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Research Article

Effects of Cassava Planting Stake Orientation, Size, and Age on Growth and Storage Root Yield

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Abstract

Cassava is an important food and commercial crop in Nigeria with a higher demand than the current production. Intensification is resource demanding and risk avoidance of smallholders prevents major changes in the production systems. Simple, low-cost, low-labour intensification approaches may be more likely to be adopted. We conducted experiments on the growth and root yield of cassava as affected by the orientation, the provenance, and the size of cassava planting stakes. Plant establishment and survival to the harvest had a variety × stake orientation interaction. Survival was lower when using stakes from the top of the mother plant stem. Inserting the planting stakes vertically into the soil produced the highest root yields in 4 of the 6 trials. Slanted stake insertion produced root yields similar to vertical planting in 5 of 6 trials. On average across the trials planting horizontally produced 16.73, slanted produced 17.89 and vertical produced 17.40 Mg ha^{-1} fresh storage roots. First season planted cassava produced higher root yields when planted slated (17.83 Mg ha^{-1}) and vertically (17.73 Mg ha^{-1}) than when planted horizontally (14.37 Mg ha^{-1}). Horizontal stake orientation had an advantage when planting in the second season (20.68 Mg ha^{-1}) over slanted, (18.01 Mg ha^{-1}) and vertical (16.86 Mg ha^{-1}). The planting stake diameter affected root yields such that high diameter stakes produced lower root yields than low diameter stakes. Sprouting a large number of shoots in the early growth phase was related to low root yields, potentially caused by higher water consumption and later shoot losses affecting the initiation of root bulking and the root number per plant. The provenance within the mother plant stem, i.e., the age of the planting stakes did not affect the root yield. For first season planted cassava vertical or slanted insertion of stakes can be recommended. When planting in the second season, shortly before the dry season, soil moisture conditions need to be considered when choosing the planting stake orientation to ensure sprouting roots are able to reach soil layers providing sufficient water to establish.

Introduction

Cassava is a major food and industrial crop in Sub-Saharan Africa. Nigeria is with an estimated annual production of > 59 million tonnes in 2019, the largest producer world-wide [1]. However, the country has not achieved producing as much cassava as local food requirements and industrial processing demand [2]. Despite its importance, formal cassava "seed" systems appear to be rather rudimentary [3], thus distribution of certified planting material lags far behind actual requirements. The use of uncertified planting material without any check on pest and disease infestation, as well as the retention of old unimproved varieties, may be a major contributing factor to Sub-Saharan cassava fresh root yields being far below the potential yield, estimated at 90 Mg ha^{-1} fresh roots [4,5]. Although several intensification measures, such as appropriate tillage [6,7], fertilizer application [5] and optimal planting and harvest dates [8,9] have been researched and could be implemented by farmers, economic constraints and risk adverse attitudes appear to limit the use of these measures.

In Nigeria about 90% of the cassava production is consumed within the country as food [10]. An estimated

30 million Nigerian farmers are growing cassava, of which 95% cultivate less than 2 ha [11]. Thus, in Nigeria cassava is a backbone of smallholder farmers who will largely be cash constrained and risk adverse. Considering the low root yields attained over the last decades ranging from 7.9 to 11.9 tons/ha [12], any yield increasing measure that is low, or no cost will likely be adopted. Farmers may be more willing to change components in their cassava production system if these do not involve additional costs and additional labour or if such investments are marginal compared with the cost of fertilizer or tractor services for tillage.

Cassava planting material is usually procured from harvested fields at practically no cost but the labour to collect and transport it. As such any intensification of cassava production relying on farmers' own planting material would probably have a higher chance of being adopted than more cost intensive approaches. The importance of sufficiently high cassava plant densities has long been established [7,13]. Optimising cassava planting density was shown in Brazil to more than double the farmers' root yield [14]. Similarly, though smaller, root yield increases were determined with increasing cassava densities when intercropped with maize in Nigeria [15]. However, in Nigeria the cassava plant density is in many fields rather low and does often not attain the current recommendation of 10000 ha^{-1} [16]. More recent results indicate that this recommendation might need revision as root yields increased with higher plant densities, albeit depending on soil fertility and chosen cassava variety [7,17].

In addition to optimising the cassava plant density, the planting stakes can be inserted into the soil vertically, or at an angle (slanted) or be buried horizontally [18], the latter is commonly practiced according to Adeniji, et al. [19] by most traditional farmers in southern Nigeria. Few studies have investigated the effects on sprouting, growth and storage root yield of cassava when planted at these different planting stake orientations. Reports on effects on root yield are conflicting [20]. Karnjanakorn [21] and Mbah, et al. [22] compared vertical, slanted (at an angle) and horizontal planting and reported that vertical planting outyielded the horizontal planting. In contrast, planting position did not affect the root yield of cassava [23,24] in The Philippines. Abdullahi, et al. [25] found higher root yields in vertically and slanted planted cassava grown, in polythene bags. Polthanee and Wongpichet [26] reported that vertical planting produced the maximum number of storage roots per plant and fresh storage root yields. Oguzor [27] reported that vertically planted cassava attained higher sprouting rates than horizontally and slanted planted stakes. Villamayor, et al. [28] found significant differences in root yield responses to planting stake orientation between varieties.

Next to the orientation with which planting stakes are inserted into the soil, the diameter and length of the planting stake or its mass might be an important factor in sprouting, thus crop establishment and potentially final root yield. Eke-Okoro, et al. [29] reported that in cassava production, root yields are dependent on the mass of the stakes used for planting. Differences in the mass of stem cuttings translate into differences in reserves [30] required to sprout and to facilitate rapid, early growth. However, there is no conclusive information on the optimum stake size or mass required to attain maximum establishment and high storage root yields.

Planting stake size, specifically the diameter is a function of the stems' age [31]. Older stems attain higher diameters at the base and along the stem the diameter declines towards the younger parts. CIAT (1984) [32] found that the section of the stem, from which cuttings were used, affected subsequent growth and yield of cassava. This may be due to the higher water content of younger shoot parts [33] and the higher risk of drying out before sufficient roots are grown to ensure sprouting and survival, thus would be a cause of low plant densities. However, conclusive information on the most suitable portion of the cassava stem to be used for planting appears to be insufficient.

