INTERACTIONS BETWEEN CASSAVA VARIETIES AND SOIL CHARACTERISTICS IN CROP PRODUCTION IN EASTERN CAMEROON

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ABSTRACT Cassava represents a staple food source in Cameroon and in many other tropical countries, as it is effectively able to combat hunger. This study was carried out to: (i) determine the growth characteristics of improved and local cassava varieties in Eastern Cameroon under repeated cultivation, (ii) assess the effects of different soils on cassava growth, and (iii) disseminate the improved varieties throughout the region. The experiment was carried out during the 2010–2011 and 2011–2012 seasons. Two improved varieties, TMS-92/0326 and TMS-96/1414, and the local *Ntolo* variety were cultivated at three sites in a randomized block design with six replications. No fertilizer was applied and the fields were weeded regularly. A two-way ANOVA (variety x site) for each season showed that variety and site were equally significant, and there were no significant interactions between varieties and sites. The improved varieties had higher yields (2.0–5.5-fold higher) than *Ntolo*, with cassava mosaic disease having seriously affected the *Ntolo* yield. Soil acidity and organic matter content in the soil surface horizon may be major factors affecting the cassava yield, with TMS-92/0326 and *Ntolo* being tolerant of higher acidity than TMS-96/1414, which suggests that variety-soil interactions should be considered when improved varieties are introduced.

Key Words: Cassava mosaic disease; Improved variety; Soil acidity; Cameroon.

INTRODUCTION

The global population is predicted to increase from 6.9 billion in 2010 to 8.3 billion in 2030 and to 9.1 billion in 2050, with a predicted 50% increase in demand for food by 2030 (70% by 2050) (FAO, 2006). As reported by Keating et al. (2011), different factors such as population growth, per capita consumption trends, diversion to biofuels and food wastage are key drivers. In a global context, food demand is more obvious in Africa where production by smallholders is too low to meet the national needs, necessitating importation of foods. However, in Cameroon the economy is predominantly agrarian, with agriculture and exploitation of natural resources remaining the driving forces behind the national economy. Population increases and hence a need for increased production for subsistence, as well as other commercial factors, have accelerated deforestation in this region. This will contribute to impoverish the soil and decrease production in the medium-to long-term if resources are not managed sustainably.

Cassava (*Manihot esculenta* Crantz) is currently the most important carbohydrate food source, after rice, sugarcane and maize for over 500 million people in the developing countries in the tropics and sub-tropics (FAO, 1999). It is a perennial woody shrub of the family Euphorbiaceae, with over 5,000 distinct varieties. The main value of this crop is in its storage roots where the dry matter contains more than 80% starch. The areal parts, mainly the leaves are also widely consumed as vegetables, supplying protein, vitamins and essential minerals (Dahniya et al., 1994, Berry, 1993). The root crop has gained industrial importance with uses in ethanol production, high-quality cassava flour in bread production, and glucose syrup production. Cassava is grown in low-fertile acidic soils, and generally without fertilizer, it is able to grow with limited input where most other crops would fail completely (Howeler & Cadavid, 1990). Root formation is photoperiodically controlled, which is enhanced by short days and delayed by long days exceeding 10–12 h (Alves, 2002). For optimum growth, it requires a warm, moist climate with temperatures ranging from 25 to 29°C, and a well-distributed annual rainfall of 1,100–2,000 mm (Onwueme, 1978; Silvestre, 1989). A poor annual rainfall may be offset by favorable soil characteristics, such as good texture, topography and drainage (Silvestre, 1989). Although it is tolerant of infertile soils and drought, continuous cultivation of cassava without efficient management can result in serious nutrient depletion of the soil and a complete crop failure. To restore soil fertility, natural long fallows were commonly practiced, but these can no longer be justified due to demographic pressure. Alternatively, the introduction of leguminous cover crops (improved fallow) that enable a shortening of the fallow cycle, is increasingly being considered in agricultural ecosystems. The use of improved varieties following a short but improved fallow is expected to have a positive impact on yields. However, before new varieties are distributed throughout a region, it is important to compare the yields with those of the local varieties.

The purposes of this article were to assess the growth characteristics of several improved cassava varieties and to compare them with local varieties in east Cameroon (Bertoua), under repeated cultivation, and to identify the key factors in yield variation; to investigate the effect of various soils on cassava growth, and to distribute the improved cassava varieties throughout the area, thus improving the welfare of local inhabitants through enhanced cassava production.

