NUTRITIONAL ASSESSMENT OF STEEPLY SLOPING SOILS FROM AIYURA IN THE EASTERN HIGHLANDS OF PAPUA NEW GUINEA

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ABSTRACT

Prior to commencing long-term soil loss studies at the Highlands Agricultural Experiment Station at Aiyura in the Eastern Highlands of Papua New Guinea, the nutritional status of soils from the experimental site was assessed by soil analysis and nutrient omission pot trial. Two soils were assessed; the first, an Orthoxic Tropudult, was located on long convex slopes with northerly aspect and the second, an Umbric Tropaquult, occupied a hummocky microtopography with short slopes and a southerly aspect. Soil tests suggested both surface (0 to 0.15 m depth) soils were strongly acid (pH 5.0 to 5.4 in 1:5 soil/water suspension), contained allophane and active Al (pH 7.9 to 8.2 in 1:50 soil/NaF solution), and were strongly P fixing (P retention >70%) with low P availability (< 4 mg kg^{-1} Olsen-P). With maize (Zea mays L.) as the test plant, short duration (35 day) omission pot trials confirmed ($P < 0.05$) these soils were P and S deficient. Plants suffering P and S deficiency were 8 to 24% shorter, and amounts of both fresh and dry matter produced were 15 to 43% lower, and S deficient plants were distinctly yellower in colour. No deficiency was apparent with omission of B, Ca, Cu, Fe, K, Mg, Mn, Mo, N, Ni or Zn. Also, addition of lime had little effect.

Key Words: *Soil test, Nutrient omission pot trial, Maize, Phosphorus deficiency, Sulfur deficiency*

INTRODUCTION

Within the International Board for Soil Research and Management (IBSRAM) Project "*PACIFIC LAND* Management of Sloping Lands in the Pacific", a series of research plots have been established on the Highlands Agricultural Experiment Station (HAES) at Aiyura in the Eastern Highlands of Papua New Guinea (Wayi and Konabe 1993). The primary objective of the IBSRAM sloping lands project in PNG is twofold: (1) to quantify soil loss and monitor fertility decline under traditional compared with improved farming practices, and (2) to develop an improved farming practice that will reduce soil loss, improve soil fertility and extend the productive use of these sloping lands (Wayi and Konabe 1993). Sweet potato (*Ipomoea batatas*) is the traditional crop. Fundamental to these objectives is the need to identify soil nutritional deficiencies as these may initially limit this crop's growth and subsequently, either singly or in combination with soil loss, determine changes in its productivity over time. The project is expected to continue for a period of 5 to 10 years.

In order to develop a sustainable and economic crop and soil management program, the nutritional status of the soil must firstly be diagnosed. Analysis of soil provides information in advance of crop establishment as to whether or not a nutrient is likely to be limiting for a particular crop, but these data are only as good as the soil test's calibration against a measured yield response. In fertility studies, it is often advisable to also look at the soil from the plant's point of view, especially if analytical and financial resources are restricted. Nutrient omission pot trials provide a cost-effective method of diagnosing nutritional limitations in soils from the plant's perspective (C.J. Asher and N.J. Grundon, pers. commun.), especially in the tropics (Sanchez 1976). For convenience, a standard test plant (e.g. maize, *Zea mays* L.) with well characterised deficiency symptoms (e.g. Grundon 1987) is often used. Fertiliser trials using the desired

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combination of crop and soil can follow to further quantify nutritional limitations.

The objectives of this assessment were to: (1) diagnose nutritional limitations of surface (0 to 0.15 m depth) soils from the IBSRAM project site by omission pot trial; and (2) suggest directions for future nutritional studies by considering how existing disorders may interact with soil loss to determine the sustainable cropping potential of these soils.

METHODS

Experimental Site

The IBSRAM project site is located at HAES (6° 19' S, 145° 55' E) at an altitude of 1700 m in the Aiyura Valley near Kainantu, Eastern Highlands Province, PNG. The Aiyura Valley is characterised by broad valleys and strongly rolling (10 to 20° slopes) topography, interrupted by occasional steeply dissected conical hills. Regional geological maps (1:250 000) indicate HAES is underlain by the Akuna intrusive complex of Lower Miocene age, and field examination of boulders embedded in the soil matrix suggests a dominant lithology of porphyritic dolerite. Although a draft mantle of volcanic ash overlies the Kainantu District, volcanic ash was not observed or mapped on the site.