The various uncertainties about the optimal planting stake orientation, their size, and their provenance in the mother plant stem, require more research to furnish farmers with reliable information on the best options in choosing and planting cassava stakes.

For the above reasons experiments were conducted to determine (a) if any of the angles at which cassava stakes can be planted has a significant root yield advantage, (b) if planting stake size (diameter) influences root yield and (c) if the position or physiological age of a planting stake within the mother plants' stems affects the root yield.

Materials and methods

Sites

Three experiments, comprising 6 trials in six sites, were conducted in southwest Nigeria between April 2016 and April 2020. Four of the trials were planted in the first season and 2 in the second season. Experiment 1 (3 trials) was conducted in three sites, two at the International Institute of Tropical Agriculture (IITA) headquarters, Ibadan, Oyo State, Nigeria in the first season (sites 'D23' lat. 7.49238, long. 3.90360 and 'WB South', lat. 7.48847, long. 3.88287) in 2016 and one at the Obafemi Awolowo University Ile Ife, Osun State, Nigeria (lat. 7.5527, long. 4.5594) in the second season of 2016. Experiment 2 (1 trial) was a single site at IITA headquarters (site 'D15', lat. 7.49159, long. 3.90075), planted in the first season 2017 and experiment 3 (2 trials) was conducted in two sites at IITA headquarters one planted in the second season 2018 (site 'WB East', lat. 7.48882, long. 3.88401) the other in the following first season 2019 ('WB West', lat. 7.48907, long. 3.88285). Coordinates are approximate positions of the centre of the trials. The first rainy season at Ibadan and Ile Ife commences in late March to early April and is followed by a short dry spell during August. The second (heavy) rainy season starts in early September with rains ceasing between the beginning and the middle of November.

Land preparation, and crop husbandry

Experiment 1: The experimental plots were ploughed, harrowed and ridged at a distance of 1m. Cassava was planted at 1m distance between ridges and 0.8m along the ridge, resulting in a plant density of 12,500 plants ha^{-1}. The gross plot had 7×7 plants, thus was 7×5.6m (39.2 m^2) and net plot size was 5×5 plants, thus was 5×4m (20 m^2). Weed control was conducted with pre-emergence herbicide Primextra Gold at 4 liters ha^{-1}; active ingredient 290 g/L S-Metolachlor + 370 g/L Atrazine, applied immediately after planting. Post emergence weed control was done manually by hand hoe around 6-8 and 12-16 weeks after planting (WAP) and when deemed necessary, yet at least two times in the crop cycle. The planting and harvesting dates and crop cycle lengths of all trials are in Table 1.

Experiment 2: Land preparation and planting pattern were as in experiment 1. Net plots were 5 m wide and 8 m long with 5×10 plants. All plots were surrounded by one line of cassava on all sides. No pre-emergence herbicide was applied and weed control was conducted at 4, 8, 12 and 24 WAP using hand hoes in half of the repetitions and a modified mechanical rotary tiller in the remaining repetitions. Cassava was harvested at 55 WAP.

Experiment 3: In both sites land preparation, planting patterns and weed control were as in experiment 1.

Experimental design and treatments

Experiment 1 was a 2×2×3×2 factorial randomized complete block design with three replications in each site. The first factor was cassava variety at two levels: TME419, an erect almost non-branching, highly CMD tolerant variety and TMS30572, an early and profusely branching, less CMD tolerant variety; the cassava varieties were selected based on their contrasting traits and relevance to agricultural research. TME419 is a widely cultivated variety known for its erect, almost non-branching growth habit and high tolerance to Cassava Mosaic Disease (CMD), making it a suitable candidate for assessing planting methods under controlled conditions. In contrast, TMS30572, an early and profusely branching variety with lower CMD tolerance, represents a different growth and disease-resistance profile. This selection ensures a comprehensive evaluation of planting stake characteristics, angles, and fertilization regimes across varying growth habits and disease resilience. Second factor was the diameter of the planting stakes at 2 levels: 15-24 mm and 25-40 mm; third factor was the angle of insertion of the planting stakes into the soil at three levels: vertical at 90°, slanted at 45° and horizontal at 0°, i.e. flat at 5-7 cm below the soil surface; fourth factor was fertilizer application at 2 levels: nil versus a total of 75, 20 and 90 kg ha^{-1} of N, P and K, respectively. The different planting stake diameters were determined by measuring diameters with a veneer caliper. The stems were cut into 25 cm long pieces and kept separate by diameter class. Planting stakes were inserted to about 2/3 of their length into the soil when planted vertically or at an angle. Fertilizer was applied in 2 dressings of 150 kg ha^{-1} of N, P_2O_5, K_2O (NPK 15-15-15) at 4 and 6 weeks after planting (WAP), followed by 65 kg/ha of urea and 50 kg/ha of KCl (MOP) at 8 WAP and further 50 kg ha^{-1} of KCl at 10 WAP. All fertilizer was placed by the side of the ridge in a furrow and covered with soil.

Table 1: Site, season, planting and harvesting dates and crop cycle length in weeks of six trials in three experiments.

