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Uncovering the Interaction between Potassium, Magnesium and Sulfur on Cassava Growth and Root Yield

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Abstract

Cassava is an important staple crop in sub-Saharan Africa, yet root yields are low and a wide range of yield limiting factors causes a large yield gap. Next to pests and diseases, nutrient deficiencies and imbalances are likely contributors to low yields. Cassava has a high potassium (K) demand, yet previous research shows that K application does not generally lead to increased yields. Potassium may have antagonistic effects on magnesium (Mg) and cause relative deficiency of Mg. The objective of this study was to determine if interactions between K and Mg affect growth and root yield of cassava. A randomized complete block design with three replicates was used in a 18 × 2 factorial arrangement. Eighteen fertilizer treatments with 4 levels of K (0,90,180 and 270 kg ha^{-1}), 3 levels of Mg (0,15.5 and 31 kg ha^{-1}) were combined with exclusion of Mg treatments but addition of sulfur (S), to account for the S in the Mg source Kieserite, at 2 levels of S (20.5 and 41 kg ha^{-1}), yet excluding Mg. The cassava varieties TME419 and TMS581 were used. Stem height, stem mass and total aboveground mass, storage root yield and starch content were evaluated. Stem height, fresh stem yield and fresh total above ground yield significantly increased with the application of K, K+Mg and K+S, compared with treatments not receiving K, emphasizing the importance of K and indicating that Mg is less important for shoot growth. Fresh and dry matter storage root yield did not respond to K application above 180 kg ha^{-1}as KCl. The application of 270 kg ha^{-1} K with 41kg ha^{-1}S attained the highest fresh and dry matter storage root yield, indicating that the lack of S had a stronger yield limiting effect than Mg availability. Starch content was highest (19.7%) with application of 0K:31Mg:41S (kg/ha) highlighting the role of Mg and S in the synthesis and accumulation of starch in the roots. Thus, it appears that at high K application levels, K_2SO_4 is the better source of K especially in S deficient soils.

Keywords

Cassava, Potassium, Magnesium, Sulfur

1. Introduction

Cassava (*Manihot esculenta* Crantz) is a rainfed crop cultivated in most tropical and subtropical countries around the globe [1]. It is the second-largest source of starch in the world and the fourth most important source of calories in Africa, providing 60% of daily calorific needs to around 300 million people [1, 2]. According to FAOSTAT [3], global cassava production is estimated at 300 million tonnes of fresh storage roots. Sixty-three percent of the cassava produced globally is recorded in Africa, with the greatest share (60 million tonnes) in Nigeria, making it the world's largest cassava producing country [3].

Despite being the largest cassava producer, cassava yields in Nigeria are low (8.2 tha^{-1} fresh mass), which is likely caused by a complex of pests and diseases, poor agronomic practices and the use of old unimproved varieties. Cassava is perceived as a crop that either does not need or does not respond to nutrient application, because it produces even on poor soils. However, recent research has shown that cassava yields increase if fertilizer is applied [4, 5]. Among the factors limiting cassava yields, nutrient imbalances and/or deficiencies have received little attention, yet, are likely to contribute to a large portion of the current yield gap [6, 7].

As a carbohydrate producer, cassava requires a large amount of K [8]. As a result, in recent decades, more emphasis has been given to K fertilizer due to its role in carbohydrate synthesis and translocation [8]. Potassium supply in adequate amounts is essential to increase cassava root yield and starch quality [9]. However, the effect of K on cassava yield is arguable, as high levels of K do not generally increase root yields [1, 9, 10, 11, 12]. This lack of response in cassava root and starch yields associated with high level of K application could be attributed to the fact that K creates an imbalance with other essential nutrients, which are sufficiently similar to K in size, charge, geometry of coordination and electron configuration, causing them to compete for the sites of adsorption, absorption, transport, and function on the root surface or within the tissues [1, 13]. Generally, at higher concentrations, K^+ exhibits a cationic antagonistic effect on the absorption of Mg^{2+} by blocking the unspecific Mg transporters at the root surface, thus inducing Mg deficiency [14, 15, 16]. Magnesium deficiency or reduced uptake impedes plant growth and biomass partitioning between root and shoot, leading to decreased root growth and an increased shoot to root ratio due to impaired carbohydrate distribution from source to sink sites [17, 18].

Since there is not enough information on the interaction between K and Mg on cassava growth and yield, the current study was initiated. We hypothesized that (1) a lack of positive cassava root yield responses to increased K application is caused by a relative Mg deficiency, potentially caused by a K – Mg antagonism, (2) additional Mg application would lead to cassava root yield increases at higher K application rates. To investigate these hypotheses, researcher managed field trials were conducted at Ibadan, southern Nigeria, with the improved cassava varieties TME419 and TMS581.

