Agro-Science
Journal of Agriculture, Food, Environment and Extension
Volume 6, Number 1 January 2007

ISSN 1119-7455 URL: http://www.agrosciencejournal.com/

THE CONTRIBUTIONS OF SOIL PROPERTIES TO CASSAVA YIELD PARAMETERS IN SUB-SAHARAN AFRICA

Asadu[1] C.L.A., Nweke[2] F.I. and Dixon[3] A.G.O.
[1]Department of Soil Science, University of Nigeria, Nsukka, Nigeria
[2]Department of Agricultural Economics, Michigan State University, East Lansing, USA
[3]International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria

ABSTRACT

The Collaborative Study of Cassava in Africa (COSCA) undertook cassava yield and soil fertility surveys in sub-Saharan Africa in 1991 with the objectives of obtaining average yields from farmers' fields and determining factors which could account for the yield differences across the various climate, altitude, population density and market access zones - the site selection factors considered in the study. In this analysis, the contributions of various soil properties determined from the fields were also obtained and evaluated. The cassava yield parameters considered were fresh root and shoot weight, harvest index and cassava stand density. The interaction between the site selection factors had a greater significant effect on the yield parameters than the individual factors. Whereas the effect of climate was not significant ($P = 0.1$), both climate x market access and population x market access interactions were highly significant ($P \leq 0.01$) on root yield. The overall mean root yield was estimated as 13.1 t/ha. It was highest in the subhumid followed by nonhumid and lowland humid zones, and least in the highland humid zone. It was significantly ($P \leq 0.05$) higher (13.6 t/ha) in the low altitude zones than in the mid (8.5 t/ha) altitude zones. The results of stepwise regression analysis showed that the total contribution of soil variables to root yield variations ranged from about 30% for the entire sub-region through 32% in the lowland and about 40% in nonhumid zones to more than 45% in the highland humid zones. The contribution of total sulphur to the total variations in root yield was consistently high in both the sub-region and across the climate zones compared to other soil variables evaluated. The overall contributions of the soil variables to shoot yield, harvest index and stand density were approximately 35%, 30% and 50%, respectively. Though the contributions of the soil properties to cassava performance confirmed that other factors are also important in cassava production, the significant roles of individual soil variables both in the sub-region and across the climate zones have been established.

Key words: cassava, soil properties, regression, subSaharan Africa

INTRODUCTION

The Portuguese settlers introduced cassava into Central Africa from South America in the 16th century. Since then, it has spread throughout sub-Saharan Africa, and has become one of the dominant starchy staples in the peoples' diet. Although the crop is grown in every country of the subcontinent, cultivation is concentrated in the humid tropical regions. Africa produces 48 million tonnes of cassava annually; this translates into an average of more than 200 calories per day for 200 million people (Dorosh 1988). Cassava is the dominant staple, in Zaire, the People's Republic of Congo, and in the Central African Republic. In the coastal regions of West Africa, from Côte d'Ivoire to Cameroon, cassava is as important as yam. Going further west along the coast, cassava is the second most important staple after rice. In East Africa, although maize is the dominant staple in most countries, cassava plays an important role in averting hunger in Mozambique, Tanzania, Uganda, and Burundi (Nweke 1996).

Nweke *et al.* (1994) have documented some abiotic determinants of cassava root yield in Africa; according to them cassava root yield depends on a wide range of factors, some of which are peculiar to cassava because of its flexibility with respect to planting and harvesting dates. Some of the factors are the age of cassava at harvest, intercropping, varying root sizes from the same plant, and piecemeal harvesting. Nweke *et al.* (1994) did not relate cassava yield parameters to specific soil nutrients. In order to explain adequately variations in cassava yield both soil and weather information at field level is required, likewise the knowledge of the interactions between the factors earlier outlined by Nweke *et al.* (1994). Asadu and Enete (1997) concluded that in eastern Nigeria soil fertility rather than human population density was responsible for the increases in cassava root yield. This study assessed the average cassava yield from farmers' fields and the contributions of soil properties to yield variations across sub-Saharan Africa.

MATERIALS AND METHODS

Site Selection and Sampling Procedures

Climate, human population density, and market infrastructure formed the bases for sampling. Following Carter and Jones (1989), four basic climatic zones were defined from temperature and duration of dry periods within the growing seasons (Table 1).

All-weather roads, railways and navigable rivers were derived from the 1987 Michelin travel maps and used to create a market access infrastructure map of the survey area. This map was divided into good and poor zones according to the density of the roads, railways or navigable waterways.