Experiment	Site	Season	Date Planted	Date Harvested	Crop cycle length Weeks
1	D23	1	09 May 2016	04 June 2017	60
1	B South	1	11 May 2016	06 June 2017	56
1	Ile Ife	2	27 Sep. 2016	25 Sep. 2017	52
2	D15	1	27 May 2017	20 June 2018	56
3	B East	2	09 Nov. 2018	15 Jan. 2020	62
3	WB West	1	01 April 2019	01 April 2020	52

Experiment 2 was a 3 × 10 factorial trial with 12 replicates. First factor was the angle of insertion of the planting stakes into the soil at three levels: vertical at 90°, slanted at 45° and horizontal at 0°, i.e., flat at 5-7 cm below the soil surface; second factor was the position within the mother plant stem from which the planting stake originated. The variety was TME419, because it produces long straight un-branched stems. Two hundred twenty-five cassava plants were harvested from a multiplication plot with a total of 269 stems deemed suitable for the trial (minimum length of mature stem > 220 cm). Each stem of each mother plant was labelled with an ID number. For every mother plant the root fresh mass and the number of stems was recorded. Stems were cut off as close as possible to their emergence point on the planting stake. The cut off stems were sawn straight with a circular saw at about 3-5 cm above the base and the diameter was measured at 10 cm above the cut. Then 10 pieces of exactly 20 cm length were sawn off each stem with a circular saw and labeled with their position within the stem with the numbers 1 to 10 with 1 at the base and 10 at the top. The diameter of the uppermost stake was measured in the middle of the stake. The numbered stakes cut from each mother plant stem were kept in a paper bag with the ID number of the mother plant stem. The 10 stakes of 5 mother plant stems were randomly allocated to plots. Each plot was either planted vertically, at an angle (slanted) or horizontally. In each plot the 10 stakes of 5 mother plant stems were allocated one ridge and the stakes from the same mother plant stem were planted in the sequence in which they were cut off the mother plant stem from number 1 (base) to number 10 (top) along the same ridge. Each plot was labeled with the planting angle (V = vertical; S = at angle or slanted; H = horizontal) and replicate number and each ridge was labelled with the mother plant stem ID number. The experiment did not receive fertilizer or any agrochemicals.

Experiment 3 was a 2×3 factorial randomized complete block design with 4 replicates in site WB East and 3 replicates in site WB West. First factor was cassava variety at 2 levels: TME419 versus TMS-IBA980581, further on called TMS581, a late but profusely branching, CMD and drought tolerant variety; second factor was the angle of insertion of the planting stakes into the soil at three levels: vertical at 90°, slanted at 45° and horizontal at 0°, i.e., flat at 5-7 cm below the soil surface.

Soil sampling and rain fall data

In all trials soil samples were collected after the tillage, yet before ridging and planting with a 2 cm diameter auger from 0-20 and from 20 to either 40 or 50 cm depth (Table 2) by replicate. In each replicate a minimum of 5 insertions were taken and soil was pooled by replicate. Soil was air-dried, passed through a 2 mm sieve before analysis. Organic C was determined by chromic acid digestion [34], total nitrogen by Kjeldahl digestion and colorimetric determination on a Technicon AAII autoanalyzer [35], soil pH was determined in water at 1:2.5 soil/water ratio, available P by the Olsen method [36] and exchangeable cations were determined by Mehlich-3 extraction. All analyses were conducted at the analytical service laboratory of the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria.

At every trial site at least one manual rain gauge was installed, and rain amounts were recorded every morning at 8:00h local time, except for Ile-Ife where the rain data for October 2016 to February 2017 were obtained from the CHIRPS [37] web site.

Plant data collection

In experiment 1, main stem counts were done in all 3 sites by counting the number of stems emerging on each planting stake in the net plot at 2, 4, 6, 8, 12, 16, 20, 24 and 52 WAP. In experiment 2 main stems were counted at the final harvest. In experiment 3 main stem counts were done in the November 2018 planted site WB East at 1, 3, 5, 7, 9 and 11 months after planting (MAP) and at the final harvest 13 MAP. In the WB West site, planted in April 2019 main stems were counted at final harvest.

The storage root harvests started with the removal of the border plants. Plant and stem numbers were counted by net plot in experiments 1 and 3 and by plant in experiment 2. The plants were then uprooted and the roots separated from the planting stakes. Roots were sorted into marketable and non-marketable roots, whereby the criteria for non-marketable roots were: a diameter < 1.5 cm, root rot and deformations hampering peeling. The marketable roots were counted and weighed per plot in experiment 1 and 3 and by plant in experiment 2. For all experiments, root yields are not including non-marketable roots. In experiment 1 and 3 root subsamples of around 500 to 800 gram fresh mass were collected by plot and dried to constant mass at 60 °C to calculate dry matter content and root dry matter yield. Root yield of experiment 2 is expressed as fresh mass.

Statistical analyses

The plant evaluation and yield data were analyzed separately for each of the six sites using parametric Linear Mixed model ANOVA procedure in SAS [38], and separation of significant means was done using the SAS LSMEANS test (pair-wise *t*-test comparisons at p = 0.05). Percent data and proportions were square root of arcus-sinus transformed. All other data were normally distributed and therefore no transformations were used in the statistical analyses.

Results

Soil properties and rain fall

The largest differences in soil properties were found in available P, with the site D23 having the highest P contents, followed by WB South and Ile-Ife. Available K was lowest at the sites D23, D15 and WB South. Organic carbon and total N were highest in the sites WB South, Ile Ife and D15. Rainfall (Table 3) followed at all sites the typical bi-modal pattern, yet total rain received during the growth period was lowest at Ile-Ife. Highest amounts of rain were received by the crop in D15, followed by the crops in sites WB East and WB West. The amount of rain fallen in the D15 trial was exceptionally high and had an unusual distribution with only one month without rain in the entire period.

Main stem production and survival to harvest

In experiment 1, fertilizer application had no effect on sprouting and main stem density in the sites planted in the first season. Stem density of cassava variety TME419 was on all dates but 8 and 12 WAP, significantly higher than that of variety TMS30572, albeit at small differences, ranging from 0.15 to 0.39 stems m^{-2}. High diameter planting stakes produced more stems than low diameter stakes on all dates. Horizontally planted stakes produced more stems as of 4 WAP than slanted and vertically planted stakes, without a difference between the latter two on all dates but at 2 WAP (Figure 1). The variety

Table 2: Soil chemical properties of the experimental sites.