2. Materials and Methods

2.1. Experimental site and conditions

This field experiment was carried out at the International Institute of Tropical Agriculture (IITA) (7°30′8″N, 3°54′37″E, and 243 m altitude) in Oyo State, Southwest Nigeria (Figure 1). The experimental site had been cropped with yam in 2015, followed by cassava in 2016 and left fallow until the commencement of this experiment. The area lies within the humid tropical lowland region, characterized by a bimodal rainfall pattern with two distinct seasons. The first rainy season starts in April and ends in July, the second rainy season lasts from early September to mid-November [12]. The long dry season typically lasts for four months (mid-November to mid-March). A short dry period in August follows the first rainy season. The experiment was established at the onset of the first rainy season of 2020. Meteorological data were recorded from planting to harvest in coordination with the IITA GIS department.

2.2. Soil sampling and analysis

At the onset of the experiment and prior to fertilizer application, soil samples were collected at (0-20 cm) and (20-50cm) using a soil auger. The soil samples were air-dried, crushed, sieved through a 2 mm sieve and analyzed in the analytical service laboratory of IITA, Ibadan, Nigeria. Soil pH was determined in water at a 1:2.5 soil:water ratio using a pH meter with a glass electrode [19]. The soil organic carbon was determined by chromic acid digestion [20], the total nitrogen by Kjeldahl digestion and colorimetric determination on a Technicon AAII autoanalyzer [21], available phosphorus by the Olsen method [22]. Exchangeable cations (K and Mg) were extracted by Mehlich-3 method and the soil particle size distribution analysis by the hydrometer method [23].

2.3. Trial establishment and experimental design

Prior to planting, the field was cleared of grass and weeds. The experimental site was ploughed with a disc plough and harrowed then ridged at 1 m distance by tractor.

The design of the experiment was a 18×2 factorial set up in a randomized complete block design (RCBD). The first factor was fertilizer treatment, consisting of eighteen nutrient combinations (Table 1). These nutrient combinations were tested to assess the impact on aboveground and storage root yields of application of N, P, K with additional supply of Mg and S versus an unfertilized control and the effect of an increased K application rate at constant N and P rates. To assess if there is a Mg deficiency the control received Mg as magnesium sulfate ($MgSO_4$). Due to the fact that Mg fertilizers are usually Kieserite and thus contain considerable amounts of S, the treatments comprised three N, P, K levels in which no Mg was applied and the K, in all other treatments applied as KCl, was partially replaced by K_2SO_4 to supply the same amount of S as was applied with the $MgSO_4$. The second factor was cassava variety at two levels: TMS581 (IITA-TMS-IBA980581) a medium branching variety with drought tolerance and TME419 (TMEB 419) a non-branching variety, not drought tolerant, both obtained from the IITA cassava breeding team.

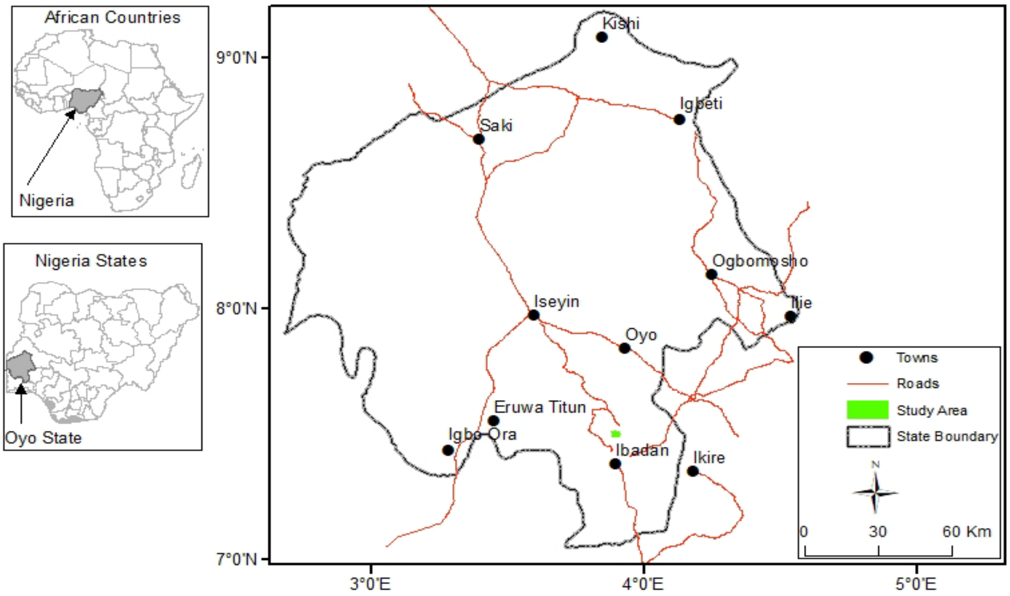

Figure 1. Map of the study area.

