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Final report

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Contents

1 Acknowledgments

Several dozen cocoa growers generously gave their time and knowledge when participating in the survey.

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Many people (listed in Appendices 11.1 and 11.2) contributed their time and expertise in the two workshops.

The PNG Cocoa Board contributed K30,000 towards holding the second workshop.

2 Executive summary

Cocoa is the primary cash crop in most coastal areas of Papua New Guinea (PNG), bringing in earnings of around K168 million per annum. About 80% of the production comes from smallholders, which total around 150,000 households. Smallholder yields are very low, generally in the range 0.3-0.4 t/ha per year, compared to yields of 4.4 t/ha per year that have been achieved in trials. Low yields have been attributed to many factors, including labour shortages, low levels of block maintenance (eg. pruning, shade control and weeding), lack of appropriate agronomic knowledge, land shortages and cocoa prices. The possibility of nutrition-related limitations to productivity has been raised in the past but not examined in detail.

The objective of this one-year study was to provide the information necessary to appropriately design and correctly target future R & D investments into soil fertility and crop nutrition management in cocoa production systems of PNG.

A survey was carried out in which 63 sites across the country were assessed and sampled for soil and tissue analysis. The sites were on smallholder blocks (48), plantations (6) and Cocoa Coconut Institute (CCI) trials (9) on wide range of soil types.

Based on leaf analyses, N and Fe deficiencies appear to be very widespread, with 95% of sampled blocks falling below the ‘critical’ level for N and 89% for Fe. P deficiencies were encountered in about a quarter of the blocks sampled. Leaf Mg concentrations were adequate in most blocks in most provinces, except for ENBP, where 64% of the blocks sampled were deficient. Deficiencies of K, Ca, Mn, B, Cu and Zn were encountered in 2-15% of sampled blocks. However, it should be noted that the published ‘critical’ levels for leaf micronutrient contents are tentative as they were based on surveys, not manipulative experiments. Similarly, the published ‘critical’ values for the macronutrients were established in different places with different planting material, so the values can only be used as an approximate guide. If the widespread N deficiencies were to be overcome it could be expected that the extent and severity of other nutrient deficiencies would increase substantially. There were significant relationships between leaf K, Ca and P concentrations and soil K, Ca and P contents. There was also a significant correlation between leaf Mg concentration and the ratio of soil exchangeable Mg:K. Growers who had used fertiliser (approximately one third of those surveyed) generally reported positive responses in growth, flowering and pod production.

In blocks that are being well maintained and regularly harvested, it is quite likely that yield is being constrained by nutrient deficiencies. It is generally agreed that management of cocoa blocks in PNG must improve dramatically for the cocoa industry to prosper, and perhaps even to survive, particularly in face of the likely spread of cocoa pod borer. Widespread replanting is also necessary. If these improvements occur, then it is likely that limitations due to nutrient deficiencies will become more important.

Although only a one year scoping study, this project has had a number of impacts. It has substantially increased the awareness of soil fertility and cocoa nutrition issues in the cocoa growing community, such as smallholders, plantation managers, and researchers. It has also raised awareness with other groups such as the Cocoa Board. In addition, it has produced the most comprehensive, representative and well-documented survey of tissue and soil nutrient status of cocoa blocks conducted in PNG.

Industry and related people agreed that a nutrition-related research program is essential for improving productivity. Recommendations fell into four main categories: a) research to improve understanding of nutrition-related limitations to production; b) production of nutrient management recommendations appropriate to different regions; c) establishment of effective pathways to adoption; and d) education and capacity-building to ensure continued improvements in nutrient management research and extension.

3 Background

Cocoa is the primary cash crop in most coastal areas of PNG with exports between 35,000 and 40,000 t of cocoa annually from an estimated 100,000-130,000 ha and bringing in export earnings of around K168 million annually. Most of the production (~80%) comes from an estimated 150,000 smallholder households, which is about 16% of the total number of households in the country according to the 2000 census. Most smallholder blocks are about 1-2 ha. The most important cocoa producing area is the Gazelle Peninsula of East New Britain, from where about 54% of national production originates. Smallholder yields are very low, generally in the range 0.3 - 0.4 tonnes of dry bean per ha per year. Yield potential is much higher, with yields of up to 4.4 t/ha/year having been observed in research trials, and yields of up to 1.5 – 2.5 t/ha/year being obtained in plantations. Thus, there is a potential for large increases in productivity. Indeed, the government and the cocoa Industry aim to export up to 100,000 t of cocoa per annum by 2012. Given the size of the smallholder contribution to the industry, even a small increase in smallholder productivity could have a substantial effect on export income.

Low yields can be attributed to many factors, but at least part of the reason appears to be nutrient deficiencies. Many existing cocoa farms in PNG have been growing cocoa in the same area for 10 to 15 years or more, with little or no fertiliser additions. These farms may have also undergone new plantings and rehabilitation with still little or no fertiliser additions. In addition, it has been observed that young cocoa developed better in completely new plantings than when replanted in existing cocoa stands. These matters suggest that the effect is related more to nutrition than anything else. Furthermore, it is estimated that 1,000 kg of dry cocoa beans can remove, through cocoa beans and pod husks, a total of 36 kg N, 6 kg P, 72 kg K, 7 kg Ca and 6 kg Mg (Wood and Lass, 1985). An average of 0.4 t/ha/year of dry cocoa beans commonly obtained in many smallholder farms in PNG, would have removed in total over 15 years from one hectare, 216 kg N, 36 kg P, 432 kg K, 42 kg Ca, and 36 kg Mg. These losses may lead to a deficiency in one or more nutrient elements, thus limiting growth, development, maximum yield potential, and sustained production of cocoa. Finally, in some areas where cocoa is grown, soils are known to have low plant-available supplies of some elements (eg. K in coralline soils).

The current yield decline in hybrids in PNG after reaching maximum production between five to seven years after planting has been suggested to be strongly linked to nutritional problems. Research data from a Shade x Spacing x Clone experiment on volcanic ash soils at CCI Tavilo showed that even where no fertiliser was used, hybrid cocoa clone can yield over 2.0 t/ha/year dry beans, where shade was removed. However, the 2002 soil analyses data in this experiment showed declining levels of Ca, K, Mg, P, CEC, organic C and N; raising concerns about the long term sustainability of these yields. The decline in soil nutrients should be a major concern, particularly when over 80 percent of the cocoa exported from PNG is produced on these volcanic ash soils in East New Britain and Bougainville provinces with little or no fertiliser additions. The problem could be very serious on the non-volcanic soils, especially coralline clay soils where K has been found to be highly deficient.

Early cocoa fertiliser trial work in PNG has been reviewed by Charles (1971), Byrne (1971) and Powell (1991). Response to fertilisers of the Trinitario seed cocoa was generally greatest under conditions of little or no shade (Powell, 1991). Based on those trials quarterly applications of N (100g/tree per application being the optimum rate) were recommended (Ling, 1988). Further trials were carried out by the Department of Agriculture and Livestock (DAL) in the 1980's, but they had many problems, including plots that were too small, and lack of understanding of the crop phenological cycle. There is little or no documentation on those trials. Ling (1988) reported that there was no significant response to N fertiliser in the first two years of application in hybrid cocoa.

Shade x spacing x fertiliser trials were done by Bridgeland and Newton on Trinitario seed cocoa (John Moxon and Gadi Ling, pers. comm.). The Cocoa Coconut Institute (CCI) also did some work on fertilisers in the 1990s without any recommendations given as trials were discontinued as a result of inappropriate experimental procedures and loss of data and information. There are recommendations in a Cocoa and Coconut Manual for fertiliser use in hybrid cocoa for PNG, but these appear to be based on observations and common understanding with little scientific basis. There is currently a fertiliser trial at Tavilo that is related to cocoa rehabilitation with and without the use of fertilisers. Responses to fertiliser were evident in the first 18 months.

Although fertiliser is generally not used by smallholders, it is applied in some plantations. Newmark applies fertiliser in all their plantations in ENB at an annual rate of approximately 60 g N, 14 g P, 20 g K and 9 g Mg per tree (100 g urea in September, 120 g NPKMg 12:12:17:2 in April and 40-50 g kieserite in April, G McNally, pers. Comm.).

The role of nutrition in relation to tree health and yield decline of the present cocoa planting material is not fully understood. It is highly likely that nutrient management, depending on the agro ecological environments and other agronomic practices (such as weed control, shade control, type of shade tree used, cocoa pruning and control of pests and diseases) could be one of the major links to tree health, bearing capacity and yield decline. This makes nutrient management a high priority area and investigations into the nutrition of cocoa are required immediately.

For biophysical limitations to production to be overcome, it is essential that agronomic factors be assessed together with socioeconomic factors. This is particularly important in PNG where income generation from cash crops is often less important than other social imperatives. In a recent ACIAR study (ASEM/2002/014) it has been found that cocoa management strategies change markedly over time; in the first few productive years of a cocoa block the crop is managed as an agricultural crop, whereas in later years it is exploited more like a resource to be gathered when some cash is required. Fertiliser is not currently used by most smallholder cocoa growers, and there are many socio-economic reasons that are likely to limit uptake of new nutrient management technologies. Marrying biophysical and socio-economic aspects of nutrient management is of critical importance in designing future research projects and planning R & D investments. Availability of such data will allow for more effective R & D investment into alleviating poverty and improving livelihoods of growers in the PNG coastal lowlands.

Clearly there is a general lack of data on (i) current soil fertility status, (ii) pest and disease incidence, (iii) crop productivity data at an individual garden scale. There is also a lack of systematic knowledge of what growers are already doing or what their attitude to a range of soil management options may be. Thus, this project highlights these constraints in a number of key cocoa growing areas with the view to designing a future research project to address these constraints, make recommendations and implement solutions.

Table 1. Abbreviations used

Abbreviation	
ACIAR	Australian Centre for International Agricultural Research
AEC	Anion exchange capacity
AQIS	Australian Quarantine Inspection Service
ARB	Autonomous Region of Bougainville
CCI	Cocoa Coconut Institute, PNG
CCEA	Cocoa and Coconut Extension Agency (incorporated into CCI in 2003)
CCRI	Cocoa and Coconut Research Institute (incorporated into CCI in 2003)
CEC	Cation exchange capacity
CIC	Coffee Industry Corporation, PNG
CB	Cocoa Board, PNG
CRI	Coffee Research Institute, PNG
CSIRO	Commonwealth Scientific and Industrial Research Organisation, Australia
CU	Curtin University, Australia
DAL	Department of Agriculture and Livestock, PNG
DPI	Department of Primary Industry, PNG
ENBP	East New Britain Province
ESP	East Sepik Province
GPS	Global positioning system
IDM	Integrated disease management
IPDM	Integrated pest and disease management
JCU	James Cook University, Australia
MaP	Madang Province
MoP	Morobe Province
NARI	National Agricultural Research Institute, PNG
NIP	New Ireland Province
NP	Northern Province
NRW	Queensland Department of Natural Resources and Water, Australia
OFT	On-farm trial
OPRA	Oil Palm Research Association, PNG
OSC	One Stop Cocoa (John Duigu), PNG
PAR	Participatory action research
PBI	Phosphate buffer index
PNGRIS	Papua New Guinea Resource Information System
PSI	Phosphate sorption index
SG1	Generation 1 hybrid cocoa released by CCI from 1982-1986
SG2	Generation 2 hybrid cocoa released by CCI from 1986-1994
SPC	Secretariat of the Pacific Communities, Fiji
UNRE	University of Natural Resources and Environment, formerly Vudal University
UQ	University of Queensland, Australia
US	University of Sydney, Australia
VSD	Vascular streak disease
WB	World Bank
WHP	Western Highlands Province
WSP	West Sepik Province
XRD	X-ray diffraction
XRF	X-ray fluorescence

4 Objectives

The objective of this study was to provide the information necessary to appropriately design and correctly target future R & D investments into soil fertility and crop nutrition management in cocoa production systems of PNG. The following activities and tasks were carried out to achieve this objective:

Activity 1.

1. Develop a benchmark data-set on constraints to cocoa productivity in relation to soil fertility and plant nutrient status, agronomic management and basic socio-economic determinants of grower decision making.

   Tasks

   1.1. Determine cocoa industry stakeholders

   1.2. Select areas for survey and sampling

   1.3. Design soil and plant sampling strategies

   1.4. Design grower survey

   1.5. Survey growers and collect soil and plant samples

   1.6. Analyse soil and plant samples

   1.7. Compile biophysical and socio-economic data into a database

Activity 2.

2. Carry out a constraints analysis to identify maximum impact sites and strategies for nutrient management R & D for cocoa.

   Tasks

   2.1. Evaluate previous work and the data collected in Activity 1.

   2.2. Design R & D strategy and program for nutrient management

   2.3. Synthesise results and recommendations in a technical report

   2.4. Write funding proposal to ACIAR for collaborative R & D project

5 Methodology

The project was executed by: running two workshops; training local staff; conducting a survey in which cocoa blocks were assessed, the growers surveyed about management and soil and plant tissue samples were taken; and by analysing the samples.

5.1 Workshop 1

Key processes and outcomes of the workshop are given here. The minutes and list of participants are given in Appendix 11.1.

5.1.1 Reviews

The following reviews were presented and discussed.

- Cocoa production systems in PNG (Lummani)
- Agronomic and plant protection aspects of cocoa production in PNG (Konam)
- Nutrient requirements of cocoa (Yinil)
- Past and current cocoa nutrition trials in PNG (Fidelis)
- CCI Extension capacities and strategies (Nongkas)
- Soil information for cocoa in PNG (Nelson)
- Nutrition and nutrient management of oil palm in PNG (Banabas)
- Socioeconomic aspects of smallholder cocoa production (Curry)

5.1.2 Group discussions

Discussions were held in one large group and in small groups, and all individuals gave their key opinions. The main discussions centred around the following topics:

- Discuss the main research components of a future project on cocoa nutrition
- Identify stakeholders
- Identify sites for tissue and soil sampling, and socioeconomic survey
- Develop protocols for survey and sampling

Development of protocols

Small groups developed protocols for soil sampling, plant tissue sampling and survey questions. The protocols were then discussed with the wider group and field tested on two smallholder blocks at Tokiala and an IPDM trial block (sampling techniques only). The final protocol for sampling and survey is given in Appendix 11.3.

Survey site selection

Using available resources such as PNGRIS, Hanson et al. (1998), and local knowledge, a working group selected the most appropriate sites to sample. The sites were intended to cover the main areas of current or potential cocoa production.

The sites were classified as 'Main areas', which are already important cocoa growing areas; and 'Other areas', which are less important in terms of cocoa production or are potential areas of cocoa production.

The regions chosen and the main soil types were identified below.

Main areas

- ENBP: cocoa growing areas mostly on coralline soils (Rendolls), volcanic ash (Andisols), Inceptisols (hilly areas, hinterland), Alluvial soils.
- ARB: Vitrandepts (main area, Tinputz, Wakunai), Tropudalfs (Buka), Hydraquents, Fluvaquents.
- ESP: Eutropepts (West coast), Tropudalfs (South coast, central highlands), Dystropepts (Maprik, Rakiki, Ambuin R), Tropofibrists (Ambunti).
- MaP: Vitrandepts (Karkar), Dystropepts, Fluvaquents (mainland).
- NIP: Rendolls (coralline soils), Dystropepts, Eutropepts.

Other areas

- WHP: Jimi Valley. Cocoa is not commercially grown in Jimi, but there is high potential and interest from the local community. Therefore, CCI intends to promote cocoa and coconut cultivation through research and development into the area.
- WSP: (Rendolls, Dystropepts, Fluvaquents).
- NP: low CEC soils of Ilimo-Papaki.
- MoP: (Rendolls, Humitropepts).

5.2 Pilot survey

Shortly after the first workshop, Dr Webb returned to PNG to further train CCI staff in the techniques needed for tissue and soil sampling. This included concepts to avoid contamination between samples, subsampling, practical techniques to minimise chances of mislabelling samples, use of the GPS, organisation of data, organisation of staff, and interviewing the landowner.

In total, 5 sites were sampled. With each consecutive site, Dr Webb had less and less of an organisational role; at the 5th site Dr Webb was one of the 'labourers', with CCI staff taking full control of the operation. During this process the protocol and recording sheet were refined. The final versions are given in Appendices 11.3 and 11.4.

5.3 Collection of soil and tissue samples, and survey data

Between April and Nov 2007, under the leadership of Chris Fidelis (CCI), 63 sites in 9 provinces were sampled and the grower surveyed. The final selection of sites and the number of sites sampled in each province depended to some extent on the practical aspects of travel, time available in the province, and the weather during travel. The advice of local CCI officers was used to select blocks.

Of the 63 sites surveyed, 48 were on smallholder blocks, 6 were on plantations, 8 were in CCI trials and 1 (site 62) was on a potential cocoa site (

Table 2). By province, 11 were in East New Britain Province (ENBP), 9 in Autonomous Region of Bougainville (ARB), 9 in New Ireland Province (NIP), 8 in Madang Province (MaP), 8 in East Sepik Province (ESP), 6 in Morobe Province (MoP), 6 in Northern Province (NP), 4 in West Sepik Province (WSP) and 2 in the Jimi Valley of Western Highlands Province (WHP). Site locations are shown in Figure 1, with GPS locations given in Appendix 11.5.

Once a site had been selected, a block of 42 (6 x 7) trees was selected for sampling. The plot was assessed for tree health and general maintenance. The grower was asked questions about this particular part of his/her block and also about their block in general. An attempt was made to estimate yield at each site, but it was not possible to get reliable estimates.

Leaves were sampled at every site (except for site 62 which is a potential cocoa site and thus had no cocoa planted) from 20 trees distributed evenly throughout the 42-tree block (see Appendix 11.4 for tree locations). The leaves chosen (2 per tree) were the third leaf of a recently hardened leaf flush at mid-canopy height. The number of leaves on the sampled flush was recorded and the length, width and fresh weight of the sampled leaves was measured. Leaves were dried as rapidly as possible, under fans or airconditioners or where possible in an oven set at 65˚C. Eventually all leaves were dried in an oven set at 65˚C, weighed and ground, and a composite sample was prepared for each site.

Pods were sampled from 8 sites: site #4 and #63 in ENBP, #8 in ARB, #18 and #25 in NIP, #34 in MoP, #35 in NP and #44 in MaP. At each site, 10 ripe pods were picked, with no more than one pod being picked per tree. The beans and husks were separated, weighed, dried and weighed again. They were then ground and mixed, and a composite subsample of husk and beans was prepared for each site.

Soil samples were taken at every site (except for site 19), at depths of 0-0.15, 0.15-0.30, 0.3-0.6 and 0.6-0.9 m depth, using an auger. Samples were taken 1m from the tree trunk at trees distributed evenly throughout the 42-tree block (see Appendix 11.4 for tree locations). The shallowest depth increments were sampled at 9 trees and the deeper increments at 5 of those trees. Soil was broken up through a 10 mm sieve, and one composite sample was prepared for each depth increment at each site. It was initially intended to dig a pit at every site and to take undisturbed cores for bulk density measurement, but that process proved too time-consuming for the limitations of the project and was abandoned.

At CCI Tavilo (SG2 Hybrid seed garden), leaf samples were taken from several clones used as parents of released hybrids (Efron, 2003).

Data for each site was recorded on a survey form (Appendix 11.4). Samples were processed (plant tissue samples dried and ground; soil samples kept at field moisture) on site and shipped to Australia for analysis with a duplicate sample being transported to CCI at Tavilo, ENBP as backup. On return to CCI, photocopies of the survey sheets were sent to Australia as backup.

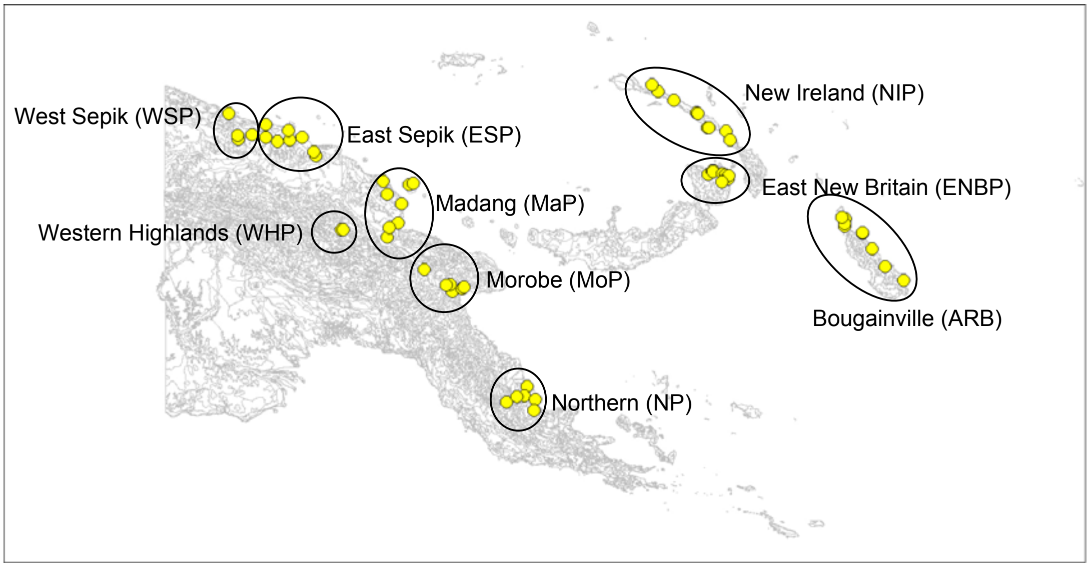


Figure 1. Location of sites surveyed and sampled in this project, showing the provinces in which they were situated.

Table 2. Location and description of sites surveyed and sampled in this project.

Site	Owner[1]	Province	LLG	Name of block
01	CCI	ENBP	Central Gazelle	11A-IDM Plot Option 4
02	CCI	ENBP	Central Gazelle	11A-IDM Plot Option 1
03	SH	ENBP	Inland Baining	CCI-OFT-SG2- small plot
04	PL	ENBP	Central Gazelle	Block.8
05	CCI	ENBP	Gazelle Central	5A (Mutant Segregant Studies)
06	SH	ENBP	Central Gazelle	
07	SH	ENBP	Kokopo/Vunamami	OFT-Bitavavar (Taliligap)
26	CCI	ENBP	Bitapaka	CCI Cocoa Breeding Trial.
27	SH	ENBP	Kokopo-Vunamami	IDM Trial Option 1
28	SH	ENBP	Bitapaka	Agronomy OFT (Intermed. plot)
63	SH	ENBP	Upper Sikut	OFT - Big hybrid plot
08	CCI	ARB	Tsitato Constit.	Budwood garden (small clones)
09	SH	ARB	Hagogohe	Mangoana Project
10	SH	ARB	Tsltalato Constit.	IPDM Option 4 plot
11	SH	ARB	Peit Constituency	Pinu
12	SH	ARB	Teop Tonita Constit.	IDM Option 2
13	SH	ARB	Teop Tonita Constit.	IDM Option 1
14	PL	ARB	Rau	
15	SH	ARB	Kokoda Constit.	Kiritana
16	SH	ARB	North Naisio Constit.	Kometu
17	SH	NIP	Tikana	
18	CCI	NIP	Kavieng Urban	Demo block
19	SH	NIP	Tikana	
20	SH	NIP	Central New Ireland	Tavinkarat
21	SH	NIP	Central New Ireland	Besen
22	SH	NIP	West Coast Central	Sevepo
23	PL	NIP	West Coast Central	Block 88
24	PL	NIP	Namatanai	Block 1
25	SH	NIP	Namatanai	Malilon
29	SH	MoP	Wampar	Bereb
30	SH	MoP	Wampar	Ngawapog
31	SH	MoP	Umi - Atzena	Kaput
32	PL	MoP	Wampar	Block 4
33	SH	MoP	Ahi	Block 1
34	SH	MoP	Ahi	Yusemba
35	SH	NP	Orobay - Ward 18	Kikiri -Gona Station
36	SH	NP	Urban	Aruro
37	SH	NP	Kokoda	Ombite
38	SH	NP	Higaturu (Ward II)	Oemhambo
39	SH	NP	Oro Bay	Kaesusu
40	SH	NP		Boikiki Plantation
41	SH	MaP	Sumkilba	IDM Option 3 Plot
42	DPI	MaP	Karkar	CCI Budwood Garden
43	PL	MaP	Karkar	Block 2
44	SH	MaP	Almami	

Site	Owner[1]	Province	LLG	Name of block
45	SH	MaP	Sumgilba	Lapdingtat
46	SH	MaP	Usino	Block 2 - Sangupuna
47	SH	MaP	Usino	Mituwa - Aikas
48	SH	MaP	Trans - Gogol	Matyau
49	SH	ESP	Turubu	Tems
50	SH	ESP	Angoram	Kablok Junction
51	SH	ESP	Marianbek	Galimo
52	SH	ESP	West Yangoru	Walein
53	SH	ESP	Numbo	Hembenjanka
54	SH	ESP	Albikes - Mamblik	Kaunoru
57	SH	ESP	Drekikir	Namulas
60	CCI	ESP	Boiken - Dagua	Demo Block
55	SH	WSP	Nuku Central	Semenumbo
56	SH	WSP	Palai	Nomongondon
58	SH	WSP	Aitape East	Kumnai
59	SH	WSP	Aitape East	
61	SH	WHP	Jimi	Damna
62	SH	WHP	Jimi	Kelngapai

[1]'SH' designates a smallholder block, 'CCI' a CCI trial, 'PL' a plantation, and 'DPI' a DPI-owned block managed by CCI as a demonstration trial.

5.4 Analysis of plant and soil samples

Analysis of plant and soil samples was carried out or arranged by Sue Berthelsen (JCU).

Plant tissue samples were subjected to Australian Quarantine Inspection Service (AQIS) approved treatment (85ºC, 8 hrs), then released from quarantine (CSIRO, Townsville). They were analysed for N by combustion (Matejovic, 1996) using an Elementar Instrument, and P, K, Ca, Mg, S, Fe, Mn, Zn, Cu, B, Ni, Co, Al, and Ti by inductively coupled plasma optical emission spectrometry following digestion in nitric acid (Zarcinas et al. 1987) All plant analyses were carried out by Waite Analytical Services, Adelaide.

Soil samples were analysed in an AQIS-approved laboratory at CSIRO, Townsville. Samples from all sites and all depths were analysed for: water content, field texture, electrical conductivity (EC) of a 1:5 soil:water extract (method 3A1) followed by pHwater (method 4A11; 1:5 soil:water, 1 hour shake) and pHCaCl2 (method 4B21; addition of CaCl2 to bring solution concentration to 0.01 M CaCl2) in the same extract, cation exchange capacity, anion exchange capacity and exchangeable cations (Gillman and Sumpter, 1986), 'Colwell' extractible P (method 9B11; 1:100, soil:solution 16 hour shake with 0.5M NaHCO3 at pH 8.5, manual colorimetric determination after acid neutralization step), extractible Al (1M KCl extractant, read colorimetrically using the pyrocatechol-violet method, modified from the method of Dougan and Wilson, 1974), organic C (Heanes,1984 and method 6B11) and total N (Kjeldahl digest, read colorimetrically using a segmented flow autoanalyser, method 7A11). Soil P was measured using the Colwell method rather than other methods previously used in the cocoa industry, because because it reflects the 'quantity' component of the labile pool of soil P thus providing an estimate of P fertility more relevant for a long-term tree crop such as cocoa. Much of the existing soil P data from PNG has been obtained using the method of Olsen et al (1954), which has a short extraction time and narrow soil/solution ratio compared to the Colwell method and is expected to reflect 'intensity' rather than 'quantity'. Samples with pHwater > 6.5 were analysed for carbonate as CaCO3 equivalent (method 19A11). Samples from the 0-0.15 m depth (all sites) were analysed for P buffer index (Burkitt et al., 2002), P sorption index (method 9I11) and DTPA-extractable Zn, Cu, Mn and Fe (method 12A11). Samples from 0.3-0.6 m depth (all sites) were analysed for pHNaF as a surrogate for allophane content, as suggested by Fieldes and Perrott (1966) (method 4D11).

Soil samples from 20 sites, selected to cover the range of soil types, were analysed for mineralogical parameters (0.3-0.6 m depth). The mineralogical parameters were pyrophosphate-extractable Al (method 13B11) and oxalate-extractable Al and Si (method 13A11), used to calculate allophane content (Parfitt and Childs, 1988), total elemental analysis by X-ray fluorescence (XRF), and mineral layer spacings by X-ray diffraction (XRD). For the XRF analyses samples were fused with lithium borate and analysed on a Philips PW1480 wavelength dispersive XRF system. For XRD analysis the samples were examined as powders. XRD patterns were recorded with a Philips PW1800 diffractometer.

It was intended that a selection of soil samples be analysed for a selected range of parameters at the NARI chemistry laboratory for comparison, but the laboratory was not operating during the period of this project.

5.5 Workshop 2

The second workshop was held to a) review the results of the plant and soil analysis from the 63 sites sampled in order to assess the nutritional status of cocoa in PNG, and b) solicit ideas, based on the results of this project, for a future project on cocoa nutrition if deemed appropriate.

To benefit from a wider experience in nutrition work in PNG, researchers from industries other than cocoa (oil palm, coffee, sugar cane) were also invited to participate. Similar to workshop 1, there were reviews as well small working groups to facilitate discussion. The agenda, list of participants, and minutes are presented in Appendix 11.2.

6 Achievements against activities and outputs/milestones

The actual milestone completion dates (Table 3) differ from those in the original project plan due to a reassessment in October 2007. The reassessment took into account disruptions to the sampling/survey program, which caused delays in subsequent activities. The main disruptions were the National elections, wet weather and changes to shipping timetables.

Table 3. Achievements against activities and outputs/milestones.

No.	Task	Outputs/ milestones	Completion date	Comments
Objective/Activity 1: Develop a benchmark data-set				
1.1	Determine cocoa industry stakeholders	Summary of related organisations, groups and projects and possible areas of interaction	Mar 2007	Completed during workshop 1
1.2	Select areas for survey and sampling	List of locations for benchmark survey	Mar 2007	Completed during workshop 1
1.3	Design soil and plant sampling strategies	Protocol for sampling and officers trained in techniques	Apr 2007	Protocols completed during workshop 1 Training completed in Apr 2007
1.4	Design grower survey	Survey forms compiled and officers trained in survey techniques	Apr 2007	Protocol completed during workshop 1 Training completed in Apr 2007
1.5	Survey growers and collect soil and plant samples	List of growers' names and locations. One completed survey form and one set of plant and soil samples for every surveyed block	Nov 2007	63 sites across 9 provinces sampled
1.6	Analyse soil and plant samples	Complete set of analytical data for each sample	Feb 2008	Set of standard analyses on 63 sites
1.7	Compile biophysical and socio-economic data into a database	Database with all survey data complete and easily accessible	Feb 2008	Excel spreadsheet
Objective/Activity 2: Constraints analysis and proposal development				
2.1	Evaluate previous work and data collected in Activity 1	Statistical analyses of results/Draft report	Mar 2008	Presented at Workshop 2
2.2	Design R,D&E strategy and program for nutrient management	Statement of needs, capacity (all possible partners) and the way forward/Draft proposal	Mar 2008	Drafted at Workshop 2
2.3	Synthesize results and recommendations in a technical report	Report synthesizing results of study. Awareness of project among potential partners	May 2008	This document
2.4	Write funding proposal to ACIAR for collaborative R,D&E project	Project proposal submitted	Jun 2008	Draft in progress

7 Key results and discussion

7.1 Constraints to productivity

7.1.1 Market demand and industry structure

Understanding and overcoming nutrition-related limitations to productivity can only occur if other limitations to production are also considered. There is a clear consensus among researchers, extension officers and many growers in PNG that the possible role of nutrition in limiting cocoa production needs to be examined. However, the main limitations to productivity are not nutrient-related. Therefore, nutrition-related research must be carried out recognising those other limitations and interactions between limitations. Another important point is that growers and the PNG government wish to increase productivity. Dependence of rural people on cash income is increasing markedly due to rising material aspirations and economic development. Cash has also become an indispensable item in many non-market exchange transactions.

The external climate for increasing productivity of PNG cocoa growers is good. World demand for cocoa is increasing rapidly and there will be a high demand for PNG cocoa into the foreseeable future, even if production were much higher. PNG cocoa is known for good and consistent quality, with particular flavour, high fat content and large beans (Lambert, 2008). PNG recently (early 2008) had its ‘Fine Flavour Status’ re-instated, which means a premium over the world market price. PNG’s fine flavour status is probably due mainly to two factors: good germplasm and good quality control, including organization of fermentation and drying. The main threat to fine flavour status of PNG cocoa is smoke taints introduced during drying of fermented beans. So, while quality and demand are good, productivity is the main limitation to incomes from cocoa.

Management inputs to smallholder cocoa blocks must improve drastically for productivity to increase. The future of the PNG industry is clearly with smallholders rather than the plantation sector. Approximately 80% of production is currently from smallholders and the plantations are contracting, mainly due to poor returns on investment. There is a large potential for increases in productivity on smallholder blocks, as smallholder cocoa blocks are currently maintained at levels far below the optimum. Cocoa is a crop that is very sensitive to management inputs, and even if nutrient management were improved, no lift in productivity would be expected without improved management of shade, pest and diseases, weeds and harvesting. The reasons for poor management are discussed in following sections. Most PNG cocoa is currently produced by a foraging system with virtually no management inputs. While it is currently possible for growers to earn some income that way, improved management will probably become critical for survival of the industry following the arrival of the pest Cocoa Pod Borer (*Conopomorpha cramerella*). Cocoa pod borer can devastate crops without high levels of management. Finally, it must be kept in mind that cocoa production is only a small aspect of the activities and livelihood of cocoa-producing households.

7.1.2 Smallholder production strategies

Cocoa producers have a variety of income sources. Other important income sources include copra, garden food, betel nut, vanilla, livestock and trade stores. For women, income from local markets is ranked most important.

Cocoa producers sell either dry bean or wet bean, which is related to the age of their cocoa trees and various other factors, including access to processing facilities. Most cocoa producers in ENB and probably throughout PNG are wet bean sellers, for reasons discussed further below. Income from cocoa is far higher for dry bean sellers than wet bean sellers. Dry bean sellers are more narrowly focussed on cocoa production and derive most of their income from cocoa. They depend on a ready supply of labour, access to a fermentery and drier, and transport for firewood and for bringing processed crop to exporters. Wet bean sellers derive most of their income from local markets, copra and other sources for most of the year. They therefore spend less effort on cocoa production. The cash earned from cocoa is spent on small items or immediate needs. Block condition and accessibility is also an important influence on dry vs wet bean production. Wet bean sellers tend to be harvesting older stands with higher levels of pests and diseases and dense shade due to lack of pruning.

Cocoa production peaks when the trees are between 3 and 7 years, and falls off after that. The decline in productivity appears to be particularly rapid with hybrids and clones planted since the 1980s. Productivity tended to last longer with lower levels of management in the Trinitario seed cocoa planted earlier.

7.1.3 Main constraints to productivity

For some time there has been awareness of limitations to cocoa productivity and attempts to overcome them, but there have been no long-lasting solutions. The limitations discussed below are from the study of Curry et al (2007) and references therein. Most of those studies were carried out in ENBP, but the general conclusions were confirmed in our survey (see Section 7.2). Common factors explaining low productivity are labour shortages, low levels of block maintenance, lack of appropriate agronomic knowledge, land shortages and cocoa prices. In addition, growers report theft as being a major limitation to productivity. Finally, Curry et al (2007) noted that accessibility of healthy ripe pods is of critical importance.

Nutrition has not been reported as a constraint in previous surveys. However, nutrition-related factors, such as ‘lack of fertiliser’ were raised as a limitation to yield by several smallholders in our survey (see Section 7.2).

Land shortages and land tenure

Land shortages are common in the main growing areas such as the Gazelle Peninsula. In the Gazelle Peninsula the land shortage is reflected in a high proportion of cocoa being planted on purchased or reserve land rather than customary land. There is a common desire among smallholders to convert tenure of cocoa blocks from customary to individual freehold, due to capital and labour investments in the block. Protracted disputes over inheritance often limit the incentive to provide labour inputs and there are rapid cultural changes occurring in inheritance practices. However, not even registered land is immune from ownership disputes. There are considerable tracts of land being purchased and planted to cocoa to ensure future security of household livelihoods. Cocoa blocks planted for this reason could be expected to have low maintenance levels, but low levels of maintenance are common across all tenure types.

Cocoa price

PNG farmers are price-sensitive, which affects their behaviour in several ways, but tends to mean that production levels and block maintenance levels are high when the price is high. As mentioned earlier, returns are much higher for dry bean than wet bean. In March 2008 growers were getting about K 320/bag (62.5 kg) of dry bean, at a world market price of USD 2,200/t. About K 40/t is paid into levies. Transport is a high proportion of the cost of production, especially for dry bean producers. The break-even yield is about 0.7 t/ha for plantations and about 0.3 t/ha for smallholders. A big constraint to replanting is the cost of seedlings.

Labour management and shortages

Labour shortages are a significant constraint to productivity. Cocoa growers rely on unpaid labour from the extended family and there are many reasons why there may not be enough labour on particular blocks at the right times. Activities that are not related to cash income, but are central to maintaining social cohesiveness and kinship networks tend to draw a lot of time and labour away from cocoa production. However, these obligations may also have the opposite effect; motivating smallholders to commit extra time and labour to raise funds for social purposes. The availability of labour is not simply demographic, but depends on many factors.

Households with an adequate supply of labour have certain characteristics:

- Access to labour of unmarried or married sons.
- Reside in multi-generational extended family units with houses clustered together. Work (subsistence and cash cropping) is carried out in multi-household units.
- Household uses indigenous mechanisms of labour mobilisation when necessary to maintain cocoa production during high crop periods.
- Head of extended family (father) maintains control over family labour, especially adult sons.
- Few intra-household disputes over labour remuneration.
- Household head allocates cocoa harvests or beans to adult household members and other relatives.

Harmonious relationships are significant, ensuring on-going commitment, which is very important for meeting peak labour demands during flush periods. Individuals must be happy that the income sharing is fair. By judiciously allocating harvest rounds to co-resident adult sons, the household head builds goodwill, allowing him to draw on their unpaid labour. Traditional methods of ensuring long-term supply of labour include adoption or recruitment of relatives to reside with the household. More common methods are shorter-term and rely on exchanges. Cash and food may be given as tokens of appreciation for the gift of labour, but not as payment.

Constraints to availability of labour may be short- or long-term. Households with labour constraints tend to have the following characteristics:

- Demographic with few adults or older children
- Health problems
- Competing demands, eg. paid work, other cash crops
- Non-economic competing activities, eg. customary, church
- Underutilisation of available labour, eg. due to inadequate remuneration
- Perception that household head is not fulfilling obligations to family
- Minimal use of traditional strategies for labour mobilisation or of hired labour

Dry bean sellers are more reliant on a ready supply of labour than wet bean sellers. They require a mean of 4.4 labourers for 2.3 days per sale, compared to wet bean sellers who require a mean of 1.8 harvesters for 0.4 days per sale (Curry et al, 2007). Wet bean sellers harvest smaller quantities, more often, and are less dependent on labour from the extended family. They are typically women working alone or with children, or elderly men.