	Soil	pH	organic	total	available	exchangeable		
	depth	(H_2O)	C	N	P	Ca	Mg	K
Site	(cm) depth		g kg^{-1} g kg^{-1}	g kg^{-1} g kg^{-1}	mg kg^{-1}	(cmol [+] kg^{-1})		
D23	0-20	6.43	5.6	0.59	28.81	1.68	0.35	0.09
	20-40	6.53	3.3	0.42	13.89	1.60	0.33	0.08
WB South	0-20	6.83	9.4	0.95	8.78	3.11	0.46	0.11
	20-40	6.83	7.3	0.76	7.83	2.24	0.39	0.10
Ile-Ife	0-20	6.07	8.5	0.81	9.68	1.04	0.33	0.17
	20-40	5.97	6.8	0.68	5.46	0.95	0.33	0.16
WB West	0-20	6.59	6.9	0.67	1.22	nd	nd	0.17
	20-50	6.42	4.7	0.45	1.01	nd	nd	0.16
WB East	0-20	6.4	6.8	0.6	1.71	nd	nd	0.15
	20-50	6.2	4.8	0.5	0.83	nd	nd	0.16
D15	0-20	6.1	7.2	0.73	2.07	2.47	0.46	0.10
	20-50	6.2	4.2	0.40	1.98	1.70	0.46	0.11

nd: not determined.

Table 3: Monthly amounts of rainfall by site.

D23	Rain	WB South	Rain	Ile - Ife	Rain	D15	Rain	WB East	Rain	WB West	Rain
09/May/2016	189	11/May/2016	189	27/Sept/2016	46	27/May/2017	28	09/Nov/2018	5	01/April/2019	175
June	289	June	202	October*	251	June	352	December	0	May	192
July	71	July	78	November*	22	July	302	January	0	June	240
August	76	August	73	December*	4	August	106	February	35	July	170
September	322	September	262	January*	6	September	221	March	96	August	193
October	142	October	33	February*	5	October	96	April	175	September	234
November	12	November	17	March	3	November	23	May	192	October	289
December	0	December	0	April	36	December	20	June	240	November	37
January	0	January	0	May	107	January	0	July	170	December	16
February	1	February	1	June	165	February	69	August	193	January	0
March	64	March	60	July	141	March	148	September	234	February	0
April	102	April	94	August	19	April	92	October	289	March	48
May	188	May	213	25/Sept/2017	172	May	191	November	37	01/April/2020	0
04/June/2017	32	06/June/2017	34			20/June/2018	194	December	16		
								15/Jan/2019	0		
Total	1488		1256		977		1842		1682		1594

* Data are estimates from CHIRPS. Cells with dates indicate the planning date from which onwards the rain amounts for the months are provided or harvest dates up to which rain amounts are provided.

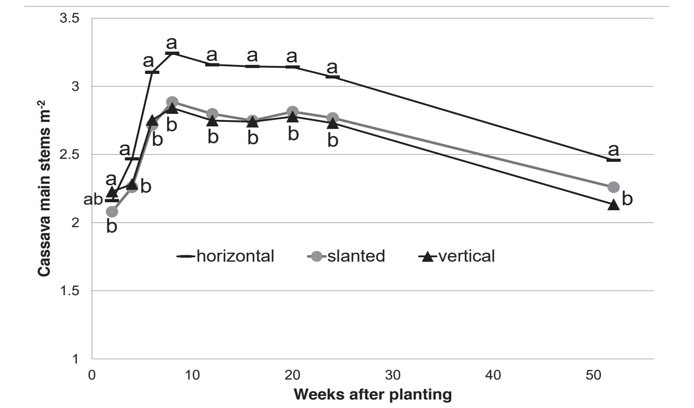

Figure 1: Cassava main stem density of horizontally, slanted and vertically planted cassava stakes over time. Main stem density (stems m^{-2}) over weeks after planting (WAP).

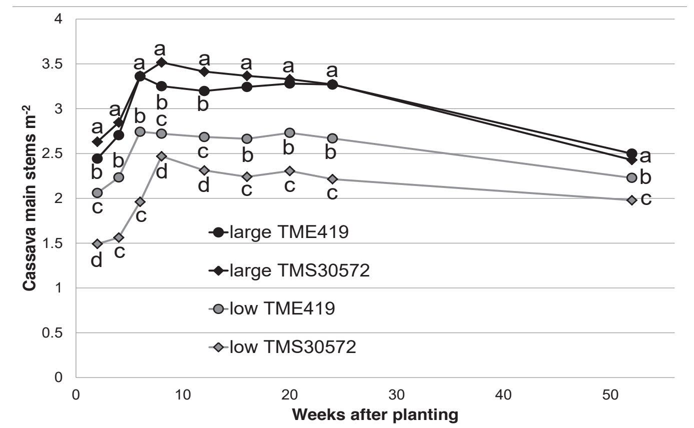

Figure 2: Cassava main stem density of large and low diameter stakes of two varieties over time.

× stake diameter interaction was significant on all dates but at the final harvest. Low diameter stakes produced generally fewer stems than large diameter stakes, yet the difference in stem number in TME419 was smaller than the difference in TMS30572 (Figure 2). For most dates the varieties were not different in stem number produced by large diameter stakes, yet stem numbers were always different between varieties at low stake diameter. Maximum stem density was attained at 6 or 8 WAP, followed by slight declines when planted with low diameter stakes. When planted with high diameter stakes this decline was stronger. In both stake diameter treatments, the decline continued to the final harvest at 52 WAP.

In the second season planted trial at Ile Ife, fertilizer application significantly reduced the main stem density up to 20 WAP. The patterns of changes in main stem density were different from those in the first season (Figure 3). Latest by 4 WAP stem density declined in both varieties to a minimum at 16 WAP, coinciding with the end of the dry season. Throughout the dry season, TME419 had more stems than TMS30572, yet after 24 WAP stem density declined in TME419 while it increased in TMS30572.