MATERIAL AND METHODS

I. Study Sites

The study was carried out at Andom village (5º 15’ N, 13º 30’ E) which belongs to the Lom and Djarém division, in Eastern region of Cameroon. In general, this area is characterized by a tropical climatic; 7 months of rainy season extending from April-October, including short dry spells from July-August, and a 4-month dry season from December-March. The average annual rainfall is 1,500 mm (Araki

& Saito, 2013), and Andom village is located at an altitude of 650 m. The average temperature in the region is 25°C, but the December-February period is the driest part of the year, when the relative humidity may reach over 60% (Johannes et al., 2010). Andom is located at the forest-savanna transition zone, with savanna forming the majority of the land. The livelihood for most villagers comes from agriculture and hunting. The primary crop cultivated in the village is cassava, and cassava stiff porridge (*ikeille pongo*) is the villagers' staple food. More than 10 local cassava varieties are cultivated in the area, but *Ntolo* is traditionally the most widely grown variety (90%) because of its average yield, its sweetness and ease of cooking, compared to other, more bitter, local varieties. In the absence of disease, this variety has large green leaves, brown stems and large white tubers at maturity.

II. Experimental Design and Cassava Trial

Three 2 km-apart sites (I, II, III), were selected as the experimental fields. They were established in coordination with farmers and village leaders in natural bush fallows where no previous crops was had been grown for over ten years. Trial crops were planted on three differing inclines (flat, gentle and relatively steep slope); site II was flatter than sites I and III. Furthermore, the three sites contained slightly different natural vegetation. The vegetation at site I comprised mainly *Chromolaena odorata* (L.), site II was dominated by *Imperata cylindrica* (L.), and site III, located in the savanna zone and traditionally used for livestock grazing, was a mosaic of *I. cylindrica* (lower density compared to site II), *C. odorata*, and a few trees.

The experiment investigated the properties of the local cassava variety (*Ntolo*) and two varieties (TMS-92/0326 and TMS-96/1414), developed through conventional breeding by the International Institute of Tropical Agriculture (IITA) and partners. These improved varieties have improved nutritional qualities and are rich in carotenoids, iron and zinc. They were selected following farms trials and based on desirable traits, including a high root yield, yield stability, food quality, plant architecture and resistance to pests and diseases. TMS-96/1414 has a branching structure with medium-sized green leaves and is shorter than TMS-92/0326 which also has bigger green leaves. Both varieties produce white tubers at maturity. The test plants were grown in six replicates, in a complete randomized block design. Site I plot size was 15 x 8 m (120 m^2), site II was 20 x 7 m (140 m^2), and site III was 15 x 8.5 m (127.5 m^2). The first trial was carried out in the 2010-2011 cropping season and repeated in the 2011–2012 season. In the first experimental year (2010–2011), 20 cm long cassava sticks with at least 5–7 buds were planted late April 2010 at a distance of 1 x 1 m apart, giving a planting density of 1 plant/m^{-2}, and the tubers were harvested in the middle of May 2011. In the second year experimental year, sticks were planted in June 2011 and cassava was harvested in July 2012. No fertilizer was used, the experiment was carried out under natural conditions, and the fields were maintained free from weeds.

III. Data Collection and Analysis

1. Monitoring of disease infection

The rates of infection with several cassava pests and diseases were monitored throughout the growing cycle in the 2010–2011 cropping season. Cassava Mosaic Disease (CMD), Cassava Bacterial Blight (CBB) and Cassava Anthracnose Disease (CAD) were recorded in September 2010, November 2010, and April 2011 at all sites. To evaluate the infection rate of a particular variety, all plants of that variety at a single site were individually monitored during each recording period. Infection scales [1–5] representing the extent of the disease symptoms were assigned, where [1] represents no symptom of a given disease, [2] disease symptoms cover up to 25% of the plant, [3] symptoms cover 50% of the plant, [4] 75% of the plant present disease symptoms, and [5] the entire plant is covered. This was carried out at each site, for each plant and for the three diseases (CMD, CBB and CAD) during the three recording periods. The mean percentages of infected plants (for the three sites combined) for each scale of infection for each growing period are reported (Table 3) and discussed in this article.

2. Variety growth parameters

Tubers and aboveground biomass were harvested from a 25 m^2 area in each plot. After recording the fresh weight of tubers and aboveground parts of all individual plants, the different parts (tubers, stems, leaves) of a single plant chosen at random were weighed. Thereafter, subsamples of known fresh weights were taken from each plant part. The subsamples were weighed again and oven-dried at 70ºC for 2 days and the dry weights were recorded. Extrapolated calculations were performed to determine the fresh and dry weights (t ha^{-1}) of cassava tubers and aboveground biomass (stems + leaves).