There is a lower return on labour for women than for men, which reduces their motivation. Men tend to spend more time and derive more income from copra than women.

Accessibility of healthy ripe pods

The accessibility of healthy ripe pods is of critical importance for productivity. Low accessibility is a major disincentive for harvesting and there is a minimum threshold below which labour inputs such as harvesting and grass slashing will not be invested. This 'quantity threshold' is more important than the 'commodity price threshold' mentioned above. The quantity threshold parallels labour strategies in subsistence gardening; in later stages of gardens nutrients are depleted and weeds build up, and less effort is spent maintaining access to crops and harvesting.

Theft is rated by growers as a major constraint to productivity. While there have been no studies on the importance of theft, it may be related to accessibility of ripe pods; high accessibility means that the most easily accessible pods are stolen, leaving the less accessible pods (eg. higher in the tree). The reduction in the quantity of ripe healthy pods that are easily accessible (because they have been stolen) reduces the blockholder's motivation to harvest.

Block maintenance

Block condition is very poor on most blocks, often with gross over-shading and high levels of pests and diseases, especially on blocks older than 8-9 years. Low levels of maintenance lead to low accessibility of healthy ripe pods, in a downward spiral of productivity. On most smallholder blocks there is virtually no pruning of cocoa, little or no shade control, no pest or disease control measures, and under-harvesting, leading to low yields and high incidence of black pod disease. Weed control is generally adequate only in younger higher producing blocks during flush periods. Weeding is mostly carried out for harvest access rather than for sanitation or tree health. Pruning, shade control and weeding are done mostly to promote growth of food crops intercropped with cocoa during the first few years of the block. They are all minimal beyond 2-3 years.

Cocoa is very sensitive to management and there is widespread recognition of losses due to black pod, canker and vascular streak disease (VSD). Black pod, caused by *Phytophthora palmivora*, has a complex disease cycle and high levels are related to poor block maintenance and under-harvesting. Curry et al (2007) found significant under-harvesting, especially in older, bigger trees, with 29% of full-size pods being dry (not harvested when ripe). VSD, caused by Oncobasidium theobromae, is a systemic pathogen that is absent in ARB, NIP and Manus. Another disease of concern in ARB and NP is Pink Disease, caused by Corticum salmonicolor.

Poor block maintenance has proven an intractable problem, despite much extension effort. The reasons appear to be mostly due to the factors discussed above. Additionally, lack of knowledge, lack of appropriate tools, and vegetation structure are factors. Farmers often express a desire for more training. Inadequate tools result in damage to flower cushions during harvest and inadequate pruning and weed control. Vegetation structure is discussed further below.

7.1.4 Synthesis of constraints into a smallholder cocoa production model

Curry et al. (2007) proposed a model that explains typical cocoa production strategies and constraints to productivity. In the model, management of cocoa blocks proceeds in 3 stages, in which tree age is a major factor. As the trees age, yields and management inputs deteriorate.

In stage I (<3 years old), the cocoa is immature, productivity is low and there is low incidence of pests and diseases. Labour inputs are moderate, but the block is well maintained, mostly because of efforts being applied to inter-cropped food gardens. Any cocoa harvested is sold as wet bean due to the low yields.

In stage II (3-8 years), the cocoa is mature, the vegetation structure is open and there are large quantities of ripe pods accessible, leading to high labour inputs and high productivity. This is the period in which cocoa may be sold as dry bean, leading to high income. The incidence of pests and diseases rises during this stage.

In stage III (7-8+ years), the cocoa is senile, accessibility of ripe pods is low due to taller, denser vegetation, labour inputs and productivity are low, and cocoa is mostly sold as wet bean. Lack of pruning and shade control, labour shortages and under-harvesting accelerate the transition from stage II to III. Although income is good in stage II, it is generally not invested in block maintenance. This downward spiral of low productivity includes lower returns to labour, and blocks are often left in this stage for a long time. Most cocoa blocks in PNG are in this stage, apart from in ARB due to the large replanting efforts there around 2000-2002.

Raising smallholder productivity is very difficult due to the complexity of the situation. Many years of extension and training have not generated significant improvements in block management or productivity. Strategies currently being proposed for delaying the transition into stage III must be innovative, must accommodate existing practices, extension efforts and smallholder needs and circumstances, and must create better incentives for devoting more time and labour to cocoa. Possible strategies are discussed in section 9.2.

7.2 Characteristics of surveyed sites

7.2.1 Block tenure, planting history and vegetation

The cocoa blocks surveyed covered a range of tenure types, age etc. Most of the smallholder blocks were on customary land (73%), with some on purchased land (23%) or state land (4%). Most of the blocks had been farmed for more than 17 years (85%) and most of the current cocoa stands were more than 7 years old (86%). The dates of clearing and cocoa plantings are shown in Table 4. Most of the planting materials were sourced from CCI, with the type of material corresponding to planting date; Trinitario open-pollinated material prior to 1982, SG1 hybrids from 1982-1986, SG2 hybrids from 1986-1994, and clones thereafter. However, some plantings made since 1982 (5 blocks) were made using Trinitario material sourced from older blocks or neighbours. Of the 63 growers interviewed, 3 were female and the rest male.

An attempt was made to calculate yields from information supplied by the grower, but it was not possible to make reliable estimates for most blocks as most smallholders do not keep production records.

There was a larger variety of plant species in smallholder cocoa blocks than in the CCI or plantation blocks. Most of the blocks had as shade trees Gliricidia (61% of blocks) or coconuts (49% of blocks) or both. Many blocks had other shade trees, including betel nut, banana, breadfruit, galip or Leucaena. Food crops were common among the cocoa, especially in younger plantings; 45% of smallholder blocks had food crops and 73% had fruit or nut trees among the shade trees, whereas the corresponding figures were 0 and 12% in CCI or plantation blocks. Most of the smallholder blocks had Gliricidia as a shade tree in the sampled plots (61%), and a small proportion (23%) had legumes in the ground cover, mostly Pueraria. The corresponding figures were much lower in CCI or plantation blocks (9 and 4%, respectively). Characteristics of each block are recorded in Appendix 11.5.

Table 4. History of block (% of responses)

	<1970	1970-79	1980-89	1990-99	2000-07
Year block first farmed	41	13	30	11	4
Year Cocoa first planted	13	16	33	24	13
Year current stand planted		4	24	48	24

7.2.2 Block management and constraints to yield (other than nutrition)

It was clear from the survey that smallholder growers considered lack of knowledge and poor management, and availability of labour to be the main factors constraining productivity. Of the smallholders interviewed, 9 were happy with their yields and 32 were not. Forty five of the smallholders gave reasons for why their yields were good or not. The reasons given for good yields were: adequate labour, good market access, absence of land disputes, good planting material, good knowledge or experience due to training or experience in plantation management, and good management, including IPDM technology (Table 5). The reasons given for poor yields revolved mostly around poor knowledge and poor management, labour shortages and disputes, or competing demands on growers' time, and old planting materials or lack of finance for replanting block (Table 5). Lack of fertiliser application and poor soil fertility were cited 19 times. That is interesting as previous surveys have not recorded that concern. This survey was possibly biased because the interviewers explained to the growers that the soil and tissue sampling exercise was intended to assess fertility and nutrient status of the soil and plants. Several growers asked about specific management issues (eg. how should I prune my cocoa? how should I rehabilitate my cocoa? how should I control pests and diseases?), reflecting the general lack of confidence in their ability to manage cocoa well. Several asked about their soil; could there be an issue with fertility? One grower had taken over a block to which fertiliser had been applied in the past. He wondered if the application of inorganic fertilisers could be affecting his production, and if the fertilisers could be detected in the soil tests. Many smallholders felt a lack of support and several wanted to know how this exercise would benefit them.

Table 5. Reasons cited by smallholders for good or poor yields. The numbers indicate the number of growers who gave that reason.

Reasons for good yield		Reasons for poor yield	
5	Labour: adequate available	22	Knowledge: lack of
5	Access good	18	Management poor
4	Land tenure secure: no disputes	17	Labour shortage/dispute/cost/other commitments
3	Planting material good (new)	11	Planting material old (Trinitario)
3	Knowledge/experience good	10	Diseases and pests
2	Management good	10	Fertiliser: lack of
		6	Finance for purchasing seedlings or tools: lack of
		5	Nutrient deficiency/soil exhaustion
		4	Theft of pods
		4	Fermentary/dryer capacity/functioning limited
		3	Waterlogging/flooding
		3	Price low
		2	Other chemicals (not fertiliser): lack of
		3	Support by govt: lack of
		1	Land shortage
		1	Bad weather destroying flowers
		1	Access poor
		1	Missing trees

Of the management factors assessed, pruning received the worst ratings, with 48% of blocks scored as poor or very poor. Shade management was also rated poorly (42% poor or very poor) and weed management scored the best (27% poor or very poor). In many cases the good score for weed management was at least partly related to the canopy being so dense (due to poor or no pruning of cocoa and shade trees) that there was not enough light for weeds to grow well. The distribution of management ratings is shown in Table 6 and scores for each block are recorded in Appendix 11.5.

Of the diseases assessed, black pod was the most widespread and severe, with 98% of blocks affected. Next came canker (91% of blocks affected), pink disease (62% of blocks affected) and VSD (55% of blocks affected). The severity of the diseases is shown in Table 7. Thread blight was noted in many blocks. Scores for individual blocks are recorded in Appendix 11.5.

Approximately one third of growers had applied fertiliser (29% of smallholders and 33% of CCI or plantation blocks). The smallholders who had applied fertiliser were mostly participating in the IPDM trials, and it was only to that part of their block (Option 4) that they had applied fertiliser. The survey sought out IPDM blocks for sampling, so the high proportion of smallholder who had applied fertiliser was not representative of the industry as a whole. However, there were a few smallholders who had applied fertiliser at some time and/or to part of their block off their own initiative. The IPDM farmers used urea and NPK. The other smallholders who had used fertilisers had mostly used NPK, but one had used urea and chicken manure. The plantations had mostly used urea and NPK, but some had used muriate of potash and sulphate of ammonia. Almost all the growers who had used fertilisers reported improvements in vegetative growth, flowering and pod production, but there were concerns about the cost (Table 8). One grower thought fertilizer should not be used because development of the industry depended on organic cocoa and because fertilizer is too expensive.

Most of the sites were on flat to moderately sloping land with reasonably deep soil (neither impeding layer nor watertable reached within 0.9 m depth). However, there were sites, particularly in NP, which had a shallow depth of soil before rock was reached. Where erosion was observed it was often attributed to poor ground cover or to steeper slopes. Landform, erosion, slope class and depth to impeding layers (if <0.9 m) are recorded in Appendix 11.5.

Table 6. Rating scores for management (% of smallholder blocks)

	Very poor	Poor	Average	Good	Very good
Tree health	0	16	30	52	2
Shade management	9	33	41	15	2
Weed management	8	19	42	29	2
Pruning	15	33	35	17	0

Table 7. Rating scores for diseases (% of smallholder blocks)

	Severe	Moderate	Low	None
Black pod	8	33	56	2
Canker	2	13	77	9
VSD	0	9	47	45
Pink Disease	0	15	48	38

Table 8. Comments on effects of fertilisers by growers who had used them (mostly NPK and/or urea). Plantation and CCI blocks are indicated by (P) and (CCI) respectively.

Site	Comments
1 (CCI)	Increased yield & healthy trees
3 (P)	Increase flowering, cherelle & pod production
4 (P)	Very significant difference in trees, harvest and yield. Clearly very high increase in yield.
7	Fertilised trees bearing more pods than the unfertilized trees.
8(CCI)	Change in leaf colour: green and healthy, and increase in flower and cherelle production. An increase in pods is predicted after NPK application.
9	Cocoa was heavily bearing fruits and healthy
10	Change in leaf growth and vegetative health and improvement of tree bark. Increased pod production, from about 0.5-1 bag to about 2.5 bags wet bean.
12	Leaf flush, flowering improved. Cherrelle and production of ripe pods increased.
13	Leaf changed to green. Flower setting, cherrelle and pod load increased.
16	Many flowers on stem. New fan branches after tipping
18 (CCI)	An increase in production responding to the application
21	Cocoa production went up. Leaves changed from yellow to green. Grower does not recommend fertilizer in the block due to cost.
24 (P)	Cocoa trees were healthy. Heavy pod load, flowering heavy and healthy leaves.

25	Increase in pod number, healthy leaves. Trees had healthy branches.
27	Leaves turn evergreen. Trees put on more flowers
31	Evergreen healthy trees. Bearing on trees from stem to secondary branches. Hot sun in the valley causes trees to lose leaves.
32 (P)	Healthy growth of trees. Trees bearing big pods
41	Decrease in black pod incidence. Tree health improved. Increase in production (PDM bloc)
46	Healthy evergreen trees with many flowers and then pods.
50	Conflicting comments: ‘Cocoa trees grew healthy, green & fast’ vs ‘Did not observe any difference (one application after planting)’

7.3 Soil and plant nutrient status

7.3.1 Introduction

While surveys of cocoa leaf nutrient concentrations and soil analyses have been carried out in PNG in the past (Leaf: Southern and Dick, 1969; Soil: Bleeker and Healy, 1980; Bleeker, 1983; Freyne et al 1996; Hanson et al., 1998), this is the first survey in PNG in which soil and cocoa leaf analyses have been carried out at the same locations, along with information on block management and history. As far as we are aware it is also the first time that pod nutrient concentrations, and leaf nutrient concentrations for different clones have been reported for PNG.

7.3.2 Leaf nutrient contents

It should first be pointed out that foliar analysis has been less useful for diagnosis and management of nutrition problems in cocoa than for other crops. That is because leaf age and light intensity usually over-ride the nutritional effects on leaf nutrient composition except when there are marked deficiencies (Wessel, 1985). We have used the values in

Table 9 for categorizing leaf nutrient concentrations as deficient or not. For trace elements those values were based on the survey and review by Southern and Dick (1969). These values have only ever been described as 'tentative' because they have not been verified by trials in PNG. Most other values reported in the literature originate from the Ivory Coast (Loué, 1961) or Trinidad (Murray, 1967), and are summarised by Wessel (1985). Those values are given in Appendix 11.6. The leaf nutrient concentrations are shown in Table 10. Values for each site are given in Appendix 11.7 and N, K, P and Fe values are shown as maps in Appendix 11.12. It should be kept in mind that although concentrations of a particular element may not be deficient at the time of sampling, correction of other deficiencies may cause that element to become deficient in the future. N appeared to be deficient at almost all sites, and correction of N is deficiency is likely to result in deficiency of other elements.

At most sites leaves appeared deficient in N, except for two sites in East Sepik and one in West Sepik provinces. Leaf N:P ratios were low, with a mean of 10.4 (range 6.5-17.4, with only 3 sites >15), indicating a deficiency of N relative to P at most sites.

At only 10% of sites did leaves appear deficient in K. This was surprising as K deficiencies have been reported, particularly on coralline soils, and many sites in this study had low soil exchangeable K contents and high ratios of exchangeable Ca:K or Mg:K. Two possible reasons for the discrepancy are a) the critical leaf value is not realistic, or b) K deficiency is not expressed because another deficiency (eg. N) is limiting.

At most sites leaf Ca concentrations were adequate, with only a few sites in NIP, MaP, NP and WSP provinces showing deficient levels.

Leaf Mg concentrations were adequate in all provinces except for ENBP, where over 60% of the sites had deficient levels. Exchangeable Mg contents generally appeared adequate in ENBP soils, but Mg uptake may be limited due to the low ratios of exchangeable Mg:K.

Leaf P concentrations were not clearly related to province. The 15 sites with low or deficient levels of P were spread over all provinces. Those sites also generally had high N:P ratios.

At no sites did leaves appear deficient in S. The critical level of 0.02 - 0.03% suggested by Fahmy (1977) is much lower than that used for many other crops (often about 0.15%), so should be treated with caution. However, even if a critical level of 0.15% is assumed, most of the sites appeared to have adequate leaf S concentrations. Hartemink and Bourke (2000) comment that S deficiency is common on a number of other crops in PNG and occurs over a range of different soil types. The common causal factors are high rainfall, leaching and loss of S through frequent burning of vegetation. This suggests that there is the potential for S deficiency to occur in cocoa crops and reliable critical levels for S need to be established.

At most sites leaves had deficient or subnormal Fe concentrations compared to the published tentative critical levels. Southern and Dick (1969) reported that Fe deficiency symptoms are common in cocoa and have been widely reported in the field. In their study they found that 75% of the cocoa sampled showed Fe deficiency symptoms and had leaf levels < 50 mg/kg Fe. They noted that in some cases where symptoms were severe, leaf levels were < 40 mg/kg. In this current study, over 70% of leaf samples had leaf levels < 40 mg/kg. To what extent mild Fe deficiency will affect yields is unknown but severe deficiency will cause defoliation, die-back and low yields (Southern and Dick, 1969). It is imperative that the critical level for Fe be reassessed, to determine if Fe deficiency is indeed widespread or not.

At only a few sites did leaves appear deficient in Mn, B, Cu or Zn. There was a wide variation in leaf Mn concentrations. Southern and Dick (1969) also commented on the wide range of concentrations of leaf Mn encountered in cocoa in PNG. They noted that severe Mn deficiency symptoms were observed at 15 mg/kg Mn, and recognisable symptoms at 20 mg/kg. In our study the lowest leaf Mn level was 25 mg/kg and the overall average was quite high at 176 mg/kg. Bleeker (1983) noted that low leaf Fe was often associated with high leaf Mn, but there did not appear to be any relationship between concentrations of these two elements in our data set. Leaf Mn concentration was significantly correlated with soil pH ($r = -0.3$) with the highest values generally occurring at a soil pHwater of < 6.0. Southern and Dick (1969) found low Mn values in neutral to alkaline soils of alluvial origin. Southern and Dick (1969) observed that deficiency symptoms of Zn, B and Cu were rarely observed in cocoa in PNG, and this is supported by our data set, with very few samples having leaf values of these elements below the levels considered critical.

There were significant correlations between many leaf nutrient concentrations. The largest correlation coefficients were between leaf Mg and Zn (+0.63) and between leaf Mg and K (-0.66) and leaf P and Ca (-0.53).

Table 9. Suggested leaf values for cocoa for PNG from Fahmy (1977). Values are based on 3rd leaf, with values defined as: deficient (< a), subnormal (a-b), tentative critical level (b), normal (b-c), above normal (> c).

Element	a	b	c
N (%)	2.0	2.3	3.0
P (%)	0.12	0.16	0.30
K (%)	1.1	1.6	2.6
Ca (%)	0.5	0.8	2.6
Mg (%)	0.3	0.4	1.0
S (%)	0.02	0.03	0.10
Mn (mg/kg)	15	30	
Fe (mg/kg)	30	50	
Zn (mg/kg)	20	30	
Cu (mg/kg)	4.0	6.0	
B (mg/kg)	15	25	

Table 10. Leaf nutrient concentrations in each province (number of sites per province in brackets). Values for each site are given in Appendix 11.7. (*Critical values for each nutrient from

Table 9)

	ENBP (11)	ARB (9)	NIP (9)	MaP (8)	ESP (8)	MoP (6)	NP (6)	WSP (4)	WHP (1)	All (62)
N% minimum	1.6	1.4	1.5	1.9	2.1	1.6	1.6	2.0		1.4
N% maximum	2.2	2.0	2.2	2.1	2.5	1.9	2.0	2.4		2.5
N% mean	2.0	1.7	1.9	2.0	2.3	1.8	1.7	2.2	2.0	1.9
Sites ≤ 2.3% N*	100%	100%	100%	100%	75%	100%	100%	75%	100%	95%
P% minimum	0.16	0.15	0.13	0.11	0.14	0.12	0.15	0.19		0.11
P% maximum	0.23	0.26	0.26	0.26	0.22	0.20	0.22	0.23		0.26
P% mean	0.20	0.19	0.20	0.19	0.18	0.17	0.19	0.22	0.25	0.19
Sites ≤ 0.16% P	9%	33%	22%	38%	38%	38%	17%	0	0	24%
K% minimum	1.9	1.6	1.3	1.9	1.4	1.9	1.6	1.7		1.3
K% maximum	2.6	2.3	2.3	2.3	2.2	2.1	2.5	2.1		2.6
K% mean	2.3	2.0	1.9	2.1	1.8	2.0	2.0	1.9	2.0	2.0
Sites ≤ 1.6% K	0	11%	22%	0%	25%	0	17%	0	0	10%
Ca% minimum	0.9	1.3	0.7	0.8	1.0	1.2	0.7	0.8		0.7
Ca% maximum	1.6	2.2	1.9	2.0	1.8	2.6	2.0	1.8		2.6
Ca% mean	1.2	1.6	1.3	1.5	1.3	1.9	1.4	1.2	1.3	1.4
Sites ≤ 0.8% Ca	0	0	11%	13%	0	0	33%	25%	0	8%
Mg% minimum	0.33	0.41	0.46	0.38	0.42	0.44	0.43	0.44		0.33
Mg% maximum	0.61	0.67	0.66	0.59	0.61	0.74	0.80	0.66		0.80
Mg% mean	0.42	0.52	0.59	0.49	0.50	0.56	0.55	0.53	0.66	0.52
Sites ≤ 0.4% Mg	64%	0	0	13%	0	0	0	0	0	13%
S% minimum	0.19	0.20	0.20	0.14	0.17	0.13	0.12	0.18		0.12
S% maximum	0.26	0.22	0.25	0.18	0.23	0.23	0.18	0.20		0.26
S% mean	0.22	0.21	0.22	0.16	0.21	0.20	0.15	0.19	0.17	0.20
Sites ≤ 0.03% S	0	0	0	0	0	0	0	0	0	0
Mn mg/kg minimum	32	143	173	25	67	42	96	44		25
Mn mg/kg maximum	430	700	350	119	210	420	189	250		700
Mn mg/kg mean	98	307	299	72	144	194	125	182	168	176
Sites ≤ 30 mg/kg Mn	0	0	0	12%	0	0	0	0	0	2%
Fe mg/kg minimum	28	24	27	21	23	39	26	33		21
Fe mg/kg maximum	97	54	37	43	109	145	33	53		144
Fe mg/kg mean	46	31	31	31	42	67	29	41	42	38
Sites ≤ 50 mg/kg Fe	82%	89%	100%	100%	88%	67%	100%	100%	100%	89%
Zn mg/kg minimum	27	27	47	46	26	35	25	41		25
Zn mg/kg maximum	98	89	142	74	96	86	108	71		142
Zn mg/kg mean	49	62	87	60	56	62	47	55	81	61
Sites ≤ 30 mg/kg Zn	18%	22%	0	0	25%	0	50%	0	0	15%

	ENBP (11)	ARB (9)	NIP (9)	MaP (8)	ESP (8)	MoP (6)	NP (6)	WSP (4)	WHP (1)	All (62)
Cu mg/kg minimum	5.1	6.3	8.3	7.2	8.2	7.0	4.5	6.9		4.5
Cu mg/kg maximum	9.2	12.5	13.2	13.5	9.6	10.0	15.7	9.1		15.7
Cu mg/kg mean	7.0	8.5	11.0	9.7	8.9	8.1	8.6	8.3	11	8.8
Sites ≤ 6.0 mg/kg Cu	27%	0	0	0	0	0	17%	0	0	6%
B mg/kg minimum	33	32	31	31	26	22	24	24		22
B mg/kg maximum	45	44	40	39	41	52	38	39		52
B mg/kg mean	38	37	35	34	32	38	33	32	27	35
Sites ≤ 25 mg/kg B	0	0	0	0	0	17%	0	25%	0	3%

7.3.3 Leaf size and dry matter content and relation with nutrient content

It has been reported (Wood and Lass, 1985) that dry matter content of leaves increases with leaf age and thus may affect nutrient concentration when expressed on a dry weight basis. Samples from the survey ranged in dry matter content from 0.29 to 0.43 as a proportion of fresh weight. While there appeared to be a reasonable relationship between fresh weight of leaves and leaf size (length x width), there was little relation between leaf size and dry matter content (Figure 2). This suggests that leaves expand to near full size early in development and then accumulate dry matter as they mature.

The accumulation of dry matter with age may also explain the negative relationship between leaf K concentration and dry matter content (Figure 3). There was a similar pattern with leaf P but not leaf N. However, comparing the total leaf K content with dry matter content shows a flat response (Figure 3). This suggests that K is accumulated in the leaf as it expands but remains the same as dry matter is accumulated. This implies that it may be better to express K concentration on the basis of fresh weight rather than dry weight. However, doing so did not improve the relationship between leaf K and soil K. Alternatively, the leaf K could be adjusted to a common dry matter content; but again this did not improve the relationship between leaf K and soil K. Similarly, adjusting for dry matter did not improve the relationship between leaf P and soil P.

Most of the leaf parameters were quite consistent across all sites and also when grouped by province (Table 11). The only exception is the number of leaves per flush, which was very low in Morobe Province compared to the others. A comparison was also done by landform, but again the parameters were consistent among those categories.

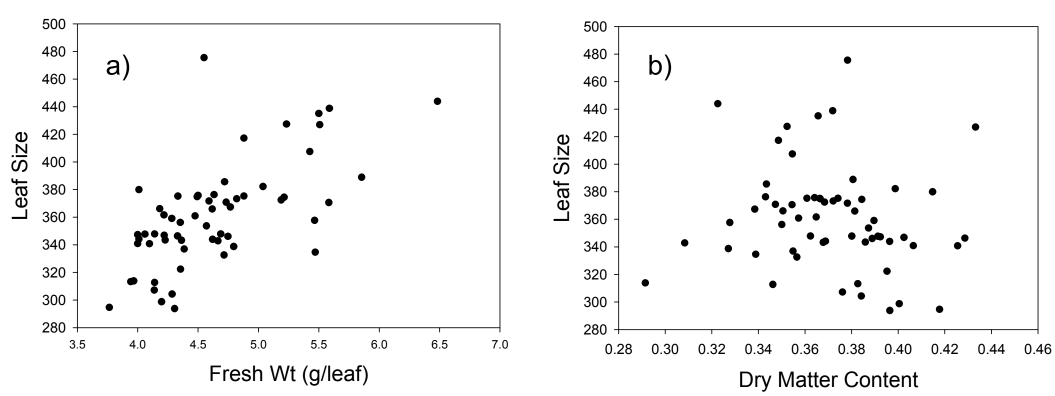


Figure 2. Relationship between leaf size (length x width, cm) and leaf fresh weight (a) or dry matter content (b).

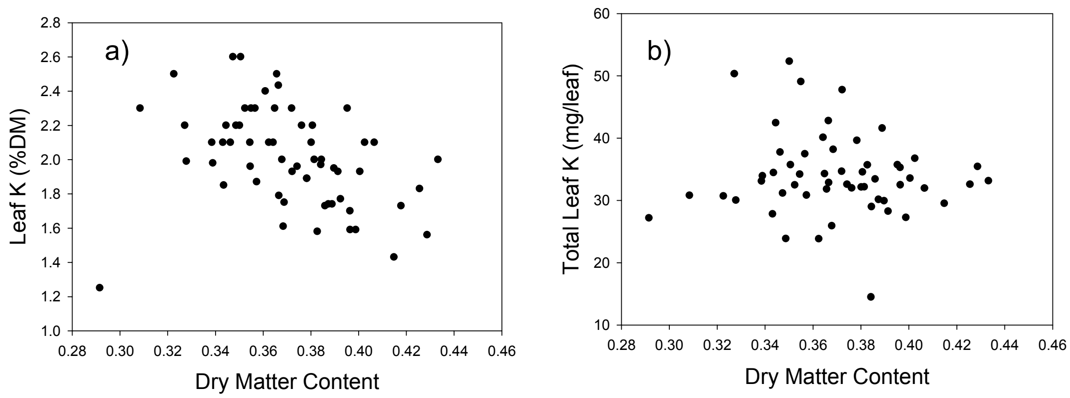


Figure 3. Relationship between leaf K concentration (a) or total leaf K (b) and leaf dry matter content.

Table 11. Leaf parameters by province (number of sites in each province in brackets)

	ENBP (11)	ARB (9)	NIP (9)	MaP (8)	ESP (8)	MoP (6)	NP (6)	WSP (4)	WHP (1)	mean	cv(%)
Shape of leaf (L/W)	2.8	2.8	2.8	2.8	2.9	2.8	2.7	3.0	2.7	2.8	6.5
Size of leaf (LxW, cm^2)	381	366	349	352	350	352	383	339	407	361	10.4
Fresh mass (g/leaf)	5.0	4.7	4.9	4.4	4.3	4.4	4.9	4.3	5.4	4.7	12.1
Dry mass (g/leaf)	1.8	2.0	1.7	1.6	1.7	1.7	1.8	1.6	1.9	1.7	11.9
Dry mass/ Fresh mass	0.36	0.42	0.35	0.37	0.39	0.39	0.37	0.37	0.35	0.37	7.9
Leaves per Flush	4.2	3.4	3.5	3.6	3.3	1.3	3.8	2.7	6.0	3.4	43.0

Mean and cv are calculated on the individual sites (61). Site 8 was excluded from the analysis as it had extreme values for some parameters.

7.3.4 Soil physical properties

For the most part the soils sampled in each province were similar to the general descriptions given by Bleeker and Freyne (1981). In ENBP most soils are volcanic ash soils derived from pumice and have medium to coarse textures (Bleeker and Freyne, 1981). All soil profiles sampled in this survey progressed from loam surface to sandy loam or clayey loam subsoils, with one exception, site 63, which had clay loam surface and medium clay with mottles at depth. On Buka Island (sites 8-11) in ARB, the soils were predominantly reddish clay soils, while on Bougainville Island they tended to have very dark loam topsoils and clay subsoils , with 2 sites (14 and 15) having sandy subsoils. All soil profiles in NIP tended to be shallow with very sticky reddish brown clay soils. In some profiles there was evidence of small shells and limestone fragments, and in others mottles and cemented layers indicating impeded drainage. Most of the sites sampled in MoP were situated around or to the west of Lae. Bleeker and Freyne (1981) describe these soils as generally having fine–medium textures, sometimes with inter-bedded sandy layers. The soils sampled in this region in this study generally fitted this description and had loam, silty loam or clay loam surfaces and progressed to either clay loams or more sandy loam subsoils. Most of the samples collected in NP were from the Mt. Lamington- Kokoda area. The soils sampled in this region in this survey were predominantly brown to gray-brown sandy loams to clayey sands and small stones and rocks were commonly encountered below the surface layers. Bleeker and Freyne (1981) describe the soils in MaP as being generally fine–textured. In this survey the 2 sites situated on Karkar Island (42 and 43) had shallow profiles and were coarse sandy loamy textures and volcanic rock fragments throughout the profile below about 30cm. The rest of the sites sampled on the mainland were all fine textured varying from clay or clay loam surface soils to light to medium clay subsoils The presence of gleyed mottling at site 45 suggests poor drainage. The soils in ESP were variable but fitted with the general description provided by Bleeker and Freyne (1981), being young alluvials with firm to friable clay and silty clay topsoils overlying stratified layers ranging from friable to firm sandy clay loams to clays. Evidence of poor drainage was common with many of the profiles having yellowish brown, brown to light gray mottles at depth. The soils in WSP were generally fine textured with loam, clay loam to light clay textures. Only two sites were sampled in WHP and both had clay loam to clay textures and mottling below 30cm. Site 61 was very stony throughout the entire profile. The landform and profile characteristics of the sites are provided in Appendix 11.5 and soil colour and field textures are in Appendix 11.8.

Root growth of cocoa is strongly influenced by the texture and structure of the soil profile. (Bleeker and Freyne, 1981; Freyne et al., 1996). Wood and Lass (1985) suggested that the ideal soil for tap root penetration and lateral root distribution needs to be composed of approximately 30-40% clay, 50% sand and 10-20% silt, but more important is the vertical distribution of textures throughout the soil profile. Freyne et al (1996) classified 63 soils from 12 provinces into 6 major types depending on their effects on root development. Soils from this study were classified into these 6 types (

Table 12) according to observations made in the field during sampling and to their texture (Appendix 11.8). The classification was approximate because the information collected in this survey did not correspond exactly with the criteria used by Freyne et al. (1996) to define the Types. It was estimated that approximately 42% of the sites had soils with little physical limitation to root growth and these were predominantly found in ENBP, MoP and MaP. The major soil characteristics encountered that could negatively impact on root growth was heavy texture (Group 3) found mainly in ARB and NIP, and the presence of gravel and stones (Group 4) which was most common in NP. The study of Freyne et al (1996) had a very similar proportion of sites in each of the 6 types as was found in this study.

Table 12. Grouping of sites according to their capacity to support root development (Freyne et al., 1996).

Category	Sites
Type 1: Soils with no physical limitation to root development within 1.5m of the surface	ENBP: sites 1, 2, 3, 4, 5, 6, 7 ARB: sites 14, 16 NIP: sites 21, 23 MoP: sites 29, 30, 31, 32, 33 NP: site 35 MaP: sites 41, 46 47, 48 ESP: sites 51, 57, 60 WSP: sites 55, 59
Type 2: Soils with imperfect to poor drainage resulting in restricted tap root development	ENBP: sites 26, 27, 28 ARB: site 2 ESP: sites 50, 53, 54 WHP: site 62
Type 3: soils with root development restricted due to heavy texture and/or poorly structured subsoils	ENBP: site 63 ARB: site 8, 9, 10, 13 NIP: sites 17, 18, 20 MaP: sites 44, 45 ESP: sites 49, 52 WSP: site56
Type 4: Soils with high content of gravel and/or stones within 1m of the surface	ARB: sites 12, 15 NIP: site 24 MoP: site 34 NP: sites 36, 37, 38, 39, 40 MaP: sites 42, 43 WSP: site 58 WHP: site 61
Type 5: Soils with hardpan, concretionary or indurated layer within 1m of the surface	NIP: site 25
Type 6: Soils <1m in depth, overlying bedrock or weathering parent material	NIP: site 22

7.3.5 Soil chemical and biological fertility

Assessing soil fertility is difficult due to the complexity of chemical, physical and biological factors involved. A comprehensive assessment of the effect of soil physical factors on cocoa root growth has been undertaken previously (Freyne et al. 1996). When it comes to chemical factors, several attempts have been made to provide critical values relevant to PNG (Table 13). There are no critical values for Colwell P for cocoa. Suggested critical levels for P based on the Olsen P method vary from 6 to 20.6 mg/kg (Table 13). Although results from the Colwell and Olsen methods are correlated, over a wide range of soils, conversion ratios (Colwell = Olsen x 1.6 for sands, x 2.0 for loams and x 3.0 for clay loams and clays) are indicative only (Victorian DPI, 2005). Generalised interpretation guidelines for Colwell P suggest critical values ranging from 20–50 mg/kg for a soil with low P status and moderate P sorption characteristics, depending on crop demand (Moody and Bolland, 1999). In addition to the critical values in Table 13, Bleeker (1983) recommended exchangeable Ca:K and Mg:K ratios of <20 and <10, respectively, for adequate K supply.

In this study, most of the soils could be considered reasonably fertile, with high exchangeable cation contents and desirable pH (

Table 14). Soil pHwater was >5 at most sites (0-0.15 m depth). pHCaCl2 was about 0.6 units less than pHwater (pHCaCl2 = 0.99 pHwater - 0.61, r2 = 0.90, over all depths). CEC was > 12 cmolc/kg at most sites (0-0.15 m depth) and was related to pHwater at the same depth (r2 = 0.39, p < 0.01), with the lowest values occurring in the most acidic soils. AEC was low, less than 3 cmolc/kg in all samples. Organic C content covered a wide range, from 1.4 to 8.1%, with a mean C:N ratio of 11 (0-0.15 m depth). Sites 51 and 60 had particularly low C contents. PBI0-15cm covered a wide range, from very low (<70) to high (>280). PBI and PSI were closely related (PBI0-15cm = 90.221Ln*PSI0-15cm - 311.3, r2 =0.99). Exchangeable K and Mg covered a wide range (

Table 14), and the relationship with leaf levels is discussed below. Soils in NIP (usually developed on raised coral) were generally acidic, with low exchangeable K contents (0-0.15 m depth). Soil properties for all depths at all sites are given in Appendix 11.8. Soil pH, CEC, exchangeable K, total N and Colwell P (0-0.15 m depth) are mapped in Appendix 11.12.

An active and balanced biological community is a critical component of soil fertility. Biological parameters were not measured, but biological activity is known to be determined principally by soil organic matter content (reported here as organic C) and the physical environment (water and air supply), and to a lesser extent by pH. The higher the organic matter content and aeration the higher the biological activity, whereas water content and pH have optimum levels, around field capacity for water content and neutral for pH. Most of the soils examined had good conditions for biological activity.

Principal components analysis was carried out to examine relationships between all soil parameters at all depths. The results showed several sites or groups of sites that stood out from the others: one site with particularly high organic C content in Northern Province; a group of sites with high CEC and exchangeable Ca contents, mostly in Morobe, one site with high salinity and exchangeable Na near the coast in New Ireland, and a group of sites with high exchangeable K contents, mostly in East New Britain (Figure 4, Table 15).

Many of the sites had ratios of exchangeable cations considered unfavourable for K uptake; 75% of sites had Ca:K ratios > 20 and 45% had Mg:K ratios > 10.

Table 13. Suggested soil 'critical' values (0-0.15 m depth) for cocoa in PNG based on existing literature.

