Nutritional Status of Cocoa in Papua New Guinea

By Paul Nelson, Michael Webb, Suzanne Berthelsen, George Curry, David Yinil, Chris Fidelis, Myles Fisher, and Thomas Oberthür

Leaf and soil nutrient status was surveyed at 63 cocoa sites in Papua New Guinea (PNG) to determine if productivity is nutrient limited and how these limitations might be overcome. Nitrogen and Fe were deficient in >89% of the sites and P was deficient in about 25%. Management of cocoa in PNG must improve dramatically for the industry to prosper. Successful management schemes should consider a full systems context due to the complexity of socio-economic-agronomic factors. Improved nutrient management will require development of tools directed towards better foliar analysis.

Cocoa is the primary cash crop in most coastal areas of PNG, growing on 100,000 to 130,000 ha. About 151,000 smallholder households, equaling 16% of the households in the country or about 1 million people, produce 80% of the crop. Many smallholders harvest the crop opportunistically with little or no management inputs. Shortages of land and labor, and lack of agronomic knowledge are major production constraints. Smallholder productivity, 0.3 to 0.4 t/ha/yr, is low compared with plantation yields of 1.5 to 2.5 t/ha/yr and the potential yield of 4.4 t/ha/yr from research plots.

World demand for cocoa is increasing, and PNG cocoa commands a premium for its 'Fine Flavor Status'. In 2007, exports were 35,000 to 40,000 t, with a value of PGK 168 million. However, the industry is threatened by cocoa pod borer, which is spreading rapidly in the country. In East New Britain, one of the worst affected provinces, production fell by about 60% to 8,000 t in 2009.

The objective of this study was to determine the nutrient status of cocoa trees and their soils throughout the cocoa-growing areas of PNG. At a workshop in March 2007, local and Australian scientists together with representatives of the local cocoa growers reviewed information on cocoa nutrition and related issues. They confirmed the need for a survey to determine current nutrient status, selected representative sampling sites, and designed the sampling protocol. At a second workshop a year later, a similar group including market-chain representatives reviewed the survey data. A total of 63 sites were surveyed, including: 48 smallholder lots, six plantations, and eight trials from the Cocoa Coconut Institute (CCI), covering the major cocoa-growing areas of the country **(Figure 1)**.

Sampled plots were 6 x 7 trees. Two samples of the third leaf of a recently hardened leaf flush were selected at mid-canopy height on each of 20 trees, and their length, width, and fresh weight were recorded, together with the number of leaves in the sampled flush. The leaves were dried, weighed, ground, and bulked for each site. Ten ripe pods were sampled at eight sites, separated into beans and husks, dried, weighed, ground, and bulked for each site. Soils of each site were sampled by auger at 15 cm intervals to the 30 cm depth, and then at 30 cm intervals to 90 cm depth. Samples were taken 1 m from the tree trunk at nine trees for the two shallow depths and five trees for the two deeper depths. Samples were bulked by depth for each site.

Leaf samples were analysed for macronutrients and micronutrients. Soils were analyzed for texture, electrical conductivity, pH, cation and anion exchange capacity, exchangeable cations, extractable P (Colwell), extractable Al, organic C, and total N. Samples with pH > 6.5 were analyzed for $CaCO_3$.

Abbreviations: N = nitrogen; P = phosphorus; K = potassium; Ca = calcium; Mg = magnesium; Al = aluminum; Fe = iron; Mn = manganese; $CaCO_3$ = calcium carbonate; C = carbon; Zn = zinc.

Note: Monetary symbol PGK = Papua New Guinea Kina (PGK 1 ≈ USD 0.39).

