Ife Journal of Agric. Vol. 11 Nos. 1 & 2 (1989)

The effect of N, P, K on Soil Chemical composition and Yield of Robusta Coffee (*Coffea canephora* Pierre)

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Abstract

One hundred and twenty eight soil samples were collected in 1978 from within 30cm depth of 64 NPK treated plots. A 4 x 4 x 2 NPK trial replicated 2 times commenced in 1972. Three harvests of coffee berry were collected from the treated plots in 1978. *Values of coffee yield were correlated with resultant values of soil N, P, K, base (K + Ca + Mg) concentration, pH and organic matter.* Significant positive correlations between *coffee yield and soil N and P* were observed. Positive correlations were observed between yield and *soil organic matter,* though the correlations were not significant. In most cases negative correlations were observed between yield and base elements. Negative correlations between yield and base elements are discussed in relation to observed low Mg/K ratio and the non-use of fertilizers containing Mg and Ca. It appeared that soil analysis result indicate the potential of soil to furnish the crop with nutrients in the near future rather than immediately.

Introduction

It has been shown that between January and June 1976, Nigeria incurred a negative balance of trade of about ₦149,000 on coffee (Adegbola, 1979). One of the major steps being taken to increase coffee production in Nigeria is fertilizer application. There is thus the need to continue to research into the influence of plant nutrients (N, P, K etc) on coffee yield. Robusta coffee *(Coffea canephora* P.) forms at least 70% of the coffee grown in Southern Nigeria. But world-wide agricultural and nutritional studies have been concentrated mainly on Arabica coffee. In Africa known references (Loue, 1957) indicate that studies on the nutrition of Robusta coffee commenced only recently.

The results from fertilizer trials on Robusta coffee in West Africa (Omotosho, 1972); Omotosho and Olojola, 1972; Verliere, 1973; Omotosho and Ojeniyi, 1978) have remained conflicting. It was concluded (Omotosho and Ojeniyi, 1978) that yearly NPK application to coffee could significantly increase berry yield after about five years. Whereas Verliere who conducted a 2^3 NPK trial on a shaly soil in the Ivory-Coast observed no yield response to NPK.

Soil scientists usually interprete soil analysis results as the previous, present or future potential of soil to furnish the crop with nutrients. In the present investigation, analysis results got from soil samples collected at a time are viewed along with crop yield at that or other times to further identify the relation between soil analysis result and plant performance. This investigation was intended to identify the type of nutrients critically determining Robusta coffee yield especially under Nigerian condition.

Materials and Methods

Field Condition:

The experiment was established at the Ondo State Coffee Plantation in Owo. The plantation was established in 1957. The portion utilized for this investigation covered about 1.5ha. The initial chemical analysis of the plantation soil was not performed, although Omotosho (1974) confirmed the deficiency symptoms of N and P on the coffee stands. The texture of typical soil profile layers are essentially: 0-5cm loam, 5-20cm standy loam, 20-47cm fine sand. 47-75cm clay sand and 75-90cm sandy clay. Coffee trees are spaced at 3m x 3m.

A 4 x 4 x 2 NPK trial was established in 1972, and there were 2 replicates. The different NPK treatments have been found (Ojeniyi, 1980) to effect statistically significant differences in the nutrient contents of the coffee plots. For example increasing levels of applied P effect increases in soil P. The four N levels applied were 0, 100, 200 and 300 kg/ha/annum, the equivalent P levels were 0, 90, 180 and 270 kg/ha/annum. The two K levels were 0, and 90 kg/ha/annum. The experiment was set up using a randomized block design with four replicates. NPK application was performed twice in each year since 1972. First application by broadcasting was at the beginning of the rain season (April—May) and the second later during the rain season (August — September).

Annual berry yield collection from each treatment plot was based on selected trees. In 1978 yield collection was performed in September, October and November with each harvest extending over 5 days. Thus there were 64 yield data per harvest covering the NPK treatment (32 treatments and 2 replicates).

Soil Sampling and Chemical Analysis:

Two composite soil samples were collected from the 0-8cm and 8-30cm surface layers of each NPK treatment plot with hand trowel; since the feeding roots of coffee trees are known to be mainly concentrated in the first 20cm of soil (Montoya et al., 1961; Aduayi, 1970; Omotosho, 1974). For the purpose of statistical correlation, the mean figures for the two depths were utilized. Therefore 64 sets of figures for each soil parameter covering 32 NPK treatments were dealt with. Soil sampling was performed in August (for the first replicate) and September (for the second replicate). Each statistical correlation was based on 32 characters. The soil chemical and statistically independent parameters were soil N (%), P (ppm), K, Ca, Mg (m.e./100g soil), pH, and organic matter (%).