	Fahmy, 1977[1]			**Bleeker& Freyne, 1981[2]**			**Hardy, 1958 [2]**	**CCRI 2002 report [3]**
	low	medium	high	low	medium	high	critical	assoc. with high yield
pH		5.5 - 6.5			6 – 7.5			>6.1
N %		> 0.20					0.2	>0.3
Org. C %		> 5			> 3.5		3.5	>4.6
C:N		8 - 10					not < 9	15.3
Ca ($cmol_c$/kg)	2 - 5	5 - 10	10 -20	4	12	24	8	>11.4
Mg ($cmol_c$/kg)	0.3 - 1	1 - 3	3 - 8	1	3	6	2	>2.7
K ($cmol_c$/kg)	0.2 - 0.3	0.3 – 0.6	0.6 - 1.2	0.20	0.35	0.55	0.24	>2.9
CEC ($cmol_c$/kg)	6 - 12	12 – 25	25 - 40	12-13 at 0–15 cm; > 5 below 15cm			> 12	>25.4
BS %							> 35	>68
Ca/Mg							not > 4	>4.2
(Ca+Mg)/K							not < 25	
P (mg/kg)	0 - 5	6 - 10	>10	20	60	120	40	>20.6

[1] 1:5 water pH, cations extracted with ammonium acetate, CEC leached with 10% NaCl, Olsen P (0.5M NaHCO3, pH 8.5, 1:20, 30 min extraction), Kjeldahl N, Walkley and Black organic C

[2] Truog P (0.001M H2SO4 + 0.3% (NH4)2SO4, 1:200, 30 min extraction)

[3] Olsen P

Table 14. Soil chemical fertility (0-0.15 m depth) in each province, with the number of sites per province in brackets. Values for each site are given in Appendix 11.8. (*Critical values for each parameter from Table 13)

	ENBP (11)	ARB (9)	NIP (8)	MaP (8)	ESP (8)	MoP (6)	NP (6)	WSP (4)	WHP (2)	All (62)
pH_{water} minimum	5.4	5.0	4.4	6.0	5.8	5.0	5.4	5.2	5.8	4.4
pH_{water} maximum	6.1	7.7	8.0	6.4	7.3	8.2	6.1	6.4	5.9	8.2
pH_{water} mean	5.8	5.9	5.9	6.2	6.5	6.4	5.7	5.8	5.9	6.1
Sites < pH 5.5*	18%	11%	25%	0	0	17%	33%	25%	0	15%
Exch. Ca min. ($cmol_c$/kg)	9.6	2.72	1.7	16.4	8.1	12.0	7.8	11.3	17.4	1.7
Exch. Ca max. ($cmol_c$/kg)	24.1	20.2	27.0	31.8	36.7	39.9	16.2	24.8	17.7	39.9
Exch. Ca mean ($cmol_c$/kg)	17.7	10.0	14.7	24.9	19.9	25.5	11.2	17.3	17.5	17.5
Sites < 5 $cmol_c$/kg Ca	0	11%	25%	0	0	0	0	0	0	5%
Exch. Mg min. ($cmol_c$/kg)	2.06	0.29	0.35	2.64	3.72	2.06	1.56	13.66	2.74	0.29
Exch. Mg max. ($cmol_c$/kg)	5.34	1.96	4.98	9.21	9.55	10.25	3.27	47.02	3.83	10.25
Exch. Mg mean ($cmol_c$/kg)	3.35	1.29	2.66	6.04	5.93	6.35	2.48	31.55	3.28	4.12
Sites < 1 $cmol_c$/kg Mg	0	11%	12%	0	0	0	0	0	0	3%
Exch. K min. ($cmol_c$/kg)	1.02	0.05	0.04	0.19	0.03	0.12	0.12	0.42	0.47	0.03
Exch. K max. ($cmol_c$/kg)	3.66	0.81	0.39	1.61	0.58	3.38	0.67	1.41	0.56	3.66
Exch. K mean ($cmol_c$/kg)	2.32	0.39	0.17	0.84	0.20	1.47	0.25	0.79	0.52	0.82
Sites < 0.31 $cmol_c$/kg K	0	33%	75%	12%	88%	17%	83%	0	0	37%
CEC min. ($cmol_c$/kg)	11.4	2.7	3.2	17.0	14.8	10.9	9.1	22.1	20.9	2.7
CEC max. ($cmol_c$/kg)	23.3	18.7	31.0	41.8	45.0	46.9	16.1	31.9	23.1	46.9
CEC mean ($cmol_c$/kg)	19.4	10.4	17.7	33.8	27.2	29.8	11.9	25.9	22.0	21.5
Sites <12 $cmol_c$/kg CEC	9%	67%	7%	0	0	33%	67%	0	0	23%
Colwell P min. (mg/kg)	17.3	7.1	7.5	9.3	3.1	1.9	9.5	16.5	49.1	1.9
Colwell P max. (mg/kg)	143.0	55.3	120.2	78.7	24.0	57.9	47.1	30.5	127.6	143.0
Colwell P mean (mg/kg)	65.6	22.7	42.0	34.0	13.0	22.1	27.6	25.9	88.4	35.8
PBI min.1	47	56	138	76	48	50	80	71	120	47
PBI max.	201	429	423	538	97	556	658	114	132	658
PBI mean	154	145	284	208	74	196	317	92	126	181
Organic C min. (%)	2.53	1.53	2.57	2.02	1.42	2.17	2.48	2.41	3.12	1.42
Organic C max. (%)	3.85	3.48	4.64	5.31	3.70	7.24	8.08	4.63	3.41	8.08
Organic C mean (%)	3.35	2.52	3.49	3.88	2.60	3.83	5.00	3.30	3.26	3.42
Extr. Zn min. (mg/kg)	1.95	0.12	0.26	0.55	0.40	0.30	0.16	0.71	3.14	0.12
Extr. Zn max. (mg/kg)	6.27	4.72	9.73	7.92	12.13	2.64	2.79	0.92	3.43	12.13
Extr. Zn mean (mg/kg)	3.34	1.91	4.53	2.06	2.29	0.88	0.91	0.77	3.29	2.34
Extr. Cu min. (mg/kg)	0.24	0.37	0.49	3.31	0.64	0.57	0.24	2.43	2.72	0.24

	ENBP (11)	ARB (9)	NIP (8)	MaP (8)	ESP (8)	MoP (6)	NP (6)	WSP (4)	WHP (2)	All (62)
Extr. Cu max. (mg/kg)	1.36	2.90	6.42	6.04	2.47	4.58	0.87	3.58	3.61	6.42
Extr. Cu mean (mg/kg)	0.78	1.38	2.66	4.62	1.47	2.59	0.53	2.82	3.20	2.06
Extr. Mn min. (mg/kg)	0.6	2.7	2.5	0.4	3.2	1.9	0.5	6.1	23.3	0.4
Extr. Mn max. (mg/kg)	29.2	126.1	144.0	18.4	28.3	8.4	9.7	13.2	34.8	144.0
Extr. Mn mean (mg/kg)	7.9	41.5	48.6	10.0	12.4	4.8	3.3	10.7	29.0	19.0
Extr. Fe min. (mg/kg)	14.7	7.7	13.2	43.2	11.3	5.4	8.2	63.5	80.0	5.4
Extr. Fe max. (mg/kg)	54.2	35.0	58.4	83.4	68.4	65.2	71.6	130.1	118.5	131.0
Extr. Fe mean (mg/kg)	35.3	21.6	32.6	53.9	36.4	39.3	30.9	93.2	99.3	41.3
CaCO3 equiv. max. (%)[2]	6.8	3.0	44.6	0	6.6	16.0	0	0	0	44.6

1 PBI ratings: <35 very, very low, 36-70 very low, 71-140 low, 141-280 moderate, 281-840 high, >840 very high

[2]*Minimum and mean not determined, because samples with pH_{water}<6.5 (which existed in all provinces) were not analysed. Minimum is probably zero in all provinces.*

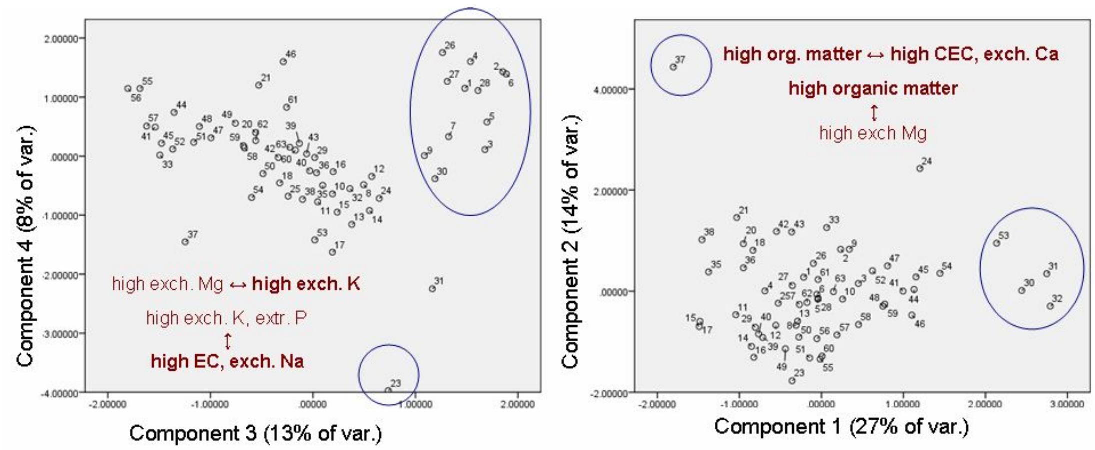


Figure 4. Grouping of sites by soil chemical properties using Principal Component Analysis. Contribution of each soil parameter to the four Principal Components shown is given in Appendix 11.10.

Table 15. Sites or groups of sites that had chemical properties distinct from the other sites.

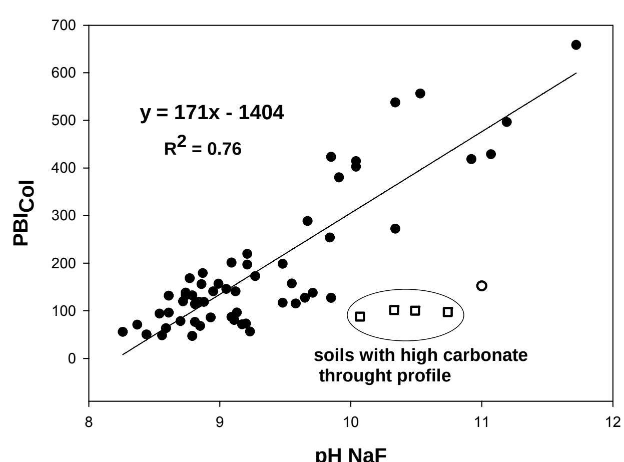
Site	Province	LLG	Name of Block
High organic matter content (>3.5% C, >0.25% N throughout profile)			
37	Northern	Kokoda	Ombite
High exchangeable Ca (>25 cmolc/kg throughout profile)			
30	Morobe	Wampar	Ngawapog
31	Morobe	Umi - Atzena	Kaput
32	Morobe	Wampar	Block 4
53	East Sepik	Numbo	Hembenjanka
High exchangeable K (>2 cmolc/kg throughout profile)			
01	ENB	Central Gazelle	11A-IDM Plot
02	ENB	Central Gazelle	11A-IDM Plot
03	ENB	Inland Baining	CCI-OFT-SG2- Hybrid small plot
04	ENB	Central Gazelle	Block.8

05	ENB	Gazelle Central	5A (Mutant Segregant Studies)
06	ENB	Central Gazelle	
07	ENB	Kokopo/Vunamami	OFT-Bitavavar (Taliligap)
26	ENB	Bitapaka	CCI Cocoa Breeding Multilocation Trial.
27	ENB	Kokopo-Vunamami	IDM Trial Option 1
28	ENB	Bitapaka	Agronomy OFT (Intermediate plot)
09	ARB	Hagogohe	Mangoana Project
30	Morobe	Wampar	Ngawapog
31	Morobe	Umi - Atzena	Kaput
Saline (Na>2.5 cmolc/kg, EC>750 µS/cm, 0-30 cm depth)			
23	New Ireland	West Coast Central	Block 88
High P (>90 mg/kg Colwell P throughout profile) and micronutrients			
21	New Ireland	Central New Ireland	Besen

7.3.6 Soil mineralogy

Soil mineralogy varied considerably between sites. However, as mineralogy was determined for selected sites only, it was not possible to comprehensively analyse the relationships between mineralogy and and nutrient status of the soils and plants. Less weathered soils were dominated by glass or feldspar, while more weathered soils were dominated by halloysite (kaolinite) and also contained iron oxides (Table 16). Degree of weathering was also evident in the relative contents of Si and Al + Fe (Table 17). Smectite dominated in soils in MoP and MaP.

Of the soils analysed for allophane, most had contents < 2% in the 0.3-0.6 m depth layer, with the highest content being 10.6% in Kokoda in NP (Table 16). All the sites in MoP and MaP had allophane contents between 2.7 and 6.2%. Allophane is very reactive and capable of strongly sorbing phosphate, and allophane content (0.3-0.6 m depth) was significantly correlated with PBI (0-0.15 m depth) (r = 0.69). Allophane content was also correlated with pHNaF (r2=0.61), so pHNaF could be used to estimate the allophane content of all soils; pHNaF> 9.5 was a fairly reliable indicator of the presence of at least some allophane. In MaP, MoP and NP, most of the sites had pHNaF > 9.5, whereas in ESP, WSP and WHP no sites had pHNaF> 9.5 (Table 18). There was a strong relationship between pHNaF and PBI for soils not containing carbonate



(

Figure 5).

Table 16. Mineralogy of selected sites (0.3-0.6 m depth, full results in Appendix 11.9)

Site	Quartz	Amorphous (Glass)	Na/Ca Feldspar	Calcite	Smectite	Halloysite	Allophane (%)	Other minor1
ENBP								
7	-	D	M	-	-	-	0.8	-
28	T	D	M	-	-	M	1.1	-
63	M	M	T	-	M	D	1.2	H, Go, Cr
ARB								
10	M	-	M	-	M	D	0.8	-
15	T	-	D	-	-	-	3.2	-
NIP								
17	M	-	-	-	-	D	0.2	Go
22	D	M	M	-	-	-	0.9	Cl, P
24	T	-	-	-	-	D	2.9	Go, Gi
MoP								
31	SD	M	SD	-	D	-	6.2	Z
33	M	CD	SD	-	CD	T	5.0	Z, Cr, P
34	T	CD	T	-	CD	M	3.4	P
NP								
37	SD	M	D	-	-	-	10.6	A, Cl
40	M	T	CD	-	-	CD	1.0	A, Cr
MaP								
43	M	D	SD	-	-	-	5.6	P
45	M	M	M	-	D	M	2.7	-
ESP								
51	D	T	SD	-	M	-	0.4	-
53	D	-	SD	SD	M	T	0.5	-
60	D	M	SD	-	M	T	1.0	-
WSP								
55	D	-	SD	-	M	-	0.7	Cl
58	CD	-	CD	-	M	-	2.1	Cl
WHP								
62	D	-	M	-	M	M	0.6	-

D is Dominant (>60%), CD is Co-dominant (sum >60%), SD is Sub-dominant (20-60%), M is Minor (5-20%), T is Trace (<5%).

1A is amphibole, Cl is chlorite, Cr is chrisobalite, Gi is gibbsite, Go is goethite, H is haematite, P is pyroxene (augite), Z is zeolite/stilbite/laumonite.

Table 17. Total elemental content of selected sites (0.3-0.6 m depth, full results in Appendix 11.9)

Site	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	MgO (%)	CaO (%)	Na_2O (%)	K_2O (%)	P_2O_5 (%)
ENBP								
7	61	16.6	5.7	1.62	4.00	3.76	2.25	0.31
28	48	17.4	10.6	4.97	4.36	1.37	1.03	0.24
63	46	26.8	9.8	1.42	2.41	0.98	0.32	0.14
ARB								
10	50	23.0	13.3	0.20	0.07	0.01	0.03	0.43

15	69	12.9	8.0	1.99	1.85	1.25	0.80	0.10
NIP								
17	33	31.1	15.5	0.50	1.45	0.06	0.08	0.48
22	60	17.8	5.9	1.27	2.89	3.22	2.12	0.23
24	51	15.4	11.2	4.81	4.48	1.86	1.17	0.17
MoP								
31	37	20.6	15.4	5.48	3.20	0.19	0.81	0.42
33	46	19.6	7.2	3.09	3.43	2.33	0.54	0.45
34	53	21.6	8.3	2.56	3.17	2.61	1.21	0.11
NP								
37	50	19.8	11.2	3.04	6.95	1.87	0.71	0.28
40	49	18.7	13.5	2.93	3.60	0.67	0.48	0.05
MaP								
43	67	14.1	6.4	1.89	1.52	2.00	0.98	0.07
45	52	13.7	6.9	1.76	10.44	1.15	0.84	0.10
ESP								
51	60	16.8	8.5	3.64	1.73	1.99	1.53	0.12
53	60	16.0	8.6	3.66	4.70	3.18	0.81	0.10
60	46	22.1	16.3	0.92	0.90	0.44	0.25	0.11
WSP								
55	62	14.9	7.5	3.54	4.40	2.88	1.00	0.12
58	61	17.6	8.6	1.19	0.63	0.95	1.45	0.09
WHP								
62	50	18.2	10.3	5.26	10.24	2.15	0.30	0.11

Table 18. pHNaF of soils with <5% CaCO3 equivalent (0.3-0.6 m depth) in each province, with the numbers in brackets giving the number of sites without CaCO3. pHNaF > 9.5 indicates the presence of allophane.

	ENBP (9)	ARB (8)	NIP (7)	MaP (3)	ESP (6)	MoP (3)	NP (6)	WSP (2)	WHP (2)	All (43)
pH_{NaF} minimum	8.74	8.37	8.99	8.88	8.26	8.44	9.11	8.61	8.72	8.26
pH_{NaF} maximum	9.55	11.1	10.0	10.3	8.85	10.5	11.7	8.81	8.74	11.7
pH_{NaF} mean	9.02	9.44	9.66	9.75	8.58	9.60	10.5	8.71	8.73	9.40
Sites with pHNaF >9.5	11%	25%	71%	67%	0%	67%	67%	0%	0%	37%

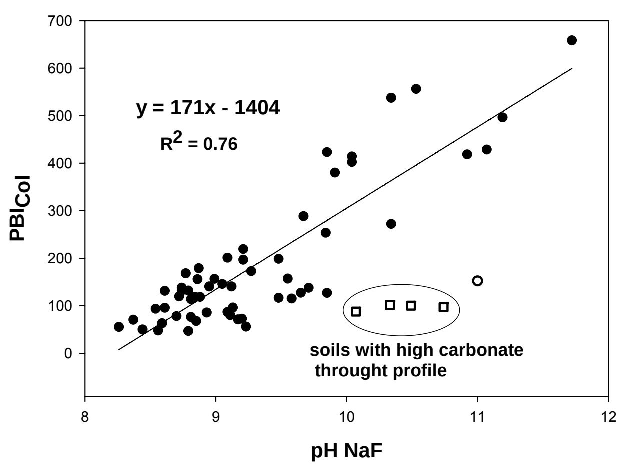


Figure 5. Relationship between PBI and pHNaF.

7.3.7 Relationship between leaf nutrient concentrations and soil properties

Principal components analysis showed several relationships between leaf nutrient concentrations and soil parameters (Figure 6). The sites with high soil exchangeable K contents had the highest leaf K values. The sites with high soil CEC and exchangeable Ca contents and smectite mineralogy had the highest leaf Ca and B values. The site with high soil organic matter did not have particularly low or high contents of any cations.

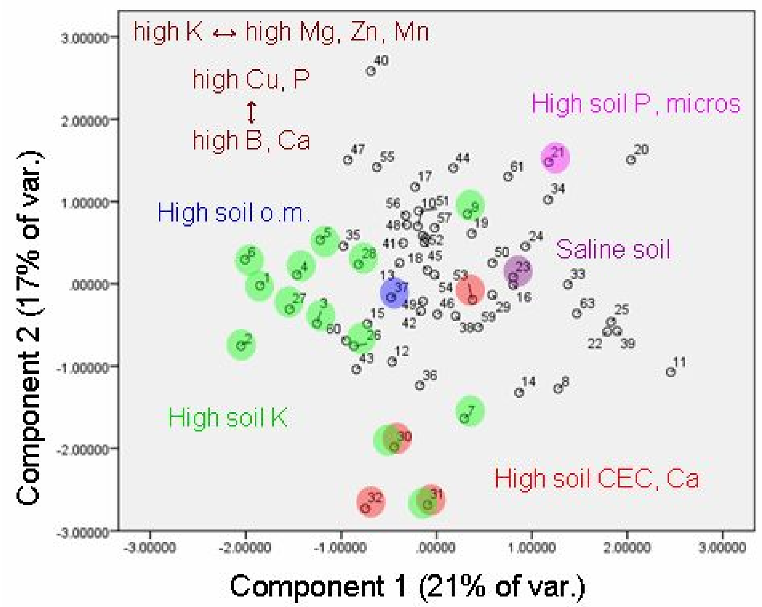


Figure 6. Principal components plot of leaf nutrient concentrations, with coloured circles and labels showing site groupings based on Principal Component analysis of soil properties. The contribution of leaf parameters to the Principal Components is shown in brown and detailed in Appendix 11.10.

There was a reasonable relationship between soil and leaf nutrient levels for K and P, but not for other nutrients. Leaf K concentration increased steeply with increasing soil exchangeable K at low soil concentrations and then reached a plateau (Figure 7). Leaf K content was also positively correlated with the ratio of exchangeable K:Ca. The relationship between leaf P and soil Colwell P was similar to that between leaf K and soil exchangeable K (Figure 7). There were no significant relationships between leaf and soil concentrations for other elements.

Bleeker (1983) noted that past nutritional studies of cocoa have shown that N deficiencies were common even when soil N status was high and this was attributed mainly to high light/poor shade conditions. There was no obvious relationship between leaf N and shade conditions in this data set. High soil C:N ratios can also be indicative of plant N deficiencies. However, there was no relationship between leaf N concentration and soil total N content or leaf N concentration and soil C:N ratio. Most sites had soil C:N rations (0-0.15 m depth) in the range 7–15, similar to the range (8-14) for PNG soils reported by Bleeker (1983).

Sites that had leaf concentrations below critical levels did not necessarily have soil concentrations below critical levels, nor vice versa. This discrepancy is likely to be due largely to inadequacy of the ‘critical levels’ being used, which have only ever been described as ‘tentative’. There is a clear need to produce reliable critical levels for PNG, particularly for leaf nutrient concentrations. In addition, there are not yet any guidelines for the adequacy of soil micronutrient concentrations. In our survey there appeared to be low or deficient concentrations of Fe in particular, and also Zn and Cu at some sites, but there are no guidelines for the required soil levels of these nutrients. However, for K and P there was a degree of correspondence between leaf and soil critical values. All sites with leaf K concentrations less than the critical level 1.6% had soil exchangeable K contents less than the critical level of 0.3 $cmol_c$/kg (Figure 7). Thirty seven % of all soils were deficient in K but only 10% of leaf samples were deficient. All sites with leaf P concentrations less than the critical level of 0.16% had soil Colwell P contents less than 25-50 mg/kg, which is the range of critical levels commonly cited for other crops (Moody and Bolland, 1999). Approximately 60% of the sites had soil P contents below this value. For Mg there was little correspondence between leaf and soil levels; 64% of sites in ENBP were classed as deficient in Mg according to leaf analyses but none of the ENBP sites had low soil exchangeable Mg contents.

Nutrient interactions, for example between Mg and K, were observed, and this could have further implications for interpretation of soil and leaf critical levels. Over all sites in all provinces there was a significant correlation between the ratio of soil exchangeable K:Mg and the uptake of leaf Mg (r = -0.51). A possible implication of this interaction is that as deficient levels of soil K are ameliorated, in cases where leaf Mg may be currently marginal, it may become deficient. This suggests that critical levels may need to be based on nutrient concentration ratios as well as absolute concentrations.

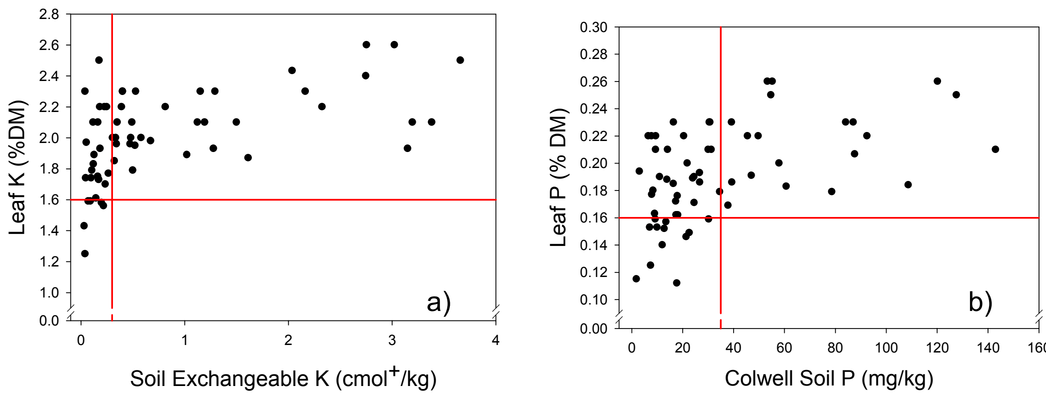


Figure 7. Relationship between (a) leaf K and soil K (0-0.15 m depth) and (b) leaf P and soil P (0-0.15 m depth). The red lines show published critical values. For soil P the critical value shown is the median of those established for other crops (25-50 mg/kg), as no critical level for Colwell P has been established for cocoa.

7.4 Interactions between nutrient contents and other factors

7.4.1 Nutrient status and planting material

There were differences in leaf nutrient concentrations between clones grown at the same site under the same management (Table 19). The clones used as male parents had lower N, K, S, Fe, Mn, B and Zn contents than those used as female parents. Both male parents were classified as deficient in N. Of the female parents, KEE43 had lower Ca, Mg, Fe and Mn concentrations than all the others. All clones had N concentrations around or below the critical concentration and S concentrations above normal. Other nutrient concentrations were in the normal range.

The differences between clones indicate that it may be possible to select for nutrient uptake properties. Before that were to be attempted it would be necessary to know if leaf nutrient contents are related to nutrient use efficiency, i.e. to total nutrient uptake by the trees and especially to yield. It would also be necessary to know if nutrient uptake traits are inherited from the male, female or both parents.

Table 19. Leaf nutrient concentrations of clones in the CCI seed garden at Tavilo, ENBP. Deficient or subnormal levels are shown in bold.

Clone	N %	K %	Ca %	Mg %	P %	S %	Fe mg/kg	Mn mg/kg	B mg/kg	Cu mg/kg	Zn mg/kg
KA2-106M	1.9	2.2	1.20	0.35	0.19	0.17	35	42	35	7.3	33
K82M	1.9	2.2	1.12	0.38	0.18	0.17	30	40	38	6.4	29
KEE12[F]	2.3	2.4	1.35	0.39	0.19	0.21	48	67	43	6.8	34
KEE47[F]	2.1	2.3	1.11	0.43	0.23	0.21	48	51	42	8.3	41
KEE43[F]	2.3	2.5	0.81	0.35	0.22	0.20	38	42	42	8.1	38
KEE5[F]	2.1	2.5	1.81	0.40	0.21	0.21	47	102	45	8.3	41
KEE23[F]	2.1	2.3	1.16	0.39	0.20	0.20	46	54	43	8.1	41
KEE42[F]	2.2	2.3	0.96	0.39	0.21	0.20	49	73	39	8.3	34

[M] Used as male parent in released hybrids. [F] Used as female parent in released hybrids

7.4.2 Nutrient status and management

Some effects of management on nutrient status were detected. Sampling of the Option 1 (minimal management inputs) and Option 4 (pruning, shade control, weeding, disease control, fertiliser) plots of the IPDM trial at Tavilo showed effects of fertiliser treatment on leaf and soil nutrient contents (Table 20). Fertiliser increased leaf P and K concentrations but not N concentrations. Soil extractible P was increased but exchangeable K content was not. Over the whole data set there were no clear relationships between leaf N concentration and management factors such as previous fertiliser applications, presence of legumes, shade management or length of time under agricultural production.

Table 20. Effect of treatment on soil and leaf nutrient concentrations at Tavilo IPDM trial.

Parameter	Plus NPK fertiliser[1] (Site 1)	No fertiliser[2] (Site 2)
Leaf N (%)	2.25	2.25
Leaf P (%)	0.21	0.18
Leaf K (%)	2.43	2.30
Soil Colwell P (mg/kg, 0-0.15 m)	88	61
Soil exchangeable K (cmolc/kg, 0-0.15 m)	2.0	2.2
Soil exchangeable K/Ca (0-0.15 m)	8.4	7.7

[1]Option 4, including following fertilisers: urea 50g/tree x2 applications per year, NPK 120g/tree x2 applications per year. [2]Option 1

7.4.3 Nutrient status and disease

The severity of black pod disease (caused by a *Phytophthora* fungus) was recorded at each site. Almost all sites recorded some level of black pod disease. As it is known from research with other species that Zn adequacy can increase resistance to some *Phytophthora* infections, we examined the relationship between black pod and Zn levels in leaf and soil. Although low levels of Zn does not necessary mean that pods will be infected, it appears (apart from one outlier) that pods that are infected come from plants with lower levels of leaf Zn (Figure 8). Similarly, again with a couple of outliers, it appears that high severity of black pod only occurs when soil Zn is low (Figure 8).

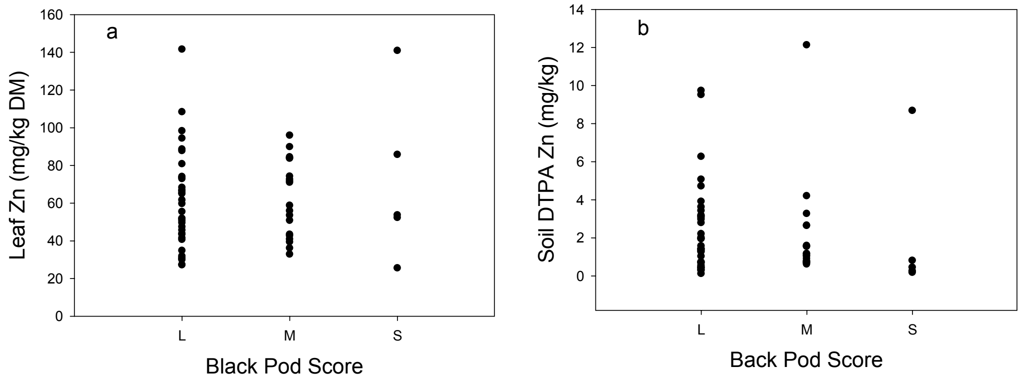


Figure 8: Relationship between Black Pod score and a) leaf Zn and b) soil Zn (L=light; M=medium, S=severe infection).

7.4.4 Nutrient status in relation to landforms and agroecological zones

Hanson et al (1998) used the Papua New Guinea Resource Information System (PNGRIS) data base to define 6 landform classes: Depositional Floodplains, Depositional Plans and Fans, Volcanic Plains and Fans, Erosional Limestone Plains, Erosional Hills, and Erosional Mountains. Sampling sites were allocated to the appropriate landform class and chemical analysis of the soils grouped according to class to determine if there was any pattern that could be used to classify the landform in terms of their soil chemistry. For example, although organic C content ranged from 1.4 to 8.1% (Figure 9), there were some patterns with landform class. Depositional Floodplains tended to have the lowest organic C content, with all sites being less than 4%. Similarly, Erosional Hills had values between 1 and 4%. By contrast, Depositional Plains and Fans had the highest and widest range of values. As expected, Total N showed a similar pattern to organic C content, with Depositional Floodplains, Erosional Limestone Plains and Erosional Hills generally low and tightly grouped compared to Depositional Plains and Fans. By contrast, Colwell P content was low and tightly grouped in Depositional Plains and Fans in comparison to Depositional Floodplains (Figure 9).

Hanson et al (1998) separated each land form into agroecological zones based on annual rainfall and rainfall seasonality. However, allocating soil chemical data to agroecological zones did not provided any clearer pattern.

Expressing soil chemical data in terms of rainfall produced some interesting patterns. While the results for organic C, total N, and Colwell P covered a wide range at any one rainfall bracket, it was only at the higher rainfall brackets that the higher levels of all 3 parameters occurred (Figure 10).

The dominant soil Great Group (Table 21) of each mapping unit was also used as a basis to compare site soil chemical characters. Again, some soils show a strong grouping and others a wide range. For example, there was no overlap in CEC between the Fluvaquents and the Tropofluvents (Table 22) and the two Haplustolls have a very high exchangeable K contents compare to most other soils examined. But it is not always so clear cut; within the Tropudalfs, there were two distinct ranges. It should be kept in mind that the allocation of soil Great Groups was made using the version of Soil Taxonomy that did not yet include the Andisol order (volcanic ash soils). Therefore, most volcanic ash soils fell into the Entisol or Inceptisol orders.

Leaf analysis showed little pattern with respect to dominant soil classification or landform.

Table 21. Dominant soil Great Groups (Soil Survey Staff, 1975) in PNGRIS mapping units sampled.

PNGRIS Code	Soil Great Group	Soil Description
113	Fluvaquents	Poorly drained, undifferentiated soils with high (>=0.2%) or variable organic C contents to >=125cm
131	Tropofluvents	Mainly well drained undifferentiated soils with high (>=0.2%) or fluctuating organic C to >=125cm
141	Troporthents	Undifferentiated, mostly shallow soils typically found in wet climates on moderate to steep slopes
232	Tropofibrists	Swampy, slightly decomposed, organic soils with interbedded mineral layers
322	Eutrandepts	Slightly weathered ash soils with high (>=50%) base saturation values and thick black topsoils
324	Vitrandepts	Slightly weather ash soils having dominantly sandy or gravelly texture and black topsoils
331	Humitropepts	Moderately weathered soils having high OC contents (>+12kg/sq m) and low base saturation subsoils
333	Eutropepts	Slightly to moderately weathered soils with altered B horizon and high (>+50%) subsoil base saturation values

334	Dystropepts	Moderately weathered soils with altered B horizon and low (<=50%) subsoil base saturation values
512	Haplaquolls	Poorly drained, weekly acid to alkaline soils with thick, dark topsoils
520	Rendolls	Shallow, dark, weakly acid to neutral soils formed on calcareous parent material
534	Haplustolls	Weakly acid to alkaline soils with thick, dark topsoils and subject to seasonal moisture stress
542	Hapludolls	Weakly acid to alkaline soils with thick dark topsoils and high (>=50%) base saturation values
632	Rhodudalfs	Well to imperfectly drained, moderately weathered soils with finer textured bright red subsoils
633	Tropudalfs	Well to imperfectly drained, moderately weathered soils with finer textured subsoils

Table 22. Range of soil chemical properties according to dominant soil Great Group in relevant PNGRIS mapping unit.

Great Group	No. Sites	pH_{CaCl2}	Organic C %	CEC ($cmol_c$/kg)	Exch. K ($cmol_c$/kg)
Fluvaquents	5	5.0-5.3	2.5-5.1	9-15	0.12-0.22; 0.39
Tropofluvents	9	5.3-6.1	1.4-3.8 (8.1)	16-24;40	0.11-0.67; 1.6-2.8
Troporthents	2	4.6-5.3	5.6-7.2	24-40	0.34-0.31
Tropofibrists	1	4.6	3.5	3	0.05
Eutradepts	10	5.1-6.1	2.2-6.2	9-20;31	0.12-0.40; 1.2-3.0
Vitrandepts	1	5.0	1.9	8	0.48
Humitropepts	1	5.4	3.1	23	0.47
Eutropepts	1	5.9	4.1	36	1.2
Dystropepts	8	4.6; 5.1-6.0	2.4-4.9	12;21-32;42	0.16-0.19; 0.4-1.0
Haplaquolls	1	5.6	3.6	30	1.12
Rendolls	4	4.1-5.7	2.6-2.9; 3.6-3.8	3-6;18-21	0.04-0.2
Haplustolls	2	5.3-7.8	2.5-2.7	11-46	3.2-3.4
Hapludolls	1	6.4	3.7	41	0.58
Rhodudalfs	4	4.9-5.8; 7.4	1.5; 2.4-3.1	7;13-19	0.24-0.81
Tropudalfs	12	5.3-7.8	1.8-4.6	15-47	0.07-1.5; 3.2-3.7

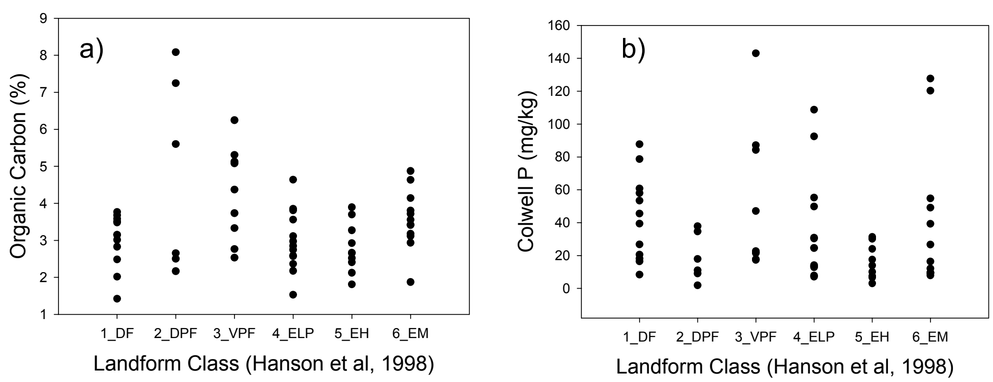


Figure 9. Soil organic C (a) and Colwell P (b) contents (0-0.15 m depth) for sampled sites grouped by landform class. Depositional Floodplains (DF), Depositional Plans and Fans (DPF), Volcanic Plains and Fans (VPS), Erosional Limestone Plains (ELP), Erosional Hills (EH), and Erosional Mountains (EM).

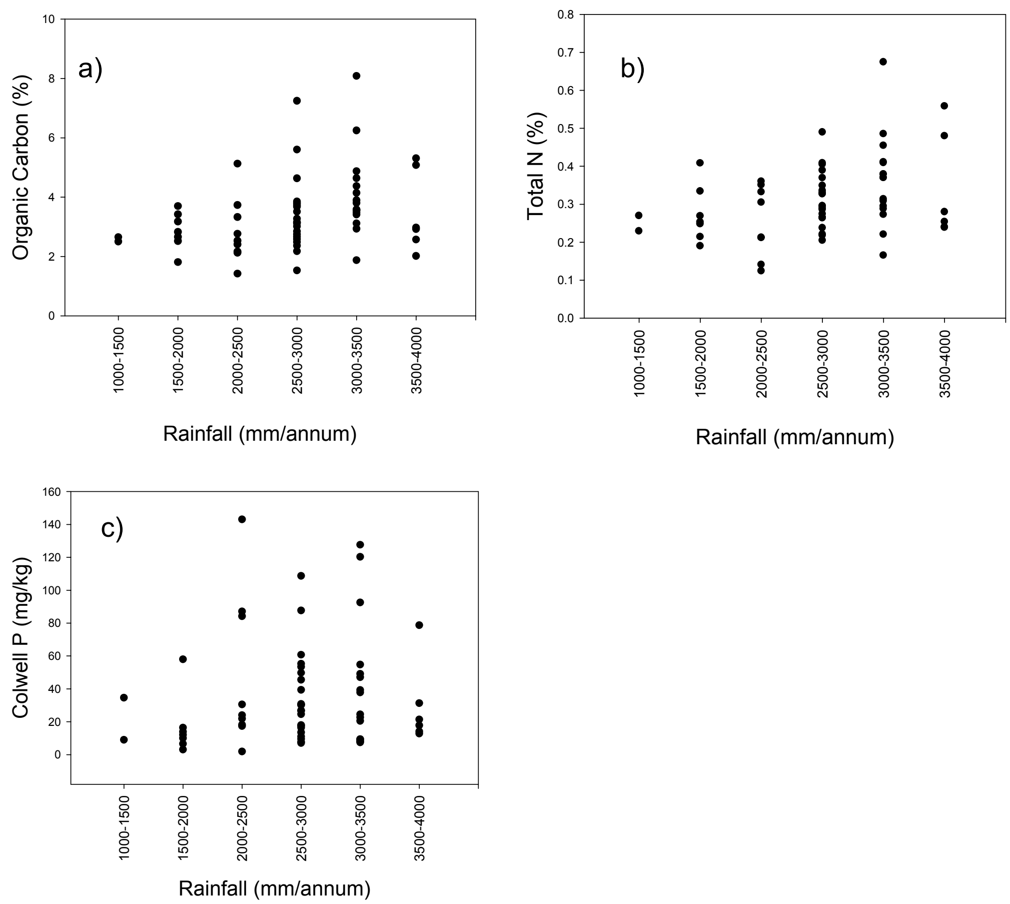


Figure 10. Relationship between a) organic C, b) total N, or c) Colwell P content of soils (0-0.15 m depth) and rainfall.