Table 1. Nutrient treatment combinations used in this study

Fertilizer treatments		N(kg/ha)	P(kg/ha)	K(kg/ha)	Mg(kg/ha)	S(kg/ha)
1	F0	0	0	0	0	0
2	F1	75	20	90	0	0
3	F2	75	20	180	0	0
4	F3	75	20	270	0	0
5	F0 + Mg1	0	0	0	15.5	20.5
6	F1 + Mg1	75	20	90	15.5	20.5
7	F2 + Mg1	75	20	180	15.5	20.5
8	F3 + Mg1	75	20	270	15.5	20.5
9	F0 + Mg2	0	0	0	31	41
10	F1 + Mg2	75	20	90	31	41
11	F2 + Mg2	75	20	180	31	41
12	F3 + Mg2	75	20	270	31	41
13	F1 - 0Mg + S1	75	20	90	0	20.5
14	F2 - 0Mg + S1	75	20	180	0	20.5
15	F3 - 0Mg + S1	75	20	270	0	20.5
16	F1 - 0Mg + S2	75	20	90	0	41
17	F2 - 0Mg + S2	75	20	180	0	41
18	F3 - 0Mg + S2	75	20	270	0	41

Fertilizer was applied by banding at 10 cm away from the planting line, in a 5 cm deep furrow, then covered with soil. Table 2 shows the fertilizer application schedule and the formulation applied.

2.4. Crop management

Plots measured 7 × 5.6 m, containing 7 by 7 = 49 plants. The inner 5 by 5 plants were used for all crop evaluations and the final harvest. Planting stakes of about 25 cm length were planted at 0.8 m distance along the crest of the ridges by inserting the stakes to 2/3 of their length into the soil at an angle of about 45-60° relative to the soil surface. Thus, the planting pattern was rectangular at 1 m × 0.8 m translating into a plant density of 12500 plants ha^{-1}. Cassava stakes that did not sprout were replaced at 4 weeks after planting (WAP). Weeding was done regularly when deemed required using hand hoes. Schedule of activities is presented in (Table 3).

Table 2. Schedule of fertilizer application

	Fertilizer combination(grams per plot)				
Code	**4WAP**	**8WAP**	**12WAP**	**14WAP**	**16WAP**
F0	0	0	0	0	0
F0+Mg1	0	308$MgSO_4$	308$MgSO_4$	0	0
F0+Mg2	0	615$MgSO_4$	615$MgSO_4$	0	0
F1	588NPK	588NPK, 256Urea	392KCl	0	0
F1+Mg1	588NPK	588NPK, 256Urea, 308$MgSO_4$	308$MgSO_4$, 392KCl	0	0
F1+Mg2	588NPK	588NPK, 256Urea, 615$MgSO_4$	615$MgSO_4$, 392KCl	0	0
F1-0Mg+S1	588NPK	588NPK, 256Urea	446K_2SO_4, 15KCl	0	0
F1-0Mg+S2	413TSP, 320Urea	320Urea, 418$K2SO_4$	418K_2SO_4	0	0
F2	588NPK	588NPK, 256Urea	366KCl	366KCl	366KCl
F2+Mg1	588NPK	588NPK, 256Urea, 308$MgSO_4$	308$MgSO_4$, 366KCl	366KCl	366KCl
F2+Mg2	588NPK	588NPK, 256Urea, 615$MgSO_4$	615$MgSO_4$, 366KCl	366KCl	366KCl
F2-0Mg+S1	588NPK	588NPK, 256Urea	446K_2SO_4	361KCl	361KCl
F2-0Mg+S2	588NPK	588NPK, 256Urea	447K_2SO_4	447K_2SO_4	341KCl
F3	588NPK	588NPK, 256Urea	601KCl	601KCl	601KCl
F3+Mg1	588NPK	588NPK, 256Urea, 308$MgSO_4$	308$MgSO_4$, 601KCl	601KCl	601KCl
F3+Mg2	588NPK	588NPK, 256Urea, 615$MgSO_4$	615$MgSO_4$, 601KCl	601KCl	601KCl
F3-0Mg+S1	588NPK	588NPK, 256Urea	446K_2SO_4, 476KCl	476KCl	476KCl
F3-0Mg+S2	588NPK	588NPK, 256Urea	447K_2SO_4, 349KCl	349KCl, 447K_2SO_4	349KCl

Table 3. Schedule of operations during the experiment

Operations	**Date**
Planting	13/05/2020
Cassava gap filling	11/06/2020
1st growth evaluation	25/06/2020
2nd growth evaluation	29/07/2020
3rd growth evaluation	10/09/2020
4th growth evaluation	22/10/2020
5th growth evaluation	30/11/2020
6th growth evaluation	20/01/2021
7th growth evaluation	26/05/2021
Harvest	31/05/2021