From aerial photographs (flown in 1986 at 1:25,000), a 2 ha area of uniform and stable slope (both north- and south-facing aspects) was selected, and a systematic grid (12.5 m by 10 m) established for soil and contour survey. Soil morphology data to 1.2 m were described from auger cores. Additional surface soil morphology data were obtained from a series of mini-pits (0.3 m by 0.3 m by 0.3 m). Soils were classified according to Soil Taxonomy (Soil Survey Staff 1990). A contour map with a 1 m contour interval was also compiled. From these surveys, separate experimental areas on north- and south-facing slopes were identified. Experimental plots were selected; eight within the north-facing site and twelve within the south-facing site (Wayi and Konabe 1993). Construction of plots to measure run off and soil loss commenced in October 1991 (Wayi and Konabe 1993). Separate surface (0 to 0.15 m) samples representing north- and south-facing soils were collected from within the experimental area. Each sample, a composite of six 80 kg subsamples, was air dried, sieved < 5 mm and stored in a sealed plastic container prior to assessment by nutrient omission pot trial. A 2 kg subsample of each soil was retained for analytical characterisation.

Soil analysis

Soils were dried at 4°C and ground < 2 mm before analysis. Soil analytical procedures followed those outlined in Rayment and Higginson (1992). Soil pH and electrical conductivity (EC) were determined on a 1:5 soil to water suspension at 25°C. Soil pH was also determined on a 1:50 soil to saturated (approximately 1M) NaF solution. Organic C was determined by Walkley and Black wet oxidation with titrimetric finish. Total N was determined following Kjeldahl digestion. Native P availability was determined following extraction in 0.5M $NaHCO_3$ at pH 8.5 for 30 min. (Olsen-P), and P in solution was determined colorimetrically by the molybdenum blue procedure. Phosphorus retention was also estimated colorimetrically following a standard addition of KH_2PO_4. Exchangeable Ca, Mg, Na and K were leached from the soil with 1 M NH_4OAc at pH 7 without pretreatment for soluble salts. After removal of excess NH_4OAc, the soil was releached with 1 M NaCl and the leachate retained for determination of CEC. Exchangeable cations were determined by atomic adsorption spectrometry, and CEC by the Kjeldahl method. Exchangeable acidity (hydrogen and aluminium) was estimated following equilibration with 1M KCl by titration with standard NaOH. Effective CEC (ECEC) was estimated as the sum of total exchange cations. Acid saturation was then estimated as [exchangeable acidity x 100 / (total exch. cations)]. Particle size analysis was determined after Bruce and Rayment (1982). Air dry and field capacity gravimetric water contents were also determined; air dry water content after drying prepared soil at 105°C for 48 h, and field capacity water content after allowing saturated soil to drain freely for 24 h and then drying at 105°C for 48 h.

Nutrient Omission Pot Trial

Diagnosis of nutritional limitations to plant growth by omission pot trial followed the procedure of

Asher and Grundon (unpublished report[4]) a procedure similar to that of Middleton and Toxopeus (1973). Pot trials utilised shadehouse and laboratory facilities of the Department of Agriculture, PNG University of Technology, Lae. North- and south-facing soils were assessed separately.

In these omission trials, the control treatment was the complete nutrient or ALL treatment. Omission treatments were then arranged to omit or lack only one element (e.g. ALL-N, ALL-P, ALL-K). In each trial, the ALL treatment was replicated 12 times and omission treatments were replicated four times with treatments completely randomised with no blocking. Experimental units were 166 mm PVC pots containing 2.4 kg air dry soil. For the ALL treatment, nutrients were applied separately to the soil in solution form at the following rates (kg ha^{-1}): 100 N as NH_4NO_3; 80 P as $NaH_2PO_4.2H_2O$; 80 K as KCl; 35 Ca as $CaCl_2$; 30 Mg as $MgCl_2.2H_2O$; 25 S as Na_2SO_4; 5 Fe as sulfate-free Fe EDTA; 2 B as H_3BO_3; 4 Zn as $ZnCl_2$; 5 Mn as $MnCl_2.4H_2O$; 3 Cu as $CuCl_2.2H_2O$; 0.4 Mo as $(NH_4)_6Mo_7O_{24}.4H_2O$; and 0.1 Ni as $NiCl_2.6H_2O$. Omission treatments were arranged identically, except to omit or lack only one element. An additional ALL + Lime treatment was included with 5 t ha^{-1} lime (as $CaCO_3$).