Table 1. Definitions of climate and altitude zones

	Characteristics		
Zone	*Daily temperature (^oC)*		**Dry season**
	Mean	**Range**	**(months)**
Lowland humid (LLH)	>22	<10	<4
Highland humid (HLH)	<22	<10	<4
Sub-humid (SH)	>22	>10	≤ 6
Non-humid (NH)	>22	>10	7-9
Low altitude (LA)	<800 meters above sea level (masl)		
Mid altitude (MA)	≥800 meters above sea level (masl)		

Population data from the United States Census Bureau (unpublished data), projected forward to 1990, were used to calculate population densities and to create a population map of Africa. This map was divided into high and low demographic pressure zones, the former comprising areas with 50 or more persons per km^2.

The three maps of climate, population density and market access infrastructure were overlaid to create zones with homogeneous climatic, demographic and market access infrastructure conditions of the cassava-producing areas. This was done with the help of a geographical model, IDRISI, (Eastman 1988). Each climate/population density/market zone with < 10 000 ha of cassava in each country was excluded as unrepresentative of cassava-growing areas. The remaining areas, which formed the potential survey regions, were divided into grids of cell 12' latitude by 12' longitude to form the sample frame for site selection. In each country, a certain number of grid cells, determined by the size of the country, were distributed among the climate/population density/market zones, in proportion to the sizes of the zones and were randomly selected. The total number of grid cells for the four sampled countries presented here is 181 (Fig. 1). One village was selected, by a random method, within each of the grid cells. Details of the site-selection procedure are outlined in Carter and Jones (1989).

In each selected village, a list of farm households was compiled and grouped into 'large', 'medium', and 'small' smallholder units with the assistance of key informants. One farm unit was selected from each stratum (Nweke *et al.* 1994). Cassava yield data were from fields 9-12 months old; this being the most frequent age of harvest in the areas surveyed. The estimation was based on a representative sample plot of 40 m^2; but where the field was small, a 20 m^2 plot was used. There were one or two plots per field, depending on the size and heterogeneity of the field in terms of soil and toposequence, that is, whether the field was sloping or flat. The number of stands per plot was taken. Both the roots and the tops were weighed separately and the harvest index was computed. Soil samples were collected from all the fields (plots) of the three selected farmers from where cassava yields were taken at 0-20 cm and 20-40 cm depth using a posthole auger. Two or more auger points were systematically selected depending on the size of the field to represent each field. Samples from each field were bulked separately before analysis. Where the field was sloping, it was divided according to slope position and samples from each topographic position bulked and analyzed separately. The altitude of each field was measured with an altimeter and all the fields were classified into either low (< 800 masl) or mid (≥ 800 masl) altitude fields.

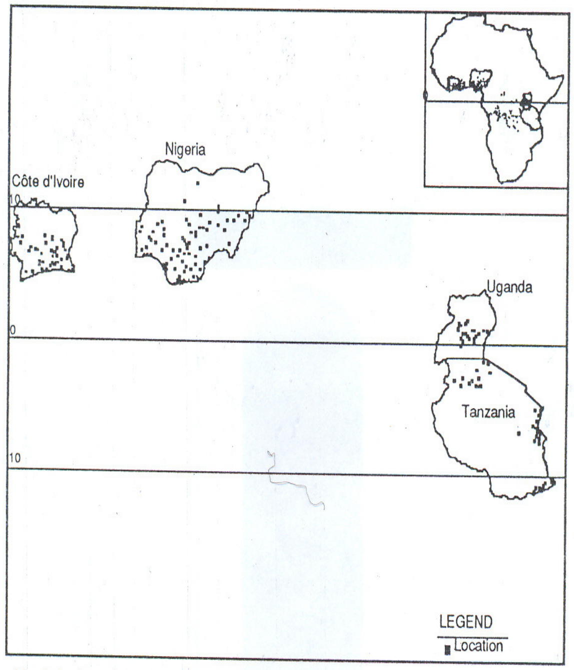

Fig. I. Locations of the countries and villages where COSCA investigations were carried out

done in the Analytical Service Laboratory of the International Institute of Tropical Agriculture (IITA) Ibadan following standard procedures outlined in the IITA (1982) Laboratory Manual. Soil properties determined include: particle-size distribution, organic matter, total N, available P, total S, exchangeable bases, acidity, and Mn, as well as soil pH. Various nutrient ratios were also calculated.

Statistical analysis

The general linear model procedure in SAS (GLM) was used to carry out the analysis of variance (ANOVA) in order to determine the effects of climate, altitude, and human population density and market access on cassava yield components and plant density. The GLM procedure uses the method of least squares to fit the linear models and has the advantage of doing ANOVA for unbalanced designs. The GLM model is

$$Y_i = \beta_o X_{oi} + \beta_1 X_{1i} + \ldots\ldots\ldots\ldots\ldots\ldots + \beta_k X_{ki} + E$$

where Y_i = response variable for ith observation

β_k = unknown parameters to be estimated

X_{ki} = design variables

E = error

A stepwise regression analysis (SAS 1985) was done to determine soil properties that were most responsible for the variation in the four cassava yield parameters, namely, root weight, shoot weight, harvest index and stand density. The analysis was done both for the entire sub-Subregion and according to the climatic zones.