2.5. Growth evaluation and harvest

Stem height of all standing plants in the net plot was measured from the ground to the tip of the newly formed leaf, using a tape measure at 6, 12, 21, 25, 30, 38 and 52 WAP (Table 3). At 52WAP all plants of each net plot were harvested and separated into aboveground materials (stems, leaves and planting stakes) and storage roots. Then the fresh mass of the main stems, cut off at the emergence point on the planting stake, was recorded. The storage roots were cleaned of soil and separated into marketable roots (sufficiently large and of good quality) and non-marketable roots (too small, misshaped, rotten or damaged by pests, generally poor quality). Marketable and non-marketable roots were counted and weighed separately. Three marketable roots were sampled from each plot, sliced into about 1 cm thick discs and mixed. A sub-sample of 500-700 g of the root mix was weighed fresh, oven-dried to constant mass at 80°C, and dry matter (DM) content was determined. The yield per hectare and dry matter (DM) content were determined using the following equations below [24]:

(1) Fresh yield per hectare

$$\left(\frac{t}{ha}\right) = \frac{\text{yield per plot (kg) x 10,000 m}^2}{\text{25 m}^2\text{(net plot size) x 1000 (kg/t)}}$$

Where 1 hectare (ha)= 10,000 m^2 and 1 tone (t)= 1000 kg

(2) The root dry matter (DM) was calculated by getting first the proportion of DM in the fresh yield using the formula

$$\frac{dry\ weight\ (g)}{fresh\ weight\ (g)},$$

Then the DM yield (t ha^{-1}) was calculated by multiplying (1) and (2).

2.6. Starch content

Starch content was determined using the gravimetric method in which about 5 kg of fresh marketable roots, randomly selected, were placed in a light-weight mesh bag, and their mass in air was recorded. Then, the roots in the mesh bag were completely immersed under water and their mass underwater was recorded using a 1000g capacity hanging balance. The starch content was then estimated from the specific gravity (SG) following [25]:

$$\text{SG} = \text{Wa}/(\text{Wa}-\text{Ww})$$

Where, SG= Specific Gravity, Wa= weight in air, and Ww= weight in water

Starch content = 210.8 SG − 213.4

2.7. Statistical analysis

All analyses were done in R software 4.1.2 version [26]. Growth and yield data were tested for normality using the Shapiro–Wilk's test. When these data showed normal distribution, they were statistically analyzed according to the procedure for a randomized complete block design, and subjected to analysis of variance (ANOVA) using the linear mixed-effect model with the *lmer* function to determine the effect of fertilizer treatments on root yield and yield components. Statistically significant means were separated in post hoc comparisons by Fisher's least significant difference test at $p \leq 0.05$.

3. Results

3.1. Weather conditions and soil properties

Total rainfall during the cassava growing phase was 1203.9 mm (Figure 2) and the average temperature was 27.7°C.

The soil physical and chemical properties of the site, summarized in Table 4, report the soil fertility of the site together with the suitability ratings for cassava production. Following the USDA soil classification, the soil texture was loamy sand, with a high percentage of sand in the top 20cm, indicating that the soil was well-drained with a loose texture that gave the roots adequate room to expand.

3.2. Effect of fertilizer treatments on stem height

The effect of fertilizer and crop age on stem height was highly significant (p<0.001) (Table 5). The interaction between fertilizer treatment and variety (p<0.01) and the interaction between variety and crop age on stem height were highly significant (p<0.001).

The effect of fertilizer on stem height over the growing phase is presented in Figure 3. The cassava stem height significantly increased with time and fertilizer application. Significant differences were observed after the first dressing of K was applied at 12 WAP. Cassava stems of TMS581 receiving K fertilizer were significantly taller than those of control (F0), 0K:15.5Mg: 20.5S(F0+Mg1) and 0K:31Mg:41S(F0+Mg2) treatments. In cassava variety TME419 the shortest stems were recorded in treatments F0+Mg2 and F0+Mg1.