3. Soil nutrients

Soil samples of the dark-colored surface horizon (0–6/29 cm: 16 cm on average) were collected from each plot at all sites in September 2010 (6 months after planting), May 2011 (time of first harvest), and June 2012 (time of the second harvest). The soil samples were composites collected from five locations inside each plot. The samples were air-dried and ground to pass through a 2- mm sieve. Soil pH in water was determined in a 1:2.5 (w/v) soil : water suspension. Organic C (%) was determined by chromic acid digestion (Black, 1982) and spectrophotometric analysis (Heanes, 1984). Total N (%) was determined by wet acid digest (Buondonno et al., 1995) and analyzed colorimetrically (Anderson & Ingram, 1993). Exchangeable Ca, Mg, K, and Na (cmol (+)/kg) were extracted using 1 M ammonium acetate and determined by atomic absorption spectrophotometry. Available P (ppm) was extracted by the Bray-1 procedure (Bray & Kurtz, 1945) and analyzed using the molybdate blue procedure described by Murphy & Riley (1962). Cation Exchange Capacity (CEC) was calculated from the organic carbon (%) using the regression equation (CEC = 3.024 x Org. C + 2.05) proposed by Araki & Sarr (2013) for oxisols of eastern Cameroon.

4. Statistical analysis

CropStat 7.2, developed by the International Rice Research Institute (Manila, Philippines) was used to analyze the data. Plant production and soil nutrient data were subjected to ANOVA ($P \leq 0.05$). A two-way ANOVA (variety x site) was performed for both crop seasons. If significant, the Least Significant Difference (LSD) obtained from Tukey's test was used to compare mean data. Furthermore, to ascertain any possible relationship between cassava yields and soil characteristics, a three-way ANOVA was applied to analyze various soil characteristics in terms of varieties, sites and cropping seasons. Finally, correlation coefficients between Tuber Fresh Weight (TFW) by variety vs. organic carbon, pH, and base saturation for both cropping seasons were calculated.

RESULTS AND DISCUSSION

I. Growth Parameters

Tables 1 and 2 show the results of the two-way ANOVA (variety x site) for the 2011 and 2012 harvests, respectively. It is clear that all growth parameters of the three varieties were significant at $P \leq 0.05$. In 2011, the TFWs of the improved varieties were 2.03–2.54-fold that of *Ntolo*. Likewise, the TDWs of the improved varieties were 1.75–2.39-fold that of *Ntolo*, indicating they contained more water. However, the differences in Aboveground Fresh Weight (AGFW) (1.28- and 1.61-fold higher than *Ntolo* for TMS-92/0326 and TMS-96/1414, respectively) and Aboveground Dry Weight (AGDW) (1.34- and 2.18-fold higher than *Ntolo* for TMS-92/0326 and TMS-96/1414, respectively) between the improved varieties and *Ntolo* was less than in the tubers, resulting in a low tuber/aboveground ratio for *Ntolo*. The data for 2012 show a similar trend for the improved varieties and *Ntolo*.

The differences in the fresh and dry yields of tubers and aboveground parts between the improved varieties and *Ntolo* were relatively large in the second cultivation. Likewise, the relative decrease in tuber weight of the *Ntolo* variety was more obvious than the decrease in the aboveground parts. During the second cultivation, the fresh tuber yield of the improved varieties was 5.46–5.62-fold higher than *Ntolo*, and the fresh aboveground yield was 2.46–2.76-fold higher. Jones (1959) reported that the average cassava yield in Africa in 1954 was 5–10 t ha^{-1}, while in the early 1990s, Nweke et al. (2002) indicated that the average cassava fresh-root yield of the six highest producers in Africa (Nigeria, Ghana, Cote d'Ivoire, Congo, Tanzania, and Uganda) was 11.9 t ha^{-1}. Currently in Cameroon, improved varieties have achieved a yield of 25–30 t ha^{-1}, in contrast to 8–10 t ha^{-1} for the local varieties (Ngome, 2013; Mbairanodji, 2013). Our trials achieved a yield of about 50% of these figures, possibly be due low fertility levels of the oxisols in the research area. Other factors, including the gentle slope of the sites, could lead to soil erosion; the rapid re-growth of weeds that compete for nutrients, particularly *I. cylindrica*, may also explain the low yield achieved

Table 1. Production by varieties over all sites in 2011 (two-way ANOVA)

Variable	TFW	TDW	AGFW	AGDW
	t ha^{-1}			
Ntolo	0.5.84 a	2.21 a	10.72 a	2.19 a
TMS-92/0326	11.84 b	3.87 ab	13.24 ab	2.94 a
TMS-96/1414	14.84 b	5.30 b	17.27 b	4.79 b
Variety Effect	**	*	*	***
Site I	14.55 b	5.00 b	19.06 b	3.30
Site II	7.89 a	2.80 a	10.20 a	2.87
Site III	10.08 ab	3.55 ab	11.98 a	3.75
Site Effect	*	*	***	ns

TFW: Tuber Fresh Weight, TDW: Tuber Dry Weight, AGFW: Aboveground Fresh Weight, AGDW: Aboveground Dry Weight, ns: not significant ($P > 0.05$), * significant level: $P \leq 0.05$, ** significant level: $P \leq 0.01$, *** significant level: $P \leq 0.001$, t ha^{-1}: tons per hectare
Two-way ANOVA (variety x site) was performed using Cropstat ver. 7.2. For varieties, values are the means of 6 replicates for 3 sites giving a total of 18 observations per variety. For sites, values are the means of 6 replicates for 3 varieties giving a total of 18 observations per site. Means with the same letter in a column are not significantly different at the indicated level of significance (Tukey's test).