7.5 Nutrient export

Nutrient exports, calculated from pod analyses, were generally within the range measured elsewhere (Hartemink, 2005), but were at low end for N export and higher than the highest previously reported values for K in beans (

Table 23). In this data set there were no significant relationships between husk or pod nutrient contents and leaf nutrient contents for N, K, Mg, Fe but there was a significant relationship between husk P and leaf P (husk P = 0.535 leaf P + 385.6, in mg/kg, $p=0.01$, $r^2 = 0.69$).

Nutrient exports in cocoa beans are not large in PNG, particularly considering the low yields. However, nutrient supplying capacity of the soil must run down over time, when other losses are considered. To ensure long-term sustainability of cocoa production the nutrients must be replaced. Of the smallholder blocks surveyed, 85% had been in agricultural production for more than 17 years, with no application of fertilisers. 62% had been producing cocoa for more than 17 years.

The concentrations of all elements measured in the pods, including heavy metals, are recorded in Appendix 11.11.

Table 23. Nutrient removed in kg per tonne of dry beans, assuming a moisture content of 7%.

	Site	N		P		K	
		beans	husks	beans	husks	beans	husks
*World minimum**		*19.2*	*10.6*	*3*	*1.3*	*7.5*	*27.2*
*World maximum**		*39.3*	*31.4*	*4.6*	*2.3*	*10.9*	*77.2*
ENB	4	17.5	10.3	4.6	1.6	13.6	41.6
ENB	63	20.5	5.9	4.6	0.8	11.3	21.8
ARB	8	18.8	5.6	4.8	0.8	11.7	27.4
NIP	18	21.1	10.4	5.0	1.3	14.8	33.2
NIP	25	20.3	10.2	3.3	0.7	11.2	29.2
MoP	34	17.6	12.1	4.7	1.9	14.0	41.6
NP	35	22.1	11.5	4.4	1.4	11.1	40.2
MaP	44	20.2	13.5	4.9	2.2	11.3	48.7

** Malaysia, Central America, South America, West Africa, summarised in Hartemink (2005)*

8 Impacts

8.1 Scientific impacts – now and in 5 years

Now

The main impact of this study has been to indicate the scope of nutrition-related issues in PNG that should be examined if cocoa productivity is to be increased and maintained.

Results of the work have already been requested and applied in other studies; Dr Jane Crozier (CABI) requested pod nutrient concentrations for a review on heavy metals in cocoa, and Nur Sholecha Ruseani, agronomist with Bah Lias Research Station (PT London Sumatra) requested leaf nutrient concentrations for comparison with their research in Indonesia.

The tissue and soil nutrient status survey conducted as part of this project is the most comprehensive, representative and well-documented survey (with records of block characteristics and location) conducted in PNG. The study has established the range of values for leaf nutrient contents and soil chemical fertility parameters across the cocoa production areas of PNG. Thus, the type of nutritional problems and their extent has been established, as well as a baseline for future research on cocoa nutrition in PNG. Although N deficiencies were expected, the widespread extent of N deficiency was greater than expected. Indeed, 95% of sites sampled had leaf N concentrations less than adequate, with every province having at least 75% of sites showing deficient levels. In addition to N deficiency, Fe deficiency was widespread and P and Mg deficiencies were common. It was expected that K deficiency would also be common, especially on soils developed on raised coral in NIP. However, only a few sites showed leaf K concentrations that could be considered deficient. By contrast, low soil exchangeable K contents were more widespread than expected, being common in several provinces in addition to NIP.

Significant relationships were established between tissue and soil nutrient contents for K, Ca and P, but not for other nutrients, which prompts several questions about mechanisms and diagnostic methods for cocoa nutrition. It is clear that most of the current critical levels for tissue and soil nutrient contents are not reliable diagnostics for cocoa in PNG.

The research in this project has also revealed previously unkown information on interactions between tissue nutrient concentration and genotype. This new information is important because it suggests the possibility of genetic selection for nutrient uptake properties.

Because of the low use of fertiliser it is important to identify nutrient loss pathways. In this project the quantity of nutrients in cocoa beans and husks has been quantified, allowing the losses of nutrient in product export to be calculated and the value of recycling husks to be assessed.

5 years

The results of the project form a basis for a focussed and effective nutrition research program which should within 5 years be able to provide explanations for the main mechanisms influencing nutrient uptake and response of cocoa in PNG.

8.2 Capacity impacts – now and in 5 years

Now

Agronomists and agronomy technical staff in CCI (7 in total) markedly improved their skills in several areas due to the project. Through training and then conducting the survey, the main areas of skills enhancement were in: organisation of staff and resources; preparation of equipment and procedures before going into the field; leaf sampling techniques; soil sampling techniques. These skills are highly relevant to other research projects carried out by CCI

Some items purchased by the project have significantly enhanced capacity for tissue and soil sampling and processing at CCI:

- 2x Soil auger
- 2x soil sieve (4 mm)
- 1x hand-held GPS
- 1x CD/DVD burner
- 2x kitchen scales
- 4x blender for grinding leaf, bean and husk samples
- 1x digital camera

5 years

The results of the project form the basis for a focussed and effective nutrition research program which should within 5 years significantly enhance capacity within CCI (data processing, field trials, sampling) and within NARI (methods of soil and plant analysis for cocoa). Examples of opportunities expected to increase capacity are:

- Data handling from field to database to reporting
- Agronomy procedures manual for CCI
- Train the trainers: eg. Short courses for key staff who can pass on those skills to other researchers as well as growers. Such course would include raining in biometrics, spreadsheets, book-keeping, communication, writing, and experimental design – especially for CCI and NARI officers
- New analytical procedures at NARI
- Improved preparation facilities at CCI
- Postgraduate study for CCI agronomists trhough the JAF scheme associated with ACIAR projects
- PNG partners undertaking short-term visits to Australian research institutions
- Encouraging students from UNRE and Unitech to be involved in discrete research projects related to the main research project
- Establishment of CCI Agronomy Section facilities at CCI station at Madang

8.3 Community impacts – now and in 5 years

Now

Even though this was only a scoping study and without specific community impact milestones, 48 smallholder households and 6 plantation managers across the country were made aware of nutrient management issues during the survey. That awareness may well flow through to management improvements. In addition, knowledge of the role of nutrition in productivity of cocoa in PNG was enhanced among the 52 participants of the second workshop. Those participants included smallholders, plantation managers, consultants, industry organisation staff and researchers from throughout the country.

5 years

Future nutrition R & D flowing from this project will aim to have major community impacts; in increased incomes for growers and improved skills and knowledge about nutrient management.

8.3.1 Economic impacts

The results of this project indicate that it will be possible to substantially increase smallholder incomes and returns on investment through improved nutrient management. Even small increases in productivity have the potential for major economic impacts, due to the large number of households involved in cocoa production. The plan is to encourage adoption of nutrient management practices with high benefit:cost ratios by linking commercial service providers with growers so that successful adoption is linked to profitability of the service providers.

Results of the pod analyses have already been requested by CABI (Dr Jayne Crozier) for a review on heavy metals on cocoa. That review is likely to affect market response to cocoa from different locations.

8.3.2 Social impacts

There have been few social impacts from the current project. However, increased income and improved means of distributing income among cocoa growers has the potential to considerably improve their living standards, including education, health and equity in communities that derive an income from cocoa.

8.3.3 Environmental impacts

There have been few environmental impacts from the current project. However, there is considerable potential for future projects to have positive environmental impacts. Currently, cocoa is often planted to secure land rather than generate income. Therefore, large areas are planted to cocoa without providing much benefit. The situation is becoming worse as population increases and the availability of land decreases. In order to decrease the rate of forest clearing it is essential that production per unit of land is increased. Productivity is at a low starting point, so the potential for more intensive production is large, with concomitant easing of pressure to clear more land.

8.4 Communication and dissemination activities

As this was a scoping project, no dissemination activities were specifically carried out other than training of CCI staff and the two workshops. However, the results of the project will be disseminated by CCI officers in their normal extension activities. The results of the analyses for each block will be sent to the relevant growers.

9 Conclusions and recommendations

9.1 Conclusions

In this project, insights into possible nutrition-related issues and recommendations for further research were developed. There are major and complex constraints to cocoa production in PNG that are not nutrition-related, and any nutrition research and extension programmes must take them into account. The main constraints relate to labour shortages, block maintenance, lack of agronomic knowledge, land shortages, cocoa prices and theft. Many growers in this survey also thought that poor soil fertility and lack of fertiliser application may be constraining productivity.

Most of the cocoa blocks surveyed contained a large variety of crop species and it appears that block management is better when other food crops are present. There were no indications that other species (eg. legumes as shade trees or groundcover) affected cocoa nutrient status. Growers who had used fertiliser (approximately one third of those surveyed) virtually all reported improvements in growth, flowering and pod production. At the IPDM trial at Tavilo, application of NPK fertiliser has increased leaf K and P, but not N concentrations.

Based on leaf analyses, N and Fe deficiencies appear to be very widespread, with 95% of sampled blocks falling below the critical level for N and 89% for Fe. P deficiencies were encountered in about a quarter of the blocks sampled. Leaf Mg concentrations were adequate in most blocks in most provinces, except for ENBP, where 64% of the blocks sampled were deficient. Deficiencies of K, Ca, Mn, B, Cu and Zn were encountered in several blocks (ranging from 2 – 15% of sampled blocks). If the widespread N deficiencies were to be overcome it could be expected that the extent and severity of other nutrient deficiencies would increase substantially.

There was a negative relationship between leaf K and P concentrations and leaf dry matter contents, suggesting that leaf K and P contents remained constant while the leaves aged and accumulated dry matter. The relationships between leaf age and nutrient concentrations are important for developing diagnostic criteria.

The sites varied in their physical limitations to root growth. About 42% of sites had no physical limitations to root growth, about 24% were stony or shallow, about 21% had heavy textured or poorly structured subsoils and about 13% had poor drainage.

Most sites had reasonably high CEC, pH and organic C contents. Sites with high soil exchangeable K had high leaf K and sites with high CEC and exchangeable Ca had high leaf Ca and B contents. There were significant relationships between leaf K and P and the amount of exchangeable K or extractible P in the topsoil. All sites with low concentrations of K or P in the leaves had low soil exchangeable K or extractible P contents, respectively. There was also a significant correlation between leaf Mg concentration and the ratio of soil exchangeable Mg:K.

It is clear that many of the tentative critical levels proposed for leaf and soil nutrient concentrations have doubtful value for PNG and need to be improved. For example, 64% of sites in ENBP were classed as deficient in Mg according to leaf analyses but none of the ENBP sites had low content of soil exchangeable Mg. Interactions between Mg and K were observed, and this could have further implications on interpretation of soil and leaf ‘critical’ levels. To ensure sustainability of the soil resource and to allow responses to nutrient applications to be assessed properly, appropriate leaf and soil sampling and analytical methodology needs to be established and standardized. For future cocoa nutrition research to be effective, correlations and calibration between soil and leaf levels must be developed so that robust diagnostic criteria for soil and leaf testing for cocoa in PNG can be established.

There appears to be genetic variation in nutrient uptake in planting materials currently being used, suggesting that it may be possible to select for nutrient use efficiency.

There were no clear relationships between the leaf or soil nutrient contents measured in this study and previously developed categories of landforms and agroecological zones. The lack of relationships is probably due to significant variation on smaller spatial scales than the broad land categories in PNGRIS. There did appear to be a relationship between soil fertility and rainfall, with soil organic C, total N and Colwell P contents tending to be highest in zones with moderately high rainfall.

Cocoa beans from PNG have higher K content than beans from other places, indicating higher export per tonne of beans

Results were incorporated into a GIS with accurate locations to the individual tree, enabling results to be used for further spatial analysis and analyses of changes over time in the future.

There are currently widespread nutrient deficiencies, particularly N and also perhaps Fe. In blocks that are being well maintained and regularly harvested, it is quite likely that yield is being constrained by nutrient deficiencies. It is generally agreed that management of cocoa blocks in PNG must improve dramatically for the cocoa industry to prosper, and perhaps even to survive, particularly in face of the likely spread of cocoa pod borer. Widespread replanting is also necessary. If these improvements occur, then it is likely that limitations due to nutrient deficiencies will become more important.

9.2 Recommendations

The main purpose of the project was to determine what cocoa nutrition research should be done in PNG. The project identified a high degree of consensus between industry and related people with regard to nutrition-related research that is required. Recommendations from the workshops are summarised here and will form the basis for a research project proposal. The recommendations fall into four main categories: a) research to improve understanding of nutrition-related limitations to production; b) production of nutrient management recommendations appropriate to different regions; c) establishment of effective pathways to adoption; and d) education and capacity-building to ensure continued improvements in nutrient management research and extension. It will be vital to build impact assessment into the research.

9.2.1 Research to improve understanding

Determine the main nutrient limitations to cocoa production in PNG. Which elements in which places? Amount of inputs required. Diagnostic criteria. How serious is nutrient decline under cocoa? What is the nutrient balance?

Methodology

- Thoroughly review past nutrition work in PNG and elsewhere.
- Set up and maintain long-term fertiliser trials in key locations (in particular the 3 main landzones)- measure agronomic and economic responses, determine diagnostic criteria. Use uniform planting material, age and shade (light-moderate). Do trials on plantations. Carry out pre-treatment yield recording. Use large plots.
- Survey areas not yet covered in the survey reported here
- Locate and resample soil at sites analysed in the past to determine nutrient decline.
- Determine genotype x nutrient use efficiency interactions.
- Determine importance of shade and cover crops on N nutrition

- Conduct omission trials to determine which nutrients are limiting. Eg. is Fe deficiency as widespread as survey indicated?
- Establish reliable methods for diagnosis of nutrient status that are applicable to PNG.
- Examine nursery nutrient management as a means of improving establishment.
- Examine interactions between cocoa nutrition and cocoa quality.

9.2.2 Production of nutrient management recommendations

Produce clear nutrient management guidelines: nutrient management appropriate to management level, aiming for an overall higher level of management (integrated with pest, disease, shade, pruning and weed control). Region specific. Genotype, age and density-specific. Include interactions with shade/cover crops. Include non-fertiliser sources of nutrients. Recommendations for growers producing for niche organic markets.

Methodology

- Produce guidelines for different areas and situations. Start with best-bet guidelines based on current knowledge and then revise using new data.
- Extend soil and plant tissue survey to regions not covered in this study
- Measure nutrient content of possible amendments from smallholder households, fermentaries, copra driers, coconut husks
- Develop soil and leaf interpretive chart.
- Produce guidelines and protocols for sampling and analytical methods

9.2.3 Establishment of pathways to adoption

Establish a process for adoption that overcomes the limitations identified by Curry et al (2007). Adoption will be major challenge, even in areas where nutrition is limiting. Methods for adoption must be integrated with other work aiming to overcome constraints to production.

Methodology

- Establish a limited number of demonstration blocks, using carefully selected farmers and ensuring good data collection. Use existing IPDM blocks where possible.
- Carry out economic analysis, including issues of credit, labour availability etc.
- Determine relevance of participatory action research (PAR) to PNG cocoa growers.
- Carry out targeted farmer training.
- Integrate with replanting (vital for improving production) strategies including recommendations for shade managements and inter-planting with food crops.
- Integrate with Nucleus Enterprise extension models that are being trialled to improve access to processing facilities, transport, credit, and training. These models rely on partnerships with commercial service providers, whose profitability is tied to smallholder productivity (Curry et al., 2007). An example of this model is operating successfully at Stockholm in ENBP, where Newmark plantations are providing transport, materials, seedlings and advice to growers in this isolated region. Production has increased from 400 to 3000 bags/year since the arrangement started. Growers have recently been asking the plantation for fertilisers (McNally, pers. comm.).

9.2.4 Education and capacity building

Build capacity within CCI (data processing, field trials, sampling) and within NARI (methods of soil and plant analysis for cocoa).

Methodology

- Data handling from field to database to reporting
- Agronomy procedures manual for CCI
- Train the trainers: eg. Short courses
- Develop alternative lab procedures (eg. MIR)
- Analytical procedures at NARI
- Preparation facilities at CCI
- Training in biometrics, spreadsheets, book-keeping, communication, writing, experimental design – especially for CCI and NARI officers
- Postgraduate study for CCI agronomists, apply for JAF.
- PNG partners work in Aust labs, OPRA, etc
- Students from UNRE, Unitech do projects

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10.2 List of publications produced by project

Nelson P. 2007. Nutritional constraints to cocoa production in PNG. ACIAR Nius: 2 (1) June 2007, 4-5.

11 Appendixes

11.1 Minutes of Workshop 1, March 2007

11.1.1 Participants

The workshop was held on 19-23 March 2007 at Tavilo, East New Britain, PNG. People who participated in some or all workshop sessions are listed below.

Participant		Position	Org.	Phone	Email
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Beneran	Hannet	Agronomy units	CCI		
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Kundi	Nelson	Agronomy units	CCI		
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Metex	Dominic	Agronomy units	CCI		
Nalina	Robert	Assist. Economist	CCI		
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Peni	Tommy	Islands Regional Man.	DAL		
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Yamb	Ralph	Soils Lecturer	Vudal	(675) 983 9144	vacademic@global.net.pg
Yinil	David	Senior Agronomist	CCI	(675) 983 9131	agronomy@ccipng.com.pg
Wartoto	Tolik	Cocoa farmer visited	Tokiala		
Vovono	Margaret	Cocoa farmer visited	Tokiala		

11.1.2 Mon 19 March 2007.

The following reviews were presented and discussed.

- Cocoa production systems in PNG (Lummani)
- Agronomic and plant protection aspects of cocoa production in PNG (Konam)
- Nutrient requirements of cocoa (Yinil)
- Past and current cocoa nutrition trials in PNG (Fidelis)
- CCI Extension capacities and strategies (Nongkas)
- Soil information for cocoa in PNG (Nelson)
- Nutrition and nutrient management of oil palm in PNG (Banabas)

In the afternoon the group visited the model farm trial of John Konam on Tavilo station. We looked at plot 1 (minimal management inputs) and plot 4 (pruning, shade control, weeding, disease control, fertiliser).

11.1.3 Tue 20 March 2007.

What should be included in a cocoa nutrition project? Post-it notes

Everyone wrote one or more Post-it notes on what should be considered in a cocoa nutrition research project for PNG. These are recorded below in approximate groups

Literature review

- Do a literature review of all fertilizer work on cocoa/situations where cocoa has been involved in PNG

Socio-economic

- An overdue work that urgently needs to be done – the approach of taking socio-economic issues into consideration is good and a lot will depend on these issues at the farmer level of what they will take up in terms of recommendations
- Over-populated areas – new areas – medium populated areas

Agronomy

- Planning a cocoa block - land preparation (marking out, spacing out, shading, planting out, cocoa type, cocoa management)
- Comparing yields of different cocoa materials at different agro-ecological zones
- Understanding processes

- A few field trials with good data recording
- Set up long term fertilizer trials
- Data is king – need to record well – even recording 'no response' is valuable if adequate replicates and low CV

Previous land use

- Site history and previous land use
- Cocoa (including intercropping) as currently practiced by farmers could be a cause of yield decline
- Old cocoa plantings – cocoa rehabilitation program – rejuvenation – cocoa pruning

Varieties

- Nutritional requirements for a) different cocoa groups (Trinitario, Upper Amazonians, Hybrids); b) different cocoa types (hybrid seedlings, hybrid clones)
- Cocoa variety tests at different levels of fertilizer applications

Interactions

- Interaction between disease/pest incidence and nutrient status of cocoa trees
- Integrated approach to factors that may be contributing to yield decline (soil physical, chemical biological factors, crop physiology factors, other)
- Somehow control interactions with shade, age and variety

Shade species/intercropping/organic cocoa

- Nutrient studies of cocoa intercropping
- Cocoa nutrients and crop diversification
- Assess nutrient contribution from shade trees
- Nutrition recording program – nutrient test of soil under different shade species
- Nutrition on companion crops as a means of helping the main cocoa crop
- Promote use of legume cover crops or leguminous trees/shrubs
- Role of Gliricidia in N nutrition
- Cocoa based cropping systems - as nutrient partitions will depend on the cropping system used as against cocoa mono-cropping
- Cocoa shade species evaluation – a) shade/light; b) shade tree as nutrition source; c) organic fertilizer
- Organic cocoa?
- Organic manuring vs inorganic, or combinations

Fertilizer

- Concentrate on most important nutrients
- Does fertilizer increase yield?
- Effect of artificial fertilizers on yield
- Is fertilizer (or other nutrient sources) beneficial (ie does it increase yield) in smallholder farming systems
- How much interaction is there between nutrition (fertilizer) and other inputs

- Effect of rainfall on nutrients
- Determining the most efficient means (amount/type/placement/spacing) of applying fertilizer
- Testing of soil for any contaminants from fertilizer
- Because fertilizers will be used as part of the project, chemical residue testing on cocoa beans must be included in this project, to monitor chemical levels in final product

Soil Type

- Select 3 agro-ecological zones out of the 29 agro-eco zones – ie sites at 0-150m, 150-350m and 350-500m
- Fertility study of soil types used for cocoa growing
- PNG – atoll soils and mainland soils
- Standardize fertilizer use depending on various locations
- Characterise areas under trees
- Investigate cocoa material suitable for swampy areas
- Nutrient research program – nutrient test on different soil conditions, physical properties (texture and structure) at different locations
- Study sites – include cocoa materials to sites and soil types
- Output – clear guidelines for different areas, ages

Analytical

- Sample after every flush
- Test for K deficiency in coralline soils
- Cocoa leaf nutrient analysis
- Sample tissues from different clones/hybrids
- Develop cocoa soil and leaf interpretation chart
- Formulation of analysis system for the whole scenario
- Improving methods of diagnosing nutrient status of cocoa trees in relation to productivity/profit/soil health
- Develop relationships between available soil nutrients – plant uptake – tissue levels – deficiency symptoms - yield

What should be included in a cocoa nutrition project? Spoken

Will Akus – collaboration with other scientists/skills, good review, contribution to the soil from Gliricidia, list of people and publications, shade and light effect on cocoa

Joachim Lummani – cost factor of nutrition, what effect on yield? Economic evaluation of trials, defining economic optimum of nutrient levels on cocoa yield

David Yinil – development of basic soil and leaf analysis guides, includes methods of analyses used, specific to PNG, in relation to shade, density and planting type, guide for cocoa farmers for smallholders and plantations

Sue Berthelsen – guidelines linking soil to leaf analysis to yield, integrated approach to yield decline (nutrition/pathology/pests/varieties/management). Other work shows it is never simple

Chris Fidelis – organic farming, legume cover crops to supply N (avoid contaminants from fertilizer), interpretation chart for PNG, effect of nutrition on pod borer

Mike Webb – nutrient status of trees for productivity and profit, including soil health, determine most effective way of supplying nutrients (timing etc), nutrient contribution from shade trees, interaction between pest and disease (healthy trees more or less attractive to pests?)

Ralph Yamb – need to see what has been done already (lit review), match hybrids/clones with soil type (3-5 groups), develop standard fertilizer rate for soil type (soil specific rates)

Peter Epaina – different nutrition needed for different hybrids (Trinitario x forestero) and clones? Interaction with areas/soil type.

Samson Laup – system analysis – how factors connect, identify information that is missing, includes above ground and below ground factors, farmers need, political factors, guidelines on research needs

Gadi Ling - socio economic issues behind low yields, actual cropping systems in use, organic gardening vs inorganic - effect on markets and soil, shade – variable vs more uniform shade and impact on nutrition

Henry Tangbil – production cf soil type, effect of other crops on nutrition (highly populated areas have more intense land use so impact on soils?), atoll soils vs mainland soils, salt input from sea

Peter Karduk – village farmer need info on how to grow cocoa, e.g. spacing, shade, clear guidelines needed, needs of different types of planting material

Murom Banabas – nutrient balance needed, reason for nil fertilizer response under shade trees? Nutrient input from shade trees. Environmental impacts of fertilizer use (e.g. groundwater impacts), water balance and soil water deficit and impact on flushes – demand for nutrients

Martin Powell – does fert increase yield?, what interaction is there between fertiliser and other management inputs (shade, pruning, weeding), need impact on smallholder as bulk of production – is it fert/if nutrition, what is the best way to improve?

Willie Maso – holistic approach needed, environment impacts (GxE), growers often illiterate, interactions of genotype, management, environment

Ephraim Tade – current management practices (including timing) and impact on nutrition, yield decline, effect of different planting material

Francis Kenny – concerns about buildup of contaminants in product (current nutrition is mainly organic), identify likely contaminants from fertilisers and analyse for this, involve cocoa quality orgs

Peter Bapiwai – nutrient needs of different planting material and different soils, test for contaminants.

Graham McNally – high yields of new plants could outstrip ability of soil to provide nutrients , smallholders 80% of yield, viability of plantations?, must have good management (weed, prune, shade, proper harvesting) before response to fertiliser, interaction between coconut and cocoa - suspect new planting material reduces soil nutrients faster under coconuts

John Talele – how can we sustain production for a few more years (past the peak), observation and dissemination in practical ways, maybe demonstration plots for extension

List of stakeholders in PNG cocoa industry

Farmers (~150,000 families, ~90,000 ha)

- subsistence

- small-scale

Plantations (~28 with 38,000 ha)

- Companies
- Churches (plantation, support)
- Other institutions

PNG Growers Assoc. (cocoa and coconut) & branches

Employees

Institutions (research, extension, education)

- Vudal
- Solomons college
- High schools (growers)
- Cocoa Board
- World Vision
- CCI
- NARI
- DAL
- PNG OPRA
- Provincial DPI's
- Churches

Administration

- National govt and members of parliament
- Land department (titles)
- District administration
- LLG
- Village elders

Buyers

Ag Bank and banks

Exporters (~28 in total, but Agmark exports 60-70% of PNG cocoa

Processors, manufacturers and retailers

Chocolate consumers

Research collaborators and research funders

- JCU, CSIRO, Curtin Uni, Reading Uni, Uni of Sydney, Melbourne Uni, Reading Uni, British History Museum, NRW, ACIAR, APCC, IPGRI, International Cocoa Organisation, Cocoa Fund Commodities, CIRAD, EU, USDA, AusAid, Masterfoods, Cadbury, PNG Sustainable Development Corporation, GoPNG Coffee and Cocoa Research Institute Indonesia, CABI, Guittard, INCO (French, mainly coconuts), SPC (Secretariat of Pacific Communities)

Other Pacific countries

11.1.4 Wed 21 March 2007

Notes from small group discussions.

Soil Sampling Protocol for ACIAR Cocoa Nutrition Project (Facilitator – Fidelis)

- Collect from between cocoa rows to include shade trees, other
- Depth 0 – 60cm (0-15; 15-30; 30-60) – cocoa roots have a depth of ~1m
- Distance of movement will depend on area of block
- Avoid water-logged areas if represent < 10% of area. Sample water-logged areas if represent > 10% of area.
- Same people to do sampling so procedures used are the same
- Send samples as fresh
- Standard labelling
- sample 50-100 cm from tree

Cocoa Leaf Sampling Procedure (facilitator: Yinil)

- More detail study on the value of sampling different leaf age on fertilized and non-fertilised trees. This study should be considered in the second part of cocoa nutrition studies on-station
- In the scoping survey, the present third leaf from a recently hardened leaf flush should be sampled. A further guide to confirm a recent leaf flush, is the differentiation of brown and green bud-wood. Recently hardened leaf flush is on the green portion of the bud-wood.
- The leaf to sample should be from a branch at mid-height and on the East. The branch must be exposed to light.
- A maximum of four leaves can be taken per tree and up to 20 trees can be sampled.
- All samples should be collected before 9.00 to reduce nutrition concentration as a result of photosynthesis
- Only healthy leaves should be sampled. All disease and damaged leaves should be avoided
- Leaves should be sampled from the different cocoa cropping systems like cocoa/coconut,
- cocoa/gliricidia, cocoa/gliricidia/coconut and Cocoa/banana/betelnut/coconut.
- Collect from 5-20 trees
- Measure leaf area (by photocopying), leaf fresh weight and dry weight
- Design a standard form to collect information related to history of site, type of trees (SG2
- hybrids, hybrid clones, old Trinitario) cropping system.

Site selection- report from group, facilitator P. Nelson

- Selection hierarchy: Province> soil type> old and young cocoa areas.
- Then, wherever possible, sample sites where information on varieties, management etc already exist. Ie. On-farm trials (plots with no fertiliser) or Konam's 12 disciples 3 sites by 12 farmers in ENB, GxE trials (in ENB and Madang, but make sure no fertiliser added) or on-station trials or blocks in recent socioeconomic survey (Gazelle). Need to talk with Yinil, Lummani and Epaina to find out where these are.

Main areas

- ENB (~20 sites): cocoa growing areas mostly on coralline soils (Rendolls), volcanic ash (Andisols), Inceptisols (hilly areas, hinterland), Alluvial soils.
- Bougainville (~20 sites): Vitrandepts (main area, Tinputz, Wakunai), Tropudalfs (Buka), Hydraquents, Fluvaquents.
- East Sepik (~20 sites): Eutropepts (West coast), Tropudalfs (South coast, central highlands), Dystropepts (Maprik, Rakiki, Ambuin R), Tropofibrists (Ambunti)
- Madang (~20 sites): Vitrandepts (Karkar), Dystropepts, Fluvaquents (mainland)
- NIP (~20 sites): Rendolls (coralline soils), Dystropepts, Eutropepts

Other areas

- Jimmy Valley:
- West Sepik: (Rendolls, Dystropepts, Fluvaquents)
- Oro: low CEC soils of Ilimo-Papaki
- Morobe: Rendolls, Humitropepts

Socio-economic survey and data processing (facilitator: Lumani)

- Mainly smallholders
- How long farming?
- What crops?
- What else with cocoa?
- Is this the first crop of cocoa – if not, when did you last replant?
- What are major problems with cocoa farming, and in order of performance?
- If fertility has been a problem what have you done to improve it?
- Have you checked new areas? What kind of production? If getting better than now – why?

Field trial of leaf and soil sampling protocols

We trialled the leaf and soil sampling procedures in IDM Plot 4 and then finalized them.

11.1.5 Thu 22 March 2007

In the morning we designed the interview form.

Then we designed the recording form.

In the afternoon we trialled the interview with two smallholder cocoa farmers at Tokiala.

11.1.6 Fri 23 Mar 2007

In the morning the following presentation was made:

- 'Socioeconomic aspects of smallholder cocoa production' (Curry, Koczberski and Omuru)

In the afternoon the sampling for soil bulk density was trialled.

We all gathered for a final lunch.

11.1.7 Workshop outputs

Ideas for a nutrition research project (recorded here)

Sampling/survey protocol for this project (separate document)

Recording form for sampling/survey (separate document)

Sample data recording spreadsheet (separate document)

11.2 Minutes of Workshop 2, March 2008

11.2.1 Participants

The final project workshop was hheld on 4-5 March 2008 at Tavilo, East New Britain, PNG. People who participated in the workshop and people who were invited but couldn't make it are listed below. There were 52 participants in total, of which 45 were from PNG and 7 from Australia. Participants included cocoa farmers, and staff from research institutions (CCI, CRI, CSIRO, NRW, OPRA), universities (CU, JCU, UNRE), industry organizations (CB, CIC), plantation companies (Newmark, Ramu), consultants (One Stop Cocoa) and companies involved in buying or processing cocoa (Mars).

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Yak	Namaliu	Plant Pathologist	CCI		
Yamb	Ralph	Lecturer/farmer	Farmer		
Yatu	Mathias	Agronomy units	CCI		
Yinil	David	Sen. Agronomist	CCI	(675) 983 9131	agronomy@ccipng.com.pg
Invited, but couldn’t participate					
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Chisolm	Richard	Sen. Agriculturalist	WB		rchisholm@worldbank.org

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11.2.2 Tue 4 March 2007

The workshop was opened by Acting CEO of CCI, Mr Hosea Turbarat, followed by an address by Mr Barnabas Toreu, on behalf of the CEO of the Cocoa Board, Mr Lauatu Tautea.

The following talks were presented and discussed:

- Nutrient research and advice in the oil palm industry, focusing on smallholders (Banabas)
- Nutrient research and management in the coffee industry (Hombunaka)
- Sustainable sugarcane farming in the Ramu valley (Bangita)
- Towards sustainable strategies of smallholder cocoa production (Curry)
- Socioeconomic considerations in smallholder cocoa production (Lummani)
- Overview of cocoa nutrition relevant to PNG and possible further studies (Yinil)
- Industry perspective on PNG cocoa (Dr Smilja Lambert)

- Benefits of IPDM with low rates of fertiliser (Namaliu)

The results of the survey carried out in the project were then presented and discussed:

- Sampling, survey and analysis (Fidelis and Berthelsen)
- Spatial view (Webb)
- Overall picture, deficiencies, management, export (Nelson)

A dinner was held at Kerevat Country Club.

11.2.3 Wed 5 March 2007.

Two sessions were held in which 6 small groups discussed the formation of a nutrition research project proposal and then reported back to the whole group, where further discussions were held. The brief to the groups was that the proposal will take the form of a submission to ACIAR for a 5-year project. A presentation was also given on the IDPM project (see Tue 4 Mar).

Session 1: What should the project aim to achieve?

Group 1

- Aim/target to get yield of 60 pods/tree/year (~2 t/year) by achieving following:
- understanding cocoa nutrition
- establishing sustainable fertilizer practices (physical and economic)
- establish fertilizer recommendation (physical & economic)
- consideration of husbandry options – eg. inclusion of legumes, genotype interactions with recommendations
- All of above in context of good crop husbandry practices so recommendations don't have a negative effect on quality of cocoa products

Group 2

- understand nutrition, pest & disease factors that result in healthy trees and maximize potential
- establish guidelines for soil management and fertilizer program that is specific to: agroecological zone, soil types, weather patterns, time of application. Especially for high yielding clones
- facilitate information transfer, eg. participatory approach to disseminate info
- survey suggests N, P, K are main nutrient elements of concern - so after 5 years we need to have gained a definite handle on how to manage these elements

Group 3

- develop fertilizer recommendations that are soil type/region/climate specific
- develop protocols for sampling and analytical methodology
- local capacity to disseminate info – training manpower, research staff & establish facilities. Specific to nutrition research but including techniques in laboratory analysis
- linkage with private/public sector to help disseminate info. Through field trials to build ownership of trails and results
- examine changes by re-sampling old sites
- transfer info into all areas (extension, sampling, analysis). Use current (new) project to develop subsequent research project into other areas not covered by this project

Specific comments from audience:

- John Duigu – staff should be trained in soil and plant analysis to do in PNG; therefore establish analytical techniques for PNG labs
- Sampson Laup – train CCI staff to do analysis then through other mechanism get equipment so CCI staff can do their own analysis

Group 4

- improve information delivery to farmers
- educate farmers and improve their understanding of fertilizer type, uses, pros and cons by setting up on-farm demo plots
- improve nutrient management and yield
- determine potential yield of cocoa
- establish appropriate fertilizer management specific to site/soil type and cocoa farms systems
- nursery nutrition trials

Group 5

- need to ask and answer the question "Is nutrition a limit to cocoa production?"
- understand soil types and design appropriate trials with the end product being site specific fertilizer recommendations
- study the socio-economics requirements of the farmers (ie. what do farmers want and need) to design appropriate extension tools

Group 6

- make use of current results in new project
- revisit responses obtained in past trials (CCI and DAL)
- examine the influence of other factors (eg. soil, pests) and understand how they may interact with nutrients
- before establishing new trials need to separate into agro-ecological zones so that recommendations will be zone specific
- important to get results to farmer by using a participatory action approach

Key factors arising from this discussion and common to all groups were (Paul Nelson):

- Improve understanding of nutrient issues/requirements
- Develop specific fertilizer recommendations/guidelines (eg genotypes, husbandry, pruning, weed management, non-fertiliser nutrient sources (eg legumes, manure, prunings)
- Establish extension / participatory action
- Develop local (CCI) capacity in nutrition related research

Session 2: What activities should be carried out to achieve the objectives?

Group 1

- Nutritional trials on station/plantation to give hard data
- Demo blocks (smallholder) based on current knowledge (limited number, < 10, but well managed with good data collection) – use IPDM blocks where possible – need careful selection (ie farmer, site etc)

- Nutrient interaction
- Review past work
- Use different experimental designs
- Define PAR
- Use uniform planting material
- Use pretreatment yield recording for plantation and SH blocks to establish variability

Group 2

- Conduct NPK (?Zn, Fe, B) trials including an economic analysis, taking into consideration following factors:
  - sites – on station or on site (plantation or SH)
  - varieties/clones – small vs large etc
  - situate on existing cocoa and/or new plantings
  - landforms (6 x Hanson) – in particular 3 main land zones
  - design - factorial or other designs
  - light/shade
  - application method eg. broadcast vs placement
  - PAR yes or no
  - Economic analysis
  - fertilizer availability (long term, govt subsidy, Cocoa board to pay for SH fertiliser for trials)

Group 3

- Understanding
- extend survey area to regions not sampled and try go back to old surveys to compare the decline in nutrient levels
- need to collect baseline data re farming practices, cocoa types, production, tree health
- Developing recommendations needs two strategies
- best bet based on current project results
- standardize sampling (eg timing) and analytical procedure
- using current info to determine nutrient requirements at establishment phase
- second set of guidelines based on outcomes of project
- need impact assessment at end project
- Education
- Appropriate packaging of information very important
- Dissemination through PAR, formal training, demo blocks
- Capacity
- Manpower training
- Train the trainers (DPI etc)

- Establish equipment (or at least some)

Group 4

- Understanding
- Need to first establish fertilizer trials in 2 main zones (altitude 0-150m, 150-250m, 250-400)
- Test all varieties released
- Plantation vs smallholder blocks
- Nursery nutrient management for better establishment
- Omission trials
- Nutrient interactions with cocoa quality (eg flavour, butter)
- Recommendations
- Sample for yield, nutrient concentrations over time (growing cycle)
- Establish benchmarks (table) of critical values
- Education
- Trials or demos on farmer blocks including PAR – creates ownership
- Capacity
- Farmer training
- Trainer training
- Farmer research
- Training in biometrics, spreadsheets, book-keeping, communication, writing, experimental design – especially for CCI and NARI officers
- Basic Lab equipment

Group 5

- Understanding – before establishing new trials need to consider:
- Baseline survey
- Agro-ecological zones (AEZ)
- planting material
- crop age
- formal trials on plantations, demo blocks on smallholders
- Recommendations
- Optimum rate for different AEZ's
- Monitor yield decline to determine best time to apply fertilizer
- Fit into IPDM programme
- Establish pot trials (eg student projects) to get interim recommendations before 5 years (end project)
- Education
- Engage students, eg Unitech, Vudal - industry training

- Train staff at CCI in soil and foliar testing – and link to other stakeholders to ensure long term sustainability after project finishes

Group 6

- Establish fertilizer trials on:
- Volcanic soils (most extensive)
- Potassium deficient (limestone plains, NIP)
- Current major areas
- New potential areas
- PAR – carry out main experiment adjacent to IPDM block to allow yield comparison
- Capacity – train technical staff and improve facilities (for drying and sample prep)
- Recommendations: Establish interim recommendations and refine later

11.2.4 Wrap-up

Perspectives from outside the project team were given by several participants:

- Otto Kuaimba (Newmark)
- John Duigu (Consultant)
- Harm van Rees (PNGOPRA)
- Murom Banabas (PNGOPRA)
- Potaisa Hombunaka (CRI)
- Boas Bangita (Ramu)

Finally, the workshop achievements were summed up by Paul Nelson, Mike Webb and David Yinil.

