Nutrient status of cocoa *(Theobromae cacao)* in Papua New Guinea: results from a survey

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Abstract
Cocoa is the primary cash crop in most coastal areas of Papua New Guinea (PNG), supporting an estimated 150,000 households. Smallholders produce most of the crop, but their yields are low, at about 10% of the maximum. Low yields have been attributed to many factors, but the possibility of nutrition-related limitations to productivity has not been examined in detail. Here we report on a survey of 63 cocoa blocks across the country. 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 ~25 % of the blocks sampled. Leaf Mg concentrations were adequate in most blocks in most provinces, except East New Britain, 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. There were significant relationships between leaf and soil contents of K, Ca, Mg and P. There is a clear need to further examine nutrition-related limitations to productivity in PNG, including establishment of more reliable critical levels for leaf nutrient concentrations.

Key Words
Critical level, deficiency, leaf nutrient content, nutrient cycling, soil fertility, tree crop.

Introduction

Cocoa is a major cash crop in Papua New Guinea (PNG), contributing substantially to the national economy in terms of employment and foreign exchange earnings (ranks third after oil palm and coffee). PNG currently exports an average of 43,000 t of cocoa annually from an estimated 100,000-130,000 ha, bringing in export earnings of about US$ 62.1 million annually. Smallholders (approximately 150,000 households) produce over 80% of PNG's cocoa, with the balance coming from plantations. Smallholder yields are very low, generally in the range 0.3 - 0.4 t/ha of dry bean annually. Yield potential is much higher, with annual yields of up to 4.4 t/ha having been observed in research trials, and up to 2.5 t/ha being obtained in plantations. 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. Most cocoa blocks in PNG can be classified as 'senile' (>8 years old), having few accessible ripe pods and low management inputs (Curry *et al.* 2007). The possibility of nutrition-related limitations to productivity has been raised in the past but not examined in detail. Most of the production comes from land that has been cropped for 15 years or more with little or no fertiliser inputs. The objective of this study was to assess the likely nutrition-related limitations to production across the main growing areas of the country.

Methods

Between April and November 2007, 63 sites across the country were surveyed (Figure 1). The survey consisted of interviews with the growers, sampling of soil and leaf tissue, and in some cases, pods and husks. Of the 63 sites surveyed, 48 were on smallholder blocks, 6 were on plantations, 8 were in Cocoa Coconut Institute (CCI) trials and 1 was on a potential cocoa site. By province, 11 were in East New Britain, 9 in Autonomous Region of Bougainville, 9 in New Ireland, 8 in Madang, 8 in East Sepik, 6 in Morobe, 6 in Northern, 4 in West Sepik and 2 in the Jimi Valley of Western Highlands. At each site, a plot of 42 (6 x 7) cocoa trees was selected for sampling. The plot was assessed for tree health and general maintenance and the grower was interviewed about block history and maintenance. An attempt was made to calculate yields, but it was not possible to make reliable estimates for most blocks as most smallholders do not keep production records. