SOIL CHEMICAL PROPERTIES UNDER PRIMARY FOREST AND COFFEE IN THE KUTUBU AREA OF PAPUA NEW GUINEA

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ABSTRACT

This paper presents some preliminary investigations in the topsoil (0-0.2 m) chemical properties under primary forest and arabica coffee in the Kutubu area (Southern Highlands). The coffee gardens were established from primary forest about 3 years prior to the soil sampling in 1996. Most of the arabica coffee in the Kutubu area is not fertilized and overall the coffee is growing poorly. Both soils under forest and coffee had moderate to low fertility levels with strongly to moderately acid soil reactions (pH H_2O: 4.7 to 5.4). There was little difference in the chemical fertility between the topsoils under forest and coffee although exchangeable calcium and base saturation were significantly higher under coffee possibly as a result of the ash addition after the forest was slashed and burned. All soils had extremely low levels of available phosphorus but high total P-levels. Nutrient deficiencies, in particular P and micronutrients, may be factors explaining the poor coffee performance in the Kutubu area but additional research is required.

Keywords: *primary forest, soil fertility changes, arabica coffee, phosphorus, Lake Kutubu area*

INTRODUCTION

The first arabica coffee (*Coffea arabica*) plantation in Papua New Guinea was probably established near Wau in 1928. In 1937, arabica coffee was planted on the Highlands Agricultural Experimental Station at Aiyura and from there coffee was planted throughout the highlands provinces (Harding *et al.* 1986). Coffee production rose from 42,000 bags green beans (60 kg/bag) in 1960/61 to 1,100,000 bags in 1993/94 (Anon 1994). Most of the coffee in Papua New Guinea is produced by smallholders and it is the major source of income for one-third of the population (Harding *et al.* 1984).

Besides having a well established coffee industry, Papua New Guinea has vast areas of primary forests which cover about 80% of the country. Annually about 113,000 ha of primary forest are cleared for logging, mining, agricultural projects and shifting cultivation (FAO 1995). A large part of the deforestation is required for the expansion of agricultural land to feed the rapidly growing population, and the planting of cash crops such as arabica coffee. In the Eastern and Western Highlands there are vast areas where coffee is a dominant crop but in the Southern Highlands relatively little coffee is grown despite various attempts to encourage coffee growing in this province (Harding *et al.* 1986). In recent years, however, a large number of farmers have planted arabica coffee in the area around Lake Kutubu. Most of these new plantings were made after cutting and burning the primary forest.

There is a fair body of literature on the changes which take place in the soil when forest is cleared and crops are planted, and excellent summaries can be found in Nye and Greenland (1960), Sanchez (1976), Lal (1986) and Lal *et al.* (1986). The burning of the vegetation and the production of ash increases the soil pH and the levels of exchangeable calcium and magnesium which is particularly beneficial in acid soils. Also, the available phosphorus and potassium levels increase after burning. The organic matter and soil nitrogen contents increase slightly after burning because of the addition of the partially burned vegetation. All nutrients decrease gradually with cultivation due to a combination of losses and crop uptake and removal.

For the Kutubu area where coffee cultivation is expanding, virtually nothing is known on changes in soil

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chemical properties when forest is cleared. The objectives of the research presented in this paper were (i) to investigate differences in soil chemical properties between primary forest and coffee gardens, and (ii) to identify possible soil chemical constraints affecting coffee production in the Kutubu area.

MATERIALS & METHODS

The site

The soil samples were taken in the Foi area (6°23' S, 143°20' E), north of Lake Kutubu along the main Mendi-Kutubu road in the Southern Highlands of Papua New Guinea. Altitude of the sampled sites was approximately 900 m a.s.l. and in the classification of agro-climatic zones of Papua New Guinea by Gurnah (1992) the area around Lake Kutubu is Premontane Perhumid (Zone II). No detailed climatic data were available for the sampled sites but average rainfall at Lake Kutubu is about 4,500 mm yr^{-1} with a mean annual temperature of 23.1°C (CSIRO 1965).

Most of the soils north of Lake Kutubu have been developed from volcanic deposits on limestone and they are generally acid with low base saturation. Similar soils have been described by Harding (1984) at Ialibu (profile no. PH001-R400) where a strongly acid soil with high aluminium saturation in the subsoil was formed on limestone. The soil at Ialibu was classified as an Andic Humitropept which is equivalent to Haplustands in the more recent Soil Taxonomy version (Soil Survey Staff 1994) or Umbric Andosol in the FAO-Unesco classification (1988).