Table 2. Production by varieties over sites in 2012 (two-way ANOVA)

Variable	TFW	TDW	AGFW	AGDW
	t ha^{-1}			
Ntolo	2.22 a	0.82 a	5.50 a	1.34 a
TMS-92/0326	12.48 b	3.35 a	11.42 b	2.56 b
TMS-96/1414	12.13 b	3.50 b	13.54 b	2.85 b
Variety Effect	***	***	***	**
Site I	8.41 a	1.57 a	10.01	1.59 a
Site II	5.36 a	1.02 a	8.79	1.48 a
Site III	13.07 b	5.08 b	11.65	3.67 b
Site Effect	**	***	ns	***

For legend, see Table 1.

by the improved varieties. However, the tested improved varieties did achieve a fresh tuber yield, which was two to five fold higher than that of the local *Ntolo* variety, and this is important for cassava production in the area. There was also a significant difference between the 2011 and 2012 yields (Tables 1 & 2), regardless of the variety. In 2011, site I achieved the highest yields (TFW, AGFW), and 2012 site III achieved the highest yield. In both years, yields obtained from site II were significantly lower compared to those from sites I and III. This variation in yield between sites could result from differences in soil fertility, and could also be associated with the higher incidence of *I. cylindrica* at site II.

II. Annual Differences in Cassava Yield

Fig.1 shows the Tuber Fresh Weights (TFW) for TMS-92/0326, TMS-96/1414 and *Ntolo* for 2012 and 2011 combined. This was to ascertain of the 2011 cassava yield had an impact on the 2012 yield. A least-square method was applied to obtain a regression line for TMS-92/0326 and TMS-92/0326 together. We obtained a regression line with a coefficient of 0.80, indicating that the cassava yield of 2012 was 80% less than that of 2011, on average. However, considering the low value of the coefficient of determination (R^2), there was no significant decrease in yield for 2012 compared to 2011. In contrast, there was a significant decrease in yield for *Ntolo*, with a lower average value in 2012.

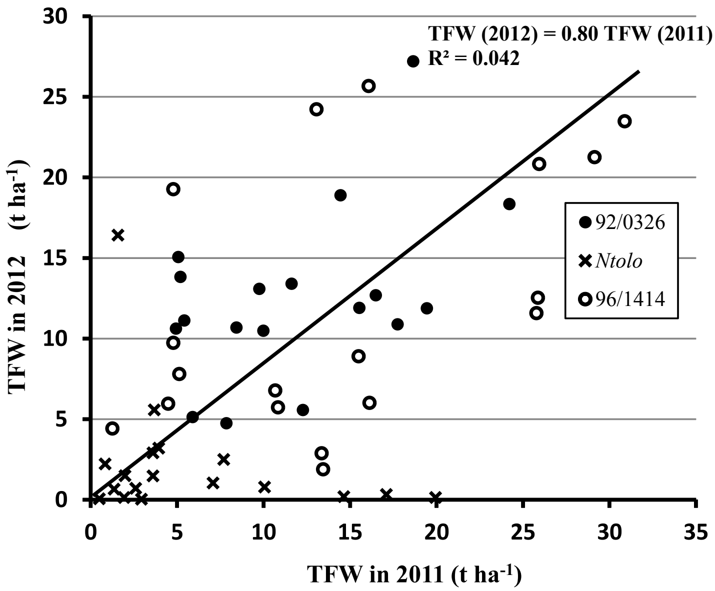

Fig. 1. Comparison of Tuber Fresh Weights (TFW) between 2011 and 2012
92/0326: TMS-92/0326, 96/1414: TMS-96/1414, t ha^{-1}: tons per hectare

III. Disease Infection

The results for all three varieties in this study are shown in Table 3. CBB and CAD were either absent or only present at low levels (scales 2–3) on all three varieties, and did not affect plant growth. CMD, however, was present on all plants, but was more prevalent on *Ntolo*. CMD was either absent or present low levels (scales 2–3) during the three recording periods on TMS-96/1414 and TMS-92/0326, however, on *Ntolo*, symptoms appeared early, and in September 2010 (6 months after planting), 67.21% of plants (an average across all three sites)

Table 3. Mean percentages (%) of infected plants (3 sites combined) on the infection scale during cassava growth

