Soil nutrient and cassava yield variations under continuous cultivation of three crop mixtures in south-eastern Nigeria

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A research farm at University of Nigeria, Nsukka, Nigeria, which was under cultivation for >25 years before it was fallowed for 8 years, was cleared in 1998 and grown to three common crop mixtures for 4 years. The aim was to assess the performance of the cassava component in terms of root yield and harvest index under continuous cultivation relative to soil nutrient variations. The crop mixtures were cassava + pigeonpea, cassava + pigeonpea + maize, and cassava + pigeonpea + maize + yam. Incorporation of crop residues from each of the respective plots into the soils and the use of a legume (pigeonpea) served as means of restoring soil fertility. The experimental design was a randomized complete block design replicated thrice each year. Changes in eight selected soil fertility indicators, namely, pH, total N, organic matter, available P, and exchangeable Ca, Mg, K, and Na were monitored for the period. An analysis of the nutrient contents of the soils under the crop mixtures indicated narrow variations over the four years, except in the cases of exchangeable cations where coefficients of variations of ≥25% were obtained. Comparatively, year-to-year variations were more substantial though not consistent. This is because in some years some nutrients decreased while others increased relative to the values obtained in the preceding year. Except in 1999 when cassava root yields from all the crop mixtures decreased substantially (>60%) relative to their 1998 respective values, the trends in other years were not consistent in all the crop mixtures. The mean yields obtained were generally below the expected mean yield for the same cassava variety in the area. The study also showed that all the soil parameters selected contributed to the variations in cassava yields, though they were not consistent in each year and in each crop mixture. However, regression analysis between the relative changes in soil nutrients and cassava yield variations showed significant contributions of total N (P = 0.05), exchangeable Ca (P = 0.01), and Mg (P = 0.001). Thus, adequate management of these soil factors is required to enhance the performance of cassava in the crop mixtures.

Keywords: Soil fertility; Cassava yield variations; Crop mixtures; Regression; Nigeria

Intercropping (polyculture) is a well-known cropping system adopted by most farmers in south-eastern Nigeria (SEN) for the production of most staple crops. The most popular crops found in mixtures are yam (*Dioscorea rotundata*), cassava (*Manihot esculenta*), maize (*Zea mays*), and pigeonpea (*Cajanus cajan*). The farmers generally adopt the mixed intercropping (mixed cropping) system, as the crops are often not planted in a special pattern.

More than 70% of the food grown in the humid tropics, especially in Africa, comes from intercropping (IITA, 1984). Even in SEN, about 80% of the farmers grow their crops in mixtures (Okigbo, 1978; Okorji, 1986). This is because of the numerous advantages of the system over sole cropping and these are well documented (Andrew, 1972; Finlay, 1974; Okigbo, 1978; Kantor, 1999) and appreciated by the farmers of SEN (Okorji, 1986; Asadu,

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1997). Generally, yam- and cassava-based systems are the most popular among the farmers in the zone (Asadu, 1989). The importance of mixed cropping in the zone emphasizes the need for more and closer studies of the system especially with respect to improving the soil management component for optimal yields and poverty alleviation.

Essentially, most studies on mixed cropping had been to establish its advantages and constraints over sole cropping, using yield parameters from component crops without due analysis of yield response to soil nutrient variations in the crop mixtures. The lack of information is more acute where continuous cultivation of the crop mixtures is practised. The importance of continuous cultivation in SEN stems from the prevalent shortened fallow period or no fallow at all due to increased population pressure on the land (Nweke *et al*., 1994). The objectives of the study were to examine the yields of cassava obtained from three crop mixtures under continuous cultivation, and to relate them to soil nutrient variations in the crop mixtures. The farmers in the location where the study was done generally grow their crops in mixtures. Thus, this analysis was restricted to crop mixtures popular among the farmers.