11.3 Survey and sampling protocol

Sampling Protocol for ACIAR Cocoa Nutrition Project

Facilities

Bougainville – no oven
NIP – OPRA facilities (ovens, balances, trays)
ENB - ovens, balances, trays
East Sepik – no oven
Madang - ovens, balances, trays
Morobe – possible Unitech Facilities (ovens, balances, trays)
Jimmy Valley
West Sepik
Oro – OPRA facilities (ovens, balances, trays)

Materials required:

To take to each site (If 2 sampling teams - x2, except for GPS, camera, balance)
1x Soil sieve
Water proof paper, soft pencils
2x Tape measure
4x permanent marking pens
1x GPS
1x Tarp for mixing soil
1x Tarp for shelter, plus ropes
5x Bucket: 1 for each soil depth plus 1 for hand-washing
4x bulk density rings
1x Sharp kitchen knife with straight section on blade (to clean off BD rings)
1x Auger
1x Screw driver (to remove soil from auger)
Bush knives
2x spades (at least one long-handled spade), crow bar to dig pits
Water for washing hands and equipment
1x battery-operated balance (0.1 g) for leaf weights
1x kitchen scales for weighing out soil samples
1x Camera
1x set of Spare batteries for camera, balance, GPS
Strong box to transport samples within province
Strong box to transport samples back to Tavilo
Carry bag for carrying equipment
28x large plastic bags – for soil collection (9 holes 0-15cm + 9 holes 15-30 cm + 5 holes 30-60 cm + 5 holes 60-90 cm)
Tissues or paper towels to wipe leaves
'Needle' and fishing line or other heavy thread (beads or pegs) for drying leaves
2x Clip boards
1x Folding table
A few large plastic bags for leaf collection (1 needed, plus some spares)

For every site:
16x plastic bags for soil samples (about 37 x 28 cm for 1 kg of soil from each depth). Ie. 4 depths x 2 samples (one left in province, one sent to Tavilo) x 2 (double bagging)
8x plastic bags for samples to be sent to Townsville (about 20 x 15 cm for the 300 g of soil for each depth). Ie. 4 depths x 2 (double bagged)
12x small plastic bags for BD soil samples (4 depths x 3 replicates)
Hammer and block of wood for BD sampling
Pegs, either premarked with 3 colours - or flagging tape in 3 colours (using a different colour to indicate corners, leaf, soil)
Enough Paper bags to hold leaves

Site Preparation and layout

1. Explain project to grower.
2. Take photo of page 1 of the reporting sheet which includes site details and location
3. Take photos of as many other things as possible that are particular to the site (eg. farmer, sampling team, cocoa trees (from distance and close up), close up of leaves etc if there are any distinctive foliar symptoms etc.)
4. Select 7 x 6 block of trees.
5. Select trees for soil and leaf sampling trees from table on recording sheet. If chosen tree is not representative, select another nearby (but not already selected by the random number table), in the same row if possible (move forward or backwards depending on condition of tree). Record on the table the actual trees sampled.
6. Mark sampling trees with coloured string or flagging tape; identifying whether the tree will be used for leaf and soil, or just leaf sampling.
7. Record GPS readings from the 4 corner sampling locations
8. Record your assessment of the site (eg. shading, weeding and pruning management, tree health etc.) on the recording sheet

For any sampling (soil or tissue), always wash hands in clean water before starting and between blocks and between soil depths.

Leaf sampling

1. Leaf sampling to be done before 0900 if possible.
2. Sample from mid-canopy height.
3. Select two undamaged leaves per tree.
4. Sample the third leaf from a recently hardened leaf flush. [A further guide to confirm a recent leaf flush, is the differentiation of brown and green bud-wood. Recently hardened leaf flush is on the green portion of the bud-wood.]
5. Record the number of leaves on the sampled flush
6. When handling leaves, only touch petiole
7. During collection, the leaves are initially placed in a pre-weighed large plastic bag and then the weight of the bag + all 40 leaves is recorded on the recording form
8. Measure leaf length and width.
9. Once weighed , put into labeled paper bags as soon as possible
10. Wipe leaves with paper towel if necessary
11. Once back in office/farmer house, measure leaf length and width if sufficient time.
12. Dry leaves as soon as possible.
    a. If no oven, string up (needle and thread) to dry (under fan or in aircon)
    b. If oven available dry at 65C in paper bags until dry – do not pack leaves tightly together – allow for airflow between leaves and between bags
13. After returning to Tavilo, the leaves should be placed into an oven at 65C to ensure they are fully dried.
14. When fully dried, record dry weight before grinding.
15. It is best to leave samples in the oven (at 65°C) and remove just prior to grinding as they quickly absorb moisture from the air and this can make grinding more difficult.
16. Before grinding, make sure all equipment is clean. Clean bech or surface with a damp cloth. Wash hands.
17. For each site, grind all leaves collected and package into a plastic bag labelled inside and outside. Mix sample well, subsample 20-25 g in to a labelled (inside and outside) plastic bag. Seal bag well. In addition to normal labelling, write Theobroma cacao on the subsampling bag. Place inside another bag and dispatch to Townsville for analysis. Be sure to include the appropriate AQIS import permits both inside the box as well as taped to the outside.

Pod sampling

1. One site per province
2. Sample no more than one ripe pod from each of the 42 trees. If <10 ripe pods in plot, go to surrounding trees until 10 pods collected
3. Separate wet bean from pod
4. Measure fresh weight of husks and bean separately
5. Dry beans in baking tray and husk on rack (will need to be done in Province of origin)
6. Measure dry weight of beans and husk separately
7. Smash up husks with a clean hammer on a clean surface. Mix well and then quarter to get a about 50 g. Grind in coffee grinder, and package into a plastic bag labelled inside and outside. Mix sample well, subsample 20-25 g in to a labelled (inside and outside) plastic bag. Seal bag well. In addition to normal labelling, write Theobroma cacao on the

subsampling bag. Place inside another bag and dispatch to Townsville for analysis. Be sure to include the appropriate AQIS import permits both inside the box as well as taped to the outside.

8. .Once beans are dry (this may take a couple of days in the oven; with regular separating and turning of beans), mix and quarter until about 50 g beans. Crush beans with a hammer, then grind in coffee grinder, and package into a plastic bag labelled inside and outside. Mix sample well, subsample 20-25 g in to a labelled (inside and outside) plastic bag. Seal bag well. In addition to normal labelling, write Theobroma cacao on the subsampling bag. Place inside another bag and dispatch to Townsville for analysis. Be sure to include the appropriate AQIS import permits both inside the box as well as taped to the outside.

Soil sampling for chemical analysis (to be done after leaf sampling)

1. Label final collection bags (2 x 1 kg, 1 x 300 g) bags with permanent marker (outside) and included water proof paper label (inside bag) BEFORE going to field.
2. Layout temporary collection bags at base of appropriate trees
3. Auger hole 100 cm from tree
4. Avoid any obvious areas of disturbance (eg stumps, hollows, paths, pruning)
5. remove loose surface litter
6. Sample 0-15 and 15-30 cm for trees 1, 5, 13, 15, 17, 25, 27, 29, 39 (or alternatives if necessary) and 30-60; 60-90 cm for trees 1, 13, 17, 27 and 39. If depth limited by rock, take and label deepest sample to the actual rock depth (eg 30-60 sample may be now 30- 53)
7. Sieve soil from each depth at each hole into a bucket and then transfer into a plastic bag. Take all plastic bags to one site for bulking (see below).
8. Record depth of any particularly hard layers and describe them (eg. 'gravelly' or 'clay')
9. Record depth to water table if encountered (for each hole), by putting a stick in the hole and measuring the distance from surface to wet part.

Soil bulking procedure

1. Lay out bags from one depth. Check labelling - this will be a good check that all samples have been collected, as there should be 9 bags of soil labelled 0-15cm, 9 bags labelled 15-30cm, 5 bags labelled 30-60cm and 5 bags labelled 60-90cm.
2. Empty bags from one depth and mix well, then quarter, mix well, then quarter etc until 2 - 3 kg remains. Approximately 300 g to be sent to TSV (double bagged) ; about 1 kg to be retained at CCI (double bagged) as a back up; and about 1 kg to be kept with in the province of origin as a backup - to be discarded when other samples arrive safely at Tavilo)
3. DO NOT AIR-DRY OR OVEN-DRY THESE SOIL SAMPLES

Soil Pit and Bulk density

1. In each block dig a pit to 90 cm depth (or to watertable or rock if they are at <90 cm depth)
2. Place ruler/tape against profile face and take photo
3. Record topsoil depth on recording sheet
4. Record depth to rock or watertable if <90 cm.
5. Record depth (top and bottom) of gleyed ('blue-grey colours') or mottled (several colours- eg. red, brown, orange, yellow, grey) layers. These indicate seasonal waterlogging, even if watertable is deeper at time of sampling.
6. Sample each of the 0-15, 15-30, 30-60, 60-90 layers (irrespective of horizon changes) by taking 3 rings per depth sampled diagonally across depth layer.
7. If possible, sample from side of pit – but if soil is too loose and sample falls out of BD rings it may be necessary to dig out shelves to collect the samples.
8. Put soil into small labelled (inside and outside) bags - make sure the bags are well sealed so there is no loss of moisture.
9. After returning to Tavilo (or in province of origin if oven is available), determine the gravimetric soil moisture content and bulk density of samples. For each sample follow the following procedure:
   - record the weight of a suitably sized metal container (W_1 g)
   - transfer the wet soil from the plastic bag into the container and record the total weight of the container + moist soil (W_2 g). Make sure that **all** the soil in the bag is removed from the bag.
   - dry at 105°C for at least 24 hours, or until completely dry
   - remove from oven, cool and reweigh container + oven-dry soil (W_3 g)
   - determine weight of moisture (W_4 g):$W_4 = (W_2 - W_3)$

$$\text{moisture (\%)} = \frac{\text{weight of moisture (g)}}{\text{weight of oven–dry soil (g)}} = \frac{W_4 \times 100}{(W_3 - W_1)}$$

$$\text{bulk density (g/cm}^3\text{)} = \frac{\text{weight oven-dry soil (g)}}{\text{volume of BD ring (cm}^3\text{)}} = \frac{(W_3 - W_1)}{\Pi \times (d/2)^2 \times h}$$

Where d = BD ring diameter (cm)
And h = BD ring height (cm)

Height(cm):	5.0
Diameter(cm):	7.3
Ring volume(cm^3)	209.27

11.4 Survey recording sheet

Site ID: ______________ Page 1 of 12

ACIAR Cocoa Nutrition Project
Site Information for soil and leaf sampling

A. General Information

Introduce yourself and explain why you have come to visit sample and ask Questions

Date: ____-__________-__________
(dd - mmm - yyyy)

Plantation/Village: __________________ Name of Grower: __________________

LLG: ____________ District: ________________ Province: ______________

Site ID: ________________

Name of Block where Sampling done: __________________

Write Site ID on top of each page

Go to sampling area, collect samples and fill in soil and tissue sampling information, fill in your observations, return to somewhere comfortable, and continue filling in the grower survey form below

Instructions on filling in this form:

[Option1/Option2/Option3] (circle)
Circle one of the above options

Eg : [Low/Medium/High] (circle)

[0.0]
Indicate number of decimal places
Eg [0.0] means one decimal place eg 6.4 g
[0] means no decimal places eg 56 cm
[0.00000] means five decimal places eg 152.02524 degrees S

If you run out of space, write on back of pages. (include site ID)

Site ID: ______________ Page 2 of 12

B. Site layout: mark where samples were actually taken

6 GPS	**7** LEAF	**18**	**19** LEAF	**30**	**31** LEAF	**42** GPS
5 LEAF SOIL(x2)	**8**	**17** LEAF SOIL(x4)	**20**	**29** LEAF SOIL(x2)	**32**	**41**
4	**9** LEAF	**16**	**21** LEAF	**28**	**33** LEAF	**40**
3 LEAF	**10**	**15** LEAF SOIL(x2)	**22**	**27** LEAF SOIL(x4)	**34**	**39** LEAF SOIL(x4)
2	**11** LEAF	**14**	**23** LEAF	**26**	**35** LEAF	**28**
1 GPS LEAF SOIL(x4)	**12**	**13** LEAF SOIL(x4)	**24**	**25** LEAF SOIL(x2)	**36**	**37** GPS LEAF

GPS readings:

Tree position	Latitude (S) [0.00000]	Longitude (E) [0.00000]
1		
6		
37		
42		

Site ID: ______________ Page 3 of 12

C. Site Assessment

Now that you have walked through the plot, give your assessment of the following characteristics:

Tree health: [very poor/poor/average/good/very good] (circle)

Shade used: ____

Shade management: [very poor / poor / average / good / very good] (circle)

Weed control: [very poor / poor / average / good / very good] (circle)

Pruning: [very poor / poor / average / good / very good] (circle)

Ground cover type: [legumes present / no legumes] (circle)

Black pod: [severe / moderate / light / none] (circle)

Canker: [severe / moderate / light / none] (circle)

VSD: [severe / moderate / light / none] (circle)

Pink disease: [severe / moderate / light / none] (circle)

Other disease: ______________________________

Any Other comments:

Site ID: ______________ Page 4 of 12

Leaf sampling information

Tree number	No. leaves on 1st flush sampled	No. leaves on 2nd flush sampled

Fresh weight of leaves:

Number of leaves in bag(s) [0]: ______________________________

Weight of leaf sampling bag (g) [0.0]: ______________________________

Weight of sample bag plus total fresh leaves (g) [0.0]: ______________________

Bag ID: ________________________________ must be in the form of:

[P]-[ss]-[ddmmmyy]-[P] where:

P = project abbreviation
s = site
d = day; m = month; y = year
P = part (L=leaf; B=beans; H=husk)

Eg : ACR-01-23mar07-L

Site ID: ______________ Page 5 of 12

Leaf dimensions:

Length (cm) [0]	Width (cm) [0]

Length (cm) [0]	Width (cm) [0]

Total leaf weight after drying (g) [0.0]: ________________________________

D. Beans and Husks (if applicable to this site)

Number of Pods collected: ______________________

Fresh weight of wet bean:

Weight of bean sampling bag (g) [0.0]: ____________________________

Weight of sample bag plus total wet bean (g) [0.0]: ____________________

Bag ID: ______________________________ must be in the form of:

[P]-[ss]-[ddmmmyy]-[P] where:

P = project abbreviation
s = site
d = day; m = month; y = year
P = part (L=leaf; B=beans; H=husk)

Eg : ACR-01-23mar07-B

Total bean weight after drying (g) [0.0]: _________________________________

Fresh weight of Husks:

Weight of husk sampling bag (g) [0.0]: ____________________________

Weight of sample bag plus total husk (g) [0.0]: ____________________

Bag ID: ______________________________ must be in the form of:

[P]-[ss]-[ddmmmyy]-[P] where:

P = project abbreviation
s = site
d = day; m = month; y = year
P = part (L=leaf; B=beans; H=husk)

Eg : ACR-01-23mar07-H

Total husk weight after drying (g) [0.0]: _________________________________

F. Soil sampling information

Landform: ____

Slope of land: [Steep/Moderate/Flat] (circle) Comment: ________________

Evidence of: [Erosion/Deposition/None] (circle) Comment:________________

Final bulked sample -sample bag ID:
Must be in the form of:

[P]-[ss]-[ddmmmyy]
[DD-DD] where:

P = project abbreviation, s = site, d = day, m = month, y = year, D = depth

Eg : ACR-01-23mar07
15-30

ACR-______-______________
0-15

ACR-______-______________
15-30

ACR-______-______________
30-60

ACR-______-______________
60-90

Auger hole characteristics

Hole	**Depth (cm) [0] and description of hard layers**	**Depth to watertable (cm) [0] (if < 90 cm)**
1		
3		
5		
7		
9		

G. Soil pit:

Depth (cm) [0] of top soil (dark surface layer): ______________________________

Depth (cm) [0] to rock layer (if <90 cm): ______________________________

Depth (cm) [0] to water table (if <90 cm):______________________________

Depth (cm) [0-0] of gleying or mottles: ______________________________

Bulk density determination:
3 samples collected per depth layer, collected diagonally across layer

Profile layer	Bag ID*	Wt of bag (g) [0.0]	Wt of bag + wet soil (g) [0.0]	W1: Wt drying container (g) [0.0]	W2:Wt. container + wet soil (g) [0.0]	W3: Wt container + OD soil (g) [0.0]
0 – 15 cm	_____-0-15-A					
	_____-0-15-B					
	_____-0-15-C					
15 – 30 cm	_____-15-30-A					
	_____-15-30-B					
	_____-15-30-C					
30- 60 cm	_____-30-60-A					
	_____-30-60-B					
	_____-30-60-C					
60 – 90cm	_____-60-90-A					
	_____-60-90-B					
	_____-60-90-C					

* Bag ID must be in the form of:
[ss]- [DD-DD]-[R]
where:

s = site
D = depth
R = replicate [A/B/C]

Eg: 01-0-15-A

Bulk Density Ring Dimensions:

Height (cm) [0.0]: ______________

Diameter (cm) [0.0]: ______________

Site ID: ______________ Page 9 of 12

GROWER INTERVIEW

Date: ____-__________-__________ Interviewer:__________________
(dd - mmm - yyyy)

Name of grower or person interviewed:______________________________

Sex: Male ☐ Female ☐

H. History of Sampling Plot:

"I would like to ask you questions just about the area we just sampled"

Planting history of sampled plot

Year the block was first farmed	Year cocoa was first planted	Year in which current stand was planted

Current Details of Sampling Plot

Spacing (m) [0.0] x [0.0] [square/ triangular] (circle)	**Source of planting material**	**Name(s) of Shade Trees**	**Planted on:** 1. customary/clan land 2. Purchased land 3. somebody's land 4. State land

Other Crops Grown on sampled plot

	Previous cocoa stands (if applicable) (circle)	Current Cocoa stand (circle)
Food Crops	[Yes../ No]	[Yes../ No]
Legume Ground Cover	[Yes../ No]	[Yes../ No]
Fruit & Nut Trees	[Yes../ No]	[Yes../ No]
Legume Trees	[Yes../ No]	[Yes../ No]

Site ID: ______________ Page 10 of 12

1. Determine if grower has used fertiliser on the plot just sampled
[Yes/No] (circle)

IF YES

a. determine what fertiliser, how much and when? (*Note: interviewer gather enough information so we can work out how much per tree, type of fertiliser*)

b. determine if the grower noticed any difference when fertiliser was applied. If so, describe the difference.

Other comments from grower or interviewer

I. General Questions relating to grower's whole cocoa block(s):

"Now I would like to ask you questions about the whole of your block"

2. Determine the grower's yield in kg/ha in last twelve months (make note of wet or dry) (*Note: Interviewer should ask the right questions to get relevant information for calculating yield/tree/year; eg total number of trees, wet bean buyer, total yield, number bags (size), income from cocoa…*)

Calculated Yield (t/ha):______________________ [wet / dry] (circle)

Perceived reliability of Calculated Yield: [Low / Medium / High] (circle)

3. Determine if the grower is happy with his/her current level of yield from his/her current number of trees. [Yes / No] (circle)

4. Determine the reasons the grower attributes to getting high or low production on his/her block. (*eg: labour availability, new plantings, fertiliser, good/bad management, land dispute, poor market access, knowledge*)

(1) ____

(2) ____

(3) ____

(4) ____

Additional notes:

Site ID: ______________ Page 12 of 12

5 Determine if grower has used fertiliser anywhere on their block.

[Yes / No] (circle)

IF YES

a. determine what fertiliser, how much and when? (*Note: interviewer to work out how much per tree, type of fertiliser*)

b. determine if the grower noticed any difference when fertiliser was applied. Describe difference if applicable

6 Has the grower has any other questions or comments?

7 Interviewer's comments

Don't forget: "Thankyou true"

11.5 Characteristics of surveyed blocks

11.5.1 Location of sites

Site	Owner[1]	Tree 1 Lat. (˚S)[2]	Tree 1 Long. (˚E)[2]	Tree 6 Lat. (˚S)[2]	Tree 6 Long. (˚E)[2]
ENBP					
01	CCI	4.30449	152.02510	4.30451	152.02525
02	CCI	4.30484	152.02507	4.30489	152.02527
03	SH	4.36561	151.94316	4.36575	151.94318
04	PL	4.30549	152.04518	4.30550	152.04507
05	CCI	4.29982	152.01640	4.29937	152.01642
06	SH	4.30851	152.03133	4.30836	152.03145
07	SH	4.35825	152.22939	4.35817	152.22929
26	CCI	4.47071	152.34088	4.47057	152.34090
27	SH	4.37841	152.29012	4.37840	152.29021
28	SH	4.39615	152.35291	4.39611	152.35304
63	SH	4.52317	152.21669	4.52312	152.21651
ARB					
08	CCI	5.41148	154.68005	5.41153	154.68016
09	SH	5.25598	154.70279	5.25587	154.70262
10	SH	5.35414	154.68344	5.35426	154.68365
11	SH	5.23872	154.62741	5.23867	154.62729
12	SH	5.54412	155.04445	5.54417	155.04459
13	SH	5.54037	155.04636	5.54043	155.04625
14	PL	5.87129	155.23348	5.87157	155.23343
15	SH	6.49049	155.87463	6.49059	155.87474
16	SH	6.22337	155.49454	6.22324	155.49457
NIP					
17	SH	2.71515	150.93091	2.71527	150.93076
18	CCI	2.57072	150.81267	2.57094	150.81270
19	SH	2.89076	151.25050	2.89080	151.25067
20	SH	3.13047	151.70842	3.13052	151.70857
21	SH	3.14358	151.72737	3.14361	15172731
22	SH	3.43161	151.92056	3.43139	151.92041
23	PL	3.43775	151.94957	3.43793	151.94951
24	PL	3.50471	152.29390	3.50461	152.29399
25	SH	3.68517	152.38042	3.68509	152.38045
MoP					
29	SH	6.71767	146.78975	6.71775	146.78992
30	SH	6.57708	146.74677	6.57709	146.74687
31	SH	6.27709	146.22078	6.27713	146.22101
32	PL	6.59064	146.67113	6.59066	146.67122
33	SH	6.65435	146.98814	6.65427	146.98831
34	SH	6.63217	147.02057	6.63211	147.02045
NP					
35	SH	8.62358	148.29237	8.62354	148.29248
36	SH	8.80717	148.23363	8.80734	148.23376

Site	Owner[1]	Tree 1 Lat. (˚S)[2]	Tree 1 Long. (˚E)[2]	Tree 6 Lat. (˚S)[2]	Tree 6 Long. (˚E)[2]
37	SH	8.93519	147.87784	8.93518	147.87791
38	SH	8.82256	148.08994	8.82284	148.08983
39	SH	8.87997	148.45892	8.88011	148.45888
40	SH	9.10033	148.43575	9.10034	148.43546
MaP					
41	SH	4.96270	145.76643	4.96258	145.76628
42	DPI	4.57105	145.91771	4.57106	145.91780
43	PL	4.54547	146.00470	4.54528	146.00478
44	SH	4.50768	145.40198	4.50753	145.40192
45	SH	4.76746	145.47699	4.76648	145.67719
46	SH	5.63012	145.48174	5.63022	145.48190
47	SH	5.43439	145.51981	5.43421	145.51976
48	SH	5.34508	145.69875	5.34478	145.69896
ESP					
49	SH	3.63264	143.76485	3.63259	143.76495
50	SH	4.00508	144.04460	4.00519	144.04468
51	SH	3.91980	143.99702	3.91968	143.99704
52	SH	3.70881	143.26439	3.70889	143.26422
53	SH	3.68984	143.51683	3.68960	143.51685
54	SH	3.62961	143.03053	3.62951	143.03040
57	SH	3.57891	142.76166	3.57888	142.76175
60	CCI	3.48980	143.48706	3.48976	143.48726
WSP					
55	SH	3.67528	142.47949	3.67534	142.47960
56	SH	3.59174	142.47165	3.59166	142.47147
58	SH	3.15627	142.29527	3.15645	142.29520
59	SH	3.36540	143.03770	3.36532	143.03749
WHP					
61	SH	5.47972	144.559938	5.48013	144.59967
62	SH	5.48453	144.60078	5.48452	144.60088

[1]'SH' designates a smallholder block, 'CCI' a CCI trial, 'PL' a plantation, and 'DPI' a DPI-owned block managed by CCI as a demonstration trial.

[2]Location of the leaf and soil sampling points relative to these locations can be seen in the sampling plot diagram in Appendix 11.4.

11.5.2 Tenure, history and vegetation of sampled plots

	Tenure[1]	Year first farmed	Year cocoa first planted	Year current stand planted	Spacing (m)	Shade Trees[2]	Food Crops	Legume Ground Cover	Legume Trees
ENBP									
01	State	1967	1972	2000	4x4	Gl,C	N	N	Y
02	State	1967	1972	2000	4x4	Gl,C	N	N	Y
03	Purch.	<1980	<1980	1998	4x2.5	Gl,C,Be	N	N	Y
04	State	1980	1980	1999	4x3	Gl	N	N	N
05									
06						Gl,Ba	Y	N	Y
07	Cust.	1951	>1951	1998	4x2.5	C,Be	N	N	N
26		1930s	1950s	2004		C,Gl			
27	Cust.	<1960	1985	1991	4x4	C	N	N	N
28	Cust.	1970s	1998	1998	4x3.5	C	N	N	N
63	Lease	1995	1998	1998	4x4	Z,R	N	N	
ARB									
08	State	1960s	1960s	1997	4x3	Gl,C	N	N	Y
09	Cust.	1957	1968	2000	4x4	Gl,C,Br,O	Y	N	Y
10	Cust.	>1943	1960s	1999	4x4	Gl,Ga	N	N	Y
11	Cust.	1958	1970	1996	4x4	C	N	N	N
12	Purch.	1960	1970s	2000	4x4	Gl,Ba,O	Y	N	Y
13	Cust.	1960	1976	2000	4x4	Z	N	Y	N
14	Purch.	1950	1950s	1984	4x4	C	N	N	N
15	Purch.	1984	1985	2005	3.5x3.5	Gl,L	N	N	N
16	Cust.	1965	1978	1999	4x4	C	N	Y	N
NIP									
17	Purch.	<1981	1981	1981	4x4	Gl	Y	Y	Y
18	State				4x4	Gl	N	N	Y
19	Cust.	?	1960s	1989 or 99?	4x3	C	N	N	N
20	Cust.	1962	1967-8	1987	4x4	C,L	N	Y	Y
21	Purch.	1960s	1987	1987	4x4	Gl,Be,O	N	N	Y
22	Purch.	1950-60s	1950-60s	1996	4x4	C,Ba,Be,Br	Y	N	N
23	Cust.	1950s	1950s	1988	4x4	C	N	N	N
24	Purch.			1989	4x3	Gl,C	N	N	N
25	Purch.	1985	1986	1986	3x2	Z	Y	Y	N
MoP									
29	Cust.	1980s	1980s	1999	4x4	C,Be	Y	N	N
30	Cust.	1982	1983	1983	4x4	C,Be	Y	N	Y
31	Cust.	1980s	1990	1990	4x4	Gl,L	Y	Y	Y
32	Purch.	<1986	1986	1986	4x2	C	N	Y	N
33	Cust.				4x4	Gl	N	N	Y
34	Purch.	1995	1996	1996	4x4	Gl	Y	N	Y
NP									
35	Cust.	1972	1985	1985	3x3	Gl,C	Y	Y	Y

	Tenure[1]	Year first farmed	Year cocoa first planted	Year current stand planted	Spacing (m)	Shade Trees[2]	Food Crops	Legume Ground Cover	Legume Trees
36	Cust.	<1982	1982	1999	4x4	Gl,C,Be	Y	N	Y
37	Cust.	2003	2006	2006	3x3	Gl	Y	N	Y
38	Cust.	1980s	1994	1994	4x3	Gl,Be	Y	N	Y
39	Cust.	1987	1987	1997	4x4	Gl,C	Y	Y	Y
40	State	1910s	1970s	1970s	4x4	Gl	Y	Y	Y
MaP									
41	Cust.	1998	1998	1998	4x4	Gl	N	N	Y
42	Purch.			2002	3x2	Gl	N	N	Y
43	Purch.		<1980	<1980	4x4	C	N	Y	N
44	Cust.	1996	1998	1998	4x4	C,Gl	N	N	Y
45	Cust.	1963	1983	2000	4x4	C,Gl	Y	N	Y
46	Purch.	1995	1998-9	1998-9	4x4	Gl	Y	N	N
47	Cust.	1989	1994	1994	4x4	R	N	N	N
48	Cust.	1984	2003	2003	4x8	C,Gl	Y	Y	Y
ESP									
49	Cust.	1950s	1992	1992	4x4	C,Be	N	N	N
50	Purch.	1983	1985	1985	4x4	Z	N	N	N
51	Purch.	1986	1987	1987	4x4	Gl	N	N	Y
52	Cust.	1960s	2002	2002	4x4	Z	N	N	
53	Cust.	1969	1974	1974	4x4	L,Be	Y	N	Y
54	Cust.	1960s	2001	2001	4x4	Gl,L	N	N	Y
57	Cust.	1960s	1996	1996	4x4	Gl	Y	N	Y
60	State	1975	1995	1995	4x4	Gl,L	N	N	Y
WSP									
55	Cust.	1970s	1986	1986	4x4	O,Gl	N	N	N
56	Cust.	1960s	1982	1982	4x4	L,Gl	N	N	Y
58	Cust.	2000	2000	2000	4x4	C,Gl	N	N	Y
59	Cust.	1988	1988	1988	6x6	C,Be	N	Y	N
WHP									
61	Cust.	1970s	2001	2001	variable	C,L,Ba,O		N	N
62	Cust.		1984						

[1] State land, purchased (Purch.), leased from the government (Lease) or customary land (Cust.)

[2] Banana (Ba), Betel nut (Be), Breadfruit (Br), Coconut (C), Galip (Ga), Gliricidia (Gl), Leucaena (L), other fruit or nut trees including pau, aila, balbal, penats, mango (O), bush regrowth (R), or no shade (Z)

11.5.3 Slope and depth to impeding layers of sampled plots

Site	Landform	Erosion / Deposition	Slope	Depth to rock or gravel (m)	Depth to watertable (m)
ENBP					
01	Flat area next to deep drain	None	Flat	>0.9	>0.9
02	Flat	None	Flat	>0.9	>0.9
03	Undulating hill	Minor erosion	Moderate	>0.9	>0.9
04	Flat to slopes	Erosion on slopes with deposition on flat	Flat-Mod	>0.9	>0.9
05	Flat	None	Flat	>0.9	>0.9
06	Undulating hill slopes to flat land	Erosion where no ground cover	Moderate	>0.9	>0.9
07	Slopes	Erosion where no ground cover	Moderate	>0.9	>0.9
26	Raised limestone cliff	Minor erosion	Moderate	>0.9	>0.9
27	Hilly	Some erosion - top soil washed off	Moderate	>0.9	>0.9
28	Flat to slopes	Minor erosion	Moderate	>0.9	>0.9
63	Hill slope	Erosion obvious	Steep	0.8- >0.9	>0.9
ARB					
08	Undulating hill	Deposition of top soil from upslope	Moderate	>0.9	>0.9
09	Slopes	Deposition	Moderate	0.5- >0.9	>0.9
10	Gravelly hill	Deposition	Moderate	0.6- >0.9	>0.9
11	Slopes	Erosion	Moderate	>0.9	>0.9
12	Slopes	Minor erosion	Moderate	0.6- >0.9	>0.9
13	Raised cliff	Minor erosion	Moderate	0.7- >0.9	>0.9
14	Seashore	None	Flat	>0.9	>0.9
15	Some water logging	None	Flat	>0.9	0.6- >0.9
16	Mountain side	Erosion	Steep	>0.9	>0.9
NIP					
17	Slopes	None	Moderate	>0.9	>0.9
18	Slopes	None	Moderate	>0.9	>0.9
19	Flat land	None	Flat		
20	Flat land at base of a hill	Erosion	Moderate	0.5- >0.9	>0.9
21	Small hill above a clear rock creek.	Erosion	Moderate	>0.9	>0.9
22	Flat land	None	Flat	>0.9	>0.9
23	Flat land	None	Flat	>0.9	>0.9
24	Slopes	None	Moderate	0.65- >0.9	>0.9
25	Slopes	Erosion	Moderate	0.6- >0.9	>0.9
MoP					
29	Base of mountain	None	Flat	0.4- >0.9	>0.9
30	Flat land (next to Nadzab Airport)	None	Flat	>0.9	>0.9
31	Ramu plains	None	Flat	>0.9	>0.9
32	Plains	None	Flat	>0.9	>0.9

Site	Landform	Erosion / Deposition	Slope	Depth to rock or gravel (m)	Depth to watertable (m)
33	Valley	None	Flat	>0.9	>0.9
34	Mountain slope	Erosion	Moderate	0.3- >0.9	>0.9
NP					
35	Plains	None	Flat	>0.9	>0.9
36	Valley boulders indicating ancient water way	None	Moderate	0.3- >0.9	>0.9
37	Mountain foot hills	None	Moderate	0.5- >0.9	>0.9
38	Small hill	None	Moderate	0.8- >0.9	>0.9
39	Valley - kunai plains.	None	Flat	0.4- >0.9	>0.9
40	Flat valley surrounded by high hills	Soil being washed into the river.	Moderate	0.5- >0.9	>0.9
MaP					
41	Flat to slight slopes	Deposition from upslope	Flat	>0.9	>0.9
42	coastal	None	Moderate	0.3- >0.9	>0.9
43	Hill slope	Erosion	Moderate	0.3- >0.9	>0.9
44	Mountain foothill	None	Flat	>0.9	>0.9
45	Hill slope	Erosion - soil washed downslope	Moderate	>0.9	>0.9
46	Valley	None	Flat	>0.9	>0.9
47	Mountain side	Erosion	Steep	>0.9	>0.9
48	Valley - water basin	None	Flat	0.6- >0.9	>0.9?
ESP					
49	Hill slope (62m ASL)	Erosion - soil washed downslope	Moderate	>0.9	>0.9
50	Hill slope (44m ASL)	Erosion	Moderate	>0.9	>0.9
51	Valley (49m ASL)	None	Flat	>0.9	>0.9
52	Hill slope (133m ASL)	Erosion - soil washed downslope	Steep	0.6- >0.9	>0.9
53	Ridge slope (253m ASL)	Erosion	Steep	>0.9	>0.9
54	Hill slope (234m ASL)	Light erosion due to ground cover type	Steep	>0.9	>0.9
57	Hill slope (392m ASL)	Some erosion - top soil washed off	Steep	>0.9	>0.9
60	River bank (33m ASL)	None	Flat	>0.9	>0.9
WSP					
55	Mountain range (243 ASL)	Light erosion	Moderate	>0.9	>0.9
56	Mountain slope (369m ASL)	Erosion	Steep	>0.9	>0.9
58	Flood plain	Deposition	Flat	>0.9	>0.9
59	Mountain foothill (59m ASL)	Erosion where no ground cover	Moderate	0.4- >0.9	>0.9
WHP					
61	Slopes (883m ASL)	High soil loss/erosion when raining	Moderate	>0.9	>0.9
62	Slopes	Light erosion	Moderate	>0.9	>0.9

11.5.4 Reasons given for good or poor yields

Sites on CCI trials have been omitted and plantation blocks are indicated with a (P).