Variety	Infection scale	September 2010			November 2010			April 2011		
		CMD	CBB	CAD	CMD	CBB	CAD	CMD	CBB	CAD
TMS-96/1414	1	77.53	55.75	81.42	73.41	48.70	71.05	65.67	2.76	59.18
	2	21.68	44.25	16.99	23.66	41.72	13.34	23.41	89.14	32.77
	3	0.79	0.00	1.59	2.94	9.36	13.52	4.22	8.10	7.20
	4	0.00	0.00	0.00	0.00	0.21	2.09	3.32	0.00	0.85
	5	0.00	0.00	0.00	0.00	0.00	0.00	3.32	0.00	0.00
TMS-92/0326	1	42.15	59.78	91.05	35.47	52.93	81.01	60.35	12.96	62.26
	2	44.95	40.22	5.89	43.59	41.10	9.74	35.61	65.74	27.15
	3	12.68	0.00	2.25	20.72	5.97	6.80	3.10	20.94	7.46
	4	0.22	0.00	0.82	0.22	0.00	2.25	0.21	0.36	2.46
	5	0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.67
Ntolo	1	1.83	48.30	84.57	0.52	47.37	70.67	3.32	9.96	71.36
	2	4.40	51.12	12.22	0.31	32.91	14.39	4.40	76.92	22.58
	3	13.35	0.58	2.91	3.61	19.28	12.45	4.79	12.65	5.13
	4	13.21	0.00	0.58	15.82	0.34	1.57	22.09	0.47	0.92
	5	67.21	0.00	0.13	79.74	0.00	0.92	65.36	0.00	0.00

CMD: Cassava Mosaic Disease, CBB: Cassava Bacterial Blight, CAD: Cassava Anthracnose Disease. [Infection scale: values of 1–5] represent to which extend the symptoms of a disease are present on individual plants. [1] no symptom of the disease is recorded on the plant, [2] disease symptoms covering up to 25% of the entire plant, [3] symptoms of the disease cover half (50%) of the plant, [4] disease symptoms cover up to 75% of the plant, [5] symptoms of the disease cover the entire plant. For each variety at during all recording periods, the percentage of cassava plants for each of the five infection scales was calculated per site. The mean percentages of infected plants (three sites combined) for each variety, infection scale, and recording period are reported.

were affected. Moreover, 13.21% of the *Ntolo* plants had CMD symptoms covering 75% of the plant. This severe CMD infection of *Ntolo* was maintained during the entire cultivation year, as shown by records from November 2010 and April 2011. CMD is transmitted by the white fly *Bemisia tabaci*, which inject the virus into the plants, causing in turn chlorotic blotches, distortion of the leaves, and a reduction in leaf area. Infected plants are estimated to sustain yield losses of 30–40% (Thresh et al., 1997). From these results, it is possible to ascribe the low yield of *Ntolo* to its relatively susceptibility to CMD (Fig. 1). Moreover, the high number of plants missing from the *Ntolo* plots (data not shown) also affected the yield. Unfortunately, many African farmers do not control pests, diseases, or termites on cassava with pesticides, because of limited access to chemicals, and because it is not profitable to apply pesticides to cassava. This study, not only adds to the existing knowledge of cassava crops, but also contributes to the dissemination of improved varieties throughout the area, enabling a progressive replacement of infected varieties with resistant cassava plants.

III. Effect of Soil Characteristics and Disease Incidence on Cassava Growth

For both test years, the cassava fresh weights differed significantly between sites. As seen in Tables 1 and 2, the order of cassava growth was as follow; site I > site III > site II in 2011, and site III > site I > site II in 2012. An analysis of the site characteristics responsible for determining the cassava growth determined that soil chemistry was a vital factor.

The results of a three-way ANOVA (Table 4) provided the average soil characteristics of individual plots according to variety, site, and year. On a variety basis, the organic carbon content in the TMS-96/1414-planted-soil was significantly higher compared to the two other varieties. As seen in Fig. 4, the high soil organic carbon content of TMS-96/1414 at site I (close to 2.5%) contributed towards this. CEC was highly significant because it was calculated based on the soil organic carbon content. On a site basis, soil pH, exchangeable K and Na, organic carbon and nitrogen contents were significant. The low organic carbon and total N contents at site II could have influenced the performance of this site. Changes in the soil characteristics over time were not significant for variables that were significant for sites, and were significant only for exchangeable bases and Bray-P. Therefore, differences in soil characteristics were expressed mainly between sites.

To clarify the effects of differing soil characteristics on the cassava yield, a correlation analysis was conducted using the yield data of each variety over the two years and the soil characteristics from three different sampling periods. As there were no significant annual differences in terms of cassava yield and soil characteristics, it was possible to compare variables obtained from different years, paticularly if a significant correlation was found. The selected soil variables were pH, base saturation, organic carbon and total nitrogen, which were all significantly different between sites (Table 4), with the exception of base saturation. Base saturation was included as it is another indicator of soil acidity besides soil pH.