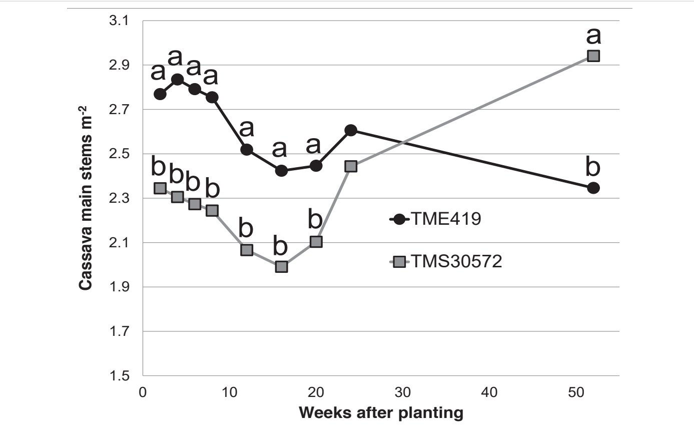

Figure 3: Cassava main stem density changes over time of variety TME419 and TMS30572 planted in the second season at Ile Ife.

Large diameter stakes produced significantly more stems than low diameter stakes, with differences ranging from 0.54 to 0.85 more stems m^{-2} on large diameter stakes between 2 and 24 WAP. At 52 WAP the difference had declined to 0.16 stems m^{-2} and was no longer significant.

Planting stake orientation affected stem density at 2, 4, and 6 WAP (Figure 4) with lower stem densities attained when planted horizontally than at an angle and vertically (2 WAP only). From 8 to 24 WAP differences were not significant and at 52 WAP the horizontally planted cassava had attained a significantly higher stem density than the vertically and slanted planted cassava. Noteworthy is that vertically and slanted planted cassava lost nearly 0.6 stems m^{-2} during the dry season, while the horizontally planted cassava lost less than 0.13 stems m^{-2}.

Plant survival to harvest had a variety × stake orientation and a variety × stake diameter interaction. Low diameter planting stakes of TMS30572 had a significantly lower survival to harvest (71.1%, $p < 0.0049$) than large diameter stakes of both varieties (85.0%) and low diameter stakes of TME419 (87.3%). Survival to harvest of TME419 was in every planting stake orientation significantly different from that of TMS30572, yet higher when planted horizontally and vertically and lower when planted at an angle (Table 4).

In experiment 2, survival to harvest was lowest with 59.7% when planted horizontally, significantly different from 67.8% when planted vertically and at an angle (68.8%). Survival declined with higher position (lower physiological age) within the mother plant stem (MPS) from around 75% to around 55% with a regression:

Survival = -2.572 position in MPS + 79.6 ($r^2 = 0.812$).

At harvest, the number of main stems per plant and per square meter was significantly greater when planted vertically (1.19 $plant^{-1}$, 1.48 m^{-2}) or at an angle (1.11 $plant^{-1}$, 1.39 m^{-2}) than when planted horizontally (0.91 $plant^{-1}$, 1.15 m^{-2}, $p < 0.0016$). Stems per plant and square meter declined with higher position (lower physiological age) in the mother plant stem from around 1.66 m^{-2} to a minimum of 1.0 m^{-2}, with the regression:

Stems m^{-2} = -0.0617 position in MPS + 1.68 ($r^2 = 0.759$).

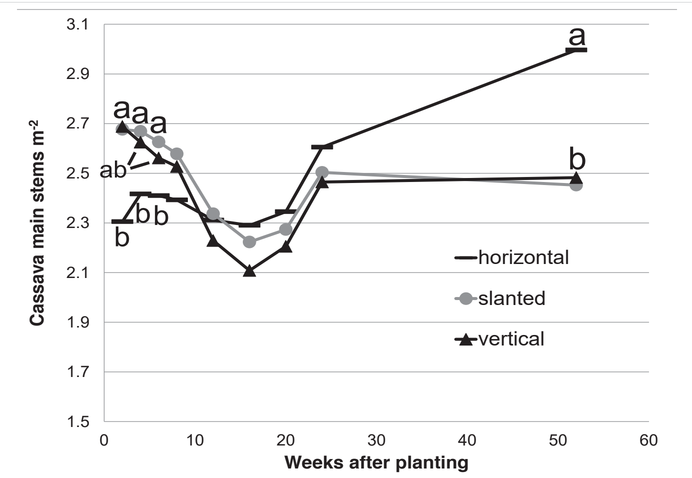

Figure 4: Cassava main stem density changes over time of horizontally, slanted and vertically planted cassava stakes, second season, Ile Ife.

Table 4: Plant survival (%) to harvest of TME419 and TMS30572 at three different planting stake orientations planted in the second season at Ile Ife.

Stake orientation	TMS30572	TME419	*p* diff varieties
horizontal	78.0 b	89.7	0.0052
slanted	84.3 a	78.7	0.0493
vertical	75.0 b	87.0	0.0268

Figures, within columns, followed by the same letter are not significantly different at $p < 0.05$.

In experiment 3, in the crop planted just before the start of the dry season in late 2018, the stem density was initially affected by the planting stake orientation (Figure 5). Vertically planted stakes produced fewer stems than the others at 1 MAP yet had the highest stem density for the remaining crop cycle, albeit not being significantly different as of 7 MAP.

Variety did not affect stem density at 1 and 3 MAP. As of 5 MAP, TME419 produced significantly fewer main stems than TMS0581 with the difference increasing towards the harvest with 2.08 stems m^{-2} in TME419 and 2.78 stems m^{-2} in TMS0581.

Plant survival to harvest was higher in TMS0581 (95.6%, $p < 0.01$) than TME419 (87.5%). Planting stake orientation had no significant effect on plant survival.

Storage root numbers

In experiment 1, the number of marketable storage roots produced per plant, was affected by the site, the variety, and the planting stake orientation, whereby site and variety interacted significantly. The largest number of storage roots was produced by vertically planted stakes (5.27 $plant^{-1}$), followed by slanted (4.75 $plant^{-1}$) and horizontal (4.02 $plant^{-1}$, $p < 0.05$ versus vertical and slanted). The site × variety interaction was such that in the first season planted sites D23 and WB South, the difference in storage roots between the varieties was around 10%, relative to the respective larger value, yet at Ile-Ife, when planted in the second season, the storage root number in variety TME419 was 25.7% lower than in TMS30572 (Table 5).