RESULTS AND DISCUSSION

Significance of Site Selection Factors

A summary of the analysis of variance by GLM procedure is given in Table 2. It shows that both climate and market availability significantly influenced plant density and shoot weight, respectively while altitude only significantly influenced harvest index.

Climate generally determines such factors as rainfall, temperature, sunshine duration and influences soil nutrient availability and all of these normally combine to influence the farmer's choice of cassava plant density. The influence of market access may be a significant factor in determining the related availability of inputs such as mineral fertilizers. The use of mineral fertilizer for cassava production has been found to be higher where market access is better than where it is poor (Nweke 1996). This may also explain the significant interaction effects obtained between human population density and market access as well as between climate and market access.

Table 2. Factors with significant effects on cassava plant density and yield parameters.

	Type III Mean square/significance level			
Sources of Variation	**Plant density $(x10^{6})$**	**Root weight$(x10^{6})$**	**Shoot weight $(x10^{6})$**	**Harvest index**
Climate (C)	73^{*}	57^{ns}	5.7^{ns}	0.03^{ns}
Altitude (A)	33^{ns}	60^{ns}	0.3^{ns}	0.01^{*}
Population (P)	24^{ns}	92^{ns}	79^{ns}	0.10^{ns}
Market (M)	53^{ns}	121^{ns}	128^{*}	0.02^{ns}
C X A	141^{**}	1.3^{ns}	15^{ns}	0.03^{ns}
P x M	106^{**}	392^{***}	233^{*}	0.12^{***}
C x P x M	3^{ns}	106^{ns}	227^{*}	0.01^{ns}
C x M	129^{**}	587^{***}	29^{ns}	0.01^{ns}
A x M	212^{**}	0.9^{ns}	32^{ns}	0.03^{ns}
Error mean square	21	91	42	0.02
Error df	199	192	188	188

Notes: ns, *,**,***: not significant, significant at 0.05, 0.01 and <

Market availability also significantly influenced cassava top or shoot weight. The mean value obtained from poor market zones (13.4 t/ha) was significantly higher than that obtained from good access zones (8.5 t/ha). Cassava leaves are used as a vegetable in some of the villages sampled. Leaf harvest affects the final shoot growth and weight of cassava generally, thus where market access is good, leaves may be harvested and sold, leading to a lower final shoot weight. This is also partly supported by the significant interaction effects between population, market and climate (Table 2). Generally, the interactions between the factors had greatest influence on the cassava yield parameters. The overall mean fresh root yield was 13.1 t/ha (Table 3) but the distribution was skewed to the lower side with a wide range from less than 1 tonne to 65 tonnes. Nweke *et al.* (1991) also found mean root yields to be 10.7 t/ha in villages around Onitsha, 9.2 t/ha in villages in the Abakaliki area and

36.9 t/ha for villages around Zaki-Biam, all in different ecological zones of southeast Nigeria. Bangwe (1990) observed a mean yield of 10.4 t/ha for cassava harvested at 30 months or less after planting, 11.3 t/ha for others harvested at 31-36 months, and 16.8 t/ha for those harvested at 37 months or more after planting in villages of northwest Zambia.

Table 3. Overall average root yield components for the four countries.

Yield component	Mean	Minimum	Maximum	Standard deviation	No. of samples
Plant density (std/ha)	9991	750	41250	4585	218
Fresh root (t/ha)	13.05	0.40	67.10	9.6	210
Fresh shoot (t/ha)	10.17	0.95	50.00	6.5	206
Harvest index	0.55	0.03	0.89	0.12	206

FAO information indicates that the average annual yield for the period 1986-88 for the Collaborative Study of Cassava in Africa (COSCA) countries was 8.5 t/ha. The figure was obtained by weighting the annual average with the number of COSCA villages in each country. The unweighted mean was only 7.1 t/ha. The information for 1991, when COSCA information was collected, gave the yield for the four countries as 9.2 t/ha. FAO derives its yield data from land area and production reports prepared by the various countries (FAO 1989; 1991).

Berry (1993) commenting on official government data for cassava, observed that it was difficult to document trends in output or yield. Yields of cassava are difficult to measure accurately, given the farmers' practice of harvesting little by little, and published data rarely state the method of measurement used. Given these problems, it is not surprising that previous production data are inconsistent and unreliable (Berry 1993). This was, however, avoided during the COSCA survey.