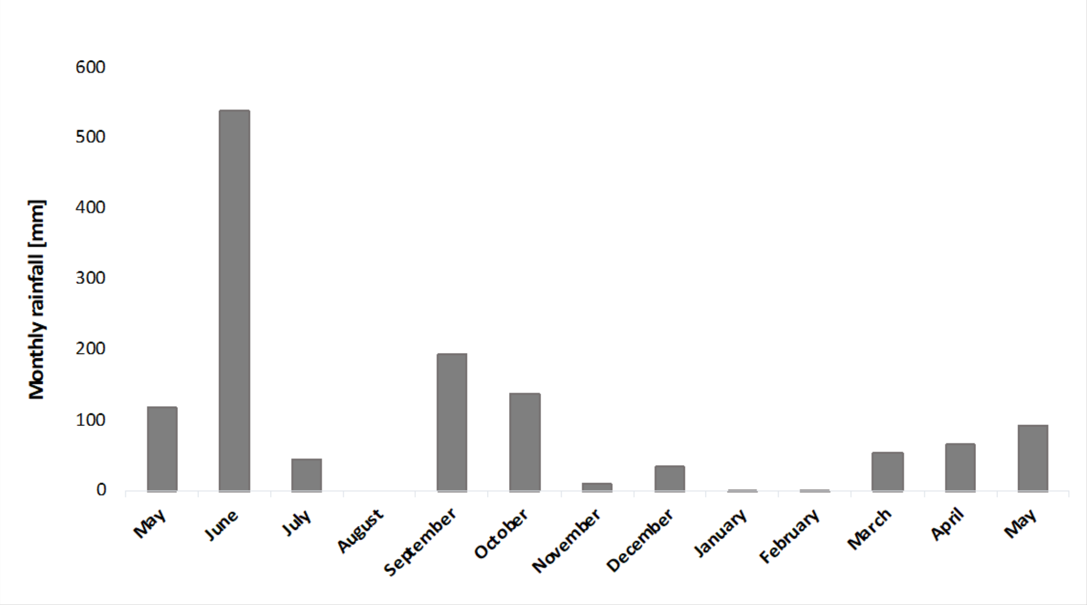

Figure 2. Monthly rainfall (mm) during the cassava growing phase.

Table 4. Physical and chemical soil properties at the experimental site prior to cassava planting

Parameter	*Depth (cm)*	*Value*	*Critical range*	*Rating*
pH($H_2$0) 1:2.5	0-20	6.09	4.5-7.0	adequate
	20-50	6.04		
Organic Carbon (%)	0-20	0.49	4.0-10.0	very low
	20-50	0.38		
Total N (%)	0-20	0.04	0.20-0.50	very low
	20-50	0.03		
Avail. P (mg kg^{-1})	0-20	2.05	<4.2	low
	20-50	1.54		
Exch. K (cmol [+] kg^{-1})	0-20	0.09	0.15-0.25	low
	20-50	0.14		
Exch. Mg (cmol [+] kg^{-1})	0-20	0.28	0.40-1.00	low
	20-50	0.32		
% SAND	0-20	78.50	~	~
	20-50	72.00		
% SILT	0-20	5.90	~	~
	20-50	6.90		
% CLAY	0-20	15.60	~	~
	20-50	21.10		

Note: ppm=parts per million, cmol/kg= centimoles per kilogram. References: pH, K, Mg [27]; OC and N[28]; P[29].

Table 5. Levels of significance of fertilizer treatment, crop age, and cassava variety and their interactions on cassava height

Factor	Stem Height
Variety (V)	0.06 ^{NS}
Fertilizer (F)	<0.001***
Crop age (C)	<0.001***
F*C	0.5 ^{NS}
F*V	0.001 **
C*V	<0.001***
F*C*V	1.0 ^{NS}

Note: *** Significant at p< 0.001, ** significant at p< 0.010, * significant at p< 0.050 and NS not significant(p > 0.050).