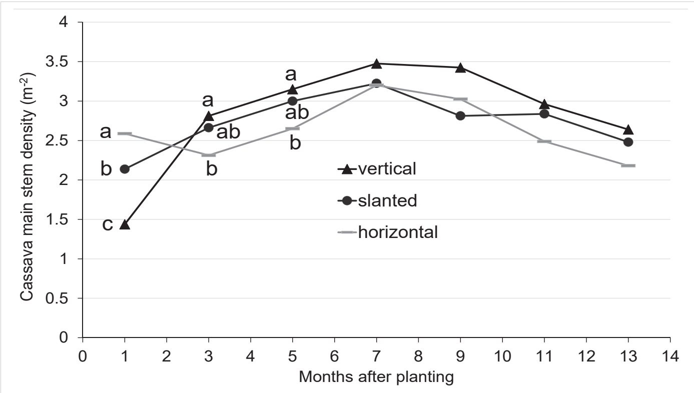

Figure 5: Cassava main stem density changes over time of horizontally, slanted and vertically planted cassava stakes, second season Ibadan site WB East. Points labelled with different letters are significantly different at $p < 0.05$.

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In experiment 3, the number of storage roots per plant was in both seasons significantly higher in variety TMS0581 than TME419 (Table 6). In 2018 the planting stake orientation was significant with horizontally planted cassava producing more roots than when planted vertically. Slanted orientation did not differ from the others. In 2019 the planting stake orientation did not affect the number of marketable storage roots.

Storage root yield

In experiment 1, storage root yield in trials planted in the first season at Ibadan, was affected by the variety, the stake diameter and the stake orientation. There were no significant interactions. Variety TME419 produced significantly higher root yields than TMS30572 (Table 7). Cassava planted with small diameter stakes produced significantly higher root yields. Stakes planted at a 45° angle (slanted) or vertically produced significantly higher root yields than stakes planted horizontally.

Contrary to the first season planted trials, the root yields in the second season trial at Ile-Ife were only affected by the cassava variety. TMS30572 produced significantly higher fresh and dry storage root yield than TME419 (Table 7). The stake diameter and planting orientation had no significant effect on root yield. However, a tendency towards higher root yields of cassava planted with small diameter stakes was found at Ile-Ife.

In the WB South site, the variety × stake orientation interaction was significant such that the fresh and dry matter storage root yield difference between TME419 and TMS30572 when planted horizontally was significantly smaller (TME419 + 57.3% dry matter yield) than when planted at an angle (TME419 + 170.7% dry matter yield) or vertically (TME419 + 73.8% dry matter yield).

In experiment 2, the fresh root yield was affected by the stake orientation, yet not by the position in the MPS (the physiological age). The root yield was significantly lower (5.14 Mg ha^{-1}) when planted horizontally than when planted at an angle (6.99 Mg ha^{-1}) or vertically (7.37 Mg ha^{-1}), without a difference between the latter two.

In experiment 3, cassava storage root yields in the trial at WB East planted in November 2018, were affected by the variety and planting stake orientation. Variety TMS0581 out-yielded TME419 significantly (Table 8) and horizontally planted cassava produced higher root yields than when planted vertically. When planted at an angle, yields did not differ from the other panting stake orientations. The trial planted in April 2019 at WB West produced similar storage root yields than the one planted in the previous second season, yet root yield did not significantly respond to variety and planting stake orientation (Table 8).

Table 5: Number of marketable storage roots per plant at harvest of two varieties planted in the first season 2017 at Ibadan, Nigeria (D23: Trial at D23 site, first season; WB South: Trial at WB South site, first season) and in the second season 2017 at Ile Ife (Trial at Ile Ife site, second season).

Site	TMS30572	TME419	Relative difference (%)
D23 (Trial at D23 site, first season)	5.37 a	4.81 ab	10.4
WB South (Trial at WB South site, first season)	4.44 bc	4.90 ab	9.4
Ile-Ife (Trial at Ile Ife site, second season)	4.90 ab	3.64 c	25.7

Different lowercase letters within columns indicate significant differences at $p < 0.05$.

Table 6: Number of marketable storage roots per plant at harvest as a function of the planting stake position of two varieties planted in the second season of 2018 (Trial at Ibadan site, second season 2018) and the first season of 2019 (Trial at Ibadan site, first season 2019), Ibadan, Nigeria.

Planting Stake Position	Second season 2018 (Trial at Ibadan site, second season 2018)			First season 2019 (Trial at Ibadan site, first season 2019)		
	TME419	TMS0581	Mean	TME419	TMS0581	Mean
horizontal	2.28	7.25	4.77 a	4.82	7.63	6.22
slanted	2.07	5.40	3.73 ab	5.74	7.29	6.51
vertical	1.29	3.79	2.54 b	5.74	6.84	6.29
mean	1.86 b	5.48 a		5.43 b	7.25 a	

Values within the same year followed by different lower-case letters are significantly different at $p < 0.05$.

Table 7: Cassava storage fresh and dry matter root yields of two varieties, different stake diameters, and planting orientation at three sites in South-West Nigeria (Trials at WB South, D23, and Ile-Ife sites).

Factor		Fresh root yield			Root dry matter yield		
		WB South (Trial at WB South site)	D23 (Trial at D23 site)	Ile-Ife (Trial at Ile-Ife site)	WB South (Trial at WB South site)	D23 (Trial at D23 site)	Ile-Ife (Trial at Ile-Ife site)
Variety	TME419	23.14	25.88	19.51	6.676	6.800	7.159
	TMS30572	12.85	18.13	31.40	3.413	4.926	10.717
	p diff variety	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.0003	0.0003
Stake	large	15.80	19.97	24.61	4.488	5.236	8.817
diameter	small	20.19	24.03	26.29	5.601	6.491	9.059
	p - value for difference between diameters	0.0004	0.0051	ns	0.0123	0.0121	ns
Stake	horizontal	15.78b	17.18b	25.87	4.201b	4.433b	8.872
orientation	slanted	18.71a	24.20a	24.42	5.300a	6.476a	8.692
	vertical	19.49a	24.63a	26.07	5.633a	6.681a	9.250
p diff horizontal *vs.* slanted		0.0453	0.0006	ns	0.0222	0.0011	ns
p diff horizontal *vs.* vertical		0.0122	0.0003	ns	0.0034	0.0004	ns
p diff slanted *vs.* vertical		ns	ns	ns	ns	ns	ns

Table 8: Fresh and dry storage root yield of two varieties planted at different stake orientations, in the second season 2018 (Trial at Ibadan site, November 2018) and the first season 2019 (Trial at Ibadan site, April 2019), at Ibadan, Nigeria.