The mean root yield from the climate zones was lowest in the highland humid and highest in the subhumid climate zones, even though the difference was insignificant (P= 0.1) (Table 4). Nweke *et al.* (1991) observed similar trends in the root yield between the forest transition zone (humid) and the guinea savanna (subhumid) zone of southeast Nigeria. The reasons suggested for the yield difference between the climate zones was the lower plant density in the humid than in the subhumid climate zones. Both the number of roots per plant and the average root weight, and hence yield per plant, were higher in the humid than in the subhumid climate zones. Perhaps the relatively low plant density was related to the low insolation and temperature in the highland humid compared to the subhumid climate zones. This is supported by the magnitude of the harvest index (Table 4) which is substantially higher in the subhumid than in the highland humid zones. Even in this present analysis, the lowest plant density was obtained from the highland humid zone. The higher ha[illegible] al[illegible] shoot weight cassava performs better in low altitude zones than in mid altitude zones.

Table 4. Means of yield parameters and plant density averaged over the climate and altitude zones.

	Root yield (t/ha)	Shoot yield (t/ha)	Harvest Index	Plant density (No/ha)
Climate zones				
Highland humid (HLH)	8.64	7.56	0.43	2313
Lowland humid (LLH)	11.45	10.04	0.55	10725
Subhumid (SH)	14.69	10.84	0.54	10393
Nonhumid (NH)	13.28	9.33	0.55	9324
C.V. (%)	21.74	14.81	11.31	48.39
LSD(0.05)	6.57	3.82	0.07	2654
Altitude zones				
Low altitude (LA)	13.64	10.39	0.55	10890
Mid altitude MA	8.47	8.52	0.50	3317
C.V. %	33.10	13.99	6.73	75.38
LSD(0.05)	5.29	2.79	0.05	1889

Soil Properties and Yield Parameters

The soil properties as specified in the last step of the multiple regression analysis and their contributions to variation in root yields are presented in Table 5. The parameter estimates of all the soil variables except that of S: P and K: S ratios were statistically significant ($P \leq 0.05$). Based on the partial R^2 values (which are reflections of the relative contributions of each soil parameter), total S accounted for the highest variation in root yield in the sub region among the variables selected by the stepwise regression procedure. This is followed

Table 4. Means of yield parameters and plant density averaged over the climate and altitude zones.

	Root yield (t/ha)	Shoot yield (t/ha)	Harvest Index	Plant density (No/ha)
Climate zones				
Highland humid (HLH)	8.64	7.56	0.43	2313
Lowland humid (LLH)	11.45	10.04	0.55	10725
Subhumid (SH)	14.69	10.84	0.54	10393
Nonhumid (NH)	13.28	9.33	0.55	9324
C.V. (%)	21.74	14.81	11.31	48.39
LSD(0.05)	6.57	3.82	0.07	2654
Altitude zones				
Low altitude (LA)	13.64	10.39	0.55	10890
Mid altitude MA	8.47	8.52	0.50	3317
C.V. %	33.10	13.99	6.73	75.38
LSD(0.05)	5.29	2.79	0.05	1889

by exchangeable Mg while K:S ratio contributed the least. The overall equation has an R^2 value of 32%, indicating that these soil variables could account for more than 30% of the variation in root yield in sub-Saharan Africa. Similarly, Table 6 shows that total S accounted for the highest variation in shoot weight in the subregion. Again all the parameter estimates associated with all the soil variables, except those of S:P and Ca:S ratios, were significant ($P \leq 0.05$) indicating that virtually all make significant contributions to the overall variation in shoot yield. However, a greater number of soil variables contributed significantly to influence shoot yield than root yield. The overall contribution of the soil variables to shoot weight is above 35%

Table 6. The contributions of soil properties to variations in shoot yield

Soil variables	Parameter estimates	Standard error	Type II sum of squares ($x10^7$)	F-value/ Sign. Level	Partial R^2 (%)
Intercept	161310.54	3779.466	27.32	18.62^{***}	-
Available P	28.59	12.697	7.44	5.07^{*}	0.5
Exch. Ca	10587.74	959.052	178.76	121.88^{***}	1.3
Exch. Mn	-2006.89	759.596	10.24	6.98^{**}	2.5
Total N.	100738.51	22781.399	28.68	19.55^{***}	1.2
K:S ratio	-22.39	4.504	36.24	24.71^{***}	0.3
Mg:K ratio	156.23	65.481	8.35	5.69^{*}	2.1
N:S ratio	66.14	40.260	3.96	2.70^{ns}	0.4
S:P ratio	13983.23	8166.039	4.30	2.93^{ns}	0.4
Ca:S ratio	3.52	1.073	15.81	10.78^{*}	2.3
C:N ratio	100.62	281.083	18.66	12.72^{***}	1.7
O.M.	-3019.17	1100.722	11.03	7.52^{**}	1.5
Silt	106.80	45.405	8.11	5.53^{*}	1.1
TEB	7701.00	752.649	153.55	104.69^{***}	2.1
Total S	-93400.84	11506.217	96.64	65.89^{***}	8.9
B.S	-331.28	39.947	100.87	68.14^{***}	4.7
Clay	-72.54	17.872	24.16	16.48^{***}	3.4
ESP	-450.83	143.506	14.48	9.87^{**}	0.6
Exch. Acidity	-3967.73	791.484	36.85	25.13^{***}	1.8
Error Df = 431, Error mean square = 1.47 x 10^7					

