts of Kiroba variety did not differ significantly upon fertilization. A research study by Mwamba et al.^[34] also observed similar results for the aerial cassava varieties to have no significant changes upon application of fertilizer.

The lowest significant ($P<0.001$) SD, PH, CL, CW, CH, CV and total root yields observed in absolute control treatment (Table 4, Table 5, and Table 6), was a result of very low inherent soil N and K nutrients. Application of $N_{150}P_{40}K_{180}$ fertilizer influenced good results on cassava aerial vegetative parts and storage root yields due to good fertilizer response following inherent low soil N and K (Table 3). Doubling the fertilizer blending ($N_{300}P_{80}K_{360}$) also increased root storage yields under the irrigated regime. However, the same treatment under the rainfed regime slightly improved the root storage yields, indicating that supplementation of N, P and K improved soil fertility and favoured cassava root yield increase.

The lowest $N_{75}P_{20}K_{90}$ application under irrigated regime improved significantly ($P<0.001$) the cassava root

yields indicating that enhancing the N, P and K balance contributes to high root yields. However, the rainfed $N_{75}P_{20}K_{90}$ treatment had a slightly lower but insignificant root yield than irrigated crop. This is due to the nature of the sandy loam textural class that may have an adverse effect on soil water retention and storage capacity which could lead to water stress. The increase of root storage yields for irrigated and rainfed $N_{75}P_{20}K_{90}$ treatments could also be related to the CH as these treatments had significant CH. A research study by de Oliveira et al.^[35] also observed that the vegetative canopy architecture has a direct influence on the growth and yield of cassava crops. Furthermore, it indicates that the cassava crop requires less nutrients for balancing required nutrients for high root storage yields, as these treatments were applied half blend of the fertilizer. However, the irrigated cassava crop was observed to have increased potential of root storage yields than rainfed crop. Other studies also supported that application of balanced N, P and K in the presence of adequate soil moisture is of paramount importance to the cassava root yield increase^[14,15].

The cassava crop grown in unfertilized soil had the highest proportion of small roots reaching the maximum of 48.96% and accounted for the total low root yields. Application of NPK fertilizer under the irrigated regime lowered small storage root proportions and favoured an increase of large storage root proportions. However, as fertilizer rates and levels increased under the rainfed regime, it favoured more increase of small roots proportions and decreased the large root proportions (Figure 1 and Figure 2). The applied higher (double) fertilizer levels, could be associated with unbalancing of NPK nutrients, thus, did not influence proper roots distributions to enhance the increase of storage root yields. Adiele et al.^[36] observed that the cassava root growth and storage yield; require a balanced supply of N and P and moderate K. On the other hand, cassava yield loss was mainly be caused by the low soil fertility and suboptimal management practices by farmers^[37].

The significantly higher storage root yields to both cropping seasons were observed to the half blend ($N_{75}P_{20}K_{90}$) treatments under the irrigated and rainfed regimes, respectively. This indicates that cassava crops require a balancing state of nutrients, and the irrigation has potential for the timely spreading and uptake of nutrients due to soil sufficient moisture as a major factor associated with root storage yield increase. The narrow gaps between the cassava small and large roots distribution were mainly observed in these treatments and hence associated with significantly high storage root yields.

Therefore, narrowing the gap between the small and large cassava roots proportion is a key determinant for the significantly higher root storage yield associated with

balancing NPK nutrients and adequate soil moisture. Furthermore, these treatments had large stem diameter, canopy height and plant height (Table 4 and Table 5) that contributed significantly to the total root yields (Table 7). Thus, SD ($r=0.70$) and PH ($r=0.63$) correlated significantly to the total root yields (Table 8). Our results are almost similar to the results obtained by Yonis et al.^[38], who observed that roots with a large size were generally heavier and reflected high root storage yields than small and roots and hence lighter in weight. The increase in cassava storage yields is influenced significantly by inappropriate nutrient balance^[35]. Furthermore, water deficit affects the development of cassava roots and, consequently reduces root storage yields^[39].

The current study reveals that the potential yields of cassava crops could be achieved using fertilizer blend within $N_{50}P_{10}K_{70}$ and $N_{100}P_{30}K_{120}$. Further research is required to review the fertilizer blends while balancing the N, P, K as the potential yields may increase beyond 25.21t ha⁻¹. Our findings suggest that balancing soil moisture and nutrients is critical for high cassava root storage yields as it narrows the gap between the small and large roots proportions.

5 CONCLUSION

Cassava crops require a less fertile soil with balanced N, P and K nutrients to achieve significant yields. In addition, the nutrients supplied through fertilizer require adequate moisture as significant factor associated with root storage yield increase. These factors, contribute significantly to the narrow gap between the small and large roots that determine the significant higher root storage yield and increased cassava yield ranging from 24.14 to 25.21t ha⁻¹. However, the current study pinpointed the potential for further research using fertilizer blends within $N_{50}P_{10}K_{70}$ and $N_{100}P_{30}K_{120}$ to identify the best fertilizer blend to increase storage root yield beyond 25.21t ha⁻¹.

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Conflicts of Interest

The authors declared no conflict of interest regarding this paper publication.

Author Contribution

Mlay DP designed the study, supervised field officers, collected data, wrote the article, revised the article; Lisuma JB performed the statistical analysis, wrote the article, revised the article. All authors contributed equally to the

manuscript and approved the final version.

Abbreviation List

CH, Canopy height

CL, Canopy length

cmol, Centimole

CV, Canopy volume

CW, Canopy width

ha, Hectare

K, Potassium

MOP, Muriate of potash

N, Nitrogen

OC, Organic carbon

PH, Plant height

P, Phosphorus

SD, Stem Diameter

t, tone

TARI: Tanzania Agricultural Research Institute

TSP, Triple superphosphate

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