The methods of chemical analysis were adapted from the methods described by Jackson (1958) and the ASA Monograph 9. Total N was measured after the usual Macro-Kjeldahl digestion (of 2.0g sample). The digest (2 — 3cc) was passed through a Technicon S.C. Colorimeter Auto-analyzer for N determination. The indicator was boric acid while titration in the Auto-analyzer was performed against 0.01N HCl. Organic carbon was determined by the Walkey-Black method, and a conversion (to organic matter) factor of 1.73 was used. For P, perchloric acid digestion was performed on 2-0g sample and molybdovanodo-phosphoric acid was added to the extract for colorimetry. P was read from a standard curve. Exchangeable Ca, Mg and K were determined by flame photometry and atomic absorption spectrophotometry respectively after extraction (of 5.0g sample) with 30ml ammonium acetate for 2 hr, three consecutive times. Soil pH in water (1 : 1 soil-water ratio) was determined using pH meter.

Results and Discussion

The mean (for 64 samples) values for N,P,K, Ca, Mg and pH for the first set of 32 coffee treatment plots were 0.10%, 8.02 ppm, 0.20 m.e./100g, 0.98 m.e./100g, 0.32 m.e./100g and 5.5 respectively. The equivalent values for the second set of 32 plots were 0.095, 8.97, 0.18, 0.91, 0.30 and 5.3. The comparatively low (Ogunwale and Ashaye, 1975) base content could be associated with the non-use of fertilizers containing Ca and Mg.

Soil samples were collected in August and September, but greater positive correlations were recorded when yield data of October and November were utilized. This indicates that soil analysis results show the potential of soil to furnish the crop with nutrients in the near future rather than immediately.

Slight differences in mean values of soil chemical parameters introduced differences in mean yield data of coffee as shown by values presented in Tables 3, 4 and 5. The mean figures are utilized to achieve clearity, although they considerably reduced the variations due to the effect of soil factors. The soil data covered 0-8 and 8-30cm depths and two replicates, while the yield data covered the replicates but dealt only with the total yield.

TABLE 1: REGRESSIONS OF COFFEE YIELD (Y) ON SOIL CHEMICAL FACTORS.:

	Dependent Factor (Yield)			
Soil Factor	Total Yield	First Harvest	Second Harvest	Third Harvest
N	Y = 27.85 N** + 6.41	Y = —2.38 N + 2.63	Y = 24.29 N + 1.94	Y = 14.71** N + 0.97
P	Y = 0.14* P + 9.20	Y = —0.004 P + 2.41	Y = 0.09* P + 3.72	Y = 0 63 P + 2.60
K	Y = 2.58 K + 8.74	Y = — 1.45 K + 2.64	Y = 5.00** K + 3.50	Y = 1.29 K + 2.26
Ca	Y = 0.40 Ca + 8.81	Y = —0.09 Ca + 2.48	Y = 1.00 Ca + 3.02	Y = 0.20 Ca + 2.30
Mg	Y = 0.83 Mg + 8.84	Y = —0.43 Mg + 2.57	Y = 1.09**Mg + 3.97	Y = 0.25 Mg + 2.38
pH	Y = —0.10pH + 8.65	Y = —0.64pH + 4.89	Y = 0.13 pH + 4.00	Y = —0.52 pH + 5.34
Organic-matter (t) carbon	Y = 0.20 t + 8.50	Y = 0.03 t + 2.48	Y = —0.17 t + 2.99	Y = 0 12 t + 3.24

* Correlation coefficient (r) was significant at 95% (T - test).

TABLE 2: REGRESSIONS OF COFFEE YIELD (Y) ON SOIL CHEMICAL FACTORS.