Materials and Methods

Study location

Nsukka is located on Lat. 06°52′ N, Long. 07°24′ E within the derived savannah zone of SEN. It is on an average elevation of 447 m above sea level. It usually has two seasons, the rainy and the dry seasons. The former usually lasts from April to October with a short break (August Break) normally in the month of August. Average annual rainfall is about 1550 mm and more than 85% of this falls within the rainy season. The total annual rainfall values for 1998, 1999, 2000, and 2001, the years the work was done are, respectively, 1288, 1345, 1735, and 1252 mm with an average of 1405 approximately 9% short of the normal average. The average minimum and maximum temperatures were about 22°C and 30°C, respectively, while the average relative humidity was rarely below 60%. The study was at the UNN research farm fallowed for eight years before the establishment of the trials in 1998. The soil has been classified as an Alfisol (Asadu, 1990).

Crop mixtures and experimental design

The following crop mixtures were selected based on prior knowledge of the most common staple food crops grown by the local farmers in SEN: cassava + yam + maize + pigeonpea (C + Y + M + P), cassava + maize + pigeonpea (C + M + P), and cassava + pigeonpea (C + P). These crop mixtures were arranged in a randomized complete block design and replicated three times for four years beginning from 1998. Specifically, the crops are the best local cultivars, namely, yam (*D. rotundata* cv. nwopoko), cassava (*M. esculenta* cv. TMS 30572), maize (*Z. mays* cv. yellow gamgam), and pigeonpea (*C. cajan* cv. gamgam).

The trials were established between 15 and 18 May each year during which all the crops were planted. Cassava and yam were planted at a spacing of 1 m × 1 m on the top of the ridges of 0.5 m high, while maize and pigeonpea were planted at the sides of the ridges at the same spacing. Each plot measured 40 m^2. However, two grains of maize and two seeds of pigeonpea were planted per hole following the local farmers' practice. The ridges were made with local hoes. In each location, an area of 20 m^2 at the centre of each plot was harvested for the analysis following the elimination of discards at the edges. Cassava yield parameters analyzed were root yield and harvest index (HI) at 12 months after planting (MAP). Yam was harvested 8 MAP, maize 3 MAP, and pigeonpea 10 MAP. This analysis was restricted to crop mixtures because the farmers in the area usually grow their crops in mixtures, knowing the overriding advantages over sole cropping.

Soil sampling and analysis

In all the four crop years, loose soil samples were collected from the three replicate plots at 0–20 cm with the help of an auger before cultivation commenced. These loose samples were used to determine chemical properties. Before analysis, the loose samples were air-dried, gently crushed, and sieved with a 2-mm sieve.

The soil pH was determined in duplicate in water using Beckman's zeromatic pH meter, in a soil:liquid suspension of 1:2.5. Exchangeable bases were extracted with neutral, 1 N am-

monium acetate (NH_4OAc), Ca and Mg were determined by atomic absorption spectroscopy, while K and Na were determined using flame photometry. Total nitrogen was determined by the macro-Kjeldahl wet oxidation method (Bremner, 1965). Organic C was determined by the method of Walkley and Black (1934), and this was converted to soil organic matter (SOM) by multiplying the percentage C by 1.724. Available P was determined by the Bray 2 method (Bray and Kurtz, 1945).

Data analysis

The percentage changes (p) in soil and cassava yield parameters between two crop years were calculated from:

$$p = 100(Y_2 - Y_1)/Y_1$$

where,

Y_1 = value of soil or cassava yield parameter in Year 1

Y_2 = value of soil or cassava parameter in Year 2 (Year 1 precedes Year 2 chronologically).

The relative changes in soil nutrients and cassava yield variations were subjected to regression analysis to show soil properties with significant contributions to root yield variations.

Results and Discussion

Soil nutrient variations

In the C + P mixture, soil pH did not change substantially throughout the four-year period. There was only a slight increase of about 2% (Table 1). There were increases in total N, SOM, exchangeable K, Ca, and Mg in 1999 relative to the original values in 1998. On the other hand, available P and Na diminished in the reference years. All the fertility indicators except available P increased in 2000 relative to the 1999 values. Virtually all the nutrients except available P decreased in 2001 relative to the 2000 values. For the four years, only the exchangeable cations, namely, K, Ca, Mg, and Na had coefficients of variation above 35%.