Soils were then wet to field capacity and sealed. After a 7 d equilibration period, six germinated maize (cv. Pioneer 6875) seeds with radical length 5 to 15 mm were planted in each pot. These were thinned to four uniform plants per pot after emergence. Pots were watered daily to field capacity with distilled water. Plants were grown until well-defined growth responses (see e.g. Grundon 1987) were produced. Individual plant heights were recorded prior to harvest 35 d after sowing (DAS), and plants tops harvested at ground level. Fresh weights were immediately recorded. Plant tops were then dried (70°C for 48h) and reweighed.

Plant height, top fresh weight and top dry weight data were expressed relative to the mean of the ALL (=100%) treatment. Since the experimental design was unbalanced, omitted nutrient effects were determined by two-sample t-test with each omission treatment compared in turn with the ALL; in total, 14 individual sets of data were analysed. Significant departures from the ALL treatment were determined at $P < 0.05$.

RESULTS

Soil morphology

Soils were deep (> 1.4 m) with rooting depths > 1.0 m, and were imperfectly to moderately well drained (Wayi and Konabe 1993). Earthworm activity was common in the A and upper B horizons. Surface soils, typically black (10YR 2/1) to very dark greyish-brown (10YR 3/2) loams to clay loams, were 0.1 to 0.4 m thick and weak to moderate, fine to medium crumbs to subangular blocky structure. There was a smooth clear boundary into gravelly loam to clay loam B horizons that were either strongly gleyed or contained a high percentage of coarse fragments dominated by irregularly shaped iron and manganese concretions up to 20 mm in diameter. Subsoil structure was weak to moderate, medium to coarse subangular blocky. Gleyed horizons became greyer (5Y 6/1 to 7/2) and concretionary horizons yellower (10YR 5/6 to 5/8) with depth. The B horizons, usually 0.9 to 1.2 m thick, overlay a mottled yellowish brown, silty clay loam B-C horizon with moderate coarse columnar structure.

Morphological data suggested local microrelief has influenced soil formation to a great extent. Generally, soils with long, north-facing convex slopes are moderately well drained, have a concretionary B horizon and have been classified as fine clayey mixed isothermic Orthoxic Tropudults. Their counterparts on south-facing slopes, however, occupy a hummocky microtopography with short slopes. Typically, these soils are imperfectly drained, have a strongly gleyed (reduced) B horizon in their depressions, and have been classified as fine clayey mixed isothermic Umbric Tropaquults (Wayi and Konabe 1993).

[4] ASHER, C.J. and GRUNDON, N.J. Diagnosis of nutritional limitations to plant growth by nutrient omission pot trial. Department of Agriculture, The University of Queensland, Brisbane Qld 4072, Australia.

Table 1. **Surface (0 to 0.15 m) soil properties (with standard error) of Orthoxic Tropudult (north-facing) and Umbric Tropaquult (south-facing) soils used in nutrient omission pot trials from Highlands Agricultural Experiment Station, Aiyura.**

Property	Orthoxic Tropudult	Umbric Tropaquult
pH (1:5 soil/water)	5.4 (0.2)	5.0 (0.2)
pH (1:50 soil/NaF) [1]	7.9	8.2
EC (1.5; dS m^{-1})	0.06 (0.01)	0.06 (0.01)
Organic C (%)	4.7 (0.01)	5.2 (0.6)
Total N (%)	0.41 (0.05)	0.40 (0.04)
Extratable P (mg kg^{-1})	3.8 (0.4)	3.4 (0.3)
P retention (%)	73 (3)	71 (6)
CEC (cmol (+) kg^{-1})	22 (3)	19 (2)
Exch. Ca (cmol (+) kg^{-1})	5.3 (1.0)	2.8 (0.5)
Exch. Mg (cmol (+) kg^{-1})	2.2 (0.3)	1.5 (0.3)
Exch. K (cmol (+) kg^{-1})	0.65 (0.11)	0.34 (0.03)
Exch. Na (cmol (+) kg^{-1})	0.02 (0.01)	0.02 (0.01)
Exch. Acidity (cmol (+) kg^{-1}) [2]	1.2	0.9
Gravimetric soil water: [2]		
Air dry (40°C, %)	16	16
Field capacity (%)	42	44
Particle size analysis: [2]		
Sand (0.2-2 mm, %)	39 (8)	31 (5)
Silt (0.002-0.02 mm, %)	27 (2)	32 (2)
Clay (< 0.002 mm, %)	34 (9)	38 (6)

[1] analysis of soil survey and site characterisation samples only
[2] analysis of soil collected for pot experiment only