Notes: *, **, ***, ns : significant at 0.05, 0.01 and <0.001 The Contributions of Soil Properties to Cassava Yield
Exchangeable Potassium Percentage.

Table 7 shows the ten soil variables which contributed significantly to variation in harvest index. Their overall effect accounted for about 30% variations in the harvest index and each of the contributions was significant ($P \leq 0.05$). Harvest index, which is a ratio between the root yield and total biological yield, may be used as a reflection of the economic performance of a crop. The C:N ratio of the soil accounted for the greatest variation in harvest index followed by Ca:Mg ratio. Exchangeable K and acidity accounted for the least variations in harvest index.

Table 7. The contributions of soil properties to variations in harvest index.

Soil Variables	Parameter	Standard	Type II sum	F-value/ Sign.	Parti

	estimates	**error**	**of squares**	**Level**	**al R^2 (%)**
Intercept	0.307	30.0476	0.2407	41.67***	-
Available P	-0.001	0.0002	0.0769	13.31***	3.8
Exch. Ca	-0.035	0.0157	0.0285	4.93*	0.3
Exch. Mn	0.031	0.0149	0.0252	4.37*	1.3
Total N.	-0.744	0.0901	0.3936	68.14***	5.7
Mn:P ratio	-0117	0.0266	0.1108	19.18***	1.8
N:P ratio	0.233	0.0956	0.0344	5.96*	0.8
Ca:S ratio	0.029	0.0040	0.3112	53.87***	5.5
C:N ratio	0.011	0.0024	0.1262	21.84***	7.9
B.S	0.002	0.0005	0.1347	23.31***	1.7
Exch. Acidity	0.055	0.012	0.124	21.52***	0.5
Error Df = 431, Error mean square = 1.47 x 10^7					

Notes: *, **, ***, ns : significant at 0.05, 0.01 and <0.001 probability levels, and not significant respectively. B.S. = Base Saturation, EPP = Exchangeable Potassium Percentage.

Table 8 shows that 19 out of the 28 properties evaluated contributed significantly ($P \leq 0.05$) to the variation in cassava stand density. Exchangeable Mn and pH accounted for the highest variations while S:P and N:S ratios, available P and silt content contributed the least in the subregion.

The contributions of the soil variables to root yield across the climate zones are summarized in Table 9. In the lowland humid (LLH) zone, soil properties could account for up to 30% of variation in root yield with total S accounting for up to 13% of the variations. All the parameter estimates except that of N:S ratio were significant ($P \leq 0.05$). In the subhumid (SH) climate zone the data for total S were not available, thus those soil variables evaluated could only account for 12% of the total variation in the root yield. However, all the parameter estimates were significant ($P<0.05$). The overall contribution of soil variables to root yield in the highland humid (HLH) zone was up to 35% out of which silt, total S and sand made the highest contributions. However, except for base saturation, all the parameter estimates of all the soil variables were significant ($P \leq 0.05$).

Table 8. **The contributions of soil properties to plant density.**

Soil Variables	**Parameter Estimates**	**Standard Error**	**Type II Sum of Squares ($x10^7$)**	**F-value Sign-Level**	**Partial R^2 (%)**
Intercept	-11.040	3.2950	1.1507	11.23^{***}	-
Available P	-0.002	0.0010	0.4791	4.67^{*}	0.5
Exch. Mg	0.732	0.1023	5.2447	51.16^{***}	1.4
Exch. Mn	-0.399	0.0681	3.5138	34.28^{***}	13.2
Total N.	-13.443	1.7045	6.3762	62.20^{***}	7.8
Mn:P ratio	0.559	0.1406	1.61919	15.80^{***}	1.1
N:P ratio	2.678	0.7165	1.4324	13.97^{***}	0.7
N:S ratio	-0.012	0.0034	1.2638	12.33^{***}	0.4
S:P ratio	-2.239	1.1295	0.4026	3.93^{*}	0.4
Ca:Mg ratio	0.218	0.0335	4.3390	42.33^{***}	1.2
C:N ratio	-0.151	0.0219	4.8450	47.26^{***}	0.6
O.M.	0.525	0.0842	3.9955	38.98^{***}	1.6
pH	0.187	0.0475	1.5927	15.54^{***}	10.1
Sand	0.116	0.0328	1.2906	12.59^{***}	3.1
Silt	0.138	0.0331	1.7872	17.44^{***}	0.5
Clay	0.123	0.0329	1.4421	14.07^{***}	1.6
ECEC	-0.116	0.0140	1.0562	68.84^{***}	1.4
EPP	0.0391	0.0094	1.7648	17.22^{***}	1.3
Exch. Acidity	0.361	0.0459	6.3278	16.73^{***}	1.9
Error Df = 429, Error mean square = 0.1025					