In the C + M + P mixture, soil pH did not vary substantially over the years (Table 2). There was a slight decrease of 2% in 1999 relative to the 1998 value, while in 2000 and 2001, slight increases of 2% each were obtained relative to the preceding years. Relative to the 1998 values, in 1999, there were increases in total N (≈10%), SOM (≈26%), exchangeable Mg (≈86%), and exchangeable Ca (>15%). Available P and exchangeable Na decreased by at least 30% while exchangeable K did not change (Table 2). In 2000, all the nutrients had increases except total N and available P which decreased respectively by about 4 and 22% relative to the 1999 values. Relative to the 2000 values, in 2001, there were increases in total N (≈6%), SOM (≈13%), and available P (≈20%). All the exchangeable cations decreased by at least 8% relative to the 2000 values (Table 2). For the four years, variations over 25% were obtained for all the exchangeable cations and available P (Table 2).

Soil pH showed the least variation both between years and across the four years in

Table 1 Mean ± SD of soil fertility indicators obtained from 0–20 cm depth in cassava and pigeonpea mixtures and relative changes over four years (1998–2001)

	Mean ± SD				Relative changes (%)			
Soil fertility indicators	1998	1999	2000	2001	1999 vs 1998	2000 vs 1999	2001 vs 2000	Overall mean (CV)
pH	4.6 ±0.26	4.7±0.20	4.8±0.06	4.9±0.00	+2.2	+2.1	+2.1	4.8 (3)
Total N (%)	0.075±0.02	0.092±0.01	0.096±0.01	0.092±0.01	+22.7	+4.3	–4.2	0.089(11)
SOM (%)	1.22±0.38	1.74±0.08	2.09±0.35	1.86±0.14	+42.6	+20.1	–11.0	1.73(21)
Avail. P (mg kg^{-1})	7.0±2.00	6.7±0.58	5.3±0.58	6.1±0.00	–4.3	–20.9	+15.1	6.3(12)
Exch K (cmol kg^{-1})	0.06±0.01	0.08±0.03	0.13±0.02	0.13±0.01	+33.3	+62.5	0.0	0.1(36)
Exch. Ca (cmol kg^{-1})	0.67±0.21	2.10±0.17	2.97±0.85	1.93±0.12	+213.4	+41.4	–35.0	1.92(49)
Exch. Mg (cmol kg^{-1})	0.57±0.21	1.37±0.60	1.60±0.36	1.27±0.46	+140.4	+16.8	–20.6	1.20(37)
Exch. Na (cmol kg^{-1})	0.15±0.03	0.08±0.03	0.26±0.04	0.19±0.02	–46.7	+223.0	–26.9	017(44)

SD, Standard Deviation; CV, Coefficient of Variation (%)
SOM, Soil organic matter

the C + Y + M + P mixtures (Table 3). In 1999, available P and exchangeable Na decreased by 17 and 39%, respectively, relative to the 1998 values. Except for exchangeable K that did not change, there were increases in other nutrients ranging from ≈22% in total N to >200% in exchangeable Ca (Table 3). Relative to 1999 values, in 2000, all the exchangeable cations had substantial increases ranging from ≈50% in exchangeable Mg to >200% in exchangeable Na. On the other hand, total N and SOM had slight decreases while exchangeable K did not change. Relative to 2000 values, in 2001, total N did not change whereas there were increases in SOM (≈13%) and exchangeable K (≈8%). Other nutrients decreased by at least 24% (Table 3). For the four years, only exchangeable cations had variations of up to 30%, the highest being 56% exhibited by exchangeable Ca.

Generally, there were slight variations in the soil nutrients in plots under each crop mixture in 1998. These variations were generally low (Tables 1–3) being <10% in all cases except in the cases of available P (14%) and exchangeable Mg (19%). The variations were within the range that was not likely to introduce bias at the beginning of the trials due to the relative positions of the plots, especially as the treatments were randomized.