Table 4. Soil characteristics of each plot (variety), and by year and site

Factors	Variables	pH	Ca	Mg	K	Na	CEC
			cmol(+) Kg^{-1}				
Variety[1]	*Ntolo*	4.98	1.06	0.74	0.145	0.05	6.87 a
	TMS-92/0326	5.00	1.09	0.75	0.132	0.051	6.93 a
	TMS-96/1414	5.05	1.31	0.84	0.138	0.051	7.19 b
	Variety Effect	ns	ns	ns	ns	ns	*
Site[2]	Site I	4.82 a	1.17	0.67	0.125 a	0.068 b	7.34
	Site II	5.04 b	1.03	0.75	0.145 b	0.044 a	6.6
	Site III	5.17 c	1.27	0.90	0.145 b	0.041 a	7.05
	Site Effect	**	ns	ns	*	*	ns
Year[3]	2010 Sept	4.93	0.91 a	0.60 a	0.131 a	0.043 a	7.17
	2011 May	5.13	1.33 b	0.86 b	0.161 b	0.055 b	7.81
	2012 June	4.96	1.23 ab	0.87 b	0.124 a	0.054 b	6.01
	Year Effect	ns	*	*	*	*	ns

Factors	Variables	OrgC	Total N	PBS	C/N	BrayP
		%				ppm
Variety[1]	*Ntolo*	1.76 a	0.110	29.05	16.04	4.70
	TMS-92/0326	1.78 a	0.112	29.46	15.89	4.39
	TMS-96/1414	1.90 b	0.118	32.70	15.81	4.64
	Variety Effect	*	ns	ns	ns	ns
Site[2]	Site I	2.00 b	0.125 b	28.82	16.07	4.86
	Site II	1.64 a	0.101 a	29.56	15.90	4.55
	Site III	1.79 ab	0.114 ab	32.85	15.77	4.31
	Site Effect	*	*	ns	ns	ns
Year[3]	2010 Sept	1.69	0.111	23.25	15.04	3.86 a
	2011 May	1.91	0.116	30.21	16.44	5.01 b
	2012 June	1.84	0.114	37.78	16.27	4.86 b
	Year Effect	ns	ns	ns	ns	*

OrgC: Organic carbon, PBS: potential base saturation [100 (Ca + Mg + K + Na)/CEC], ns: not significant ($P > 0.05$), * significance level: $P \leq 0.05$, ** significance level: $P \leq 0.01$. Three-way ANOVA (variety x site x year) was performed using CropStat ver. 7.2.
1(variety): Average values of 54 observations (6 replicates per site for 3 sites and 3 sampling periods).
2(site): Average values of 54 observations (6 replicates per variety for 3 varieties and 3 sampling periods).
3(year): Average values of 54 observations (6 replicates per variety for 3 varieties and 3 sites). Mean values in each column with the same letter are not significantly different at the indicated level of significance (Tukey's test).

The results are shown in Table 5. TMS-92/0326 in 2011 was correlated significantly correlation with organic carbon (2010) and pH (2010, 2011, 2012).

Although not significant, a similar trend was seen in 2012 in terms of a negative correlation with pH (2010, 2012). In 2011, *Ntolo* showed a significant correlation with pH (2012), and TMS-92/0326 exhibited a similar trend for organic carbon and pH (2010, 2011). Here, TMS-92/0326 and *Ntolo* responded to soils in the same manner. The *Ntolo* yield in 2012 was correlated significantly with all of the soil variables. Since the yield decreased by half (from 5.8–2.2 t ha^{-1}

on average), factors other than the soil composition including CMD damage might have been involved. TMS-96/1414 behaved differently to the other two varieties; there was a significant positive correlation with Percentage Base Saturation (PBS) during both years.

Fig. 2 details the contrasting responses to soil pH of TMS-92/0326, *Ntolo* and TMS-96/1414. The figure also shows that at the same pH level, TMS-92/0326 gave a higher yield than *Ntolo*. However, CMD could have reduced the *Ntolo* yield.