Soil analysis

Orthoxic Tropudult and Umbric Tropaquult surface soils had similar properties (Table 1). Interpretive indices follow Bruce and Rayment (1982) and Landon (1991). Both soils were strongly acid (pH 5.0 to 5.4, 1:5 soil/water) with low levels of soluble salts. With pH (1:50 soil/NaF) levels of 7.9 to 8.2, both soils were also likely to be derived from volcanic ash suggesting the presence of allophane and active Al. Organic C and total N levels were medium to high. Extractable P levels were low (< 4 mg kg^{-1} Olsen-P) and soils appeared strongly P fixing with P retention values >70%. Levels of CEC and exchangeable Ca, Mg and K were medium to high whereas levels of exchangeable Na were low. Effective CEC levels were low (<10 cmol (+) kg^{-1}). Base saturation levels were medium at 25 to 37%. Exchangeable acidity levels were <1.2 cmol (+) kg^{-1}, with low acid saturation levels of 13 to 16%, suggesting that only Al-sensitive crops are likely to affected.

In these very strongly acid soils, problems due to low P availability are likely and crop responses to fertiliser P are probable. Lime may need to be

Table 2. **Plant height, top fresh weight and top dry weight (expressed relative to the ALL treatment = 100%) data for a nutrient omission pot trial conducted on an Orthoxic Tropudult (north-facing) soil from Highlands Agricultural Experiment Station. Aiyura.**

TREATMENT	Plant data (with standard error) expressed relative to ALL treatment (=100%)		
	PLANT HEIGHT	FRESH WEIGHT	DRY WEIGHT
ALL	100 (0.8)	100 (3.9)	100 (4.2)
ALL + Lime	105 (1.6)	106 (4.3)	110 (5.0)
ALL-B	100 (2.5)	93 (7.2)	95 (4.8)
ALL-Ca	100 (1.8)	101 (8.2)	99 (7.6)
ALL-Cu	95 (2.3)	88 (7.0)	88 (7.1)
ALL-Fe	95 (3.4)	97 (8.8)	96 97.0)
ALL-K	103 (2.9)	100 (6.8)	102 (7.6)
ALL-Mg	100 (1.7)	94 (6.3)	95 (6.6)
ALL-Mn	100 (2.1)	102 (8.0)	101 (8.2)
ALL-Mo	98 (1.6)	94 (9.0)	98 (8.6)
ALL-N	97 (1.4)	99 (3.2)	101 (2.2)
ALL-Ni	100 (0.9)	105 (6.7)	109 (6.0)
ALL-P	89 (0.3)*	72 (3.2)*	81 (2.0)*
ALL-S	92 (2.0)*	82 (3.9)*	85 (3.3)*
ALL-Zn	96 (2.5)	102 (8.6)	107 (7.5)

* values in the same column are different (P < 0.05) from the ALL treatment.

applied to raise pH levels above 5.5, and a lime requirement of some 5 t ha^{-1} to a depth of 0.15 m was suggested. However, liming these ash-derived soils may induce micro-nutrient (e.g. Fe, Mn, Cu or Zn) deficiency or cation imbalance (e.g. Ca:K ratio) due to low ECEC levels. Omission pot trials should resolve this issue.

Nutrient omission pot trials

Similar maize growth responses to omission treatments were observed in Orthoxic Tropudult and Umbric Tropaquult soils. From ca. 17 DAS, plants in ALL-P pots were visibly smaller than those of the ALL. There were no distinct symptoms other than a mild purple discolouration of the leaf sheaths similar to that suggested by Grundon (1987). From the same time, ALL-S plants were visibly smaller and distinctly chlorotic (Grundon 1987). This chlorosis uniformly affected the whole plant (i.e. young and old leaves and stems were yellow) with some reddening of stems and the tips of older leaves being necrotic. Other treatments including ALL+ Lime appeared similar to the ALL suggesting that lime (at 5 t ha^{-1}) did not induce any potential micro nutrient deficiency, or cation imbalance.

Orthoxic Tropudult. At harvest, plant heights ranged from 53 to 96 cm, top fresh weights from 29 to 55 g pot^{-1} and top dry weights from 2.32 to 4.26 g pot^{-1}, and variations in these parameters were highly inter-correlated (r values > 0.75, n = 66, P < 0.01). Mean values for the ALL treatment were: plant height 81 cm; fresh weight of tops 45 g pot^{-1} ; and dry weight of tops 3.33 g pot . Mean values for the omission treatments expressed relative to the ALL treatment (= 100 %) are given in Table 2. Reductions (P < 0.05) in plant height and fresh and dry weights of plant tops were observed for ALL-P and ALL-S. With omission of P, plants were 11%