Site	Happy?	Reasons given by grower for good or poor yield
ENBP		
03	Y	Missing trees, Swampy area, Knowledge
04 (P)	Y	Good management , Fertilizer, Clones
06		
07	Y	Land shortage, Theft, Knowledge, Management
27	N	Limited labour, Other commitments, Fertilizer & tools shortage, Theft of ripe pods.
28	N	Knowledge of cocoa husbandry, Lacking good management practices.
63	N	Poor management, Pruning, May be fertilizer.
ARB		
09		Knowledge, Labour, fertilizer & chemicals, Finance for seedlings & tools, Pests & diseases, Possibly soil exhaustion
10		Bad management of neighbouring farms source of pests & diseases, Lack of labour, Planting material
11	N	Labour cost high (4 children all elsewhere), Theft, Poor management, Maybe soil exhaustion
12	N	Old material (Trinitario), Labour limited, Access to credit to purchase inputs
13	N	Bad management, Finance to purchase tools materials, Soils exhausted, Areas waterlogged
14 (P)		Senile cocoa, Bad management, Lack of knowledge new IPDM technology
15	Y	No fertilizer and chemicals limits increase in yield, Labour expensive
16		Wants to adopt IPDM to increase production
NIP		
17	Y	
19	N	No records due to family members harvesting beans without growers knowledge.
20	N	Low management input, Require training on block management, Require block rehabilitation
21	N	No proper management, Require training on block management.
22	N	
23 (P)	N	Lack of new planting materials, Very old cocoa stands (19 years), Management needs to be updated
24 (P)	N	Old trees, Knowledge (lack of new update of technology), Maybe due to lack of soil nutrient factors.
25	N	Poor maintenance, Cocoa dryer inoperable, Rain & wind destroying flowers, Family labour, bird pest
MoP		
29		Black pods disease, Production per tree is low, Lacking good management
30	N	Other commitments, Price rise in vanilla in the past, Knowledge lacking on good management
31	N	Pest & diseases eg. Black pod, rats, longicorn, Lack knowledge on good management, Change in price
32 (P)	N	Poor maintenance, Pest & diseases eg: termites & black pod, Previous waterlogging, Close spacing
33	N	Fermentary capacity not sufficient, No pruning, No enough labour, Pest & disease eg: black pod.
34	N	Labour dispute, Lacking of knowledge on good management, Fermentary capacity not sufficient.
NP		
35	N	Price is low in town, Lack of extension services, Limited assistance from government

Site	Happy?	Reasons given by grower for good or poor yield
36	N	Soil not suitable in valley, Pest & disease, Not enough shade, Big area but less labour.
37	N	Few trees bearing with more yet to bear, Knowledge on good management, Black pod
38	N	Pest & disease, Lack of knowledge, Limited assistance, Need nursery.
39	N	Limited supply of new planting material, Lack of good management practices.
40	N	Pests & diseases, Poor management, Lack of tools, Limited labour, Fermentery & dryer in bad condition.
MaP		
41	N	Lack knowledge on good management, Other commitments apart from cocoa
43 (P)	N	Missing trees, Thieves, Same areas of plantation stony
44	Y	Adequate labour, Good planting materials, No land disputes, Experience as plantation manager
45	Y	Knowledge acquired as a CCI contact farmer, Sufficient family labour, Good access, No land dispute
46	Y	IPDM technology, Sufficient labour, 3 recruited and 3 family members, Good materials, Good access
47	N	Probably low soil fertility, Poor planting material, Lack of skills & knowledge on management.
48	Y	Good management, Good experience as farmer & DPI officer, Good access, No land dispute.
ESP		
49	Y	Good road access to market, No land dispute, Only family labour
50	N	Old planting materials, Lack of knowledge & skills, Poor management, Limited labour
51	N	Lack of knowledge on husbandry, Limited labour, Insufficient planting material, No use of fertiliser
52	Y	New planting, Good family labour, Easy market access.
53	N	Very old planting materials, Poor management, No extension of new knowledge
54	N	Lacks cocoa skills, Unrecommended planting material, No fertiliser application
57	N	Lack skills and knowledge on establishment and manage., Poor planting material, No fertiliser used.
WSP		
55	N	Very old planting materials, no fertiliser application, Poor management, Lacks skills and knowledge
56	N	Limited labour, old planting materials, No fertiliser application, Low block management
58	N	Frequent flooding, Low price, Limited knowledge on management, No fertiliser
59	N	Limited knowledge on management, Committed to other obligations, No fertiliser used
WHP		
61		Lack of knowledge, Very poor market access, Bad management
62		

11.5.5 Management and incidence of diseases

Tree health and block management scores[1]					Disease score[2]			
	Tree Health	Shade	Weeding	Pruning	Black Pod	Canker	VSD	Pink Disease
ENBP								
01	G	VG	G	G	L	L	L	N
02	G	VG	VG	G	L	N	L	N
03	G	A	G	G	M	L	L	L
04	G	VG	VG	VG	L	L	L	L
05		G	G	A	M	N	L	N
06	A	G	A	A	L	L	L	L
07	G	G	G	G	L	L	L	L
26	G	G	G	G	L	L	L	N
27	A	A	A	P	L	L	N	N
28	G	A	A	A	L	L	L	N
63	G	P	G	A	L	L	L	L
ARB								
08		G	G	G	L	L	L	N
09	A	A	A	G	L	L	N	M
10	G	A	G	G	L	L	N	L
11	A	A	A	A	M	N	L	M
12	G	A	G	A	L	L	L	L
13	A	VP	A	P	M	L	L	L
14	P	P	P	P	S	M	N	M
15	P	P	G	A	L	L	N	L
16	G	G	A	A	L	L	N	N
NIP								
17	P	VP	VP	P	S	L	N	L
18	G	A	G	G	L	L	N	L
19	A	A	P	P	L	L	N	M
20	P	P	P	VP	S	L	N	L
21	G	A	G	A	L	L	N	L
22		A	A	A	L	N	N	L
23	A	A	A	A	M	L	N	L
24	A	P	A	A	M	L	N	L
25	A	A	P	P	M	M	N	L
MoP								
29	G	A	A	P	M	L	N	N
30	A	A	A	P	L	L	N	N
31	G	A	G	A	L	L	M?	L
32	G	G	G	A	L	L	L	N
33	A	P	G	VP	S	L	N	N
34	G	A	A	A	M	L	N	N
NP								
35	P	P	P	P	M	L	N	L

Tree health and block management scores[1]					**Disease score**[2]			
36	A	A	G	A	M	L	M	M
37	G	G	G	G	N	N	N	N
38	P	P	P	P	S	S	M	M
39	G	A	A	A	L	L	N	L
40	A	P	P	P	M	M	N	N
MaP								
41	G	VG	G	G	L	L	L	L
42	G	G	G	G	N	L	L	L
43	A	P	P	P	L	L	L	L
44	G	G	G	A	L	L	L	L
45	G	P	P	P	L		L	N
46	VG	G	VG	G	L	L	N	N
47	P	VP	VP	VP	M	L	M	L
48	G		A	G	L	L	N	N
ESP								
49	A	P	VP	VP	M	M	N	L
50	G	P	A	VP	M	M	L	M
51	A	P	A	P	L	L	L	N
52	G	P	A	VP	M	L	L	L
53	A	P	P	P	L	L	L	N
54	G	P	A	A	L	L	L	N
57	G	P	A	P	L	L	L	N
60	G	A	G	G	N	L	N	N
WSP								
55	A	VP	VP	VP	M	M	M	M
56	P	A	A	P	M	M	M	L
58	G		A	A	L	L	N	N
59	A	A	P	VP	M	L	N	N
WHP								
61	G	G	G	A	L	N	N	L
62								

[1] *Very good (VG), good (G), average (A), poor (P), very poor (VP), assessed on the sampled plots*

[2] *Severe (S), moderate (M), low (L), none (N), assessed on the sampled plots*

11.6 Critical leaf levels applied outside PNG

Nutrient concentrations (% of dry matter) in deficient and normal cocoa leaves (Wessel, 1985)

Nutrient	Criteria according to Loué (1961)			Criteria according to Murray (1967)		
	Severely deficient	Moderately deficient	Normal	Deficient	Low	Normal
N (%)	<1.80	1.8-2.0	2.35-2.50	<1.8	1.8-2.0	>2.0
P (%)	0.08-0.10	0.10-0.13	>0.18	<0.13	0.13-0.20	>0.20
K (%)	<1.0	1.0-1.2	>1.2	<1.2	1.2-2.0	>2.0
Ca (%)				<0.3	0.3-0.4	>0.4
Mg (%)				<0.20	0.20-0.45	>0.45
				Criteria according to de Geus (1973)		
Fe (mg/kg)				50		65-175
Zn (mg/kg)				15-20		30-65
B (mg/kg)				8.5-11		25-75

11.7 Leaf nutrient contents

11.7.1 Main essential elements

Site	N %	K %	Ca %	Mg %	P %	S %	Fe mg/kg	Mn mg/kg	B mg/kg	Cu mg/kg	Zn mg/kg
ENB											
1	2.2	2.43	1.06	0.37	0.21	0.20	42	34	41	6.9	32
2	2.2	2.30	1.07	0.33	0.18	0.20	48	34	45	5.1	27
3	2.0	2.40	1.42	0.40	0.19	0.20	39	93	39	6.7	39
4	2.2	2.30	1.01	0.39	0.21	0.21	54	57	37	7.5	41
5	2.2	2.20	1.16	0.40	0.22	0.19	41	41	35	8.9	43
6	2.1	2.60	0.87	0.36	0.23	0.21	43	32	37	6.6	30
7	**1.6**	1.93	1.64	0.56	0.17	0.26	97	65	35	7.0	68
26	**1.8**	2.10	1.20	0.40	0.18	0.21	33	111	41	5.4	50
27	2.0	2.60	1.14	0.43	0.23	0.23	33	82	43	5.5	44
28	**1.7**	2.50	1.14	0.42	0.23	0.22	**28**	95	38	8.4	67
63	**1.9**	1.89	1.47	0.61	0.16	0.26	44	430	33	9.2	98
ARB											
8	**1.6**	1.79	2.20	0.56	0.16	0.22	37	400	35	7.7	65
9	**1.7**	2.20	1.41	0.49	0.26	0.21	**27**	250	38	12.5	88
10	**1.8**	2.30	1.32	0.41	0.22	0.20	**24**	270	32	10.2	65
11	**1.4**	1.70	1.87	0.67	0.15	0.22	**24**	700	35	7.4	84
12	**1.9**	2.00	1.78	0.43	0.17	0.21	**30**	195	37	6.3	30
13	**1.8**	2.30	1.25	0.47	0.22	0.22	**27**	188	37	9.3	56
14	**1.5**	1.58	1.56	0.65	0.16	0.20	54	143	35	6.3	52
15	2.0	1.97	1.29	0.44	0.18	0.21	**25**	197	44	8.3	27
16	**1.8**	2.00	1.29	0.52	0.18	0.20	**28**	420	36	8.3	89
NIP											
17	2.0	2.30	0.71	0.46	0.21	0.24	37	320	33	13.2	54
18	**1.9**	2.20	1.44	0.46	0.19	0.20	**28**	350	39	11.4	47

Site	N %	K %	Ca %	Mg %	P %	S %	Fe mg/kg	Mn mg/kg	B mg/kg	Cu mg/kg	Zn mg/kg
19	2.1	1.99	1.30	0.52	0.22	0.22	34	350	40	11.7	73
20	2.2	1.25	1.17	0.66	0.25	0.22	35	270	33	13.1	141
21	2.1	1.74	1.01	0.65	0.26	0.22	34	340	35	13.1	94
22	**1.9**	1.61	1.90	0.62	0.15	0.23	**30**	173	37	9.2	142
23	**1.5**	2.20	1.02	0.62	0.21	0.25	**27**	330	33	8.3	74
24	**1.8**	1.85	1.40	0.66	0.22	0.20	**28**	210	31	9.4	72
25	**1.6**	1.59	1.32	0.64	0.13	0.23	**30**	350	31	9.6	90
MoP											
29	**1.9**	2.10	1.94	0.55	0.20	0.20	39	200	29	7.7	84
30	**1.8**	1.93	1.97	0.47	0.16	0.23	45	125	52	7.0	43
31	**1.8**	2.10	2.60	0.59	**0.12**	0.21	94	42	45	8.5	35
32	**1.7**	2.10	1.87	0.44	0.18	0.23	145	210	52	7.2	41
33	**1.6**	1.96	1.62	0.74	0.19	0.18	40	164	26	8.0	86
34	**1.8**	2.00	1.24	0.58	0.18	0.13	39	420	22	10.0	84
NP											
35	**1.6**	2.20	0.71	0.43	0.20	0.12	28	115	34	6.8	36
36	**1.6**	1.83	1.89	0.52	0.19	0.17	31	96	38	4.5	33
37	**1.9**	1.98	1.43	0.49	0.17	0.17	**26**	113	35	8.7	25
38	**1.7**	1.89	1.32	0.59	0.15	0.18	**29**	189	34	8.9	26
39	**1.7**	1.56	2.00	0.80	0.19	0.15	33	136	34	6.7	108
40	2.0	2.50	0.83	0.44	0.22	0.12	**29**	100	24	15.7	53
MaP											
41	2.1	1.95	1.26	0.50	0.21	0.18	34	94	35	9.5	55
42	**1.9**	2.10	1.66	0.50	0.15	0.18	35	25	31	8.4	61
43	2.0	2.30	1.95	0.43	**0.11**	0.15	**26**	36	39	7.2	46
44	2.1	2.30	1.83	0.59	0.26	0.18	**21**	95	31	13.5	74
45	2.0	1.93	1.42	0.49	0.16	0.14	**24**	56	33	10.9	60
46	2.0	1.87	1.71	0.54	0.18	0.17	43	119	36	8.5	52
47	2.1	2.10	0.78	0.38	0.23	0.16	**29**	67	32	11.3	59
48	2.0	2.10	1.23	0.52	0.22	0.14	34	83	35	8.7	74
ESP											
49	2.1	2.20	0.96	0.50	0.19	0.22	109	210	37	9.4	96
50	2.1	1.73	1.33	0.59	0.19	0.22	32	164	30	8.2	73
51	2.5	1.74	1.13	0.50	0.22	0.23	32	130	32	9.5	62
52	2.2	2.00	1.84	0.42	0.19	0.17	**23**	190	26	9.5	51
53	2.3	1.43	1.52	0.61	0.14	0.20	**27**	97	29	8.2	31
54	2.2	1.59	1.16	0.48	0.15	0.19	31	128	32	8.6	52
57	2.2	1.75	1.03	0.49	0.19	0.21	35	165	28	9.6	51
60	2.4	1.77	1.49	0.42	0.16	0.23	47	67	41	8.4	26
WSP											
55	2.2	2.10	0.83	0.44	0.23	0.19	33	194	24	9.0	41
56	2.1	2.10	0.97	0.50	0.21	0.18	42	250	27	8.2	43
58	2.4	1.79	1.01	0.66	0.23	0.20	53	44	39	9.1	66
59	2.0	1.73	1.80	0.53	0.19	0.18	36	240	38	6.9	71
WHP											
61	2.0	1.96	1.34	0.66	0.25	0.17	42	168	27	11.3	81

Site	N %	K %	Ca %	Mg %	P %	S %	Fe mg/kg	Mn mg/kg	B mg/kg	Cu mg/kg	Zn mg/kg
All											
Min.	*1.4*	*1.25*	*0.71*	*0.33*	*0.11*	*0.12*	*21*	*25*	*22*	*4.5*	*25*
Max.	*2.5*	*2.60*	*2.60*	*0.80*	*0.26*	*0.26*	*145*	*700*	*52*	*15.7*	*142*

11.7.2 Trace metals

Site	Mo mg/kg	Co mg/kg	Ni mg/kg	Na mg/kg	Al mg/kg	Ti mg/kg	Cr mg/kg	Cd mg/kg	Pb mg/kg	Se mg/kg
ENB										
1	< 0.8	< 0.7	< 0.8	0.8	3.5	1.0	1.1	< 0.3	< 2	< 7
2	< 0.8	< 0.8	< 0.8	< 0.4	5.0	1.9	< 0.5	< 0.2	< 2	< 7
3	< 0.8	< 0.7	< 0.8	< 0.4	4.3	1.2	< 0.5	0.25	< 2	< 7
4	< 0.8	< 0.8	< 0.8	< 0.4	6.1	2.7	< 0.5	< 0.2	< 2	< 7
5	< 0.8	< 0.7	< 0.8	17	3.5	1.5	< 0.5	< 0.2	< 2	< 7
6	< 0.8	< 0.8	< 0.8	< 0.4	4.6	1.9	< 0.5	< 0.2	< 2	< 7
7	< 0.8	< 0.7	3.8	74	32	4.4	1.9	< 0.2	< 2	< 7
26	< 0.7	< 0.7	< 0.8	330	2.7	0.48	< 0.4	0.40	< 2	< 7
27	< 0.7	< 0.7	< 0.8	114	< 0.1	0.25	< 0.4	0.21	< 2	< 7
28	< 0.8	< 0.7	< 0.8	250	< 0.1	0.16	< 0.5	0.41	< 2	< 7
63	< 0.8	25	2.3	45	18	1.0	< 0.5	< 0.2	< 2	< 7
ARB										
8	< 0.7	1.8	1.5	240	12	0.46	0.62	0.69	< 2	< 7
9	< 0.8	0.93	< 0.8	161	3.0	< 0.1	< 0.5	1.5	< 2	< 7
10	< 0.8	0.87	< 0.8	112	< 0.1	< 0.1	< 0.5	1.1	< 2	< 7
11	< 0.7	3.7	< 0.8	97	< 0.1	< 0.1	0.40	1.4	< 2	< 7
12	< 0.7	< 0.7	< 0.8	108	2.5	0.13	< 0.4	0.77	< 2	< 7
13	< 0.8	0.77	< 0.8	250	3.4	< 0.1	< 0.5	0.71	< 2	< 7
14	< 0.7	< 0.7	< 0.8	163	19	1.6	0.83	< 0.2	< 2	< 7
15	< 0.7	1.8	< 0.8	45	< 0.1	0.12	< 0.4	< 0.2	< 2	< 7
16	< 0.8	1.2	0.87	25	< 0.1	< 0.1	< 0.5	2.0	< 2	< 7
NIP										
17	< 0.8	2.7	2.1	94	13	0.20	< 0.5	< 0.2	< 2	< 7
18	< 0.8	3.9	1.2	115	4.9	0.14	< 0.5	1.4	< 2	< 7
19	< 0.8	1.0	0.97	42	3.2	0.21	< 0.5	1.3	< 2	< 7
20	< 0.8	3.0	1.2	68	5.5	0.17	0.50	5.5	< 2	< 7
21	< 0.7	1.8	< 0.8	59	5.7	0.22	< 0.4	7.3	< 2	< 7
22	< 0.7	1.2	< 0.8	210	1.3	0.25	< 0.4	0.51	< 2	< 7
23	< 0.8	1.5	< 0.8	155	< 0.1	< 0.1	< 0.5	2.9	< 2	< 7
24	< 0.8	2.0	< 0.8	250	< 0.1	< 0.1	< 0.5	0.47	< 2	< 7
25	< 0.8	7.5	1.5	177	0.63	0.12	< 0.4	0.32	< 2	< 7
MoP										
29	< 0.8	2.0	20	18	1.3	0.23	< 0.5	1.0	< 2	< 7
30	1.2	0.89	2.9	46	11	1.1	< 0.5	< 0.2	< 2	< 7
31	< 0.8	< 0.8	3.8	47	44	3.9	0.61	0.44	< 2	< 7
32	< 0.7	2.1	5.1	65	95	5.8	0.65	0.21	< 2	< 7
33	0.86	2.5	1.3	52	8.2	1.0	< 0.5	0.25	< 2	< 7

34	< 0.7	5.9	2.1	28	6.5	0.68	< 0.4	0.44	< 2	< 7
NP										
35	< 0.8	0.98	3.1	93	2.5	0.31	< 0.5	0.31	< 2	< 7
36	3.4	0.70	< 0.8	51	2.1	0.34	< 0.5	0.32	< 2	< 7
37	< 0.8	< 0.8	< 0.9	13	1.0	0.28	< 0.5	0.24	< 2	< 7
38	< 0.8	0.81	0.88	41	6.1	0.61	< 0.5	0.44	< 2	< 7
39	1.2	2.1	6.1	119	5.0	0.37	0.54	0.68	< 2	< 7
40	< 0.7	1.8	3.9	19	6.3	0.42	< 0.4	0.41	< 2	< 7
MaP										
41	< 0.8	1.0	2.7	230	7.2	0.32	< 0.5	0.30	< 2	< 7
42	< 0.8	< 0.8	< 0.8	220	11	0.44	< 0.5	< 0.2	< 2	< 7
43	< 0.8	< 0.8	< 0.8	330	5.4	0.20	< 0.5	< 0.2	< 2	< 7
44	< 0.8	< 0.8	13	105	2.6	< 0.1	< 0.5	0.53	< 2	< 7
45	< 0.8	0.73	2.5	147	2.1	< 0.1	< 0.5	< 0.2	< 2	< 7
46	< 0.8	1.5	16	18	11	0.67	< 0.5	0.44	< 2	< 7
47	< 0.8	1.2	12	32	4.4	0.25	< 0.5	0.21	< 2	< 7
48	< 0.8	0.98	9.7	130	7.9	0.48	< 0.5	0.27	< 2	< 7
ESP										
49	< 0.8	5.2	72	49	53	1.6	< 0.5	0.48	< 2	< 7
50	< 0.8	4.6	24	62	8.1	0.14	< 0.5	< 0.2	< 2	< 7
51	< 0.8	1.7	60	17	4.7	0.14	< 0.5	0.50	< 2	< 7
52	< 0.8	1.6	34	9.6	1.6	< 0.1	< 0.5	1.2	< 2	< 7
53	< 0.8	1.7	16	72	3.7	0.10	< 0.5	0.51	< 2	< 7
54	1.0	1.7	23	12	5.8	0.22	< 0.5	0.56	< 2	< 7
57	< 0.8	3.3	76	19	6.1	0.16	< 0.5	0.27	< 2	< 7
60	< 0.8	2.5	24	58	9.3	0.37	< 0.5	0.21	< 2	< 7
WSP										
55	< 0.8	3.1	91	3.2	8.0	0.15	< 0.5	0.21	< 2	< 7
56	< 0.8	6.4	87	19	13	0.35	< 0.5	0.37	< 2	< 7
58	0.90	1.0	3.8	41	21	1.2	< 0.5	0.25	< 2	< 7
59	< 0.8	2.7	23	158	11	0.49	< 0.5	0.68	< 2	< 7
WHP										
61	2.6	2.9	2.6	< 0.4	19	0.68	< 0.5	0.42	< 2	< 7
62										

11.8 Soil properties (all sites)

11.8.1 Colour, texture, pH, EC (all depths)

Site	Depth (cm)	Colour and field texture	approx % clay1	pH_{water}	pH_{CaCl2}	EC (dS/m)
ENBP						
1	0-15	dk br, loam	25	5.7	5.4	0.152
	15-30	v dk br, clay loam	30 - 35	5.9	5.4	0.085
	30-60	dk br, sandy clay loam	20 - 30	6.4	5.6	0.036
	60-90	dk gry br, clayey sand	5 - 10	6.7	5.6	0.017
2	0-15	dk br, loam	25	6.5	6.1	0.126
	15-30	dk br, clay loam	30 - 35	6.8	6.4	0.082
	30-60	dk br, sandy clay loam	20 - 30	6.8	5.9	0.031
	60-90	br, clayey sand	5 - 10	6.8	5.9	0.021
3	0-15	dk br, loam	25	6.4	6.0	0.130
	15-30	dk gry br, clay loam	30 - 35	6.5	5.9	0.065
	30-60	br, clayey sand	5 - 10	8.3	7.8	0.095
	60-90	br, clayey sand	5 - 10	8.6	8.0	0.078
4	0-15	dk br, loam	25	6.1	5.5	0.130
	15-30	dk br, sandy loam	10 - 20	6.2	5.4	0.064
	30-60	dk gry br, clayey sand	5 - 10	6.2	5.3	0.037
	60-90	dk gry br, clayey sand	5 - 10	6.1	5.2	0.031
5	0-15	dk br, silty clay loam	30 - 35	6.3	5.7	0.119
	15-30	dk br, silty clay loam	30 - 35	6.3	5.7	0.124
	30-60	br, clayey sand	5 - 10	6.3	5.6	0.054
	60-90	gry br, sand	< 5	6.5	5.5	0.024
6	0-15	v dk br, loam	25	6.6	5.6	0.015
	15-30	v dk gry br, clay loam	30 - 35	6.1	5.5	0.072
	30-60	dk br, clayey sand	5 - 10	6.2	5.5	0.035
	60-90	gry br, sand	< 5	6.5	5.5	0.019
7	0-15	v dk br, sandy loam	10 - 20	6.5	6.1	0.121
	15-30	dk br, loamy coarse sand	~ 5	6.6	5.9	0.045
	30-60	dk br, loamy coarse sand	~ 5	6.6	5.8	0.036
	60-90	dk br, loamy coarse sand	~ 5	6.5	5.6	0.035
26	0-15	blk, loam	~ 25	6.4	5.8	0.090
	15-30	blk, clay loam	30 - 35	6.4	5.6	0.041
	30-60	v dk gry br, sandy clay loam	20 - 30	6.4	5.5	0.026
	60-90	v dk gry br (with light br gry mottle), sandy clay loam	20 - 30	6.5	5.5	0.019
27	0-15	v dk br, loam	~ 25	6.0	5.5	0.081
	15-30	v dk gry br, sandy loam	10 - 20	6.3	5.7	0.038
	30-60	dk gry br (with light br gry mottle), sandy clay loam	20 - 30	6.6	5.8	0.023
	60-90	gry br, clayey sand	5 - 10	6.2	5.8	0.017
28	0-15	v dk br, loam	~ 25	6.2	5.7	0.105
	15-30	v dk gry br, loam	~ 25	6.5	5.6	0.042
	30-60	dk gry br, sandy clay loam	20 - 30	6.4	5.5	0.022

Site	Depth (cm)	Colour and field texture	approx % clay1	pH_{water}	pH_{CaCl2}	EC (dS/m)
	60-90	gry br, clayey sand	5 - 10	6.4	5.5	0.015
63	0-15	dk br, clay loam	30 - 35	7.0	6.0	0.105
	15-30	dk br, light clay	35 - 40	7.0	5.7	0.046
	30-60	dk yel br (with pale br mottle), medium clay	45 - 50	6.4	4.9	0.029
	60-90	dk br, medium heavy clay	> 50	5.4	4.0	0.017
ARB						
8	0-15	dk br, light clay	35 - 40	6.2	5.8	0.100
	15-30	dk br, medium clay	45 - 50	6.5	5.8	0.031
	30-60	dk red br, heavy clay	> 50	6.5	5.9	0.037
	60-90	dk red br, heavy clay	> 50	6.6	6.1	0.025
9	0-15	dk br, light clay	35 - 40	7.7	7.4	0.200
	15-30	dk br, medium clay	45 - 50	8.1	7.5	0.165
	30-60	red br, heavy clay	> 50	7.1	6.5	0.060
	60-90	dk red br (with yel red mottle), heavy clay	> 50	7.7	7.1	0.069
10	0-15	dk br, light clay	35 - 40	6.3	5.8	0.155
	15-30	dk br, medium clay	45 - 50	6.2	5.4	0.050
	30-60	dk red br, heavy clay	> 50	6.6	6.1	0.060
	60-90	dk yel br, heavy clay	> 50	7.4	6.9	0.064
11	0-15	dk red br, loam	~ 25	5.3	4.9	0.142
	15-30	dk br, loam	~ 25	5.8	5.0	0.032
	30-60	dk br (with yel br mottle), light clay	35 - 40	5.4	4.4	0.018
	60-90	yel br, medium clay	45 - 50	5.3	4.2	0.015
12	0-15	v dk br, sandy loam	10 - 20	6.2	5.8	0.132
	15-30	v dk gry br, loamy sand	~ 5	6.3	5.7	0.054
	30-60	v dk gry br, sandy light clay	35 - 40	6.2	5.4	0.039
	60-90	dk red br, sandy medium clay	45 - 50	6.3	5.6	0.028
13	0-15	v dk br, sandy loam	10 - 20	5.9	5.4	0.119
	15-30	v dk gry br, sandy clay loam	20 - 30	5.9	5.2	0.050
	30-60	dk red br, sandy light clay	35 - 40	6.0	5.2	0.025
	60-90	dk red br, heavy clay	> 50	8.0	7.5	0.201
14	0-15	blk, sandy loam	10 - 20	5.5	5.2	0.169
	15-30	v dk br, loamy sand	~ 5	5.8	5.1	0.028
	30-60	v dk gry, sand	< 5	6.1	5.7	0.012
	60-90	dk gry br, sand	< 5	8.5	7.3	0.050
15	0-15	dk br, clay loam	30 - 35	5.0	4.6	0.098
	15-30	dk yel br, sandy clay loam	20 - 30	5.1	4.9	0.033
	30-60	dk yel br, clayey sand	5 - 10	5.3	5.1	0.019
	60-90	dk yel br, sand	< 5	5.6	5.3	0.012
16	0-15	dk red br, clay loam, sandy	30 - 35	5.5	5.0	0.076
	15-30	red br, sandy clay loam	20 - 30	5.8	5.1	0.023
	30-60	dk br, sandy light medium clay	40-45	6.0	5.1	0.019
	60-90	br, sandy medium clay	45 - 50	6.0	5.0	0.017
NIP						

Site	Depth (cm)	Colour and field texture	approx % clay1	pH_{water}	pH_{CaCl2}	EC (dS/m)
17	0-15	dk br, light clay	35 - 40	4.4	4.1	0.104
	15-30	dk br, light clay	35 - 40	4.3	4.2	0.267
	30-60	red br, medium clay	45 - 50	4.6	4.1	0.029
	60-90	strong br, medium clay	45 - 50	4.4	4.0	0.137
18	0-15	dk red br, light clay	35 - 40	6.1	5.8	0.092
	15-30	dk red br, light clay	35 - 40	6.0	5.5	0.056
	30-60	dk red br, medium clay	45 - 50	5.9	5.5	0.043
	60-90	red br, medium clay	45 - 50	6.0	6.1	0.033
20	0-15	dk red br, light clay	35 - 40	5.5	5.1	0.112
	15-30	dk red br, light clay	35 - 40	5.7	5.0	0.031
	30-60	dk red br, light medium clay	40 - 45	5.7	4.9	0.024
	60-90	red br, medium clay	45 - 50	5.5	4.7	0.017
21	0-15	dk red br, light clay	35 - 40	6.1	5.7	0.118
	15-30	dk red br, light clay	35 - 40	5.9	5.4	0.040
	30-60	dk red br, light clay	35 - 40	5.8	5.3	0.018
	60-90	dk red br, light medium clay	40 - 45	5.2	4.8	0.012
22	0-15	dk br, sandy clay loam	20 - 30	5.8	5.3	0.108
	15-30	dk br, sandy clay loam	20 - 30	5.9	5.2	0.043
	30-60	dk br, clayey sand	5 - 10	6.0	5.1	0.014
23	0-15	dk yel br, light clay	35 - 40	5.2	5.0	0.890
	15-30	dk yel br, fine sandy light clay	35 - 40	5.0	4.7	0.791
	30-60	dk yel br, fine sandy medium clay	45 - 50	5.6	4.8	0.028
	60-90	dk yel br, fine sandy medium clay	45 - 50	5.7	4.9	0.015
24	0-15	pinkish white, light clay	35 - 40	8.0	7.7	0.183
	15-30	dk red br, light clay	35 - 40	8.1	7.6	0.192
	30-60	red br, medium clay	45 - 50	7.9	7.5	0.139
	60-90	red br, medium heavy clay	> 50	7.7	7.4	0.132
25	0-15	dk br, clay loam	30 - 35	6.1	5.5	0.124
	15-30	dk br (with white mottle), light medium clay	40 - 45	5.8	5.0	0.048
	30-60	br (with white mottle), medium clay	45 - 50	5.4	4.3	0.022
	60-90	light br (with white mottle), medium clay	45 - 50	5.6	4.5	0.028
MoP						
29	0-15	v dk gry, clay loam	30 - 35	5.6	5.2	0.097
	15-30	v dk gry br, light clay	35 - 40	5.7	5.1	0.031
	30-60	gry br, sandy light clay	35 - 40	5.9	5.2	0.014
	60-90	gry br, coarse sandy light clay	35 - 40	5.9	5.2	0.021
30	0-15	v dk br, loam	~ 25	8.2	7.8	0.150
	15-30	v dk gry br, loam	~ 25	8.3	7.9	0.121
	30-60	v dk gry br, silty loam	~ 25	8.5	8.0	0.101
	60-90	v dk br, fine sand	~ 5	8.6	8.0	0.087
31	0-15	br, silty loam	~ 25	8.2	7.8	0.148
	15-30	br, silty loam	~ 25	8.2	7.8	0.124
	30-60	dk br, silty loam	~ 25	7.9	7.4	0.058

Site	Depth (cm)	Colour and field texture	approx % clay1	pH_{water}	pH_{CaCl2}	EC (dS/m)
	60-90	dk br, sandy loam	10 - 20	7.9	7.5	0.034
32	0-15	v dk gry br, silty clay loam	30 - 35	5.7	5.3	0.137
	15-30	v dk gry br, light clay	35 - 40	8.0	7.7	0.146
	30-60	dk br, light clay	35 - 40	8.3	7.9	0.163
	60-90	dk br, light clay	35 - 40	8.4	8.0	0.184
33	0-15	blk, silty clay loam	30 - 35	5.7	5.3	0.079
	15-30	blk, silty clay loam	30 - 35	5.7	5.0	0.030
	30-60	v dk br, silty clay loam	30 - 35	5.7	5.1	0.043
	60-90	v dk br, light medium clay	40 - 45	6.3	5.2	0.008
34	0-15	blk, silty clay loam	30 - 35	5.0	4.6	0.122
	15-30	blk, silty clay loam	30 - 35	4.9	4.4	0.057
	30-60	v dk br, silty clay loam	30 - 35	5.1	4.5	0.025
NP						
35	0-15	v dk gry, loam	~ 25	5.4	5.0	0.071
	15-30	v dk gry br, loam	~ 25	5.4	4.9	0.042
	30-60	gry br, fine sand	~ 5	5.7	5.1	0.010
	60-90	light br gry, fine sand	~ 5	5.8	5.3	0.004
36	0-15	v dk gry, loam	~ 25	6.1	5.7	0.054
	15-30	v dk gry, loam	~ 25	6.1	5.5	0.031
	30-60	v dk gry br, clayey sand	5 - 10	6.2	5.5	0.017
	60-90	dk gry br, sand	< 5	6.2	5.5	0.012
37	0-15	blk, clay loam	30 - 35	5.8	5.3	0.117
	15-30	blk, clay loam	30 - 35	5.4	5.0	0.051
	30-60	v dk gry, clay loam	30 - 35	5.2	5.1	0.022
	60-90	v dk gry, clay loam	30 - 35	5.3	5.4	0.020
38	0-15	v dk br, loam	~ 25	5.5	5.1	0.077
	15-30	v dk gry br, loam	~ 25	5.5	5.0	0.027
	30-60	dk br, sandy clay loam	20 - 30	5.7	5.5	0.010
	60-90	dk gry br, clayey sand	5 - 10	5.9	5.4	0.006
39	0-15	v dk gry, sandy loam	10 - 20	5.8	5.2	0.035
	15-30	v dk gry br, sandy clay loam	20 - 30	6.0	5.2	0.016
	30-60	dk br, sandy clay loam	20 - 30	6.2	5.3	0.011
	60-90	dk br, clayey sand	5 - 10	6.3	5.3	0.009
40	0-15	v dk gry br, loam	~ 25	5.8	5.3	0.087
	15-30	v dk gry br, sandy clay loam	20 - 30	5.9	5.2	0.041
	30-60	dk br, sandy light clay	35 - 40	5.9	5.0	0.019
	60-90	dk br, coarse sandy light clay	35 - 40	6.0	5.0	0.015
MaP						
41	0-15	dk red br, light clay	35 - 40	6.2	5.8	0.080
	15-30	dk red br, light medium clay	40 - 45	6.4	5.8	0.045
	30-60	dk red br, medium clay	45 - 50	6.6	5.8	0.024
	60-90	dk red br, medium clay	45 - 50	6.6	5.8	0.022
42	0-15	dk br, sandy loam	10 - 20	6.1	5.7	0.095
	15-30	dk br, loamy sand	~ 5	6.2	5.7	0.050
	30-60	dk yel br, loamy sand	~ 5	6.4	5.7	0.020

Site	Depth (cm)	Colour and field texture	approx % clay1	pH_{water}	pH_{CaCl2}	EC (dS/m)
	60-90	dk yel br, loamy sand	~ 5	6.5	5.7	0.015
43	0-15	blk, loam	~ 25	6.2	5.8	0.130
	15-30	blk, loamy sand	~ 5	6.4	5.7	0.046
	30-60	v dk br, loamy sand	~ 5	6.6	5.7	0.023
	60-90	v dk br, clay loam, sandy	30 - 35	6.7	5.6	0.022
44	0-15	v dk gry br, medium clay	45 - 50	6.4	5.8	0.063
	15-30	v dk gry br, medium heavy clay	> 50	6.5	5.8	0.037
	30-60	dk gry br, heavy clay	> 50	6.5	5.8	0.025
	60-90	br, heavy clay	> 50	6.5	5.8	0.022
45	0-15	blk, light medium clay	40 - 45	6.3	5.9	0.094
	15-30	blk, medium heavy clay	> 50	6.5	5.8	0.056
	30-60	light br gry (with v dk gry br mottle), sandy heavy clay	> 50	6.8	5.9	0.034
	60-90	pale br (with dk gry br mottle), sandy medium clay	45 - 50	7.0	5.8	0.014
46	0-15	dk br, silty clay loam	30 - 35	6.0	5.3	0.082
	15-30	dk br, silty clay loam	30 - 35	6.2	5.4	0.042
	30-60	dk br, sandy clay loam	20 - 30	6.4	5.6	0.020
	60-90	dk br, sandy clay loam	20 - 30	6.6	5.6	0.013
47	0-15	v dk gry br, clay loam	30 - 35	6.4	5.9	0.141
	15-30	dk br, light clay	35 - 40	6.5	5.7	0.046
	30-60	dk br, light medium clay	40 - 45	6.5	5.6	0.022
	60-90	br, coarse sandy medium clay	45 - 50	6.5	5.4	0.015
48	0-15	dk br, clay loam	30 - 35	6.2	5.6	0.077
	15-30	dk br, light medium clay	40 - 45	6.4	5.6	0.035
	30-60	dk br, medium clay	45 - 50	6.6	5.6	0.019
	60-90	dk br, medium clay	45 - 50	6.6	5.5	0.012
ESP						
49	0-15	dk gry br, light medium clay	40 - 45	5.9	5.3	0.091
	15-30	dk gry br, medium clay	45 - 50	5.8	4.9	0.036
	30-60	dk gry br (with light gry mottle), medium heavy clay	> 50	5.9	4.9	0.026
	60-90	br (with v pale br mottle), medium heavy clay	> 50	5.4	4.3	0.043
50	0-15	dk gry br, coarse sandy light medium clay	35 - 40	6.4	6.1	0.074
	15-30	dk gry br, coarse sandy medium heavy clay	45 - 50	6.8	6.1	0.032
	30-60	dk yel br (with br mottle), coarse sandy heavy clay	> 50	6.2	5.1	0.027
	60-90	yel br (with red br mottle), coarse sandy heavy clay	> 50	5.6	4.6	0.054
51	0-15	dk gry br, silty clay loam	30 - 35	5.8	5.3	0.083
	15-30	dk gry br, light clay	35 - 40	5.8	4.9	0.034
	30-60	br, light medium clay	40 - 45	5.9	4.8	0.020
	60-90	br, medium clay	45 - 50	6.0	5.1	0.026
52	0-15	blk, medium clay	45 - 50	6.9	6.4	0.125
	15-30	blk, heavy clay	> 50	6.3	5.5	0.049