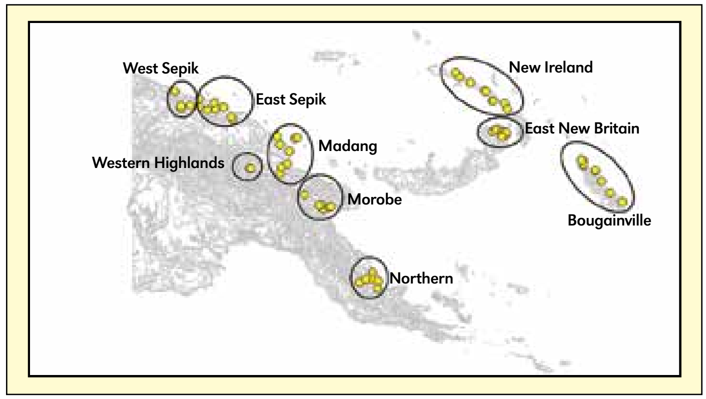


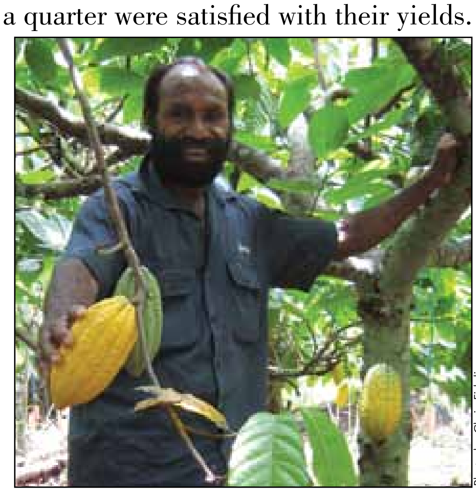
Figure 1. Location of the sites surveyed and the PNG provinces in which they were situated.

Results

Management Only 15% of the sites had been farmed for less than 17 years and only 14% of the trees were less than 7 years old. The planting material was sourced from CCI with open-pollinated material before 1982, hybrids until 1994, and clones thereafter. Most smallholder sites were shaded with Gliricidia, coconuts, and other species, and food crops were common, especially in younger plantings. About a quarter had legume groundcover, mostly Pueraria. Most sites were flat or moderately sloping with reasonably deep soil.

Smallholder growers identified lack of knowledge, poor management, and scarce labor as the main constraints to productivity; less than a quarter were satisfied with their yields. **Table 1** summarizes smallholders' perceptions for good or poor yields. Lack of fertilizer application and poor soil fertility were cited in about a third of the cases.

Almost half the sites were poorly or very poorly pruned and shade management scored nearly as badly. Weed management was rated somewhat better, with less than 30% scoring



In a well-managed cocoa block, Marex Mareka is checking integrated pest management and disease management options in Madang Province. Good pruning, weed control, and disease prevention are key management factors.

Table 1. 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	Labor: adequate, available	22	Lack of knowledge
5	Access good	18	Poor management
4	Land tenure secure: no disputes	17	Labor shortage/dispute/cost/other commitments
3	Planting material good (new)	11	Old planting material (Trinitario)
3	Knowledge/experience good	10	Diseases and pests
2	Management good	10	Lack of fertilizer
		6	Lack of finance for purchasing seedlings or tools
		5	Nutrient deficiency/soil exhaustion
		4 ea.	Theft of pods; Fermentary/dryer capacity/ functioning limited
		3 ea.	Water logging/flooding; Low prices; Lack of government support
		2	Lack of other chemicals (not fertilizer)
		1 ea.	Land shortage; Bad weather destroying flowers; Poor access; Missing trees

very poor, although in many cases heavy shade reduced weeds more than farmers' management. Almost all sites were affected with black pod disease and canker and over half with pink disease and vascular streak disease.

One-third of both CCI plots and plantations received fertilizer. Almost one-third of smallholders had participated in district fertilizer trials so that part of their cocoa had received some fertilizer. But few had applied it elsewhere on their farms. Fertilizer gave better growth, flowering, and pod yield, but farmers thought it was costly.

Physical accessibility to ripe pods is critically important and is compromised when thieves steal the easily-accessible, low-hanging pods.

Nutrient status We used Wessel's (1985) critical values for macronutrients and data for micronutrients based on survey information by Southern and Dick (1969). Most sites were deficient in N **(Figure 2a)** with a low mean N:P ratio of 10.4, indicating N was more deficient than P. Only 10% of sites were K deficient despite low soil K analyses, possibly because the widespread N deficiency was more limiting and masked its expression. Calcium and Mg were generally satisfactory. About a quarter of the sites indicated P deficiency, uniformly distributed over the survey area. There was no indication of other macronutrient deficiencies. Iron deficiency appears to be widespread **(Figure 2b)**, although the critical value needs to be reassessed as does its relation with Mn concentrations. Other micronutrients did not appear to be deficient. Black pod disease, caused by *Phytophthora palmivora*, was more prevalent on plants growing on low-Zn soils. Leaf analysis showed little pattern with respect to dominant soil classification or landform.

Both N and Fe deficiencies showed regional grouping, and hence site specificity, with N deficiency occurring rather more generally in all but the Sepik. Iron deficiency followed a similar regional pattern, but with some occurrences in the Sepik and none in Morobe.