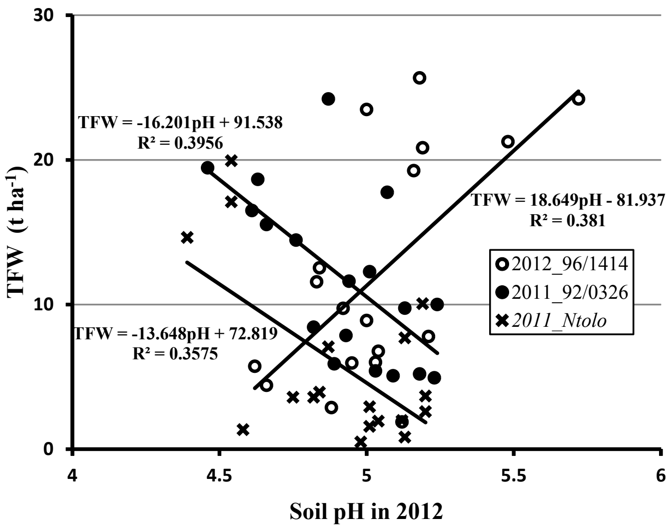

Fig. 2. Relationship between Tuber Fresh Weight (TFW) of two cassava varieties and soil pH in 2012
For 96/1414, TFWs were measured in 2012. For 92/0326 and *Ntolo*, TFWs were measured in 2011. 92/0326: TMS-92/0326, 96/1414: TMS-96/1414 variety, t ha^{-1}: tons per hectare

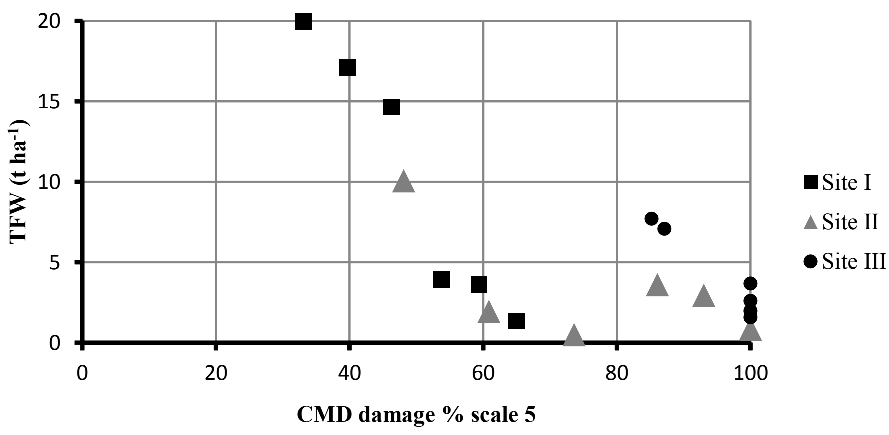

Fig. 3. The relationship between CMD damage % of scale 5-infected plants and TFW of *Ntolo* in 2011
CMD: Cassava Mosaic Disease, TFW: Tuber Fresh Weight. CMD damage rating was estimated from 6 plots at each site. The % of scale 5-infected plants per plot is presented for each site. t ha^{-1}: tons per hectare

Fig. 3 shows how CMD damage at a scale-5 level suppressed *Ntolo* yield to 10 t ha^{-1} when CMD affected more than 50% of plants, but if fewer than 50% of plants were affected then the yield was not reduced severely.

The mechanisms of the reverse effects of pH on TFW in different varieties are complex, because a negative correlation between yield and pH is often associated with a positive correlation between yield and organic carbon (Table 5). This implies that accumulation of organic matter in soil induces acidification. Since soil organic matter is the major source of nitrogen, the disadvantages of fewer basic cations at a low pH are compensated for by an increased supply of nitrogen. Whatever the mechanisms, different varieties are able to adapt better to these conditions, as in the case of TMS-92/0326 and TMS-96/1414, in which the former adapts better to the acidic soil conditions, in a similar fashion to *Ntolo*.

Table 5. Correlation coefficients between Tuber Fresh Weight (TFW) and soil chemical characteristics

Year	TFW	OrgC_2010	TotalN_2010	PBS_2010	pH_2010	OrgC_2011	TotalN_2011
2011	92/0326	0.564*	0.376	-0.16	-0.492*	-0.056	-0.163
2011	96/1414	-0.075	-0.113	0.552*	-0.129	-0.198	0.077
2011	*Ntolo*	0.353	0.272	-0.302	-0.416*	0.025	0.198
2012	92/0326	-0.037	-0.122	-0.284	-0.26	-0.046	-0.011
2012	96/1414	-0.156	-0.218	0.153	-0.028	-0.063	0.172
2012	*Ntolo*	0.093	0.198	0.116	0.367	0.243	0.217
Year	TFW	PBS_2011	pH_2011	OrgC_2012	TotalN_2012	PBS_2012	pH_2012
2011	92/0326	-0.345	-0.405*	0.124	0.095	-0.049	-0.629**
2011	96/1414	-0.212	-0.345	0.04	0.108	0.519*	0
2011	*Ntolo*	-0.163	-0.422*	-0.457	-0.238	-0.391	-0.598**
2012	92/0326	0.189	0.193	-0.032	-0.143	-0.185	#
2012	96/1414	0.104	0.247	0.197	0.252	0.801**	0.617**
2012	*Ntolo*	0.034	0.328	0.27	0.353	0.128	0