Table 3. **Plant height, top fresh weight and top dry weight (expressed relative to the ALL treatment = 100%) data for a nutrient omission trial conducted on an Umbric Tropaquult (south-facing) soil from Highlands Agricultural Experiment Station, Aiyura.**

TREATMENT	Plant data (with standard error) expressed relative to ALL treatment (=100 %)		
	PLANT HEIGHT	FRESH WEIGHT	DRY WEIGHT
ALL	100 (0.7)	100 (2.5)	100 (2.6)
ALL + Lime	95 (1.9)	99 (8.1)	100 (7.4)
ALL-B	104 (3.4)	113 (3.6)	107 (3.2)
ALL-Ca	104 (4.0)	107 (4.7)	106 (5.6)
ALL-Cu	104 (2.4)	105 (6.1)	101 (5.8)
ALL-Fe	100 (4.5)	104 (9.7)	105 (10.5)
ALL-K	97 (3.2)	83 (8.6)	83 (9.0)
ALL-Mg	105 (3.4)	106 (3.1)	103 (3.5)
ALL-Mn	106 (1.9)	120 (7.9)	115 (8.8)
ALL-Mo	100 (3.2)	103 (8.7)	94 (5.7)
ALL-N	101 (4.6)	103 (10.5)	94 (9.8)
ALL-Ni	99 (3.3)	101 (9.1)	96 (8.0)
ALL-P	91 (1.6)*	65 (3.6)*	74 (4.4)*
ALL-S	76 (8.6)	57 (10.9)*	57 (10.0)*
ALL-Zn	101 (4.5)	96 (10.0)	93 (9.3)

* values in the same column are different ($P < 0.05$) from the ALL treatment.

shorter, top fresh weights 28% lower and top dry weights 19% lower than the ALL. With omission of S, plants were 8% shorter, top fresh weights 18% lower and top dry weights 15% lower than the ALL.

Umbric Tropudult. At harvest, plant heights ranged from 10 to 110 cm, top fresh weights from 12 to 59 g pot^{-1} and top dry weights from 1.33 to 5.42 g pot^{-1} and variations in these parameters were highly inter-correlated (r values > 0.87, n = 66, $P < 0.01$). Mean values for the ALL treatment were: plant height 83 cm; fresh weight of tops 45 g pot^{-1} ; and dry weight of tops 4.14 g pot^{-1}. Mean values for omission treatments expressed relative to the ALL treatment (= 100%) are given in Table 3. Reductions ($P < 0.05$) in plant height and fresh and dry weights of plant tops were observed for ALL-P and ALL-S, whereas an increase ($P < 0.05$) in plant fresh weight only was recorded for ALL-B. With omission of P, plants were 9% shorter, top fresh weights 35% lower and top dry weights 26% lower than the ALL. With omission of S, plants were 24% shorter, top fresh weights 43% lower and top dry weights 43% lower than the ALL. With omission of B, plant fresh weight was 13% greater than the ALL suggesting a possible oversupply of B (2 kg ha^{-1}) in the ALL treatment. However, there was no significant difference in dry weight of plants in the ALL and ALL-B treatments.

DISCUSSION

For Orthoxic Tropudult and Umbric Tropaquult soils, omission of P and S caused a decrease ($P < 0.05$) in plant height and amounts of fresh and dry matter produced relative to the control treatment. These results suggest the supply of P and S from the soil was limiting for plant growth, and deficiencies of these elements are likely (but not certain) to occur in the field. With inherent P and S deficiency in these soils prior to commencement of the IBSRAM PACIFICLAND Project, it is likely that nutrition and soil loss will act in combination to determine changes in crop productivity over time, and effects due to soil loss alone will be difficult to quantify. Nutrient omission experiments may be repeated in time to determine if the severity of P and S deficiency has increased or if other nutrients have become limiting.

The ultimate test of a nutrient disorder is to demonstrate responses in yield, growth rate and/or quality as a consequence of corrective measures. Fertiliser P and S rate experiments using sweet potato as a test plant are planned to quantify growth responses to both applied and solution P and S. The recognition of foliar symptoms of nutrient disorders in sweet potato during the course of the IBSRAM project will be facilitated by: (1) visual comparison with photographs (e.g. O'Sullivan *et al.* 1993) and (2) analytical comparison of measured and "critical" nutrient concentrations in plant tissue (e.g. O'Sullivan *et al.* 1993). Regular collection and analysis of leaf samples will allow nutrient stresses to be monitored over time, and provide a basis for describing the nutritional degradation of these soils.

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