Notes: *, **, ***, ns : significant at 0.05, 0.01 and <0.001 probability levels, and not significant respectively. B.S. = Base Saturation, EPP = Exchangeable Potassium Percentage.

In the nonhumid (NH) zones exchangeable potassium percentage (EPP) accounted for 18% of the overall yield variation while its total contribution was more than 45%. Both total S and clay also contributed significantly to the root yield variation.

Table 9. The contributions of soil properties to root yield by the climate zones.

Soil Variables	Parameter Estimates	Standard Error	Type II Sum of Squares ($x10^7$)	F-value Sign-Level	Partial R^2 (%)
		Lowland humid zone (Error : df = 304, ms = 1.2 x 10^7)			
Intercept	11617.26	2188.466	34.18	28.18^{***}	-
Available P	-50.07	9.597	33.01	27.27^{***}	4.8
Mn^{++}	-6421.18	783.012	81.57	67.25^{***}	6.9
N:S ratio	-13.47	8.646	2.947	2.43^{ns}	0.5
pH	744.27	314.214	6.81	5.61^{*}	1.2
Total S	-66331.44	8523.409	73.46	60.56^{***}	13.1
ESP	-499.34	119.546	21.16	17.45^{***}	5.1
		Subhumid zone (Error:df = 632, ms=7.9x10^7			
Intercept	10221.79	3202.923	80.64	10.18^{**}	-
Exch. Ca	-769.67	170.966	160.46	20.27^{***}	1.5
Exch. Mn	240.68	45.118	225.30	28.46^{***}	4.1
N:P ratio	-5373.53	2634.198	32.95	4.16^{*}	0.6
pH	2943.27	491.438	283.98	35.87^{***}	3.2
Sand	-135.25	27.757	187.98	3.98^{*}	0.5
Ca:Mg ratio	83.20	41.693	31.52	9.56^{**}	0.6
ESP	-276.64	89.486	75.67		1.4

Notes: *, **, ***, ns : significant at 0.05, 0.01 and <0.001 probability levels, and not significant respectively; ESP = Exchangeable Sodium Percentage, EPP = Exchangeable Potassium Percentage, ms = mean square.

Table 10 is a summary of the contributions of the soil variables to shoot yield, harvest index and stand density. In the HLH zone, eight variables contributed significantly ($P \leq 0.05$) to shoot yield with Mg: K ratio contributing the highest (≈ 28%) and exchangeable Na the least (<1.5%). Other variables were not relevant, based on the stepwise procedure used. Only four variables made significant contributions in the SH zone, with soil pH and clay contributing the highest (≈ 5% each) and others < 2%. In the LLH zone, 13 variables made significant contributions, the highest being from both clay and total S (≈10% each).

Table 9 (contd). The contributions of soil properties to root yield by the climate zones.

Soil Variables	Parameter Estimates	Standard Error	Type II Sum of Squares (x10^7)	F-value Sign-Level	Partial R^2 (%)
Highland humid (Error : df = 101, ms = 0.39 x10^7)					
Intercept	10871.80	8794.352	0.59	1.53^{ns}	-
Exch. Mn	2897.12	1498.498	1.45	3.74^{*}	1.0
Mn:P ratio	-2708.67	995.807	2.89	7.40^{**}	1.0
Ca:Mg ratio	1637.84	289.588	12.65	32.43^{***}	1.4
C:N ratio	-735.52	165.929	7.67	19.65^{***}	2.9
Sand	127.17	27.042	8.63	22.11^{***}	8.7
Silt	524.81	98.012	11.18	28.67^{***}	10.5
Total S	-131481.09	21306.701	14.85	38.08^{***}	9.1
B.S	-147.97	91.987	1.01	2.59^{ns}	0.8
Exch. Na	7278.97	1921.567	5.60	14.35^{***}	2.1
Exch. Acidity	-3646.49	1110.028	4.21	10.79^{**}	1.0
Non-humid zone (Error:df = 13, ms= 2.1.x10^7					
Intercept	1293.70	1217.206	0.24	1.13^{ns}	-
Available P	59.43	33.456	0.67	3.15^{ns}	5.8
Mg:K ratio	-76.01	49.255	0.51	2.36^{ns}	2.7
Total S	-71627.34	17030.058	3.76	17.69^{***}	11.6
Clay	220.73	27.561	13.65	64.14^{***}	8.9
EPP	515.26	176.452	1.81	8.53^{*}	17.9

Notes: *, **, ***, ns : significant at 0.05, 0.01 and <0.001 and not significant respectively; B.S = Base Saturation, ms = mean square.