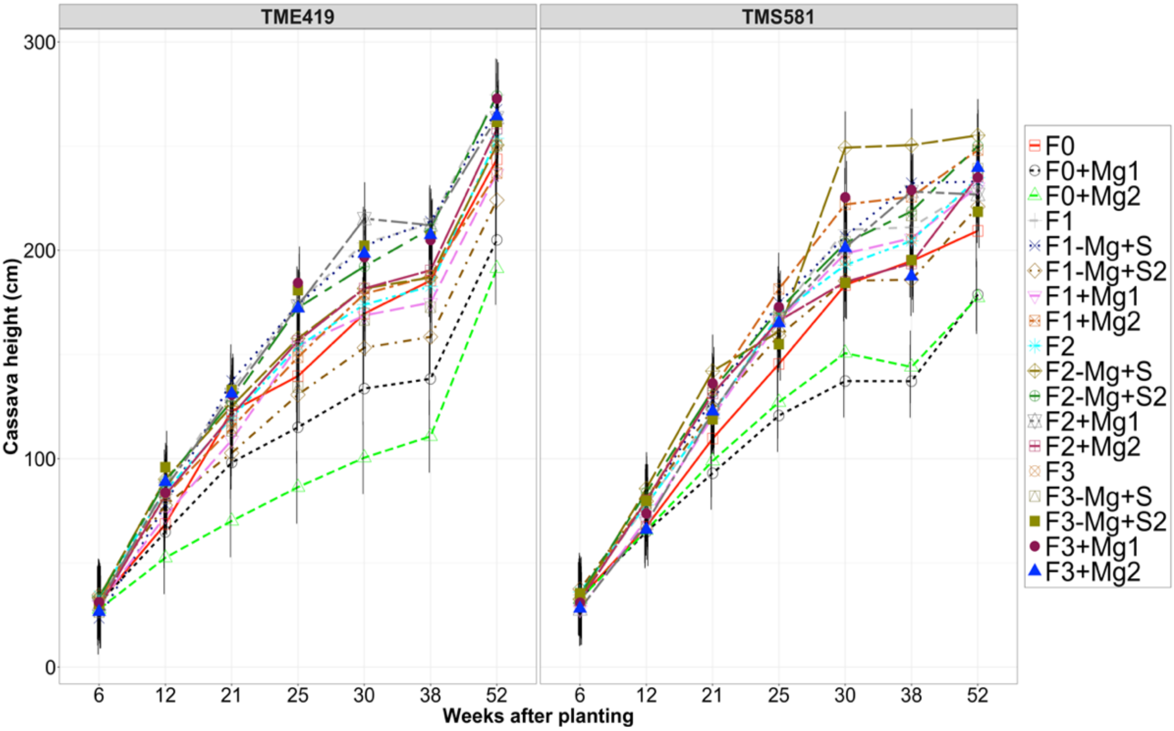

Figure 3. Stem height of cassava variety TME-419 and TMS581 as affected by application of different fertilizer treatments. Error bars represent SE of the means.

3.3. Shoot growth, storage root yield and yield components

Fertilizer application affected the fresh main stem and total above ground fresh yield (Table 6). The varieties produced highly significantly different fresh main stem and total above ground fresh yields. The fresh and DM storage root yield and starch content were significantly different between the varieties. There was no fertilizer by variety interaction.

Table 6. Levels of significance of fertilizer and cassava variety, and their interactions on cassava yield and yield components

Factor	Fertilizer (F)	Variety (V)	F*V
Fresh stem yield	0.018 *	0.002 ***	0.97 ^{NS}
Fresh total aboveground yield	0.012*	<0.001 ***	0.93 ^{NS}
Fresh root yield	0.55 ^{NS}	<0.001 ***	0.37 ^{NS}
Root DM yield	0.64 ^{NS}	<0.001 ***	0.27 ^{NS}
Starch content	0.64 ^{NS}	<0.001 ***	0.84 ^{NS}

*** Significant at p < 0.001, ** significant at p < 0.010, * significant at p < 0.050 and NS not significant (p > 0.050).

3.4. Fresh stem and total aboveground yield at final harvest

Cassava receiving K generally produced high stem and total above ground biomass yields, irrespective of the level and combination with Mg and S (Table 7). The lowest stem (9.58 t ha^{-1}) and aboveground yield (20.03 t ha^{-1}) were recorded in treatment F0+Mg2 (0K:31Mg:41S) next to F0+Mg1 (0K:15.5Mg:20.5S) with 10.79 t ha^{-1} stem yield and 21.48 t ha^{-1} total aboveground yield. Treatment F1-0Mg+S (90K:20.5S) gave the highest stem yield of 23.51 t ha^{-1} and F2+Mg1 (180K: 15.5Mg: 20.5S) yielded the maximum total aboveground biomass of 35.42 t ha^{-1}. Cassava variety TMS581 produced 21.46 t ha^{-1} fresh stems and 34.75 t ha^{-1} total above ground fresh biomass, significantly more than TME419 with 17.40 t ha^{-1} stem and 27.90 t ha^{-1} total above ground fresh biomass.

Table 7. Fresh stem yield and total aboveground yield variation with fertilizer and cassava variety

	Fresh stem (t/ha)		Fresh total aboveground (t/ha)
Treatments			
F0	15.61 ± 7.86	bcd	26.70 ± 9.89 abc
F0+Mg1	10.79 ± 2.47	cd	21.48 ± 4.16 bc
F0+Mg2	9.58 ± 2.45	d	20.03 ± 5.78 c
F1	19.56 ± 7.67	ab	30.94 ± 8.20 a
F1-0Mg+S	23.51 ± 5.19	a	35.27 ± 6.75 a
F1-0Mg+S2	19.28 ± 7.70	ab	30.49 ± 9.59 ab
F1+Mg1	17.84 ± 6.39	abc	29.41 ± 8.16 ab
F1+Mg2	21.61 ± 7.24	ab	33.27 ± 8.37 a
F2	20.72 ± 4.19	ab	33.64 ± 6.78 a
F2-0Mg+S	22.08 ± 9.15	ab	33.68 ± 11.23 a
F2-0Mg+S2	22.71 ± 2.56	ab	35.34 ± 3.75 a
F2+Mg1	22.54 ± 8.67	ab	35.42 ± 10.23 a
F2+Mg2	19.81 ± 4.19	ab	32.55 ± 5.98 a
F3	18.80 ± 5.73	ab	31.63 ± 6.63 a
F3-0Mg+S	19.78 ± 4.56	ab	31.67 ± 6.83 a
F3-0Mg+S2	21.77 ± 8.93	ab	33.65 ± 9.40 a
F3+Mg1	21.96 ± 9.24	ab	33.90 ± 9.86 a
F3+Mg2	21.78 ± 7.45	ab	34.81 ± 7.48 a