Soil sampling and analysis

Soil samples were collected under primary forest and coffee gardens in March 1996. Sampling sites were at Kunufalu, Aliago, Iputaba, Tanuga, Gesege turn off, Inu Junction, Yaipa, and Tubaga. The coffee gardens were established from primary forest in 1993 and some were intercropped with food crops during the first few seasons. None of the coffee gardens had been fertilized. Sampling procedures were the same in the forest and coffee gardens, as follows: The mulch layer (O-horizon) was removed from the soil whereafter a mini-pit of 0.2 m depth was dug using a spade. From these pits about 0.5 kg soil was taken from the 0-0.2 m soil horizon. In total, 10 such pits were dug in an area of 50 m by 50 m. The soil was bulked and a subsample of about 2 kg was taken to the National Analysis Laboratory in Lae for analysis. Soils were air dried, ground and passed through a 2 mm sieve. For total P determinations the samples were ground to pass through 150 mesh.

Soil samples were analysed at the National Analysis Laboratory in Lae following standard procedures as described in Page *et al.* (1982). The following methods were used: pH H_2O in 1:5 suspension of soil and water; pH KCl in a 1:5 soil and 1*M* KCl solution; electrical conductivity in a 1:5 suspension of soil and water; organic carbon by $K_2Cr_2O_7$ and H_2SO_4 oxidation; available P by NH_4F and HCl extraction (Bray I); total P by perchloric acid digestion; exchangeable cations Ca, Mg, K, Na and CEC after percolation with 1 *M* NH_4OAc followed by spectrophotometry (K, Na), AAS (Ca, Mg) and titration (CEC); and exchangeable acidity (H, Al) extraction by 1 *M* KCl. In addition, pH-NaF was measured in a 1:50 soil and 1*M* NaF solution at the laboratories of the Department of Agriculture. The effective cation exchange capacity (ECEC) was calculated as the sum of exchangeable calcium, magnesium, potassium, sodium and exchangeable acidity (hydrogen and aluminium).

RESULTS

At Inu Junction and Aliago, soil samples were taken in primary forest and an adjoining coffee garden. The distance between the two samplings was less than 100 m. At Inu Junction, the soil sample was taken in a forest with large trees and undergrowth of ferns. In the adjoining coffee garden, the forest was cleared in 1993 and coffee was planted intercropped with sweet potato (*Ipomoea batatas*), sugar cane (*Saccharum* sp.) and banana (*Musa* sp.). The coffee showed stunted growth in this garden.

Differences in soil chemical properties between the forest and the coffee garden were marginal (Table 1). Both soils were strongly acid with moderate amounts of organic carbon and extremely low levels of available phosphorus. The soil under coffee had, however, slightly higher levels of exchangeable bases and CEC, and as a result, a lower aluminium saturation. The pH-NaF is close to 9.4 in both soils.

At the Aliago site, the forest consisted of large trees including pandanus species and ferns undergrowth. In

Table 1. **Soil chemical properties (0-20 cm) of paired samples under primary forest and coffee in the Kutubu Area**

	Inu Junction		Aliago	
	primary forest	coffee garden	primary forest	coffee garden
pH water (1:5)	4.8	4.9	4.7	4.9
pH KCl (1:5)	4.7	4.6	4.0	4.2
pH NaF (1:50)	9.2	9.0	8.8	8.8
EC (μS cm^{-1})	24	59	82	94
organic C (g kg^{-1})	29	38	38	38
Total N (g kg^{-1})	2.7	2.6	3.5	4.0
C/N	11	15	11	10
Available P (mg kg^{-1})	1	traces	1	2
Total P (mg kg^{-1})	860	1100	1300	1100
CEC ($mmol_c$ kg^{-1})	68	98	146	211
Exchangeable Ca ($mmol_c$ kg^{-1})	5	17	18	77
Exchangeable Mg ($mmol_c$ kg^{-1})	4	5	8	24
Exchangeable K ($mmol_c$ kg^{-1})	0.7	1.2	1.8	4.5
Base saturation (%)	15	24	19	50
Exchangeable Al ($mmol_c$ kg^{-1})	1.2	1.6	17.9	5.9
Al saturation (%)[a]	15	8	42	7

Table 2. **Soil chemical properties (0-20 cm) under primary forest and coffee in the Kutubu Area (values reported are the arithmetic mean ±1 SD)**

	primary forest (n=5)	coffee gardens (n=5)	difference
pH water (1:5)	5.0± 0.22	5.0± 0.24	n.s.
pH KCl (1:5)	4.4± 0.26	4.5± 0.24	n.s.
pH NaF (1:50)	9.1± 0.5	8.9± 0.3	n.s.
EC (μS cm^{-1})	52± 28	69± 24	n.s.
organic C (g kg^{-1})	3.9± 0.86	3.9± 0.14	n.s.
Total N (g kg^{-1})	3.0± 0.52	3.2± 0.53	n.s.
C/N	13± 2.0	12.6± 1.8	n.s.
Available P (mg kg^{-1})	0.6± 0.5	1.0± 1.0	n.s.
Total P (mg kg^{-1})	1152± 220	1116± 229	n.s.
CEC ($mmol_c$ kg^{-1})	107± 29	142± 48	n.s.
Exchangeable Ca ($mmol_c$ kg^{-1})	10± 6	41± 28	P=0.05
Exchangeable Mg ($mmol_c$ kg^{-1})	5± 3	11± 10	n.s.
Exchangeable K ($mmol_c$ kg^{-1})	1.2± 0.4	2.1± 1.5	n.s.
Base saturation (%)	15± 4	36± 18	P=0.04
Exchangeable Al ($mmol_c$ kg^{-1})	6.2± 6.7	6.5± 6.2	n.s.
Al saturation (%)[a]	28 ±13	17±17	n.s.