Generally, the mean soil pH values in both 1998 and 1999 were very strongly acid in the range (ph 4.5–5.0) based on the USDA–SCS

Table 2 Mean ± SD of soil fertility indicators obtained from 0–20 cm depth in cassava + maize + pigeonpea mixtures and relative changes over four years (1998–2001)

	Mean ± SD				Relative changes (%)			
Soil fertility indicators	1998	1999	2000	2001	1999 vs 1998	2000 vs 1999	2001 vs 2000	Overall mean (CV)
pH	4.8±0.15	4.7±0.15	4.8±0.1	4.9±0.00	–2.1	+2.1	+2.1	4.8(2)
Total N (%)	0.082±0.02	0.090±0.01	0.086±0.01	0.091±0.00	+9.8	–4.4	+5.8	0.087(5)
SOM (%)	1.41±0.38	1.77±0.15	1.79±0.07	2.02±0.08	+25.5	+1.1	+12.8	1.75(14)
Avail. P (mg kg^{-1})	8.7±3.51	6.0±1.00	4.7±0.58	5.6±0.46	–30.0	–21.7	+19.1	6.3(28)
Exch. K (cmol kg^{-1})	0.07±0.00	0.07±0.01	0.13±0.02	0.12±0.00	0.0	+85.7	–7.7	+0.10(33)
Exch. Ca (cmol kg^{-1})	0.70±0.20	2.03±0.75	3.27±1.62	1.97±0.15	+190	+61.1	–39.8	+1.99 ()
Exch. Mg (cmol kg^{-1})	0.70±0.20	1.30±0.52	1.47±0.72	1.27±0.50	+85.7	+13.1	+13.6	1.19(28)
Exch. Na (cmol kg^{-1})	0.14±0.04	0.07±0.03	0.26±0.02	0.18±0.00	–50.7	271.4	–30.5	0.16(48)

SD, Standard Deviation; CV, Coefficient of Variation (%)
SOM, Soil organic matter

Table 3 Mean ± SD of soil fertility indicators obtained from 0–20 cm depth in cassava + maize + pigeonpea + yam mixtures and relative changes over four years (1998–2001)

	Mean ± SD				Relative changes (%)			
Soil fertility indicators	1998	1999	2000	2001	1999 vs 1998	2000 vs 1999	2001 vs 2000	Overall mean (CV)
pH	4.6±0.35	4.6±0.12	4.8±0.06	4.9±0.00	0.0	+4.3	+2.1	4.7(3)
Total N (%)	0.076±0.01	0.093±0.01	0.092±0.01	0.092±0.00	+22.4	–1.1	0.0	0.088(9)
SOM (%)	1.31±0.23	1.91±0.08	1.77±0.21	2.00±0.21	+45.8	–7.3	+13.0	1.75(16)
Avail. P (mg kg^{-1})	9.3±2.51	7.7±1.15	7.7±1.15	5.8±0.46	–17.2	0.0	–24.7	7.6(19)
Exch. K (cmol kg^{-1})	0.07±0.03	0.07±0.02	0.12±0.00	0.13±0.00	0.0	+71.4	+8.3	0.10(33)
Exch. Ca (cmol kg^{-1})	0.63±0.06	2.07±0.75	3.52±0.71	2.33±0.42	+228.6	+70.5	–34.0	2.14(56)
Exch. Mg (cmol kg^{-1})	0.47±0.12	1.27±0.46	1.93±0.11	1.23±0.35	+170.2	+52.0	–36.3	1.23(49)
Exch. Na (cmol kg^{-1})	0.13±0.03	0.08±0.03	0.24±0.04	0.18±0.00	–38.5	+200.0	–25.0	0.16(43)

SD, Standard Deviation; CV, Coefficient of Variation (%)
SOM, Soil organic matter