3.5. Cassava fresh and dry matter storage root yield and starch content

Fresh root yield increased with K application up to 180K kg ha^{-1} and decreased at the highest level of 270K kg ha^{-1} when applied as KCl. However, the combination of 270K + 41S kg ha^{-1}gave the highest fresh root yield (27.16 t ha^{-1}), followed by F2 (180K) and F2+Mg1 (180K:15.5Mg:20.5S) with 26.91 t ha^{-1} and 25.7 t ha^{-1} fresh root yield, respectively. The same trend was observed in root DM yields with a yield advantage of 21.1% in treatment F3-0Mg+S2 followed by F2, F1+Mg2 and F2+Mg1 with 18.0%, 17.0% and 15.1%, respectively compared with the control (F0) (Table 8). A 17.7% and 19.9% difference on fresh root yield and root DM yield, respectively, was recorded between the two cassava varieties. Variety TMS581 produced significantly higher fresh root and root DM yields than variety TME419 (Table 8).

The starch content in roots of variety TMS581 was significantly lower than that of TME419.

Treatment F0+Mg2 (0K:31Mg:41S) had the highest starch content of 19.65%, while treatment F2 (180K) had the lowest (16.12%) (Table 8).

Table 8. Effect of variety and fertilizer on cassava fresh root yield, root dry matter yield and starch content

	Fresh root (t/ha)		Root DM (t/ha)		Starch content (%)	
Treatments						
F0	22.40 ± 5.04	abc	6.71 ± 1.86	a	18.08 ± 1.67	ab
F0+Mg1	23.70 ± 4.06	abc	6.94 ± 1.32	a	17.98 ± 2.55	ab
F0+Mg2	20.62 ± 6.93	c	6.14 ± 2.31	a	19.65 ± 1.97	a
F1	21.29 ± 4.12	abc	6.44 ± 1.13	a	18.98 ± 1.73	ab
F1-0Mg+S	21.57 ± 2.40	abc	7.22 ± 0.92	a	19.01 ± 2.65	ab
F1-0Mg+S2	23.05 ± 6.61	abc	7.23 ± 1.89	a	18.01 ± 2.05	ab
F1+Mg1	22.15 ± 6.83	abc	6.70 ± 2.47	a	17.68 ± 2.77	ab
F1+Mg2	24.22 ± 3.95	abc	7.85 ± 1.52	a	17.23 ± 1.89	ab
F2	26.91 ± 5.21	ab	7.92 ± 2.63	a	16.12 ± 3.34	b
F2-0Mg+S	21.08 ± 6.65	bc	6.58 ± 2.38	a	18.12 ± 1.95	ab
F2-0Mg+S2	23.97 ± 5.15	abc	7.18 ± 1.81	a	16.46 ± 1.49	b
F2+Mg1	25.70 ± 3.80	abc	7.73 ± 1.38	a	17.59 ± 1.88	ab
F2+Mg2	23.21 ± 4.13	abc	6.52 ± 1.33	a	17.94 ± 3.88	ab
F3	24.38 ± 5.12	abc	6.64 ± 1.47	a	17.15 ± 4.31	ab
F3-0Mg+S	23.08 ± 7.31	abc	6.31 ± 2.09	a	16.48 ± 3.30	b
F3-0Mg+S2	27.16 ± 4.60	a	8.13 ± 1.23	a	17.13 ± 3.81	ab
F3+Mg1	23.14 ± 5.43	abc	6.51 ± 1.86	a	16.74 ± 3.01	ab
F3+Mg2	23.81 ± 3.98	abc	6.88 ± 1.13	a	18.64 ± 1.07	ab
Variety						
TME419	21.34 ± 4.95	b	6.28 ± 1.66 b		18.62 ± 2.46	a
TMS581	25.48 ± 4.46	a	7.67 ± 1.52 a		16.83 ± 2.50	b

4. Discussion

Due to the high potassium (K) demand of cassava, K fertilizer has been inculcated as a prerequisite for maximizing cassava root yield and quality; and quality and yet it does not generally increase the storage root yield. This study supports the argument that high K applications might have an antagonistic effect on Mg, causing relative Mg deficiency, which could be the reason for the lack of response to high K application rates