Soil physical properties Root growth was restricted in almost 60% of sites; at eight sites by poorly-drained soils, at 13 sites (mainly in Bougainville and New Ireland), by heavier-textured soils, and at another 13 sites (mainly in the Northern Province), by gravelly and stony soils. There was little physical limitation to root growth at about 40% of sites, mainly in East New Britain, Morobe, and Madang.

Soil chemical and biological fertility Most soils were reasonably fertile with high exchangeable cation contents and acceptable pH. Biological fertility, as indicated by organic C, was generally good for most of the surface soils examined. Ratios of Ca:K >20 and Mg:K >10, which are unfavorable to K uptake, were measured at 75% and 45% of sites, respectively. There was a reasonable relationship between soil and leaf nutrient levels for K and P, but not for other nutrients. All sites having leaf P concentrations less than the critical level of 0.16% had soil Colwell P contents less than 25 to 50 mg/kg, which is the range of critical levels commonly cited for other crops as deficient (Moody and Bolland, 1999).

Discussion

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. Nitrogen and Fe deficiencies in particular appear to be widespread in cocoa in PNG, with 95% of the sampled sites falling below the critical level for N and 89% for Fe. Phosphorus deficiencies were encountered in only about a quarter of the blocks sampled. Nitrogen deficiency is likely to limit the yield increasing potential of other nutrients.

Agronomic aspects Root growth of cocoa is strongly influenced by the texture and structure of the soil profile (Freyne et al., 1996). Wood (1985) suggested that the ideal soil for tap root penetration and lateral root distribution should be composed of approximately 30 to 40% clay, 50% sand, and 10 to 20% silt, but more important is the vertical distribution of textures throughout the soil profile. Only 40% of the profiles examined were found to be free of physical limitations to root growth.

There is no definitive evidence to show that nutrient depletion is the cause of the onset of tree senility after 8 years, but it seems plausible that it contributes. It is likely that nutrient management, together with sound agronomy such as control of weeds and shade, the type of shade, suitable pruning of the cocoa trees and control of pests and diseases, could improve tree health, productivity, and longevity.

Cocoa production falls into three stages depending on age of the stand: less than 3 years old there are few beans but smallholders integrate cocoa into food-crop gardens which are well managed with low levels of pests and diseases. The second stage from 3 to 8 years is when the cocoa reaches full production, with a high demand for labor to harvest large quantities of ripe pods, which are readily accessible. The incidence of pests and diseases rises during this stage, but the cocoa generates high income. In the third stage, the trees advance into senility with lower yields of less accessible pods, declining management inputs, and high levels of pests and diseases. Most smallholder plots in PNG are in this latter condition.

Technical aspects Leaf age and light intensity

Photo by John Armour

Growers and researchers discuss constraints to cocoa productivity in East New Britain. David Yinil, Senior Agronomist, Cocoa Coconut Institute, is second from right.

usually override the nutritional effects on leaf nutrient composition except when there are marked deficiencies (Wessel, 1985). We controlled for leaf age in the sampling protocol, but we could not fully control for light. This remains an unknown variable.

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. In particular, N was deficient at almost all sites, and correcting it is likely to result in deficiency of other elements.

As with other crops and elsewhere there are indications that deficiencies are site-specific **(Figure 2)**. More intensive work is required for definitive analysis such as nutrient response trials on different soil types.

Sustainable intensification Of the smallholder sites surveyed, 85% had been in agricultural production for more than 17 years, with no application of fertilizers. The nutrient-supplying capacity of the soil will run down over time, and long-term sustainability of cocoa production will require that depleted nutrients be replaced.

Nutrient exports were similar to those elsewhere (Hartemink, 2005), but were at the low end for N and higher than the reported range for K. Cocoa beans from PNG have higher K content than beans from other places, indicating higher export per tonne of beans. This needs to be kept in mind for the longer term future of the industry. The nutrients removed per 1,000 kg of dry beans are 18 to 22 kg N, 3 to 5 kg P, 11 to 15 kg K, 1 to 2 kg Ca, and 3 to 4 kg Mg. At the average yield of 0.4 t/ha/yr, a total of 120 kg N, 24 kg P, 78 kg K, 9 kg Ca, and 21 kg Mg would be removed from each hectare in 15 years. The amount removed by plantation crops would be 5 to 6 times these quantities, and for crops achieving potential yield would be 10 to 11 times.

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 with the rapid spread of cocoa pod borer. If improved management is implemented, it is likely that limitations due to nutrient deficiencies will become more important, also with respect to the crop's disease resistance. Foliar analysis is a key tool for site-specific nutrient management.