* significant at 5% level; ** significant at 1% level,
OrgC: Organic carbon, PBS: Potential Base Saturation, 92/0326: TMS-92/0326, 96/1414: TMS-96/1414

Despite the different varietal responses to the soil environments, the overall effects of site on TFW were clear. In Fig. 4 depicts the relationships between soil organic carbon and TFW in 2011 for TMS-92/0326, TMS-96/1414 and *Ntolo*. At all plots (six replications), soil organic carbon increased, and at the same time, yield variances increased within the sites, but the average yield of each site increased according to the organic carbon level. This indicates that the soil organic carbon content is an important characteristic of a site, and an important determinant of cassava yield.

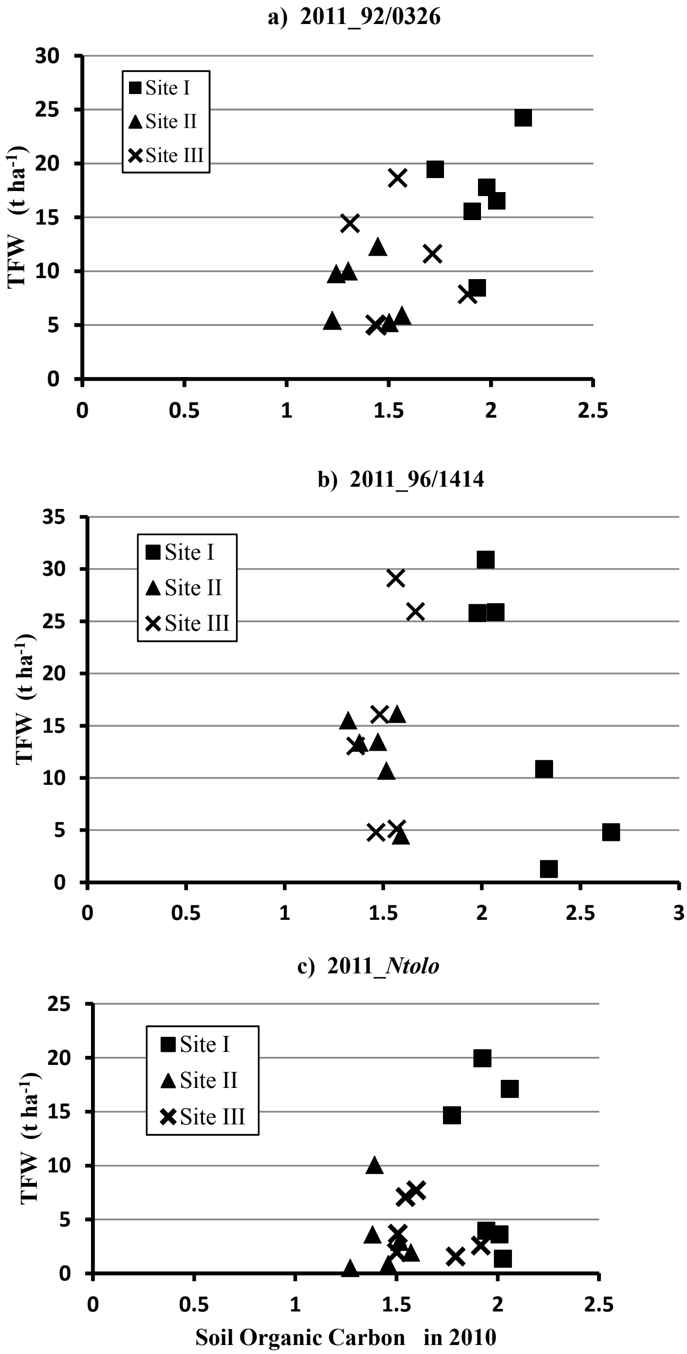

Fig. 4. The relationship between Tuber Fresh Weight (TFW) of the three varieties in 2011 and soil organic carbon content in 2010
92/0326: TMS-92/0326, 96/1414: TMS-96/1414, t ha^{-1}: tons per hectare.

CONCLUSION

Because local cassava varieties are more susceptible to disease, dissemination of improved stocks is important to maintain a sustainable cassava production. The results of this study suggested the higher production potential of improved vari eties compared with a local variety. As a direct result of the study, a rapid dissemination of improved varieties took place in the area; the newly introduced stocks have been adopted by most households. Furthermore, the neighboring villages have also received the new planting stock. These new varieties are much appreciated as they are easy to process and have a high nutritional value. Over the 2 years of the experiment, we observed no decline in the yields of the improved varieties. However, the varieties did respond differently to the various soil environments, suggesting that variety-soil relationships should be taken into account in dissemination of improved varieties across a new region.

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