The least (<1%) came from exchangeable Na. In the NH zone, C: N ratio made the highest (≈ 53%) significant contribution while the least values (≈ 3% each) were from both available P and ECEC.

Table 10. Summary of the contributions of soil properties to yield parameters by climate zone based on partial R^2 (%)

Soil Variable	Shoot weight				Harvest index				Plant density			
	HLH	SH	LLH	NH	HLH	SH	LLH	NH	HLH	SH	LLH	NH
Available P	0.9	nr	2.2	3.3	4.8	Nr	3.4	Nr	6.2	nr	6.8	Nr
Exch. K	nr	nr	nr	Nr	2.3	Nr	Nr	5.7	2.0	nr	2.2	Nr
Exch. Mg	1.9	1.5	4.2	Nr	nr	1.3	nr	Nr	1.4	nr	nr	Nr
Exch. Mn	nr	nr	3.5	Nr	1.1	2.7	nr	Nr	Nr	nr	16.5	Nr
Exch. Na	1.4	nr	0.5	Nr	nr	Nr	nr	Nr	0.9	nr	nr	Nr
Exch. Acidity	16.8	nr	1.8	Nr	nr	Nr	0.5	Nr	Nr	nr	8.7	Nr
TEB	nr	nr	3.1	14.1	nr	5.4	nr	Nr	2.2	nr	1.1	Nr
ECEC	nr	nr	nr	3.3	1.1	Nr	N	Nr	Nr	nr	nr	Nr
O.M	4.1	0.5	nr	Nr	nr	0.3	10.2	Nr	5.6	1.2	nr	Nr
Ph	nr	4.7	nr	Nr	1.2	0.7	0.7	Nr	1.2	0.9	0.4	Nr
Silt	6.9	nr	1.1	Nr	Nr	0.5	nr	Nr	9.6	2.3	3.0	Nr
Clay	nr	4.8	10.4	Nr	40.6	3.2	4.4	Nr	Nr	nr	1.2	9.9
B.S	nr	nr	1.2	Nr	Nr	Nr	13.3	Nr	0.5	nr	nr	Nr
Total S.	7.3	nr	10.3	Nr	1.7	Nr	nr	Nr	1.0	nr	nr	16.2
C:N ratio	nr	nr	5.6	52.6	2.1	Nr	nr	33.6	Nr	0.7	nr	16.5
Mg:K ratio	27.8	nr	4.0	Nr	1.0	0.3	2.7	Nr	57.2	0.3	3.2	Nr
Mn:P ratio	nr	nr	nr	13.3	1.8	0.4	1.8	10.8	Nr	nr	nr	13.7
Ca:S ratio	nr	nr	2.1	Nr	4.2	Nr	nr	Nr	1.0	nr	nr	26.0
EPP	nr	nr	nr	Nr	11.5	0.5	nr	13.9	0.8	nr	0.9	nr

Note: HLH, SH, LLH, NH, highland humid, Subhumid, Lowland humid and Nonhumid respectively, nr = not relevant, TEB = Total Exchangeable bases, ECEC = Effective cation Exchange Capacity, O.M = Organic Matter, B.S = Base Saturation, EPP = Exchangeable Potassium Percentage.

Twelve variables made significant ($P \leq 0.05$) contributions to harvest index (HI) in the HLH zone with the highest (≈ 41%) and the least (≈13%), being from clay and Mg: K ratio, respectively. In the SH zone TEB made the highest contribution while in the LLH zone base saturation made the highest contribution. In the NH zone, the highest contribution was made by the C: N ratio.

In the highland humid zone, Mg: K ratio accounted for more than 50% of the total variation in stand density. In the SH zone most of the variables were not relevant (Nr) with the overall contribution being about 5%. In the LLH zone, the most important soil variable contributing to the variations in stand density was exchangeable Mn while in NH zone, Ca: S ratio was the most important.

The general relationships obtained between soil variables and cassava yield parameters showed that soil properties are important in determining cassava performance. This is also because the soil reflects the effects of other factors of crop production including cultural practices (Asadu and Ugwu 1997). For example, the use of soil amendments such as mineral fertilizers are correlated with agricultural intensification and population density (Nweke *et al* 1994) but this is similar to soil amendment x population density interaction found to significantly affect soil pH (Asadu and Enete 1997).