Socioeconomic considerations often weigh more heavily with smallholders than high-quality crop husbandry. Nevertheless, there is a clear need to define the crop husbandry that will give optimum crop productivity in relation to other constraints.

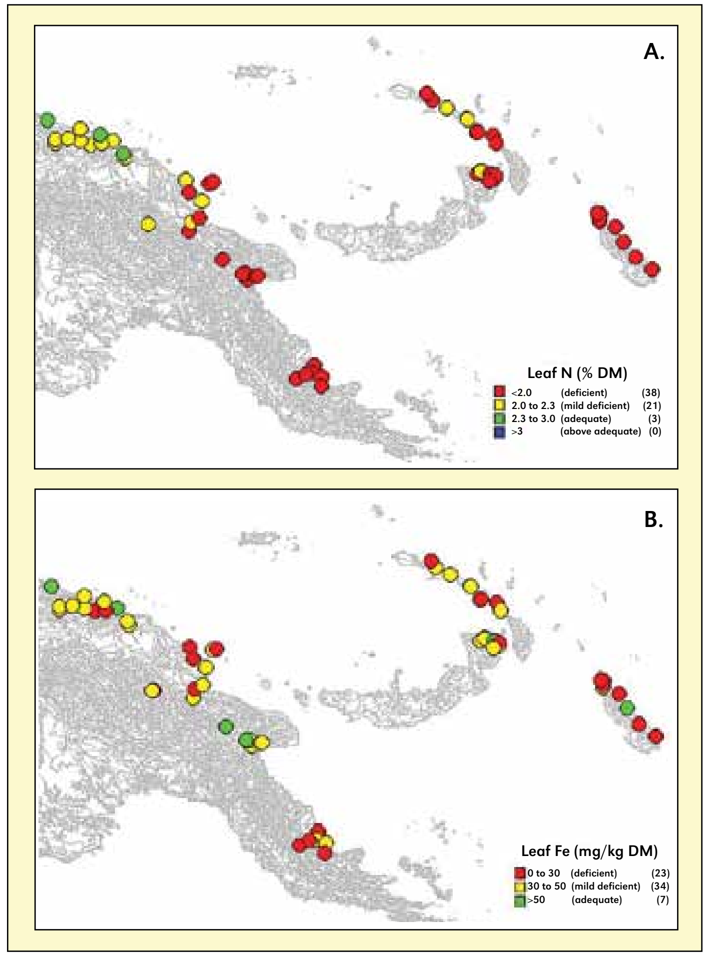


Figure 2. Maps of leaf (A) N and (B) Fe concentrations at the surveyed sites.

Acknowledgments

This research was funded by the Australian Centre for International Agricultural Research and the information presented was first published by Nelson et al. in 2011.

Dr. Nelson and Ms. Berthelsen are with James Cook University, Townsville and Cairns, Australia. Dr. Webb is with CSIRO Land and Water, Townsville, Australia. Prof. Curry is with Curtin University of Technology, Perth, Australia. Mr. Yinil and Mr. Fidelis are with the Cocoa Coconut Institute, Tavilo, Papua New Guinea. Dr. Fisher is with Centro Internacional de Agricultura Tropical, Cali, Colombia. Dr. Oberthür is Director, IPNI Southeast Asia Program, Penang, Malaysia; e-mail: tobertHur@ipni.net.

References

Freyne, D.F., P. Bleeker, B.M. Wayi, P. Jeffery. 1996. Port Moresby: Land Utilisation Section, Department of Agriculture and Livestock.

Hartemink, A.E. 2005. Adv. Agron. 86:227-253.

Moody, P.W. and M.D.A. Bolland. 1999. Chapter 12, Phosphorus. *In* Peverill, K.I., L.A. Sparrow, and D.J. Reuter. (eds.) Collingwood, Australia: CSIRO Publishing 187-220.

Nelson, P.N., M.J. Webb, S. Berthelsen, G. Curry, D. Yinil. and C. Fidelis. 2011. Nutritional status of cocoa in Papua New Guinea. ACIAR Technical Report No. 76. Australian Centre for International Agricultural Research: Canberra.

Southern, P.J. and K. Dick. 1969. Research Bulletin No. 7. Port Moresby: Department of Agriculture, Stock and Fisheries.

Wessel, M. 1985. Shade and nutrition. *In* Wood, G.A.R and Lass, R.A. Cocoa. Harlow, U.K: Longman 166-194.

Wood, G.A.R. 1985. Environment. *In* Wood, G.A.R and Lass, R.A. Cocoa. Harlow, U.K: Longman 38-79.