Site	Depth (cm)	Colour and field texture	approx % clay1	pH_{water}	pH_{CaCl2}	EC (dS/m)
	30-60	v dk gry br, heavy clay	> 50	5.9	5.1	0.033
	60-90	dk gry br (with yel br mottle), heavy clay	> 50	6.0	5.1	0.024
53	0-15	dk gry br, light clay	35 - 40	7.3	7.0	0.193
	15-30	dk br (with mottle), medium heavy clay	> 50	7.7	7.2	0.165
	30-60	pale br (with mottle), medium clay	45 - 50	8.3	7.6	0.127
	60-90	light yel br (with mottle), light clay	35 - 40	8.4	7.6	0.096
54	0-15	dk gry br, light medium clay	40 - 45	6.6	6.1	0.097
	15-30	dk gry br, medium heavy clay	> 50	6.5	5.7	0.065
	30-60	gry br, medium heavy clay	> 50	8.1	7.5	0.141
	60-90	light yel br (with mottle), light clay	35 - 40	8.4	7.6	0.103
57	0-15	v dk gry br, light clay	35 - 40	6.7	6.3	0.124
	15-30	dk gry br, medium clay	45 - 50	5.8	5.1	0.047
	30-60	dk br, medium heavy clay	> 50	5.6	4.6	0.028
	60-90	br, medium clay	45 - 50	6.0	4.7	0.016
60	0-15	dk gry br, loam	~ 25	6.1	5.4	0.064
	15-30	gry br, sandy loam	10 - 20	6.4	5.6	0.034
	30-60	gry br, loamy sand	~ 5	6.6	5.7	0.018
	60-90	gry br, loamy sand	~ 5	6.7	5.8	0.013
WSP						
55	0-15	dk gry br, light clay	35 - 40	5.2	4.6	0.095
	15-30	dk br, light medium clay	40 - 45	5.6	4.7	0.034
	30-60	br, light clay	35 - 40	6.3	5.4	0.015
	60-90	br, light clay	35 - 40	6.4	5.5	0.016
56	0-15	v dk gry br, light clay	35 - 40	5.7	5.1	0.116
	15-30	dk gry br, light medium clay	40 - 45	5.5	4.7	0.050
	30-60	dk br, medium heavy clay	> 50	5.6	4.5	0.022
	60-90	dk yel br, medium clay	45 - 50	5.8	4.7	0.015
58	0-15	v dk br, loam	~ 25	6.4	5.9	0.073
	15-30	dk br, clay loam	30 - 35	6.8	6.3	0.037
	30-60	dk br, sandy clay loam	20 - 30	7.1	6.4	0.031
	60-90	dk br, sandy clay loam	20 - 30	7.2	6.3	0.021
59	0-15	v dk gry br, light clay	35 - 40	6.1	5.4	0.075
	15-30	dk br, coarse sandy light clay	35 - 40	6.8	6.0	0.036
	30-60	dk gry br, coarse sandy medium clay	45 - 50	7.4	6.6	0.046
	60-90	dk br, coarse sandy medium clay	45 - 50	6.8	5.8	0.016
WHP						
61	0-15	dk br, sandy clay loam	20 - 30	5.9	5.4	0.110
	15-30	dk br, sandy clay loam	20 - 30	6.1	5.3	0.066
	30-60	dk br (with mottle), coarse sandy light clay	35 - 40	6.3	5.3	0.044
	60-90	br (with mottle), coarse sandy light clay	35 - 40	6.6	5.2	0.014
62	0-15	dk br, light clay	35 - 40	5.8	5.3	0.181
	15-30	dk br, light medium clay	40 - 45	6.1	5.3	0.068

Site	Depth (cm)	Colour and field texture	approx % clay1	pH_{water}	pH_{CaCl2}	EC (dS/m)
	30-60	dk br (with mottle), medium clay	45 - 50	6.4	5.2	0.023
	60-90	br (with mottle), medium clay	45 - 50	6.6	5.2	0.010

[1]*based on texture*

11.8.2 Exchangeable ion contents (all depths)

Site	Depth (cm)	AEC cmolc/kg	CEC cmolc/kg	Exch. Ca cmolc/kg	Exch. Mg cmolc/kg	Exch. K cmolc/kg	Exch. Na cmolc/kg	Exch. acid cmolc/kg
ENBP								
1	0-15	0.03	17.16	19.29	2.64	2.04	0.20	0.01
	15-30	0.06	20.11	19.61	2.46	2.25	0.37	0.01
	30-60	0.02	15.23	12.76	1.75	2.76	0.54	0.01
	60-90	0.04	7.57	5.84	0.76	1.92	0.51	0.02
2	0-15	0.02	20.37	22.15	3.65	2.16	0.11	0.01
	15-30	0.07	24.62	25.20	3.38	2.88	0.20	0.01
	30-60	0.03	14.15	10.99	1.91	2.92	0.64	0.01
	60-90	0.03	8.65	6.67	1.10	1.80	0.65	0.01
3	0-15	0.01	22.80	22.73	2.53	2.75	0.11	0.01
	15-30	0.01	18.15	16.23	1.58	2.35	0.43	0.01
	30-60	0.04	13.01	10.54	0.71	1.55	0.49	0.01
	60-90	0.06	13.40	7.30	0.53	1.20	0.40	0.01
4	0-15	0.09	11.44	9.57	2.15	1.29	0.11	0.01
	15-30	0.18	8.85	7.18	1.41	1.59	0.23	0.02
	30-60	0.13	7.22	5.41	1.31	1.62	0.31	0.03
	60-90	0.21	6.90	5.03	1.20	1.62	0.36	0.03
5	0-15	0.06	18.29	17.14	2.84	2.33	0.22	0.01
	15-30	0.06	19.05	16.23	2.21	2.40	0.53	0.01
	30-60	0.03	12.17	8.71	1.37	2.23	0.87	0.04
	60-90	0.03	7.20	5.37	0.91	1.56	0.77	0.03
6	0-15	0.03	18.66	16.14	3.36	3.02	0.22	0.01
	15-30	0.07	18.08	15.04	2.88	3.21	0.47	0.01
	30-60	0.04	10.62	6.89	1.66	2.38	0.71	0.03
	60-90	0.14	7.24	4.83	1.36	1.85	0.80	0.04
7	0-15	0.11	12.59	11.79	2.06	1.28	0.17	0.01
	15-30	0.12	8.98	6.03	1.28	1.89	0.12	0.01
	30-60	0.15	9.81	6.74	2.02	2.51	0.14	0.01
	60-90	0.11	11.73	9.91	1.57	3.11	0.26	0.01
26	0-15	0.03	21.87	19.36	5.34	3.20	0.17	0.01
	15-30	0.00	19.55	16.62	3.61	3.42	0.32	0.01
	30-60	0.00	14.11	12.88	1.95	2.33	0.44	0.01
	60-90	0.02	9.90	8.07	1.41	0.96	0.40	0.01
27	0-15	0.04	19.01	14.48	3.71	2.75	0.14	0.01
	15-30	0.02	15.93	12.05	2.57	3.04	0.24	0.01
	30-60	0.03	11.82	9.25	1.73	1.78	0.27	0.01
	60-90	0.03	8.88	6.48	1.16	1.75	0.30	0.01
28	0-15	0.16	22.61	17.58	5.26	3.66	0.26	0.01

Site	Depth (cm)	AEC cmolc/kg	CEC cmolc/kg	Exch. Ca cmolc/kg	Exch. Mg cmolc/kg	Exch. K cmolc/kg	Exch. Na cmolc/kg	Exch. acid cmolc/kg
	15-30	0.15	20.12	14.55	4.05	3.62	0.58	0.01
	30-60	0.06	10.41	7.30	1.74	2.43	0.67	0.02
	60-90	0.08	5.81	3.66	0.85	1.24	0.52	0.02
63	0-15	0.05	28.34	24.14	3.29	1.02	0.12	0.01
	15-30	0.55	22.11	15.76	3.54	0.79	0.17	0.01
	30-60	1.32	22.51	12.19	6.73	0.52	0.25	0.04
	60-90	1.40	23.10	9.86	9.35	0.16	0.36	4.26
ARB								
8	0-15	0.51	12.60	11.48	1.24	0.50	0.11	0.01
	15-30	1.08	11.21	9.21	0.98	0.36	0.21	0.01
	30-60	1.17	8.13	6.85	0.70	0.06	0.43	0.01
	60-90	0.87	13.06	10.58	0.72	0.59	0.53	0.01
9	0-15	0.15	18.69	20.17	1.32	0.81	0.16	0.01
	15-30	1.20	24.39	19.13	0.90	0.79	0.18	0.01
	30-60	1.48	13.36	12.23	1.02	0.89	0.40	0.01
	60-90	2.23	13.44	12.04	0.97	0.92	0.43	0.01
10	0-15	0.28	17.17	16.33	1.96	0.53	0.16	0.01
	15-30	0.70	15.33	13.22	1.41	0.28	0.24	0.01
	30-60	1.56	19.91	21.52	1.57	0.40	0.44	0.01
	60-90	1.83	30.05	28.44	1.14	0.13	0.60	0.01
11	0-15	0.22	6.75	6.70	1.03	0.24	0.22	0.07
	15-30	0.64	6.65	5.34	0.75	0.13	0.24	0.09
	30-60	2.86	10.11	6.20	1.21	0.18	0.24	1.10
	60-90	2.84	11.39	6.60	1.46	0.16	0.26	3.79
12	0-15	0.06	10.93	11.87	1.22	0.34	0.10	0.01
	15-30	0.05	6.87	6.93	0.62	0.32	0.12	0.01
	30-60	0.26	9.40	7.64	0.85	0.45	0.26	0.01
	60-90	1.21	9.96	9.23	1.38	0.86	0.33	0.02
13	0-15	0.05	10.14	8.94	1.62	0.40	0.16	0.01
	15-30	0.04	6.80	5.46	0.74	0.23	0.21	0.01
	30-60	0.18	8.39	6.59	1.16	0.16	0.27	0.01
	60-90	1.08	16.50	19.68	1.70	0.24	0.66	0.01
14	0-15	0.07	6.45	6.06	1.32	0.20	0.07	0.02
	15-30	0.06	2.83	2.66	0.21	0.06	0.05	0.04
	30-60	0.07	1.58	1.47	0.07	0.05	0.03	0.01
	60-90	0.05	8.66	3.47	0.22	0.05	0.03	0.03
15	0-15	0.18	2.72	2.72	0.29	0.05	0.06	0.32
	15-30	0.28	1.12	1.21	0.08	0.05	0.06	0.15
	30-60	0.27	0.58	0.46	0.03	0.02	0.03	0.04
	60-90	0.22	0.44	0.30	0.03	0.03	0.03	0.02
16	0-15	0.10	8.00	5.61	1.63	0.48	0.08	0.04
	15-30	0.11	6.08	5.21	1.29	0.37	0.10	0.06
	30-60	0.12	7.66	5.51	1.44	0.29	0.12	0.05
	60-90	0.34	11.53	7.51	2.40	0.27	0.14	0.04
NIP								
17	0-15	0.19	3.20	1.72	0.35	0.04	0.11	2.06

Site	Depth (cm)	AEC cmolc/kg	CEC cmolc/kg	Exch. Ca cmolc/kg	Exch. Mg cmolc/kg	Exch. K cmolc/kg	Exch. Na cmolc/kg	Exch. acid cmolc/kg
	15-30	0.37	2.73	0.63	0.28	0.04	0.45	2.07
	30-60	1.97	4.74	0.40	0.10	0.02	0.05	3.46
	60-90	2.80	7.22	0.25	0.30	0.04	0.62	6.15
18	0-15	0.20	18.96	14.56	2.41	0.25	0.06	0.01
	15-30	0.57	11.58	9.71	1.42	0.09	0.07	0.01
	30-60	1.26	8.20	7.66	0.94	0.11	0.11	0.01
	60-90	1.14	8.02	8.06	0.91	0.23	0.14	0.01
20	0-15	0.32	18.04	15.79	1.97	0.04	0.06	0.02
	15-30	0.50	14.09	11.63	0.98	0.02	0.07	0.05
	30-60	0.82	12.70	10.27	0.50	0.02	0.08	0.06
	60-90	1.09	9.06	7.85	0.42	0.02	0.07	0.18
21	0-15	0.35	21.17	16.88	4.98	0.10	0.06	0.02
	15-30	2.42	12.85	9.50	1.85	0.03	0.08	0.02
	30-60	2.90	10.38	9.02	1.44	0.02	0.10	0.02
	60-90	2.37	10.16	7.85	0.88	0.01	0.15	0.08
22	0-15	0.08	14.89	13.45	1.99	0.15	0.14	0.02
	15-30	0.07	9.46	8.77	1.48	0.10	0.13	0.12
	30-60	0.10	6.71	6.27	1.43	0.15	0.15	0.45
23	0-15	0.12	13.05	9.10	4.62	0.39	3.04	0.05
	15-30	0.20	10.69	7.22	3.25	0.28	2.77	0.57
	30-60	0.21	13.28	10.16	2.06	0.11	0.15	0.72
	60-90	0.15	15.81	11.50	2.32	0.14	0.22	0.64
24	0-15	0.03	31.03	27.04	2.73	0.32	0.04	0.01
	15-30	0.63	33.28	29.46	1.27	0.29	0.05	0.01
	30-60	1.17	20.37	22.16	0.69	0.27	0.09	0.01
	60-90	0.42	23.22	23.57	0.51	0.19	0.12	0.01
25	0-15	0.19	20.92	19.06	2.24	0.07	0.11	0.01
	15-30	0.41	6.31	15.21	2.05	0.06	0.20	0.10
	30-60	0.37	4.93	14.90	2.43	0.02	0.18	3.11
	60-90	0.37	5.75	21.47	3.32	0.06	0.46	2.74
MoP								
29	0-15	0.03	11.58	11.96	2.06	0.12	0.08	0.01
	15-30	0.03	10.19	9.95	1.29	0.07	0.04	0.02
	30-60	0.03	8.24	6.89	1.30	0.04	0.03	0.02
	60-90	0.03	7.95	6.47	1.93	0.04	0.07	0.05
30	0-15	0.02	46.13	30.21	5.39	3.15	0.20	0.01
	15-30	0.00	47.61	19.82	3.67	2.26	0.28	0.01
	30-60	0.00	44.90	30.54	4.37	0.79	0.77	0.01
	60-90	0.00	34.41	20.09	4.79	0.09	1.07	0.01
31	0-15	0.00	46.86	39.87	3.22	1.50	1.59	0.01
	15-30	0.00	15.40	43.92	3.89	0.50	1.76	0.01
	30-60	0.00	13.61	41.58	5.69	0.14	1.71	0.01
	60-90	0.00	35.76	22.92	3.50	0.08	1.12	0.01
32	0-15	0.00	10.86	27.84	8.39	3.38	0.49	0.07
	15-30	0.00	47.30	34.66	8.43	1.24	0.86	0.01
	30-60	0.00	63.58	28.36	7.21	0.24	1.01	0.01

Site	Depth (cm)	AEC cmolc/kg	CEC cmolc/kg	Exch. Ca cmolc/kg	Exch. Mg cmolc/kg	Exch. K cmolc/kg	Exch. Na cmolc/kg	Exch. acid cmolc/kg
	60-90	0.01	55.76	37.65	8.40	0.17	1.40	0.01
33	0-15	0.05	38.89	28.21	10.15	0.34	0.21	0.02
	15-30	0.08	32.65	23.87	7.16	0.33	0.26	0.43
	30-60	0.10	27.59	18.40	5.03	0.20	0.27	0.14
	60-90	0.26	18.97	13.73	3.44	0.14	0.20	0.03
34	0-15	0.16	24.22	14.71	8.84	0.31	0.04	0.08
	15-30	0.44	20.99	9.94	6.08	0.14	0.05	0.27
	30-60	0.67	16.47	8.20	4.39	0.10	0.06	0.22
NP								
35	0-15	0.09	9.32	7.99	2.23	0.18	0.06	0.05
	15-30	0.10	5.06	4.42	1.20	0.14	0.05	0.15
	30-60	0.16	1.96	0.60	0.20	0.05	0.04	0.07
	60-90	0.07	0.90	0.41	0.10	0.05	0.04	0.09
36	0-15	0.03	15.63	16.02	2.26	0.12	0.04	0.01
	15-30	0.00	9.62	9.27	1.25	0.10	0.03	0.01
	30-60	0.07	3.77	2.94	0.51	0.07	0.03	0.02
	60-90	0.09	1.88	1.24	0.18	0.07	0.02	0.02
37	0-15	0.24	16.13	16.20	2.33	0.67	0.02	0.02
	15-30	0.56	6.97	5.85	0.73	0.17	0.02	0.16
	30-60	1.35	2.30	1.18	0.14	0.05	0.02	0.08
	60-90	1.75	1.86	0.96	0.10	0.05	0.01	0.02
38	0-15	0.19	9.07	9.23	1.56	0.13	0.07	0.06
	15-30	0.41	4.51	4.18	0.57	0.06	0.04	0.11
	30-60	0.62	1.42	1.02	0.12	0.04	0.04	0.02
	60-90	0.33	1.21	1.05	0.16	0.05	0.06	0.03
39	0-15	0.01	9.74	7.80	3.27	0.22	0.06	0.02
	15-30	0.00	9.25	6.65	3.03	0.17	0.08	0.01
	30-60	0.01	8.83	5.79	3.38	0.16	0.13	0.01
	60-90	0.02	8.41	4.77	3.57	0.16	0.15	0.02
40	0-15	0.01	11.47	9.93	3.22	0.18	0.04	0.01
	15-30	0.01	7.42	5.52	2.37	0.14	0.09	0.02
	30-60	0.12	6.76	3.68	3.01	0.10	0.20	0.12
	60-90	0.13	7.64	3.51	3.57	0.18	0.31	0.14
MaP								
41	0-15	0.00	41.48	23.41	8.28	0.52	0.19	0.01
	15-30	0.10	41.97	24.05	8.69	0.31	0.21	0.01
	30-60	0.15	41.01	25.24	11.89	0.14	0.32	0.02
	60-90	0.08	41.27	22.48	10.47	0.17	0.39	0.02
42	0-15	0.00	16.95	16.39	2.64	0.49	0.17	0.01
	15-30	0.02	13.58	12.68	2.13	0.46	0.16	0.01
	30-60	0.03	11.15	9.20	2.21	0.42	0.28	0.02
	60-90	0.05	14.46	10.95	3.07	0.55	0.38	0.03
43	0-15	0.01	31.05	18.18	4.47	1.15	0.18	0.01
	15-30	0.04	13.80	10.78	2.50	1.03	0.14	0.01
	30-60	0.05	9.81	6.89	1.22	0.92	0.08	0.01
	60-90	0.08	15.52	10.55	2.48	1.30	0.18	0.01

Site	Depth (cm)	AEC cmolc/kg	CEC cmolc/kg	Exch. Ca cmolc/kg	Exch. Mg cmolc/kg	Exch. K cmolc/kg	Exch. Na cmolc/kg	Exch. acid cmolc/kg
44	0-15	0.00	40.59	31.76	6.77	0.40	0.13	0.01
	15-30	0.48	41.08	30.97	8.13	0.16	0.12	0.01
	30-60	1.04	39.05	28.01	9.55	0.07	0.17	0.01
	60-90	0.88	41.03	26.52	11.03	0.05	0.28	0.03
45	0-15	0.00	32.07	28.29	9.21	0.19	0.23	0.01
	15-30	0.05	32.22	27.63	9.87	0.05	0.32	0.01
	30-60	1.36	34.00	25.98	12.63	0.02	0.48	0.01
	60-90	0.00	38.86	22.30	10.68	0.03	0.56	0.02
46	0-15	0.01	41.81	30.23	5.92	1.61	0.11	0.03
	15-30	0.00	42.79	26.82	5.64	1.14	0.22	0.07
	30-60	0.00	42.14	27.07	6.20	0.96	0.39	0.18
	60-90	0.00	43.95	26.95	6.03	1.47	0.62	0.17
47	0-15	0.06	36.25	29.36	5.14	1.19	0.05	0.01
	15-30	0.48	33.01	24.90	5.30	0.44	0.10	0.01
	30-60	0.73	34.24	24.09	6.74	0.11	0.20	0.07
	60-90	0.12	39.81	26.47	7.61	0.09	0.16	0.18
48	0-15	0.00	30.20	21.78	5.87	1.12	0.13	0.01
	15-30	0.00	33.61	21.18	6.39	0.54	0.19	0.01
	30-60	0.22	36.45	23.48	9.21	0.16	0.21	0.39
	60-90	0.26	35.28	22.41	9.18	0.12	0.25	0.13
ESP								
49	0-15	0.12	14.75	8.10	5.76	0.23	0.07	0.01
	15-30	0.12	12.20	6.67	5.45	0.18	0.10	0.07
	30-60	0.23	15.18	8.47	8.71	0.08	0.15	0.29
	60-90	0.65	18.00	7.01	11.04	0.08	0.19	2.05
50	0-15	0.05	15.45	12.41	4.23	0.17	0.04	0.01
	15-30	0.31	12.50	9.45	3.59	0.09	0.06	0.01
	30-60	1.17	14.75	6.91	6.02	0.04	0.11	0.04
	60-90	1.52	17.18	5.51	9.25	0.00	0.20	0.88
51	0-15	0.07	20.43	12.58	7.23	0.05	0.08	0.01
	15-30	0.23	18.35	9.38	6.85	0.02	0.10	0.08
	30-60	0.27	18.40	7.60	8.19	0.02	0.12	0.18
	60-90	0.78	24.72	9.23	12.70	0.02	0.18	0.10
52	0-15	0.64	41.23	29.46	6.89	0.58	0.05	0.00
	15-30	1.37	39.72	25.10	6.90	0.24	0.06	0.01
	30-60	0.86	32.27	22.59	7.77	0.05	0.11	0.02
	60-90	0.39	38.10	23.66	7.66	0.04	0.17	0.07
53	0-15	0.00	44.95	36.69	4.53	0.03	0.07	0.01
	15-30	0.00	47.17	39.62	2.27	0.03	0.06	0.01
	30-60	0.00	42.70	33.88	0.28	0.01	0.04	0.01
	60-90	0.00	39.38	28.26	0.11	0.02	0.04	0.00
54	0-15	1.47	36.30	28.95	5.56	0.09	0.03	0.01
	15-30	1.18	39.52	25.41	5.13	0.05	0.06	0.01
	30-60	1.32	39.32	32.32	4.31	0.04	0.07	0.01
	60-90	0.13	41.88	28.38	2.93	0.03	0.06	0.01
57	0-15	0.15	24.55	16.44	9.55	0.16	0.04	0.01

Site	Depth (cm)	AEC cmolc/kg	CEC cmolc/kg	Exch. Ca cmolc/kg	Exch. Mg cmolc/kg	Exch. K cmolc/kg	Exch. Na cmolc/kg	Exch. acid cmolc/kg
	15-30	1.33	22.21	11.05	10.12	0.07	0.04	0.06
	30-60	1.63	26.52	10.45	14.40	0.05	0.09	1.00
	60-90	1.36	30.80	11.39	18.64	0.05	0.14	1.09
60	0-15	0.01	20.10	14.86	3.72	0.27	0.07	0.01
	15-30	0.03	17.36	13.26	3.24	0.17	0.08	0.01
	30-60	0.02	17.99	12.28	3.52	0.27	0.08	0.03
	60-90	0.01	17.56	12.15	3.59	0.26	0.10	0.02
WSP								
55	0-15	0.23	22.07	11.32	10.23	0.16	0.04	0.27
	15-30	0.83	23.73	10.79	11.08	0.11	0.06	0.32
	30-60	0.10	22.79	10.51	11.80	0.06	0.07	0.09
	60-90	0.03	23.66	9.06	13.55	0.07	0.07	0.06
56	0-15	0.70	26.08	14.31	10.25	0.35	0.03	0.01
	15-30	2.64	23.18	10.53	10.69	0.23	0.05	0.32
	30-60	1.92	23.41	8.84	13.47	0.13	0.07	1.35
	60-90	0.88	25.41	8.92	16.27	0.09	0.10	0.87
58	0-15	0.06	23.53	18.61	6.10	0.11	0.17	0.01
	15-30	0.04	22.40	13.91	6.91	0.05	0.20	0.01
	30-60	0.02	20.40	10.95	7.28	0.05	0.25	0.01
	60-90	0.01	21.89	11.24	7.78	0.07	0.26	0.01
59	0-15	0.82	31.91	24.82	3.97	0.17	0.11	0.01
	15-30	0.28	31.12	25.59	3.53	0.06	0.11	0.01
	30-60	0.04	33.96	26.34	3.66	0.05	0.12	0.01
	60-90	0.02	32.94	25.41	4.78	0.05	0.14	0.03
WHP								
61	0-15	0.11	23.08	17.35	3.83	0.47	0.05	0.01
	15-30	0.04	22.11	17.38	3.47	0.84	0.04	0.01
	30-60	0.02	20.91	15.91	3.13	1.05	0.03	0.01
	60-90	0.09	24.20	18.49	3.35	0.07	0.07	0.20
62	0-15	0.16	20.90	17.69	2.74	0.56	0.03	0.01
	15-30	0.29	17.93	14.23	2.41	0.26	0.04	0.01
	30-60	0.34	20.34	14.96	3.39	0.16	0.07	0.04
	60-90	0.16	25.15	15.92	4.00	0.16	0.08	0.12

11.8.3 Organic C, total N, Colwell P and carbonate contents (all depths)

Site	Depth (cm)	Org. C (%)	Total N (%)	Col. P (mg/kg)	Carbonate (% CaCO3 equiv.)
ENBP					
1	0-15	3.15	0.33	87.7	ND
	15-30	2.77	0.32	55.0	ND
	30-60	1.01	0.10	18.5	ND
	60-90	0.32	0.01	6.6	3
2	0-15	3.77	0.39	60.8	6
	15-30	3.27	0.35	123.7	7
	30-60	0.70	0.06	29.6	6
	60-90	0.61	0.02	2.8	5
3	0-15	3.68	0.41	39.4	ND
	15-30	2.25	0.21	12.5	6
	30-60	0.41	0.05	3.7	5
	60-90	0.25	0.02	0.8	5
4	0-15	2.76	0.30	143.0	ND
	15-30	1.78	0.17	176.4	ND
	30-60	0.46	0.06	84.5	ND
	60-90	0.55	0.05	31.4	ND
5	0-15	3.01	0.35	45.5	ND
	15-30	2.02	0.24	24.6	ND
	30-60	0.76	0.05	4.3	ND
	60-90	0.23	0.01	0.1	5
6	0-15	3.33	0.33	84.1	7
	15-30	2.05	0.25	49.2	ND
	30-60	0.52	0.06	11.7	ND
	60-90	0.29	0.01	2.8	5
7	0-15	2.53	0.21	17.3	6
	15-30	0.91	0.09	17.3	5
	30-60	1.10	0.09	15.1	5
	60-90	1.18	0.10	30.2	4
26	0-15	3.85	0.33	108.7	ND
	15-30	2.81	0.25	72.6	ND
	30-60	1.30	0.11	36.9	ND
	60-90	0.47	0.04	10.2	3
27	0-15	3.73	0.35	87.1	ND
	15-30	1.98	0.23	57.0	ND
	30-60	0.82	0.08	17.3	3
	60-90	0.43	0.04	3.2	ND
28	0-15	3.81	0.37	30.8	ND
	15-30	2.33	0.24	19.4	7
	30-60	0.50	0.06	13.8	ND
	60-90	0.10	0.01	1.0	ND
63	0-15	3.27	0.30	17.5	6
	15-30	1.59	0.21	8.4	5

Site	Depth (cm)	Org. C (%)	Total N (%)	Col. P (mg/kg)	Carbonate (% CaCO3 equiv.)
	30-60	1.02	0.11	6.6	ND
	60-90	0.39	0.06	4.4	ND
ARB					
8	0-15	1.53	0.22	30.3	ND
	15-30	0.95	0.15	13.1	3
	30-60	0.47	0.11	4.3	4
	60-90	0.49	0.07	3.1	3
9	0-15	2.75	0.29	55.3	3
	15-30	1.97	0.27	82.2	3
	30-60	0.91	0.16	72.1	6
	60-90	0.51	0.09	55.7	6
10	0-15	2.36	0.29	49.7	ND
	15-30	1.25	0.16	18.7	ND
	30-60	0.91	0.13	6.4	4
	60-90	0.62	0.10	0.5	4
11	0-15	3.11	0.34	7.1	ND
	15-30	1.21	0.18	4.2	ND
	30-60	0.67	0.10	16.5	ND
	60-90	0.51	0.07	14.9	ND
12	0-15	2.18	0.26	24.6	ND
	15-30	1.17	0.14	23.4	ND
	30-60	0.80	0.09	12.9	ND
	60-90	0.33	0.06	2.6	ND
13	0-15	2.85	0.27	7.8	ND
	15-30	1.11	0.15	3.7	ND
	30-60	0.63	0.10	1.7	ND
	60-90	0.55	0.11	0.0	4
14	0-15	2.58	0.24	13.5	ND
	15-30	1.31	0.11	3.7	ND
	30-60	0.45	0.03	2.0	ND
	60-90	0.26	0.01	1.5	2
15	0-15	3.48	0.22	8.4	ND
	15-30	1.56	0.13	2.6	ND
	30-60	1.04	0.05	7.9	ND
	60-90	0.49	0.02	12.3	ND
16	0-15	1.87	0.17	7.9	ND
	15-30	0.78	0.07	10.1	ND
	30-60	0.50	0.05	23.0	ND
	60-90	0.34	0.02	22.1	ND
NIP					
17	0-15	2.93	0.27	9.4	ND
	15-30	1.86	0.16	3.8	ND
	30-60	1.21	0.08	3.7	ND
	60-90	0.69	0.08	13.2	ND
18	0-15	3.56	0.31	24.5	ND

Site	Depth (cm)	Org. C (%)	Total N (%)	Col. P (mg/kg)	Carbonate (% CaCO3 equiv.)
	15-30	2.40	0.25	24.7	ND
	30-60	1.42	0.18	51.5	ND
	60-90	0.86	0.11	85.8	ND
20	0-15	3.55	0.37	54.7	ND
	15-30	2.10	0.24	46.1	ND
	30-60	1.65	0.16	95.4	ND
	60-90	0.98	0.09	125.5	ND
21	0-15	3.80	0.45	120.2	ND
	15-30	2.04	0.24	93.2	ND
	30-60	1.27	0.18	161.4	ND
	60-90	0.88	0.12	221.5	ND
22	0-15	2.97	0.28	12.8	ND
	15-30	1.69	0.17	6.3	ND
	30-60	0.61	0.04	6.1	ND
23	0-15	2.57	0.24	14.1	ND
	15-30	1.27	0.13	4.3	ND
	30-60	0.56	0.04	3.2	ND
	60-90	0.33	0.02	4.5	ND
24	0-15	4.64	0.38	92.5	45
	15-30	2.82	0.33	86.2	20
	30-60	1.96	0.15	69.1	6
	60-90	0.87	0.10	85.3	7
25	0-15	3.89	0.31	7.5	ND
	15-30	2.05	0.21	1.2	ND
	30-60	0.84	0.07	0.0	ND
	60-90	0.77	0.03	4.5	ND
MoP					
29	0-15	2.83	0.25	57.9	ND
	15-30	1.32	0.17	27.0	ND
	30-60	0.51	0.08	14.3	ND
	60-90	0.34	0.06	27.0	ND
30	0-15	2.50	0.27	9.1	15
	15-30	1.42	0.12	1.8	16
	30-60	0.53	0.04	0.0	18
	60-90	0.16	0.01	0.0	15
31	0-15	2.17	0.12	1.9	16
	15-30	1.42	0.12	2.3	27
	30-60	1.36	0.12	3.3	30
	60-90	0.84	0.05	1.4	23
32	0-15	2.65	0.23	34.6	ND
	15-30	1.88	0.14	7.8	27
	30-60	0.58	0.04	1.8	13
	60-90	0.79	0.05	0.1	13
33	0-15	5.60	0.41	11.0	ND
	15-30	3.57	0.30	7.5	ND

Site	Depth (cm)	Org. C (%)	Total N (%)	Col. P (mg/kg)	Carbonate (% CaCO3 equiv.)
	30-60	2.20	0.19	2.8	ND
	60-90	1.55	0.09	5.7	ND
34	0-15	7.24	0.49	18.0	ND
	15-30	5.36	0.39	9.8	ND
	30-60	2.51	0.25	4.1	ND
NP					
35	0-15	5.13	0.36	21.8	ND
	15-30	4.95	0.30	13.3	ND
	30-60	0.94	0.08	23.9	ND
	60-90	0.20	0.02	19.9	ND
36	0-15	4.37	0.38	47.0	ND
	15-30	3.06	0.29	22.0	ND
	30-60	1.22	0.13	12.2	ND
	60-90	0.53	0.05	14.4	ND
37	0-15	8.08	0.67	37.9	ND
	15-30	7.37	0.58	14.6	ND
	30-60	4.51	0.40	5.4	ND
	60-90	3.53	0.26	3.4	ND
38	0-15	6.25	0.49	22.7	ND
	15-30	3.87	0.41	6.6	ND
	30-60	1.29	0.16	0.7	ND
	60-90	0.57	0.04	11.0	ND
39	0-15	2.48	0.20	26.8	ND
	15-30	1.48	0.15	18.5	ND
	30-60	0.77	0.08	20.7	ND
	60-90	0.45	0.04	28.0	ND
40	0-15	3.72	0.27	9.5	ND
	15-30	1.41	0.18	2.5	ND
	30-60	0.58	0.05	3.3	ND
	60-90	0.36	0.03	17.4	ND
MaP					
41	0-15	2.92	0.25	31.3	ND
	15-30	2.00	0.23	15.1	ND
	30-60	1.02	0.08	10.2	6
	60-90	1.35	0.11	22.4	7
42	0-15	5.31	0.48	21.4	ND
	15-30	3.36	0.35	11.5	ND
	30-60	1.38	0.13	6.9	ND
	60-90	1.11	0.11	6.9	2
43	0-15	5.08	0.56	17.7	ND
	15-30	2.66	0.31	13.6	ND
	30-60	1.14	0.11	10.5	5
	60-90	1.28	0.10	14.6	6
44	0-15	3.15	0.30	53.3	ND
	15-30	2.10	0.20	42.7	6

Site	Depth (cm)	Org. C (%)	Total N (%)	Col. P (mg/kg)	Carbonate (% CaCO3 equiv.)
	30-60	1.28	0.09	22.6	5
	60-90	0.57	0.06	11.9	6
45	0-15	4.87	0.41	9.3	ND
	15-30	3.36	0.29	1.2	7
	30-60	1.35	0.10	0.0	7
	60-90	0.26	0.02	0.0	8
46	0-15	2.02	0.24	78.7	ND
	15-30	1.45	0.17	49.4	ND
	30-60	0.61	0.05	36.7	ND
	60-90	0.29	0.02	35.9	10
47	0-15	4.14	0.41	39.3	ND
	15-30	2.58	0.31	15.4	7
	30-60	0.90	0.13	10.5	7
	60-90	0.34	0.06	16.8	6
48	0-15	3.58	0.29	20.5	ND
	15-30	1.88	0.21	8.8	ND
	30-60	0.72	0.08	7.2	6
	60-90	0.53	0.04	18.5	7
ESP					
49	0-15	2.12	0.21	24.0	ND
	15-30	1.18	0.10	5.9	ND
	30-60	0.71	0.09	1.9	ND
	60-90	0.52	0.06	17.7	ND
50	0-15	2.52	0.21	3.1	ND
	15-30	1.19	0.13	0.6	3
	30-60	0.71	0.08	0.0	ND
	60-90	0.54	0.06	0.0	ND
51	0-15	1.81	0.19	6.6	ND
	15-30	0.99	0.12	5.4	ND
	30-60	0.60	0.07	4.3	ND
	60-90	0.98	0.05	4.3	ND
52	0-15	3.70	0.33	13.9	7
	15-30	1.93	0.20	9.7	ND
	30-60	1.45	0.16	6.9	ND
	60-90	0.77	0.11	6.7	ND
53	0-15	3.42	0.41	12.1	6
	15-30	2.29	0.23	5.9	6
	30-60	0.72	0.10	4.0	26
	60-90	0.40	0.05	5.2	31
54	0-15	2.66	0.25	10.0	5
	15-30	2.07	0.23	7.4	6
	30-60	1.24	0.15	7.7	6
	60-90	0.44	0.05	4.7	13
57	0-15	3.18	0.27	16.4	6
	15-30	1.40	0.15	6.4	ND

Site	Depth (cm)	Org. C (%)	Total N (%)	Col. P (mg/kg)	Carbonate (% CaCO3 equiv.)
	30-60	0.89	0.10	5.7	ND
	60-90	0.43	0.07	11.7	ND
60	0-15	1.42	0.14	18.1	ND
	15-30	0.73	0.08	14.8	ND
	30-60	0.56	0.04	14.6	4
	60-90	0.41	0.02	16.0	4
WSP					
55	0-15	2.41	0.21	30.5	ND
	15-30	1.19	0.15	18.8	ND
	30-60	0.61	0.08	31.9	ND
	60-90	0.34	0.05	38.1	ND
56	0-15	2.66	0.26	30.1	ND
	15-30	1.41	0.19	26.8	ND
	30-60	0.73	0.10	39.1	ND
	60-90	0.58	0.07	43.6	ND
58	0-15	3.51	0.33	16.5	ND
	15-30	1.48	0.13	11.2	6
	30-60	0.49	0.05	10.1	6
	60-90	0.60	0.03	11.6	8
59	0-15	4.63	0.22	26.7	ND
	15-30	1.23	0.13	14.7	6
	30-60	0.60	0.07	44.3	6
	60-90	0.38	0.04	67.9	7
WHP					
61	0-15	3.12	0.29	127.6	ND
	15-30	1.92	0.21	63.5	ND
	30-60	1.54	0.16	15.0	ND
	60-90	0.44	0.06	13.8	8
62	0-15	3.41	0.37	49.1	ND
	15-30	2.02	0.25	16.8	ND
	30-60	0.71	0.10	7.8	ND
	60-90	0.35	0.05	12.0	4

ND. Not determined (samples with pH_{water} <6.5)

11.8.4 P sorption indices, micronutrient contents and pH_{NaF}

Phosphate buffer index (PBI), Phosphate sorption index (PSI) and DTPA-extractible Zn, Cu, Mn and Fe are all for the 0-0.15 m depth layer. pH_{NaF} is for the 0.3-0.6 m depth layer.