Table 4 Summary of cassava root yield and harvest index from the three crop mixtures and relative changes over four years (1998–2001)

	Root yield (t ha^{-1})				Relative changes (%)		
Soil fertility indicators	1998	1999	2000	2001	1999 vs 1998	2000 vs 1999	2001 vs 2000
C + P	10.0	2.4	2.5	2.4	–76.0	+4.2	–5.1
C + M + P	11.9	2.3	3.2	2.9	–80.7	+39.1	–9.1
C + M + P + Y	8.4	3.1	2.2	4.0	–61.7	–29.0	+84.3
			Harvest index				
C + P	0.67	0.63	0.55	0.61	–6.0	–12.7	+10.9
C + M + P	0.67	0.53	0.57	0.61	–23.2	+7.5	+7.0
C + M + P + Y	0.66	0.58	0.60	0.64	–12.1	+3.4	+6.7

c, Cassava; M, Maize; P, Pigeonpea; Y, Yam
(+), Increase; (–), Decrease in the succeeding year

(1974) classification. These values are generally below the range (5.2–7.0) recommended for cassava by the FAO (1998).

The mean values of total N in each year appeared to be low and below the critical levels for cassava (Metson, 1961; Enwezor *et al*., 1989) despite some observed increases. Similarly, the contents of SOM and available P appeared to be inadequate for good performance of cassava each year, based on the recommendation of Howeler (1996). The mean exchangeable K values obtained were generally below 0.2 cmol kg^{-1}, the critical level below which most crops will respond to K application (Meredith, 1965). The increases in exchangeable K obtained in 2000 under each crop mixture could be due to the incorporated crop residues, since organic materials are also sources of K in soils (Asadu and Nweke, 1999). The mean values of exchangeable Ca obtained in each year appeared to be adequate since all were well above 0.2 cmol kg^{-1}, the critical level that will elicit Ca response by most crops (Meredith, 1965). The increases in exchangeable Ca in 1999 and 2000 may also be attributed to the incorporated organic material from crop residues. The exchangeable Na contents in the soils were not high enough (>15% ESP) to induce deleterious effects on the crops (Landon, 1991).

Cassava yields and soil nutrient variations

The root yields obtained from the crop mixtures were not significantly affected by the number of crops in each mixture. The highest mean values obtained were at the beginning of the trials in 1998 (Table 4). These were the only values fairly close to those obtained using the same cassava variety (TMS 30572) in the Nsukka environment (Nnodu *et al*., 1995). The highest yield depressions (≈62–81%) occurred in 1999. The soil nutrient that might have accounted for these was the observed decrease in the available P (Tables 1–3). The soil under the C + M + P mixture with the highest decrease in available P (30%, Table 2) produced the highest decrease in root yield (80%, Table 4). The decrease in available P could have caused some negative nutrient interactions among other nutrients leading to decreased root yield, since available P is one of the major nutrients required by cassava in large amounts (Howeler, 1996).

The slight increases (≈4%, Table 4) in

Table 5 Regression parameters obtained between the relative yields of cassava and relative changes in soil nutrients in Nigeria

Soil parameter	Intercept	Slope	R^2/ significant level
pH	–37.1	13.4	0.19 ns
Total N (%)	8.1	–3.7	0.5*
SOM (%)	7.9	–1.4	0.28 ns
Avail. P (mg kg^{-1})	–17.6	–0.3	<0.01 ns
Exch. K (cmol kg^{-1})	–24.5	0.3	0.05 ns
Exch. Ca (cmol kg^{-1})	15.5	–0.04	0.61**
Exch. Mg (cmol kg^{-1})	16.0	–0.6	0.69***
Exch. Na (cmol kg^{-1})	–22.5	–0.1	0.13 ns

ns, *, **, ***, Not significant, significant at 0.05, 0.01, and 0.001 probability levels, respectively
SOM, Soil organic matter