Soil Factor	Dependent Factor (Yield)			
	Total Yield	First Harvest	Second Harvest	Third Harvest
N	Y = 8.60 N + 8.30	Y = 3.81 N + 3.15	Y = 5.16 N + 3.20	Y = 0.70 N + 1.81
P	Y = 0.06 P + 8.60	Y = 0.04*P + 3.15	Y = 0.02 P + 3.50	Y = 0.003P + 1.90
K	Y = —9.56K + 8.12	Y = 1.40*K + 3.79	Y = —0.31**K + 4.04	Y = —0.64*K + 2.01
Ca	Y = 0.49Ca + 8.67	Y = —0.52Ca + 3.98	Y = 0.23Ca + 3.90	Y = —0.27Ca + 2.13
Mg	Y = —0.43Mg + 8.90	Y = —0.19Mg + 4.03	Y = —1.65Mg + 4.19	Y = —0.10Mg + 2.17
pH	Y = 2.38**pH — 3.60	Y = —0.44pH + 5.83	Y = —0.02pH + 3,68	Y = 0.18 pH + 0.92
Organic-carbon (t)	Y = 0.03t + 9.07	Y = —0.17 t + 2.99	Y = 0.06 t + 3.55	Y = 0.32 t + 1.18

* Correlation coefficient (r) was significant at 95% (T — test).

TABLE 3: EFFECT OF SOIL N AND P ON COFFEE BERRY YIELD (Kg/12 TREES)

Mean Soil N (%)	Number of Plots	Mean Berry Yield	Mean Soil P (ppm)	Number of Plots	Mean Berry Yield
0.07	4	34. 7	4.2	7	36.5
0.08	6	41. 1	5.4	4	41.2
0.09	6	42. 2	6.6	4	39.0
0.10	7	40. 6	7.9	5	42.0
0.11	3	40.0	10.8	8	40.0
0.16	6	42.0	19.0	4	42.2

TABLE 4 EFFECT OF CONCENTRATION OF BASE (K + Ca + Mg) ELEMENTS (BASE CONC.) AND pH ON COFFEE BERRY YIELD (Kg/12 Trees)

Mean BASE CONC. (m.e/100g)	Number of Plots	Mean Berry Yield	Mean pH	Number of Plots	Mean Berry Yield
0.81	4	30.3	5.1	7	29.5
1.17	4	43.0	5.2	5	43.2
1.30	4	39.6	5.4	8	39.4
1 40	8	41.0	5.6	4	41.7
1.58	8	40.0	5.8	4	42.1
2.48	4	38.8	5.9	4	38.8

TABLE 5 EFFECT OF SOIL ORGANIC CARBON CONTENT (t) ON COFFEE BERRY YIELD (Kg/12/Trees)

Mean t (%)	Number of Plots	Mean Berry Yield
1.5	3	37.0
2.3	3	45.4
3.0	8	40.4
4.1	7	40.4
4.8	6	43.9
6.6	3	37.3

Effects of Soil N and P:

Tables 1 and 2 suggest that coffee yield responded more consistently and positively to soil N and P than to any of the major or secondary nutrients studied. Greater number of significant correlations with coffee berry yield were recorded when soil N and P were considered. Table 3 shows that increases in soil N and P above their least values effect increases in coffee yield, although the relationship was not linear. Various field and laboratory investigations performed on arabica coffee in East Africa and Papua New Guinea (Jones et. al., 1961; Hart, 1969; Aduayi, 1970; 1973; Kimeu and Kabaara 1975) have also indicated that coffee was most responsive to N and P among all major and secondary nutrients. This observation is also consistent with the fact that up till 1972, deficiency symptoms of N and P respectively were the ones so far recorded in Western Nigeria (Omotosho and Olojola, 1972).

Higher correlations were observed between coffee berry yield and soil N or P when the 32 treatment plots of the first replicate were considered than when the plots of the second replicate were considered. Higher mean pH were recorded for the first set of 32 plots than for the second set. The mean (for 64 samples) pH for the first set of plots was 5.8, while the value for the second set of plots was 5.0. Increased pH has been related to increased mineralization of organic N and P and their increased uptake by crop (Agarwai et. al., 1972; Enwezor, 1978). The higher mean pH recorded for the first set of plots could also have caused increased availability of base elements such as K and Mg. Table 1 (based on the first set of plots) shows significant positive correlations between yield and K and Mg, whereas Table 2 which is based on the second set shows negative correlations.

Effect of Base Elements:

Unlike in case of N and P, negative correlations were mostly recorded between coffee yield and soil content of exchangeable K, Ca and Mg. There is no consistent trend between concentrations of base elements and values of yield as shown in Table 4. Wessel (1971) who discussed soil K values in Western Nigeria in relation to the dry matter yield of mature cocoa trees also recorded significantly negative correlations of between 0.60 and 0.80.