[a] Aluminium saturation was calculated as: Al/ECEC = Al/ (Ca, Mg, K, Na, H, Al)*100

1993, some of the forest was cleared for growing coffee which performed poorly in 1996. As was found at Inu Junction, both soils had a low pH, extremely low available P and moderate amounts of organic C (Table 1). Levels of exchangeable bases as well as the CEC were higher under coffee than under primary forest. Under coffee, aluminium saturation of the ECEC (Effective Cation Exchange Capacity) was 7% whereas this was 42% under primary forest.

In total five soil samples were taken in coffee gardens and five under primary forest. Mean values of the soil chemical data for both land-use systems are given in table 2. Variation in soil chemical parameters was considerable as can be seen from the standard deviations. Despite this variation both exchangeable calcium and base saturation were significantly higher in the soils under coffee but no significant differences were found in other soil chemical properties.

A striking feature of both the soils under forest and coffee is the extremely low available phosphorus level (≤ 2 mg P kg^{-1} soil). Total levels of phosphorus ranged from 860 to 1600 mg kg^{-1}. Although the data are only few, total P tended to increase at higher organic C contents.

Some soils had a moderately high pH in NaF which is generally an indication of the presence of allophane and aluminium. The hydroxyl groups of the various components in soils enriched with volcanic deposits containing active aluminium, react strongly with fluoride ions, the so-called ligand exchange (Mizota & van Reeuwijk 1989). The ligand exchange between F^- and OH^- result in a rapid increase in pH (Uehara & Ikawa 1985). This was found in some of the soils of the Kutubu area, and 2 of the 10 sampled soils had a pH NaF ³ 9.4.

DISCUSSION

Despite variation in the soil analytical data both soils under coffee and primary forest had a moderate to low fertility with moderate levels of aluminium saturation. Soils under tropical forest are commonly, but not always, acid with a low fertility (Wild 1989). A large part of the soil fertility is found in the above and below ground biomass i.e. the forest. For example Grubb & Edwards (1982) found in a lower montane forest in the Eastern Highlands of Papua New Guinea 835 kg N ha^{-1}, 49 kg P ha^{-1} and 699 kg K ha^{-1}. These nutrients become partly available following the slashing and burning of the forest vegetation. Under coffee, levels of exchangeable calcium and the base saturation was significantly higher. This is likely to be due to the addition of ashes containing several salts, including carbonates, hydroxides and silicates, which raise the soil pH and levels of exchangeable bases (Wild 1989). As the slashing and burning of the forest vegetation had taken place 3 years prior to the soil sampling, the effect of the ash addition had almost disappeared due to losses and crop removal.

Most of the P in the Kutubu soils under primary forest and coffee was not extractable by NH_4F and HCl and levels of available phosphorus were extremely low (≤ 2 mg kg^{-1}). Total phosphorus was, however, between 860 and 1600 mg kg^{-1} which is high to very high (Landon 1991). The soils have a high P retention capacity which is common in soils of the Southern Highlands (Radcliffe & Gillman 1985). Indeed the pH-NaF of the soils was between 8.5 and 9.8 which may be a clear indication that the soils are derived from volcanic ash. Although most of the phosphorus may be fixed in inorganic compounds, some phosphorus is in the organic form which is likely to be an important source of plant-available phosphorus as was also found in other tropical soils with cropping systems receiving little or no fertilizers (Beck & Sanchez 1994).

At all sites it was observed that the coffee was growing poorly. The pH of the soils is below optimal for coffee, which is generally believed to be between 5.2 and 6.0. It should be noted, however, that some arabica coffee is successfully grown in soils with pH 4.6 (Wrigley 1988). The organic C content is low but total levels of N are generally sufficient. Levels of exchangeable bases are moderate and also the aluminium saturation is probably not limiting arabica coffee production since it can tolerate aluminium saturation up to 80% (Sanchez 1976). Micronutrient deficiencies, notably boron, are widespread throughout the soils under coffee in the highlands of Papua New Guinea (Harding *et al.* 1986) and may perhaps explain why the coffee is growing so poorly in this part of the Southern Highlands. Other explanations may be unfavourable soil physical properties (e.g. limited rooting depth, impeded drainage) and the occurrence of pests and diseases but data to support this are not available.

It can be concluded that there were only marginal differences in soil fertility between primary forest and coffee gardens in the Kutubu area. Although several factors may be limiting high yielding coffee cultivation, levels of phosphorus and micronutrients are likely to be suboptimal for arabica coffee, particularly when the coffee is young.

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