Site	PBI	PSI	Zn (mg/kg)	Cu (mg/kg)	Mn (mg/kg)	Fe (mg/kg)	pH_{NaF}
ENBP							
1	201	159	3.1	0.8	4.5	52.8	9.09
2	197	161	3.9	0.5	4.6	29.5	9.21
3	157	141	2.7	0.5	9.3	26.5	9.55
4	141	115	2	1.3	4.1	28.7	9.12
5	179	153	3.3	0.8	5.4	33.3	8.87
6	138	122	3.1	0.7	8.6	46.3	8.74
7	47	53	2	0.2	5.6	15.7	8.79
26	156	130	6.3	1.1	5.8	54.2	8.86
27	173	144	2.2	0.5	0.6	41.9	9.27
28	141	132	3.2	0.6	9.7	44.9	8.95
63	168	151	5.1	1.4	29.2	14.7	8.77
ARB							
8	87	90	3.6	2.9	126.1	29.6	9.09
9	127	118	4.7	1.8	25.2	7.7	9.65
10	73	74	3	1.8	74.9	25.5	9.2
11	219	179	1.2	1.2	53.7	23.1	9.21
12	56	61	1.6	0.8	12.8	18	9.23
13	71	79	1.2	1.2	19.2	35	8.37
14	127	125	0.5	0.6	3.7	8.9	9.85
15	429	243	0.1	0.4	2.7	13.8	11.07
16	117	118	1.4	1.8	55.8	34.1	9.48
NIP							
17	380	232	0.3	0.5	4.9	39	9.91
18	414	238	0.7	3.4	54.8	13.2	10.04
20	289	200	8.7	6.4	41.9	42.3	9.67
21	423	231	9.5	5.2	144	29.5	9.85
22	138	132	9.7	0.6	2.5	23.7	9.71
23	157	144	1.5	1.9	51.3	58.4	8.99
24	272	190	4.2	2	20.4	13.9	10.34
25	199	169	1.6	1.3	68.9	40.7	9.48
MoP							
29	50	49	2.6	0.6	8.4	39.8	8.44
30	100	105	0.3	2	1.9	5.3	10.49
31	115	118	0.4	3.4	1.9	11.6	9.58
32	102	102	0.3	4.6	8.2	65.2	10.33
33	254	193	0.8	2.6	4.3	59.3	9.84
34	556	267	0.8	2.4	4.2	54.5	10.53
NP							
35	419	240	0.7	0.2	1.8	17	10.92
36	152	137	0.6	0.4	1.7	20.9	11
37	658	281	0.2	0.4	0.5	8.2	11.72

Site	**PBI**	**PSI**	**Zn (mg/kg)**	**Cu (mg/kg)**	**Mn (mg/kg)**	**Fe (mg/kg)**	**pH_{NaF}**
38	496	256	0.2	0.5	2.4	21	11.19
39	80	84	2.8	0.7	3.3	71.6	9.11
40	96	101	1	0.9	9.7	46.9	9.13
MaP							
41	119	116	1.4	3.4	18.4	43.2	8.84
42	402	236	7.9	5.8	0.5	56.7	10.04
43	538	264	1.9	4.2	0.4	55.6	10.34
44	76	76	1.3	3.3	15.8	44.9	8.81
45	146	138	1.3	6	15.6	43.2	9.05
46	118	108	0.5	4.3	6.4	83.4	8.88
47	132	125	1.1	4.2	11.9	46.9	8.79
48	132	127	1	5.6	10.9	57.4	8.61
ESP							
49	63	69	12.1	1.6	15.2	67.9	8.59
50	78	87	0.8	1.6	28.2	24.8	8.7
51	56	64	0.7	1.9	14.6	68.4	8.26
52	94	99	1.6	1.4	6.1	19.8	8.54
53	97	102	0.4	0.6	6.3	11.3	10.74
54	88	94	0.5	1.2	10.9	24.6	10.07
57	68	75	1.4	0.9	14.8	22.2	8.85
60	48	54	0.9	2.5	3.2	52	8.56
WSP							
55	96	98	0.7	2.8	12.2	130.1	8.61
56	114	112	0.7	2.5	13.2	106.7	8.81
58	86	91	0.7	3.6	6.1	72.7	8.93
59	71	76	0.9	2.4	11.3	63.5	9.17
WHP							
61	120	102	3.4	2.7	23.2	80	8.72
62	132	123	3.1	3.7	34.8	118.5	8.74
All							
Min.	47	49	0.1	0.2	0.4	5.3	8.26
Max.	658	281	12.1	6.4	144	130.1	11.72

11.9 Soil properties (selected sites)

11.9.1 Allophane content (0.3-0.6 m depth)

Site	pH NaF	Pyr Al %	Oxal Al %	Oxal Si %	molar Al:Si	Allophane (%)
ENBP						
7	8.79	0.06	0.26	0.10	2.0	0.8
28	8.95	0.05	0.33	0.14	2.0	1.1
63	8.77	0.37	0.33	0.20	-0.2	1.2
ARB						
10	9.2	0.09	0.30	0.13	1.7	0.8
15	11.07	0.21	1.03	0.50	1.7	3.2
NIP						
17	9.91	0.32	0.30	0.03	-0.8	0.2
22	9.71	0.12	0.35	0.16	1.4	0.92
24	10.34	0.07	0.61	0.13	4.2	2.92
MoP						
31	9.58	0.04	1.09	1.27	0.9	6.2
33	9.84	0.26	1.30	0.96	1.1	5.0
34	10.53	0.95	1.77	0.60	1.4	3.4
NP						
37	11.72	0.71	3.48	1.48	2.0	10.6
40	9.13	0.04	0.30	0.15	1.7	1.0
MaP						
43	10.34	0.10	1.43	1.02	1.4	5.6
45	9.05	0.66	0.45	0.40	-0.5	2.7
ESP						
51	8.26	0.12	0.13	0.07	0.1	0.4
53	10.74	0.04	0.16	0.07	1.8	0.5
60	8.56	0.01	0.21	0.20	1.0	1.0
WSP						
55	8.61	0.03	0.21	0.11	1.7	0.7
58	8.93	0.02	0.36	0.42	0.8	2.1
WHP						
62	8.74	0.04	0.19	0.11	1.5	0.6

11.9.2 Mineralogy from XRD and XRF (0.3-0.6 m depth)

XRD

Site	Quartz	Cristobalite	Amorphous (Glass)	Na/Ca Feldspar	Pyroxene (Augite)	Amphibole	Zeolite Stilbite/ Laumontite
ENBP							
7	-	-	D	M	-	-	-
28	T	-	D	M	-	-	-
63	M	M	M	T	-	-	-
ARB							
10	M	-	-	M	-	T	-
15	T	-	-	D	-	T	-
NIP							
17	M	-	-	-	-	-	-
22	D	-	M	M	M	-	-
24	T	-	-	-	-	-	-
MoP							
31	SD	-	M	SD	-	-	M
33	M	M	CD	SD	M	-	M
34	T	-	CD	T	M	-	-
NP							
37	SD	-	M	D	-	M	-
40	M	M	T	CD	-	M	-
MaP							
43	M	-	D	SD	M	-	-
45	M	-	M	M	T	-	-
ESP							
51	D	-	T	SD	T	T	-
53	D	-	-	SD	-	-	-
60	D	-	M	SD	T	T	-
WSP							
55	D	-	-	SD	T	-	-
58	CD	-	-	CD	T	T	-
WHP							
62	D	?M	-	M	-	-	-

D - Dominant (>60%); CD - Co dominant (sum >60%); SD - Sub-dominant (20-60%); M - Minor (5-20%); T - Trace (<5%); ? Indicates possible identification

XRD (continued)

Site	Hematite	Goethite	Gibbsite	Calcite	Smectite	Halloysite	Chlorite	Mica
ENBP								
7	-	-	-	-	-	-	-	-
28	-	-	-	-	-	M	-	-
63	M	M	-	-	M	D	-	-
ARB								
10	-	-	-	-	M	D	-	-
15	-	-	-	-	-	-	-	-
NIP								
17	-	M	-	-	-	D	-	-
22	-	-	-	-	-	-	M	-
24	T	M	M	-	-	D	-	?T
MoP								
31	-	-	-	-	D	-	-	-
33	-	-	-	-	CD	T	-	-
34	-	-	-	-	CD	M	-	-
NP								
37	-	-	-	-	-	-	M	-
40	-	-	-	-	-	CD	-	-
MaP								
43	-	-	-	-	-	-	-	-
45	-	-	-	-	D	M	-	-
ESP								
51	-	-	-	-	M	-	T	-
53	-	-	-	SD	M	T	-	-
60	-	-	-	-	M	T	T	-
WSP								
55	-	-	-	-	M	-	M	T
58	-	-	-	-	M	-	M	-
WHP								
62	-	-	-	-	M	M	-	-

D - Dominant (>60%); CD - Co dominant (sum >60%); SD - Sub-dominant (20-60%); M - Minor (5-20%); T - Trace (<5%); ? Indicates possible identification

XRF Major elements

Site	SiO2 (%)	TiO2 (%)	Al2O3 (%)	Fe2O3 (%)	MnO (%)	MgO (%)	CaO (%)	Na2O (%)	K2O (%)	P2O5 (%)	SO3 (%)	Cl mg/kg
ENBP												
7	61	0.82	16.6	5.7	0.16	1.62	4.00	3.76	2.25	0.31	0.06	1346
28	48	1.01	17.4	10.6	0.21	4.97	4.36	1.37	1.03	0.24	0.02	35
63	46	1.10	26.8	9.8	0.32	1.42	2.41	0.98	0.32	0.14	0.03	99
ARB												
10	50	1.83	23.0	13.3	0.06	0.20	0.07	0.01	0.03	0.43	0.08	35
15	69	0.67	12.9	8.0	0.14	1.99	1.85	1.25	0.80	0.10	0.02	<8
NIP												
17	33	1.35	31.1	15.5	0.20	0.50	1.45	0.06	0.08	0.48	0.04	27

22	60	0.91	17.8	5.9	0.17	1.27	2.89	3.22	2.12	0.23	0.06	1246
24	51	0.98	15.4	11.2	0.22	4.81	4.48	1.86	1.17	0.17	0.03	32
MoP												
31	37	1.18	20.6	15.4	0.28	5.48	3.20	0.19	0.81	0.42	0.03	42
33	46	0.98	19.6	7.2	0.16	3.09	3.43	2.33	0.54	0.45	0.04	99
34	53	1.16	21.6	8.3	0.15	2.56	3.17	2.61	1.21	0.11	0.02	63
NP												
37	50	0.61	19.8	11.2	0.20	3.04	6.95	1.87	0.71	0.28	0.07	162
40	49	0.99	18.7	13.5	0.30	2.93	3.60	0.67	0.48	0.05	0.01	32
MaP												
43	67	0.99	14.1	6.4	0.14	1.89	1.52	2.00	0.98	0.07	0.01	<8
45	52	0.86	13.7	6.9	0.08	1.76	10.44	1.15	0.84	0.10	0.03	22
ESP												
51	60	0.97	16.8	8.5	0.13	3.64	1.73	1.99	1.53	0.12	0.01	13
53	60	0.88	16.0	8.6	0.14	3.66	4.70	3.18	0.81	0.10	0.01	85
60	46	1.70	22.1	16.3	0.36	0.92	0.90	0.44	0.25	0.11	0.03	91
WSP												
55	62	0.91	14.9	7.5	0.11	3.54	4.40	2.88	1.00	0.12	0.01	29
58	61	1.06	17.6	8.6	0.14	1.19	0.63	0.95	1.45	0.09	0.02	<8
WHP												
62	50	0.81	18.2	10.3	0.17	5.26	10.24	2.15	0.30	0.11	0.02	252

XRF Minor elements

Site	As mg/kg	Ba mg/kg	Br mg/kg	Ce mg/kg	Co mg/kg	Cr mg/kg	Cu mg/kg	Ga mg/kg	Ge mg/kg	I mg/kg
ENBP										
7	9	435	7	40	14	<6	20	15	<3	<15
28	8	522	12	<33	13	<6	17	16	3	<15
63	27	323	8	44	52	39	75	24	3	<15
ARB										
10	14	365	12	59	30	61	75	25	3	25
15	5	255	4	<33	17	14	17	22	3	<15
NIP										
17	38	97	8	43	10	147	50	22	<3	26
22	13	126	3	<33	23	17	36	12	3	<15
24	56	149	13	68	33	84	144	29	3	35
MoP										
31	7	173	<2	<33	32	110	95	17	<3	<15
33	6	171	23	<33	43	206	95	15	3	<15
34	8	268	35	41	57	265	154	20	<3	22
NP										
37	14	190	48	54	26	77	31	19	<3	21
40	6	767	6	81	30	165	21	24	3	<15
MaP										
43	13	480	17	40	31	20	188	16	<3	<15
45	10	317	13	38	56	307	112	15	3	<15
ESP										
51	7	220	5	<33	28	320	32	13	3	<15

53	11	185	11	33	23	132	31	13	3	<15
60	7	198	2	<33	25	152	43	13	<3	<15
WSP										
55	10	244	2	35	34	296	51	16	3	<15
58	5	164	7	<33	27	110	59	15	3	<15
WHP										
62	10	222	3	<33	19	44	44	16	3	<15

For all sites, concentrations were below detections limits (mg/kg) for: Ag (<6), Bi (<6), Cd (<7), Cs (<15), Hf (<17), Hg (<27), Sb (<16), Sm (<19), Sn (<6) and Ta (<15). The WHP sample was unusually high in U and Yb.

XRF Minor elements (continued)

Site	La mg/kg	Mn mg/kg	Mo mg/kg	Nb mg/kg	Nd mg/kg	Ni mg/kg	Pb mg/kg	Rb mg/kg	Sc mg/kg	Se mg/kg
ENBP										
7	<26	1191	<2	5	20	9	<5	35	15	<3
28	<26	1263	<2	5	24	4	<5	38	13	<3
63	27	2890	2	6	22	13	5	10	25	<3
ARB										
10	33	2531	<2	13	29	29	6	11	22	<3
15	<26	1276	<2	6	<18	7	<5	12	15	<3
NIP										
17	<26	210	5	7	32	33	<5	<5	27	5
22	<26	1070	<2	3	<18	7	<5	21	24	<3
24	41	1413	5	8	52	41	12	5	30	<3
MoP										
31	<26	1637	<2	95	<18	51	<5	31	26	<3
33	<26	1683	<2	95	18	64	<5	24	34	<3
34	<26	2329	<2	154	21	74	<5	18	44	<3
NP										
37	<26	1230	<2	31	28	27	10	20	13	<3
40	36	1188	<2	21	37	64	14	42	18	<3
MaP										
43	<26	1723	<2	188	21	9	<5	22	34	<3
45	<26	2338	<2	112	18	49	<5	11	50	3
ESP										
51	<26	986	<2	8	19	118	<5	41	16	3
53	26	615	<2	6	18	54	<5	36	10	<3
60	<26	814	<2	5	<18	57	<5	30	22	<3
WSP										
55	<26	980	<2	8	<18	186	5	54	21	<3
58	<26	1052	<2	4	<18	41	<5	18	27	3
WHP										
62	<26	1046	<2	7	<18	19	6	60	20	<3

XRF Minor elements (continued)

Site	Sr mg/kg	Te mg/kg	Th mg/kg	Tl mg/kg	U mg/kg	V mg/kg	Y mg/kg	Yb mg/kg	Zn mg/kg	Zr mg/kg
ENBP										
7	374	<14	<8	8	4	61	33	<22	82	141
28	357	<14	<8	10	5	55	36	<22	85	175
63	134	<14	<8	8	5	383	28	<22	88	175
ARB										
10	265	<14	<8	11	7	154	34	<22	106	204
15	1032	<14	<8	6	8	98	17	<22	51	57
NIP										
17	475	<14	<8	10	13	259	23	<22	62	171
22	140	<14	<8	11	4	146	17	<22	87	63
24	111	<14	8	7	12	266	52	<22	127	184
MoP										
31	255	<14	<8	9	4	230	24	<22	105	97
33	310	<14	<8	9	<4	253	23	<22	84	89
34	173	<14	<8	7	<4	351	21	<22	116	84
NP										
37	428	<14	8	9	6	128	25	<22	85	175
40	667	<14	11	8	10	153	16	<22	77	232
MaP										
43	380	<14	<8	8	<4	334	17	<22	102	46
45	257	<14	<8	11	4	361	24	<22	74	73
ESP										
51	140	<14	<8	10	5	142	18	<22	75	167
53	204	<14	<8	9	4	160	18	<22	75	115
60	296	<14	<8	8	5	179	17	<22	65	99
WSP										
55	149	<14	10	9	4	177	22	<22	92	159
58	246	<14	<8	9	4	216	20	<22	88	108
WHP										
62	141	9	12	4	191	17	<22	77	201	<15

11.10 Principal component analysis

Contribution of soil parameters to Principal Components 1-6, order of most positive at the top to most negative at the bottom. Prescripts denote depths: a 0-0.15 m, b 0.15-0.3 m, c 0.3-0.6 m, d 0.6-0.9 m.

PC 1 27% of var.)	PC 2 (14% of var.)	PC 3 (13% of var.)	PC 4 (8% of var.)	PC 5 (7% of var.)	PC 6 (7% of var.)
cExCa	bN	cExK	aColP	dColP	aExNa
bExCa	bOrgC	bExK	bColP	cColP	bExNa
dCEC	cOrgC	dExK	cExK	aDTPAMn	aEC
aExCa	aN	aExK	bExK	aDTPAZn	bEC

bCEC	cN	cExNa	dExK	bColP	aDTPAFe
cCEC	aOrgC	dExNa	aDTPAFe	aColP	aDTPACu
cpHwater	dOrgC	bColP	aExK	aDTPACu	aExMg
dExCa	dN	bExNa	cColP	aCaCO3	aColP
dCaCO3	aPSI	aColP	aDTPAZn	apHwater	bExMg
bpHwater	aExCa	dpHwater	bExMg	bpHwater	cColP
cCaCO3	aCaCO3	cpHwater	aExMg	cEC	aDTPAZn
aCEC	apHwater	bpHwater	cExMg	dEC	bColP
bCaCO3	aColP	bCaCO3	dExMg	dExCa	dColP
dpHwater	bColP	bEC	bCEC	dN	aDTPAMn
cEC	cColP	cEC	dColP	cpHwater	aPSI
apHwater	bExCa	apHwater	cCEC	cExCa	aExK
cExNa	aCEC	aExNa	aCEC	aEC	bExK
dExNa	dColP	aCaCO3	aDTPACu	bCaCO3	cExMg
bExMg	cEC	dEC	aExCa	cN	cExNa
aExMg	bpHwater	aEC	bN	dCaCO3	cExK
cExMg	bCaCO3	cCaCO3	bExCa	cCaCO3	dExNa
aCaCO3	dCaCO3	dCaCO3	aN	bEC	dExMg
dEC	aDTPAZn	aDTPAZn	bpHwater	dCEC	bN
aExK	cCaCO3	cColP	apHwater	dpHwater	dExK
dExMg	bCEC	aPSI	cExNa	bExCa	aN
aDTPACu	cpHwater	aN	dCEC	cCEC	aCEC
bExNa	cExCa	bExCa	cpHwater	aExCa	bExCa
aExNa	aDTPACu	bN	dExNa	bCEC	bOrgC
bExK	aExK	aDTPAMn	bOrgC	aCEC	cOrgC
bEC	cExK	bOrgC	cExCa	aExNa	dOrgC
aEC	bExK	aExCa	aOrgC	aPSI	cCEC
aDTPAFe	dpHwater	dColP	dExCa	aDTPAFe	bCEC
cExK	dExK	cExCa	aDTPAMn	bExNa	aExCa
dExK	dExCa	aOrgC	dpHwater	cOrgC	cExCa
bColP	dEC	bCEC	cN	dOrgC	aOrgC
aColP	cExNa	dExCa	aCaCO3	dExNa	dCEC
cColP	cCEC	cOrgC	dN	dExMg	cN
dColP	aDTPAMn	aCEC	cOrgC	cExNa	dN
aDTPAZn	dExNa	dOrgC	dOrgC	dExK	dExCa
cOrgC	dCEC	cN	aPSI	cExMg	bCaCO3
aDTPAMn	aExMg	cCEC	dCaCO3	aN	aCaCO3
dOrgC	bEC	aDTPAFe	cEC	aExMg	cCaCO3
bN	aEC	dN	bCaCO3	cExK	dCaCO3
dN	aExNa	dCEC	cCaCO3	bExMg	apHwater
bOrgC	bExNa	aDTPACu	dEC	bN	cEC
cN	bExMg	aExMg	bExNa	bExK	bpHwater
aN	cExMg	bExMg	aEC	aOrgC	cpHwater
aOrgC	aDTPAFe	cExMg	aExNa	aExK	dEC
aPSI	dExMg	dExMg	bEC	bOrgC	dpHwater

Contribution of leaf parameters to PCs 1 and 2, in order of most positive to most negative.

PC1	PC2
Mg	Cu
Zn	P
Mn	N
Ca	Zn
Cu	K
S	Mn
Fe	Mg
P	S
B	Fe
N	B
K	Ca

11.11 Pod analyses

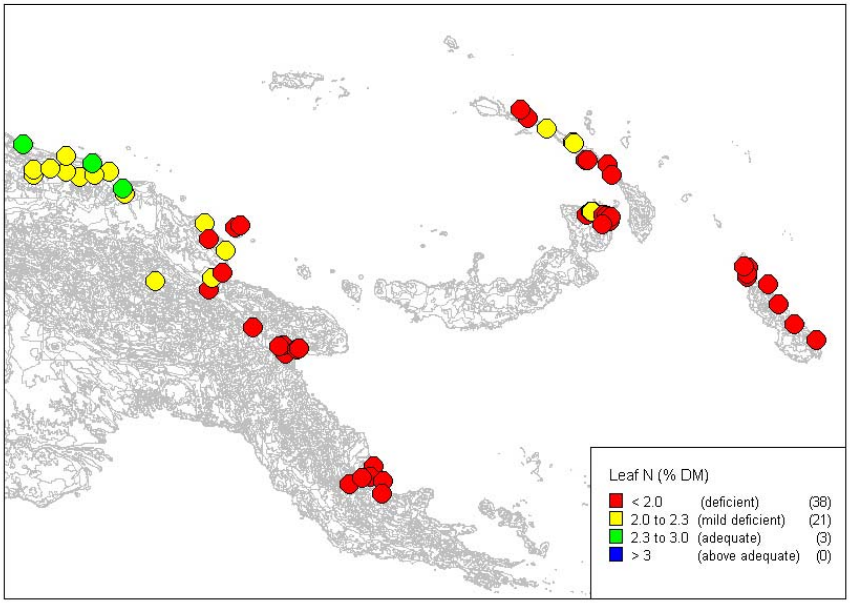
Values are in mg/kg, except for N and K, which are in %

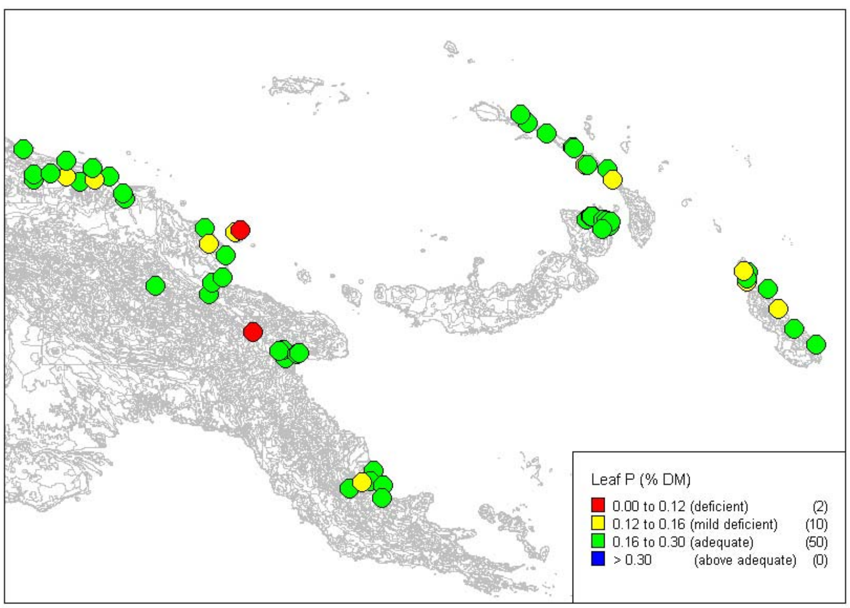
	Site 4	Site 63	Site 8	Site 18	Site 25	Site 34	Site 35	Site 44	Mean
	ENBP	ENBP	ARB	NIP	NIP	MoP	NP	MaP	
Beans									
N	1.9	2.2	2.0	2.3	2.2	1.9	2.4	2.2	2.12
K	1.46	1.21	1.26	1.59	1.20	1.51	1.19	1.22	1.33
Ca	1350	950	1300	1630	1240	1080	1080	1210	1230
Mg	3300	3100	3900	3500	3300	3300	3300	3400	3388
P	4900	4900	5200	5400	3600	5000	4700	5300	4875
S	1310	1260	1490	1330	1520	1320	1360	1260	1356
Zn	40	1530	75	870	590	2800	2200	5800	1738
Fe	32	33	28	32	37	35	36	55	36
Mn	16	24	28	39	19	29	22	19	24
B	20	20	24	19	22	18	30	24	22
Cu	15	38	29	37	36	37	16	33	30
Mo	< 0.8	< 0.8	< 0.8	< 0.8	< 0.8	< 0.7	< 0.8	< 0.8	< 0.8
Co	< 0.7	1.5	< 0.7	0.80	0.90	1.0	< 0.7	< 0.7	1.1
Ni	< 0.8	2.1	0.89	1.6	2.2	2.5	9.6	11	4.3
Na	< 0.4	49	< 0.4	< 0.4	< 0.4	< 0.4	1.9	1.2	17.5
Al	0.60	5.0	< 0.1	2.1	1.9	11	11	13	6.4
Ti	< 0.1	0.11	< 0.1	0.19	0.25	0.49	0.52	0.36	0.3
Cr	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	1.2	0.70	1.0	1.0
Cd	< 0.2	< 0.2	0.28	1.0	< 0.2	0.28	< 0.2	< 0.2	0.5
Pb	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2
Se	< 7	< 7	< 7	< 7	< 7	< 7	< 7	< 7	< 7
Husks									
N	0.94	0.97	0.88	1.1	1.2	1.0	1.2	1.0	1.04
K	3.8	3.6	4.3	3.5	3.3	3.5	4.2	3.7	3.74
Ca	3800	4600	4500	4700	3700	3400	4900	5200	4350

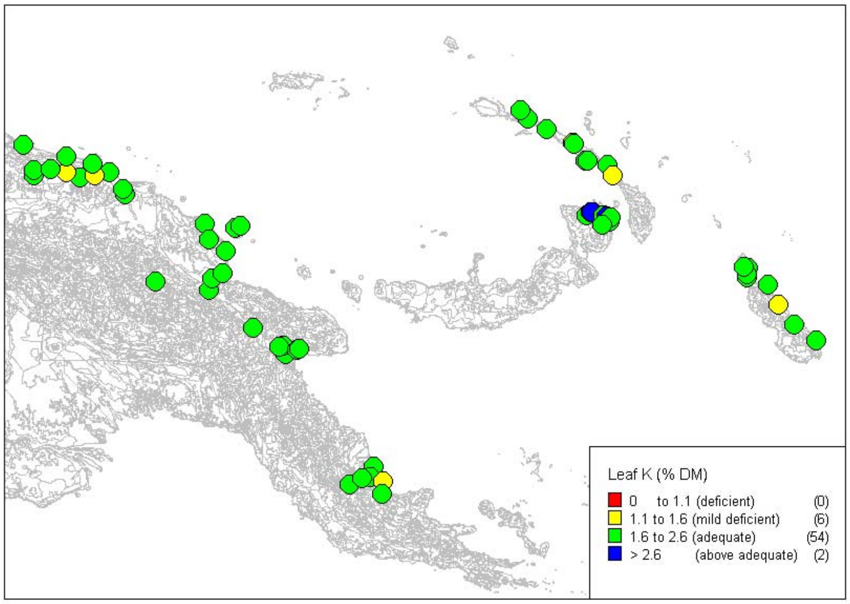
Mg	1570	2300	2400	1960	2500	2500	3100	3300	2454
P	1450	1330	1260	1400	840	1620	1420	1700	1378
S	1570	1520	1630	1530	1810	850	790	1630	1416
Zn	33	56	56	54	95	56	37	72	57
Fe	18	17	22	17	20	17	19	21	19
Mn	13	54	48	61	25	66	41	29	42
B	21	26	27	20	26	20	47	29	27
Cu	5.9	16	10	16	18	18	6.1	17	13
Mo	< 0.8	< 0.8	< 0.7	< 0.8	< 0.8	< 0.7	< 0.8	< 0.8	< 0.8
Co	< 0.7	1.7	< 0.7	1.1	< 0.7	1.1	< 0.7	< 0.7	1.3
Ni	< 0.8	< 0.8	< 0.8	< 0.8	< 0.8	1.3	1.6	7.8	3.6
Na	< 0.4	< 0.4	0.73	< 0.4	< 0.4	< 0.4	< 0.4	< 0.4	0.7
Al	5.5	5.0	< 0.1	< 0.1	2.3	< 0.1	7.7	7.2	5.5
Ti	0.48	0.20	< 0.1	< 0.1	0.27	< 0.1	0.21	0.68	0.4
Cr	< 0.5	< 0.5	< 0.4	< 0.5	< 0.5	< 0.4	< 0.5	< 0.5	< 0.5
Cd	< 0.2	< 0.2	0.29	0.94	< 0.2	0.44	< 0.2	< 0.2	0.6
Pb	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2
Se	< 7	< 7	< 7	< 7	< 7	< 7	< 7	< 7	< 7

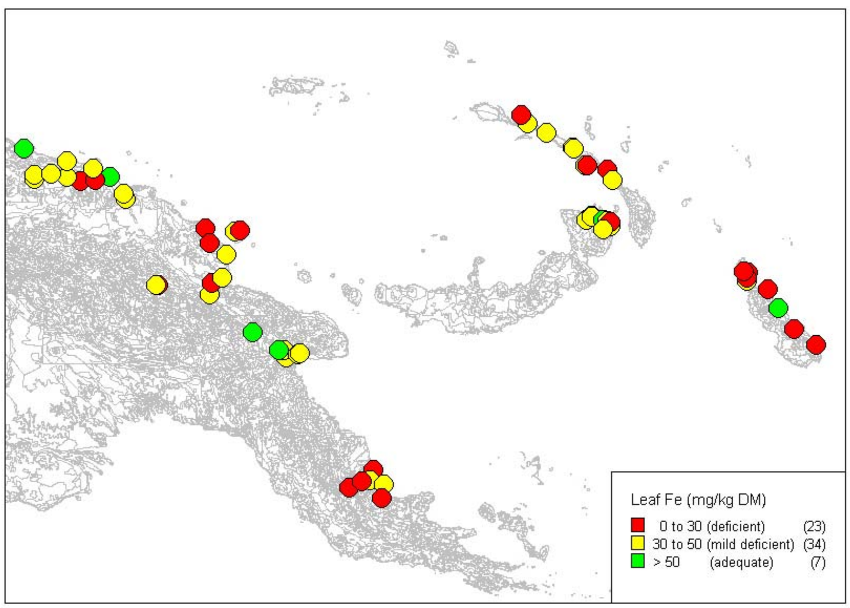
High Zn and Ti concentrations suggest contamination of bean samples (most probably from galvanised iron trays used for drying) at all sites except 4 and 8.

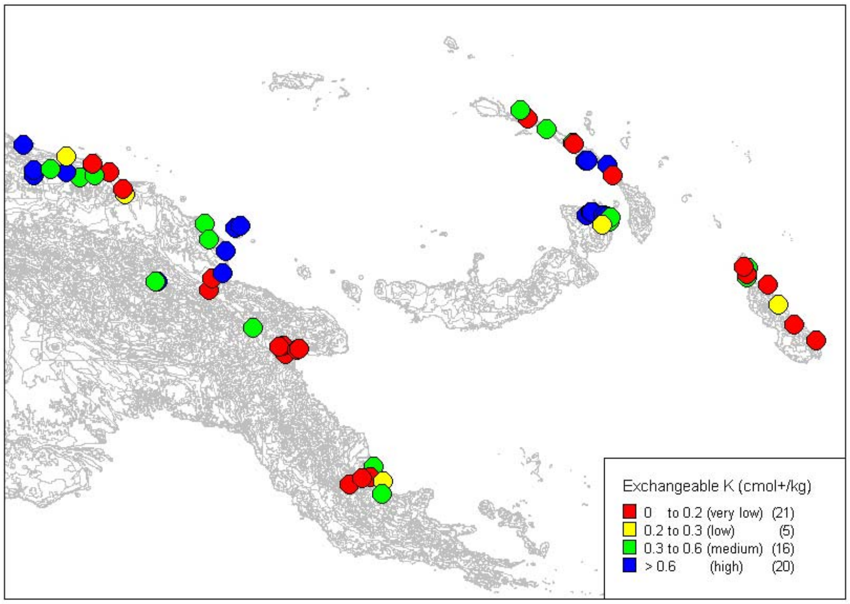
11.12 Maps of leaf and soil (0-0.15 m depth) nutrient status

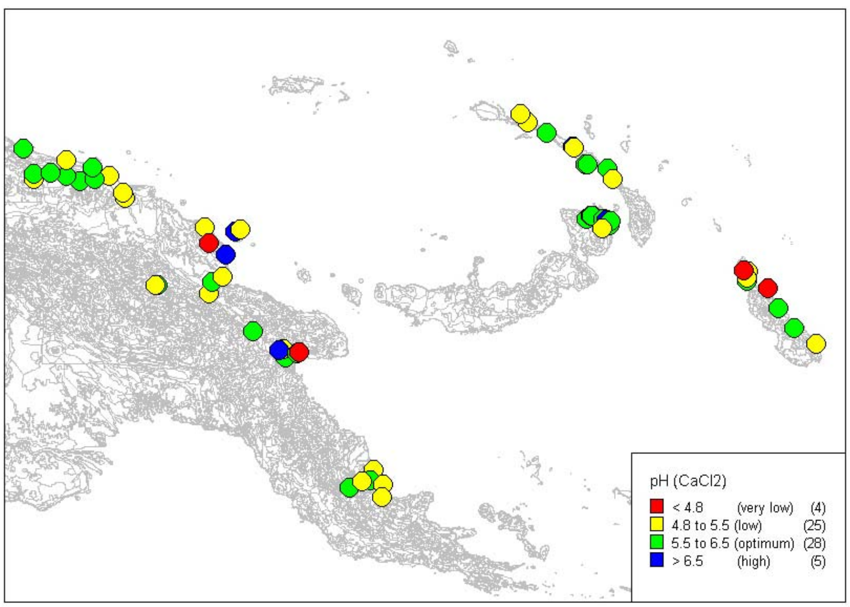


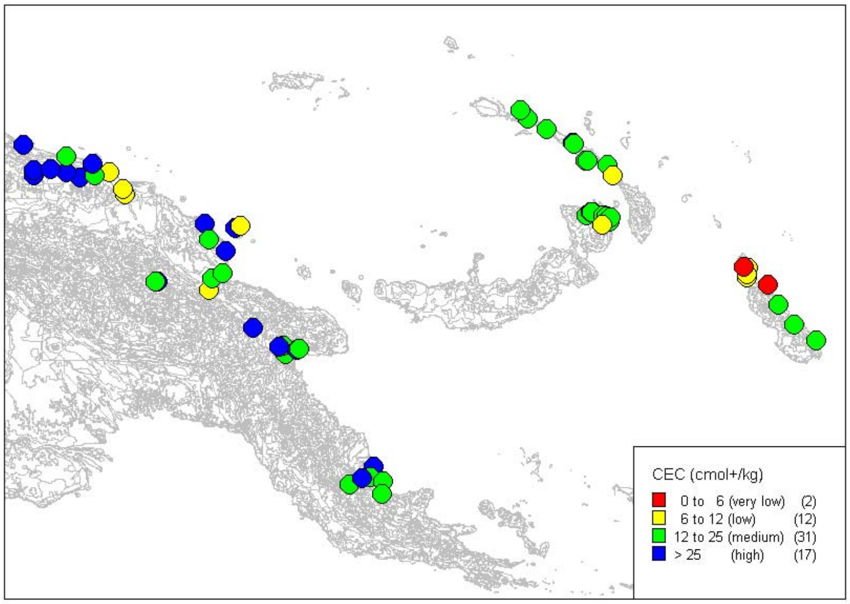


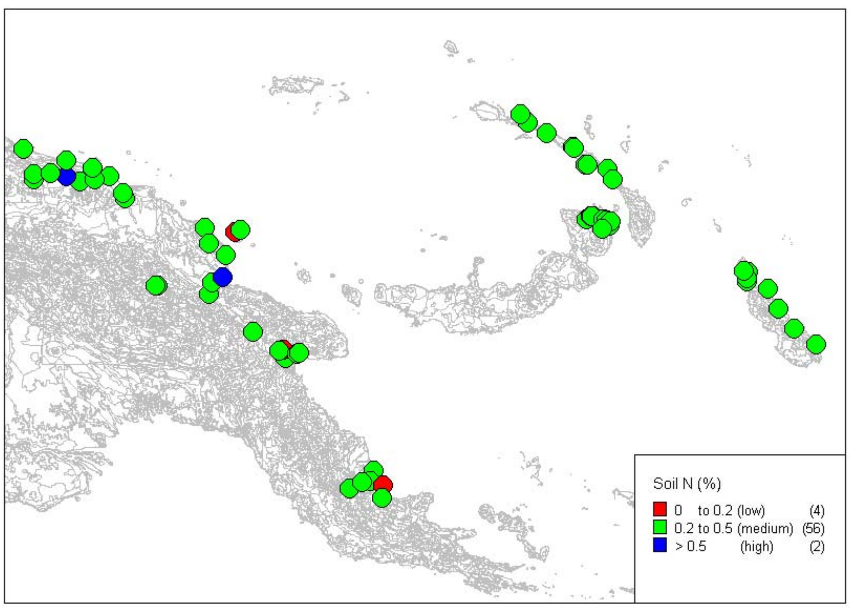

Leaf K (% DM)
0 to 1.1 (deficient) (0)
1.1 to 1.6 (mild deficient) (6)
1.6 to 2.6 (adequate) (54)
> 2.6 (above adequate) (2)

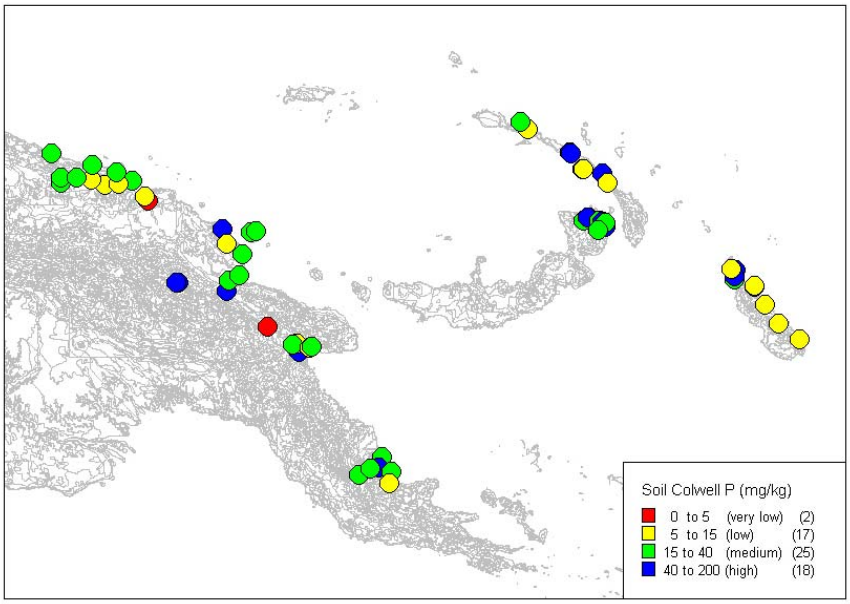

Leaf Fe (mg/kg DM)
0 to 30 (deficient) (23)
30 to 50 (mild deficient) (34)
> 50 (adequate) (7)


Exchangeable K (cmol+/kg)
0 to 0.2 (very low) (21)
0.2 to 0.3 (low) (5)
0.3 to 0.6 (medium) (16)
> 0.6 (high) (20)


pH (CaCl2)
< 4.8 (very low) (4)
4.8 to 5.5 (low) (25)
5.5 to 6.5 (optimum) (28)
> 6.5 (high) (5)


CEC (cmol+/kg)
0 to 6 (very low) (2)
6 to 12 (low) (12)
12 to 25 (medium) (31)
> 25 (high) (17)


Soil N (%)
0 to 0.2 (low) (4)
0.2 to 0.5 (medium) (56)
> 0.5 (high) (2)


Soil Colwell P (mg/kg)
0 to 5 (very low) (2)
5 to 15 (low) (17)
15 to 40 (medium) (25)
40 to 200 (high) (18)