Measurement of the content of exchangeable bases were found (Hart and Southern, 1969) not to give precise guidance as to whether the soil was able to provide those nutrients in adequate amounts to arabica coffee in Papua New Guinea. Hart and Southern observed no significant correlation between leaf and soil contents of N, K and Mg. Secondly the soil acidity and low Mg/K ratio observed in this study might have been unfavourable for adequate uptake of base elements. The coffee plots considered had most of their pH values less than 5.5. While pH of between 5.5 and 6.5 most favour coffee growth (Mehlich, 1968); Hart, 1969; Aduayi, 1971). The acidic soils of Brazil (NAS, 1972) with pH mostly lower than 5.5 was discovered to have an appreciable Al content of between 0.1 and 3.8 m.e./100g soil. The root distribution and Ca uptake for example were observed to be restricted when soil Al was greater than 0.02 m.e./100g. On the basis of these observations it could be suggested that the increased concentrations of base elements in this case might partly be due to the restriction of their uptake by coffee crop. Lombin and Fayemi (1978) who investigated the prospects of Mg deficiency in soils of Western Nigeria also observed that Mg uptake was lower when Mg/K ratios was below 2.

They suggested that the yield of maize would be adversely affected if Mg/K ratio falls bellow 0.8 or when the exchangeable Mg is below 0.4 m.e./100g. Among the 64 coffee plots being dealt with, only 16 plots had Mg level greater than or equal to 0.4 m.e./100g. The mean Mg/K ratio and Mg concentration were 2.3 and 0.43 m.e./100g respectively for the first set of plots, while they were 1.5 and 0.30 for the second set. On this basis also it is very likely that increased K or Mg content in the coffee soil would have resulted in decreased uptake of these elements by the coffee crop.

Thirdly the excessive use of NP fertilizers compared with K fertilizers or non-use of fertilizers containing Mg or Ca could have been an influential factor. This factor could have caused positive *r* values recorded when vield was evaluated in connection with soil N or P and negative or insignificant correlations recorded when base elements were evaluated with yield in the case of the second set of plots. Chew et. al. (1976) reported that N application increased available N in soil and thus N content of Napier grass in Malaysia. Thornton (1964) and Jones and Stockinger (1976) have also related available Mg, Ca, N, P and K with the amounts applied in fertilizer. Soil nutrients derived in concentrated forms from fertilizer are expected to be more available to the crop than native and partly fixed nutrients.

Coffee Yield and pH:

The pH values recorded for the Robusta coffee plots varied mainly between 4.7 and 6.1. Both positive and negative (correlation coefficient) values were recorded between pH (within this range) and coffee yield. As in case of base elements, trend in pH values do not impose consistent trend on yield data (Table 4). This infers that within this pH range, pH value might not matter considerably in relation to berry yield. And this is consistent with the earlier suggestions (Mehlich, 1968; Hart, 1969) that coffee thrives on soils with slightly acidic to neutral reaction. The trend in yield data recorded when pH was considered followed the trend when base element(s) concentration was considered. (Table 4). This is also consistent with the fact that pH is often synonymous with soil content of base elements (Mehlich, 1968).

Influence of Organic Matter:

Soil organic matter content, though have been connected with increased availability of soil nutrients (Ogunwale and Ashaye, 1975), was rarely correlated directly with the yield of tree crops. Table 3 shows increases in coffee yield due to increases in soil organic carbon from less than 2% to values between 2.3 to 4.8%. The highest yield was however recorded at 2.3% mean organic carbon content. In the Wynaad district of India (Iyengar, 1977) coffee soils with organic matter content of between 2 to 5% are considered fertile. However, direct correlation between total yield and soil organic matter was insignificant through positive (Tables 1 and 2).

Conclusion

It seems erroneous to base the availability of base elements, or yield of tree crop like coffee on the concentration of base elements in soil. Higher soil concentration of base elements might not reflect on coffee yield. However the productivity of a coffee plantation could directly be related with the organic matter, N and P contents of soil. It was observed that there was yield response to 90 Kg/ha/annum K. Findings based on this paper therefore corroborate the impression that application of fertilizers containing N, P and K on coffee plantations would be necessary to increase coffee yield.

Acknowledgements

This investigation forms part of the research programme of the Cocoa Research Institute of Nigeria (CRIN). The permission to publish this paper was granted by the Director. The Author acknowledges the assistance received from Mr. S.A. Adisa and his staff at the CRIN Central Laboratory and the field support provided by Mr. S.A. Oyeranmi. The field treatments were mainly initiated by Dr. T.I. Omotosho.

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