The study generally showed that several factors interact to affect cassava performance in the subregion but the contributions of soil properties were shown to be very significant. This supports the finding that the soil fertility constraint is the most essential factor limiting agricultural production in the humid tropics (Okigbo 1989). This analysis surprisingly indicated the relevance of total sulphur to the variations in cassava yield. This nutrient has not been addressed adequately in earlier research about its effects on cassava growth and root yield. Nutrient ratios were also shown to contribute significantly to the variations in cassava yield parameters, thus supporting the need to use nutrient ratios to assess soil nutrient balances as earlier stated by Landon (1991).

Acknowledgement

The services of all the COSCA team members in individual countries who assisted in the study, both staff of the IITA Analytical Service Laboratory and the COSCA unit of RCMD are gratefully acknowledged. The study was funded by the Rockefeller Foundation and the core budget of IITA with collaboration of CIAT, Cali; NRI, London and ICHU, Uppsala.

REFERENCES

Asadu, C.L.A., Enete, A.A. (1997). Food crop yields and soil properties under population pressure in sub-Saharan Africa: the case of cassava in southeast Nigeria. *Outlook on Agriculture* 26-34.

Asadu, C.L.A., Ugwu, B.O. (1977). Soil management for sustainable crop production with particular reference to three arable crops in sub-Saharan Africa *In: pp 23-37, Advances in Crop Engineering for the 21st Century. Proceedings of Symposium on New Genetic Engineering*. 23-27 Feb. 1997. Tango jam Pakistan. Atomic Energy Agricultural Research Centre.

Bangwe, L.M. (1990). Traditional cassava cultivators of northeastern Zambia: roduction,utilization and factors determining productivity. *Paper presented at the Fourth East and Southern Africa's Root Crops Research Network (ESARRN) Workshop.* Mansa, Zambia. 1990. 22 pp.

Berry, S.S. (1993). Socio-economic aspects of cassava cultivation and use in Africa: Implications for the development of appropriate technology. *COSCA Working Paper No. 8.* Collaborative Study of Cassava in Africa, Ibadan, Nigeria. International Institute of Tropical Agriculture. 17 pp.

Carter, S.E., Jones, P.G. (1989). COSCA Selection Procedure. *COSCA Working Paper No. 2.* Collaborative Study of Cassava in Africa, Ibadan, Nigeria. International Institute of Tropical Agriculture. 19 pp.

Dorosh, P. (1988). The economics of root and tuber crops in Africa. *Resource and Crop Management Program; Research Monograph No.1.* International Institute of Tropical Agriculture. Ibadan, Nigeria.

Eastman, J.R. (1988). IDRISI. *A grid-based geographic analysis. Mass version 3.0.* Worcester Clard University Graduate School of Geography.

Food and Agriculture Organizations of the United Nations (FAO). (1989). *Production Yearbook vol. 42, 1988.* Rome, Italy: FAO.

Food and Agriculture Organizations of the United Nation (FAO). (1991). *Production Yearbook vol. 45, 1988.* Rome, Italy: FAO.

Gomez, A.K., Gomez, A.A. (1984). *Statistical Procedures for Agricultural Research. 2nd edition.* New York, John Willey and Sons.

International Institute of Tropical Agriculture (IITA). (1982). *Automated and Semi-automated methods for soil and plant analysis manual series No 7.* Ibadan, Nigeria. IITA. 33 pp.

Landon, J.R. (ed.). 1991. Booker Tropical Soil Manual: *A handbook for soil survey and agricultural land evaluation in the tropics. New York U.S.A.* John Wiley and Sons Inc. 474 pp.

Nweke, F.I., Dixon, A.G.O., Asiedu, R., Folayan, S.A. (1994). Cassava varietal needs of farmers and potentials for production growth in sub-SaharanAfrica.*COSCA Working Paper No 10.* Collaborative Study of Cassava in Africa, IITA, Ibadan, Nigeria

Nweke, F.I. (1996). Cassava: A cash crop in Africa. *COSCA Working Paper No. 14.* Collaborative Study of Cassava in Africa. Ibadan, Nigeria: International Institute of Tropical Agriculture. Ibadan, Nigeria. 79 pp.

Nweke, F.I., Ugwu, B.O., Asadu, C.L.A., Ay, P. (1991). Production costs in the yam-based cropping systems of southeastern Nigeria. Resource and Crop Management Program *Research Monograph No. 6.* Ibadan, Nigeria: International Institute of Tropical Agriculture. 29 pp

Okigbo, B.N. (1989). Development of sustainable agricultural production systems in Africa: Roles of the international and national research systems. First Distinguished African Scientist Lecture Series. International Institute of Tropical Agriculture. Ibadan , Nigeria,

Statistical Analyses System (SAS). (1985). SAS User's guide: Statistics, Version 5 edition, North Carolina, U.S.A SAS Institute Inc. 456 pp