		Storage root yield (Mg ha⁻¹)			
Planting date		November 2018 (Trial at Ibadan site, second season 2018)		April 2019 (Trial at Ibadan site, first season 2019)	
Variety		Fresh (Mg ha^{-1})	Dry (Mg ha^{-1})	Fresh (Mg ha^{-1})	Dry (Mg ha^{-1})
	TME419	13.797b	5.441b	18.342	6.779
	TMS0581	24.596a	8.503a	21.771	7.803
	p diff variety	<.0001	<.0001	0.0651	0.211
Stake	horizontal	22.607a	8.131	19.356	6.838
orientation	slanted	20.235ab	7.128	21.403	7.987
	vertical	14.748b	5.658	19.410	7.048

Figures within stake orientation and column followed by the same letter are not significantly different at $p < 0.05$.

Discussion

Cassava is mainly grown for its starch-rich storage roots as food and for industrial processing. However, with a growing awareness of the advantages of using certified pest- and disease-free improved varieties, the production of quality stems as planting material is gaining importance FGN/IFAD VCDP [39].

Stem production

Our results from experiment 1 demonstrate that the production of main stems, which provide the largest portion of planting material in varieties branching late, is higher when planting large diameter planting stakes. Eke-Okoro, et al. [29] showed that planting stakes with a higher mass produced more stems. The larger number of stems on planting stakes from the base of the mother plant stem in experiment 2 confirms this, as the stems at the base are usually of larger diameter than those at the upper and thus younger part of the stem [31]. One reason for the higher number of stems emitted by large diameter planting stakes could be that the stem portions at the base have more nodes per unit length, because they are formed when the plant is young and not exposed to competition for light, thus has no tendency to stretch or suffer from etiolation. Although not determined in this study, a larger amount of resources in large diameter stakes, to produce sprouts may have contributed to the larger number of main stems on large diameter stakes.

The differences in stem production between cassava varieties are likely genetically determined [40-42] and may be connected to the branching habit. Variety TME419 branches very late, if at all, compared with variety TMS30572, which branches early. To form a canopy, the early branching variety TMS30572 does not need as many main stems because the early formation of primary branches and later secondary branches will provide the canopy from early stages. In TME419 more mainstems are required to form a canopy because branches appear very late, thus would not contribute to the production of leaves over a long period of growth. The second variety in experiment 3, TMS0581 forms relatively large diameter mainstems compared with TME419 and this is likely the reason for the larger number of mainstems of TMS0581 than TME419. Sanginga, et al. [43] observed more main stems per plant on TMS0581 than on TME419 in a nearby site. The patterns of main stem emission are strongly season dependent. Second season crops experiencing drought short after planting lose main stems over the dry season but recover to or over the pre-dry season numbers during the following rainy season.

Stake orientation had an inconsistent effect on the patterns of changes in main stem numbers per plant and per m^2 over time and the final number of main stems per plant at harvest, was depending on the planting season. The higher number of main stems when planted horizontally in the first season (experiment 1) is probably due to the nodes not experiencing any dominance due to the orientation and thus more nodes sprouting. In the slanted and vertically planted stakes the upper nodes would suppress the lower ones and thus create a mechanism limiting the number of main stems. Abdullahi, et al. [25] and Polthanee & Wongpichet [26] reported horizontally planted stakes produced the highest number of stems per plant.

In the second season planting (experiment 1 at Ile Ife), about 6 weeks before the dry season, the initial stem reduction may have resulted from early-season drought stress. In the second season crop of 2018, horizontally planted stakes produced the lowest number of main stems, which may have been related to the fact that the crop received just 5 mm of rain before rains ceased completely until February. Vertically and slanted planted stakes would reach slightly deeper soil layers and thus have a higher chance of their roots reaching layers with sufficient moisture, required to sprout and produce stems, while the horizontally planted stakes were probably not buried deep enough to have a similar access to water. Toro & Atlee [43] reported horizontally planted stakes to be less likely to dry out due to less exposure to dry conditions. However, under conditions as in the 2018 planted trial, with upper soil layers already dried out, it appears that the first roots reaching soil depth with sufficient water was more important.

Storage root yields

In this study, the stake diameter and the stake orientation affected the fresh and dry matter storage root yield of cassava, yet the response was dependent on the planting season.

Several studies have reported root yield advantages from vertical or slanted stake insertion such as Legese, et al. [44] from Ethiopia, [26] from Thailand and using cassava grown in polythene bags in Malaysia. These results concur with the higher storage root yields of the vertically or slanted planted cassava in the two sites planted in the first rainy season of experiment 1 and could be attributed to the patterns of stem production. The horizontally planted cassava produced rather rapidly a large number of stems, being more than 3 per plant between 6 and 24 WAP. Slanted and vertically planted stakes produced significantly fewer stems and thus lost fewer stems through the dry season. The high stem numbers of the horizontally planted stakes appear to have been above the optimum and thus constituted an investment in biomass ultimately lost, compromising assimilate distribution to the storage roots. A higher number of stems per plant may be associated with a larger leaf area and thus a higher water demand. With the cessation of the rains the plants with more stems and leaves would have exhausted a larger proportion of the available soil moisture earlier, leading to higher stem losses and possibly negatively affecting the initiation of storage roots. In the second season planted trial of experiment 3, the stem numbers were between 1.5 and close to 3 per m^2, from planting to the end of the dry season, with horizontally planted stakes having the lower stem numbers, yet the highest root yield, while the vertically planted stakes had the highest stem number, yet produced the lowest root yield. [41] reported cassava root yield reductions with an increasing number of stems per plant. However, there is no defined optimum number of stems on a cassava plant to produce maximum root yields. Such an optimum stem number is likely dependent on the growing conditions, the variety and its branching habit, nutrient and water supply and other agronomic factors. In experiment 2, higher root yields were attained with higher stem numbers, yet at stem numbers per plant being about half those found in experiment 1 and 3. Experiment 2 suffered from severe and long-lasting weed infestation, probably caused by the first two months of growth receiving each > 300 mm of rain and the highest total rainfall among the trials, requiring frequent and intensive mechanical weed control. Thus, competition with weeds and damages through weeding operations may have resulted in stem numbers that remained below the assumed optimum and contributing to low root yields.