Results of this study reveal that the response in vegetative growth to fertilizer application was variable, and plants that received K, K+Mg and K+S fertilizer had longer stems (Figure 3), and higher fresh stem yields and higher above ground biomass yields than the control and plants fertilized with treatment F0+Mg1 (0K:15.5Mg:20.5S) and F0+Mg2 (0K:31Mg:41S) (Table 7). This indicates that there is no antagonism of K against Mg discernible in shoot growth and yield. It is reported that K deficiency significantly reduces shoot biomass in many crops such as cassava and potatoes, while Mg deficiency does not reduce stem height and shoot growth [30-32]. Thus, the supply of K might have increased the photosynthetic rate, which ultimately led to higher shoot biomass production since K is of major importance in stem growth due to its role in cell multiplication and photosynthesis [33-35]. The superior shoot growth obtained with the K fertilizer concurs with the findings of [35-38]. The difference in above ground biomass yield between the two varieties could be connected to their different growth patterns and ability to branch as well as the drought tolerance of TMS581. The high above ground biomass yield ofTMS581could be due to it branching and thus providing more sinks for assimilates in above ground parts. While TME419 hardly ever branches and is as well producing a limited number of main stems, thus provides fewer sinks above ground. In addition, it is to be considered that TMS581 is a so called "stay green" variety with a good drought tolerance and the ability to maintain canopy through the dry season and accordingly being able to use the first rains to produce biomass, while TME419 sheds all leaves and needs to regenerate the canopy by mobilizing resources from the roots and the stems. Both factors would explain the lower above ground and root biomass production in TME419 [12, 39].

In our study, root yield did not decrease at K levels above 180 kg ha^{-1} if neither Mg nor S were amended. The highest root yield achieved with 270K+41Skg ha^{-1} (F3:0Mg:S2) (Table 8) suggests that there was a sulfur deficiency. Potassium applied as KCl or K_2SO_4 can generate distinct responses in root production owing to their accompanying anions [40], and that K_2SO_4 is more efficient in favoring the formation and redistribution of carbohydrates. The results of our study agree with findings of [41], reporting that KC1 + S and K_2SO_4 produced the same cassava yields when the soil available S was adequate, and this was mainly attributed to the sulfur. Further, it does appear that the soil of our experimental site was S deficient and the cassava efficiently utilized the S supplied with $MgSO_4$ and K_2SO_4, leading to root yield increases. Thus, although cassava has low S requirements, S seems to be more limiting than Mg, when high rates of K are applied. However, it cannot be excluded that the SO_4^{2-} anion has a positive impact on Mg uptake in the presence of high K concentrations in the soil solution. Nevertheless, the controversy with previous findings on K fertilization could be attributed to many factors such as climatic condition, soil type and the source of K used in the different experiments. Findings of [35] reported that cassava yield response to K is highly dependent on soil type. Though it seems that the right K source at the right rate could principally be the reason behind the yield decline as [42] reported that KCl is more efficient when applied at low rates while K_2SO_4 is superior at high rates.

Starch content was lowest with application of 180 kg ha^{-1} K. Application of K as KCl may have a “hidden cost” by reducing the starch content due to the adverse consequences of the Cl^- ion, which intensifies the decline in starch content [43]. This confirms the assertion of [41], that high levels of K have some deleterious effects on starch accumulation, potentially due to negative effects of the chloride ion. Although not a direct confirmation of the former, the highest starch content achieved in this study with 0K:31Mg:41S (F0+Mg2) could be due to beneficial effects on starch synthesis and accumulation of Mg and S in cassava roots [44].

The differences in root yield between the two varieties, with TMS581 recording the highest, could be because, as a late bulking variety, TMS581 bulking rate continued as the crop aged, while that of TME419 as an early-bulking variety, declined with crop age. These results concur with the findings of [12, 45, 46], yet [39] found no difference in storage root yield between TME419 and TMS581. The high starch content of TME419 could be due to the fact that it had reached its maximum since it bulks earlier and faster, while TMS581, as a late bulking variety, might still have been in or before the peak phase of starch synthesis and accumulation, since it is believed that at later stages of the growth cycle, the synthesis and allocation is more towards accumulation of starch in the roots rather than expanding the mass and volume of roots.

5. Conclusion

The present study underscores the need for farmers to fully adopt a balanced fertilizer regime that would keep the soil nutrients balanced and be beneficial in terms of storage root, starch yield, as well as stem for multiplication in subsequent seasons. Therefore, since cassava is a crop with high K demand, requiring large dressings of K fertilizer, K_2SO_4 seems to be a better source of K and S as sulfur seems to be more limiting than Mg under the south/western Nigerian conditions.

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