cassava root yields in 2000 relative to the 1999 values in the C + P mixture might be attributed to slight increases in total N, SOM and all the exchangeable bases (Table 1). The slight decrease in root yield in 2001 (Table 4) in the C + P mixture is explained by the slight decreases in total N and SOM as well as decreases in exchangeable Ca, Mg, and Na (Table 1). In the case of the C + M + P mixture, the ≈40% yield increase was surprising because except for the substantial increases in exchangeable cations, there was only a slight increase in SOM (Table 2). On the other hand, the slight decrease in yield (≈9%) obtained with the C + M + P mixture, might be associated with the observed decreases in all the exchangeable cations (Table 2). The 30% decrease in root yield obtained in C + M + P + Y mixture (Table 4) was also surprising because there were only slight decreases in total N and SOM in the reference years (Table 3). The increase in yield in the C + P + M + Y mixture might be associated with the observed increases in total N (≈13%), and exchangeable K (≈8%) (Table 3).

The results of the regression analysis between the soil nutrients and cassava root yield variations (Table 5) indicated that three soil nutrients, namely, total N and exchangeable Ca and Mg contributed more significantly than other soil properties to cassava root yield. Nitrogen is one of the nutrients required in large amounts by cassava. It is possible that the roles of both Ca and Mg may be in moderating the acidity of the soil, since all the pH values were below 5.2–7.0, which is the optimum range for cassava (FAO, 1998).

The changes in HI were generally small. However, there were consistent decreases between 1999 and 1998, and consistent increases between 2001 and 2000 (Table 4). The former may be associated with slight decrease in available P in the C + P mixture, and decreases in total N and available P in the C + M + P mixture as well as in total N and SOM in the C + P + M + Y mixture (Tables 1–3). The 13% decrease in HI in the C + P mixture in 2000 could be due to the decrease in available P (Table 2), and the slight increases in HI in 2000 relative to 1999 in the other two crop mixtures, to observed increases in all the exchangeable cations (Tables 2 and 3). Again, the slight increases in HI in all the crop mixtures in 2001 relative to 2000 values (Table 4) could be due to an increase in available P in the case of C + P mixture (Table 1), increases in total N, SOM, and available P in the case of C + P + M mixture (Table 2), and increases in SOM and available P in the case of C + P + M + Y mixture (Table 3).

The overriding role of soil nutrient variations as a major factor contributing to cassava yield variations is strengthened by the inconsistent trends between rainfall over the years and yield variations. For example, there was an increase from 1288 mm in 1998 to 1345 mm in 1999, but the largest yield depression occurred then. In 2000, the highest rainfall (1735 mm) was obtained, yet there were decreases in yields in both the C + P and C + M + Y + P plots (Table 4).

Summary and Conclusion

An analysis of the variations in eight soil fertility indicators over four years in three crop mixtures in SEN indicated that only the exchangeable cations, namely, K, Ca, Mg, and Na varied substantially with coefficients of variations (CVs) ranging from about 25 to 56%. However, year-to-year comparisons indicated more substantial but inconsistent variations.

Cassava root yields decreased substantially (>60%) in all the crop mixtures in 1999 relative to the 1998 values. In 2000, there were slight increases (<5%) in C + P and large increase (≈40%) in C + P + M mixtures, and up to a 29% decrease in the C + P + M + Y mixture relative to the 1999 values. On the other hand, the 2001 yields from C + P and C + P + M mixtures were above 90% of the respective yields obtained in 2000, indicating slight decreases whereas there was an increase of about 80% in the C + P + M + Y mixture relative to the 2000 yield. The HI decreased in all the crop mixtures in 1999 relative to the 1998 values and in the C + P mixture in 2000. There were slight increases in both C + M + P and C + M + P + Y mixtures in 2000 and in all the crop mixtures in 2001. Generally, the trends in cassava yield variations over the four years appeared to be more strongly associated with soil fertility indicators than rainfall variations, implying clear evidence of interactions among the nutrients. Thus, these indicators need to be adequate in the soils for cassava to perform well in the crop mixtures.

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