Similar to our results in the second season planted trial at Ile Ife (experiment 1) and the first season (April 2019) planted trial in experiment 3, Tizon [23], in the Philippines, found no differences in root yields of cassava, whether planted vertically, slanted or horizontally. For the second season planted trial at Ile Ife the patterns of stem production can provide some explanation, because stem numbers were not different between the planting stake orientations from 8 to 24 WAP and the vertically and slanted planted stakes had produced more stems at the earlier stages. No such explanation can be provided for the lack of response in the first season planted trial in experiment 3.

The root yield difference between large and small diameter planting stakes in experiment 1 (first season sites) is as well likely connected with the stem numbers produced in the early growth phases. Plants grown from large diameter stakes had more than 3 stems from 6 to 24 WAP and lost about 0.5 stems towards the harvest. Here again an investment in biomass later lost may be the reason for lower root yields.

The higher storage root yield attained by TME419 than TMS30572 in the first season trials of experiment 1 can be ascribed to genotypic differences between the varieties. TME419 sprouts rapidly, forms relatively large leaves and is highly tolerant of the cassava mosaic disease (CMD). This gives it an advantage in the early stages of growth. TMS30572 sprouts slower, invests early in forming primary branches and is susceptible to CMD, causing it to grow slower. For first season plantings these differences could have caused the later differences in storage root yields. When planted in the second season at Ile Ife, there was no advantage in TME419, likely due to its lack of drought tolerance, the rapid production of more stems, thus more canopy than TMS30572 and the fact that it starts forming storage roots early compared with TMS30572. The formation of the storage roots was thus likely impeded by water deficiency in the dry season, aggravated by the higher water demand of the larger plants, followed by the canopy reduction. TMS30572 forms storage roots later and thus may have initiated the storage roots with the recommencement of the rains, under conditions permitting continuous growth. This would be supported by the fact that TMS30572 recovered the stem number and kept forming new stems towards the harvest, while TME419 did not recover to pre-dry season stem numbers but declined towards the harvest.

The lower yields of TME419 than TMS0581 in the second season planted trial in experiment 3 were most likely caused by a similar set of conditions, potentially aggravated by the even lower amounts of rain available before rains ceased completely. The number of storage roots per plant at harvest in TME419 was 1.86 versus 5.48 in TMS0581, indicating strongly that the early storage root initiation in TME419 was a disadvantage when coinciding with a phase of water deficiency. The non-significant root yield advantage of TMS0581 in the first season planting (April 2019) of experiment 3 was as well accompanied by a higher number of storage roots at harvest. In the trials planted in November 2018 and April 2019 (experiment 3) the root yield was correlated with the number of storage roots as:

Root yield (Nov 2018) = 3.005 × root number; $r^2 = 0.95$.

Root yield (Apr 2019) = 4.449 root number, $r^2 = 0.88$.

The lack of a response to fertilizer application in experiment 1 was unexpected as several studies have shown that fertilizer application can increase storage fresh root yields in sole cassava [7] and when intercropped with maize [46]. Such effects, however, are not reliable and are strongly site dependent [9]. The soil properties of the sites in experiment 1 were all within the suitable range for cassava [47], thus factors other than nutrient supply may have been more important in yield formation and yield response to fertilizer.

The lack of a root yield response to the position within the mother plant stem (physiological age) from which the planting stake originated was as well unexpected as the stem diameter and thus the mass and resources and the age of the stakes were reported to affect root yields [29,30] and that younger stakes with a higher risk of drying out and not sprouting [33] would lead to lower root yields. Here the risk of drying out of younger stakes was very low due to the high amounts of rain fall in the first two months after planting. The good water supply, yet in combination with the intense weed competition appears to have eliminated any advantage of older (CIAT, 1984) [47] and higher diameter stakes. Although there is no direct evidence, the fact that older stakes produced more stems yet not more root yield may support this explanation.

Conclusion

Cassava root yield responses to the orientation of the planting stake remain inconclusive, although in our experiments most of the results indicate a higher probability of higher root yields when planting vertically or slanted. In all situations the planting date needs to be considered because second season plantings short before the dry season appear to respond differently from first season plantings. The root yield differences between varieties planted in different seasons require more research to inform farmers about the suitability of the varieties for specific planting dates or windows. A potential problem in the future might arise when more cassava is planted mechanically because most planters place the stakes horizontally in the soil. The significantly lower root yields in three of our experiments indicate that if this planting method is used over larger areas root production in Nigeria may decline. However, for the vast majority of Nigerian smallholder cassava farmers this remains a non-issue. The study shows that with minor adjustments to stake insertion depth and orientation, the root yields can be increased with minimal additional cost. Although smallholder farmers currently lack practical means to regulate stem production on cassava stakes, our results indicate that overproduction of stems in early growth phases, specifically short before the dry season may be the cause of root yield losses. This issue warrants further investigation, particularly through breeding for varietal suitability.

Author's contribution

Conceptualization: S. Hauser (SH), O. Aluko (OA), M. Egwakhide (ME), N. Dankaro (ND), R. Enesi (RE), Methodology: SH, ME, RE, Analysis: SH, OA, RE, Investigation: SH, OA, ME, ND, RE, Initial draft preparation: SH, OA, Review: OA, ME, ND, RE.

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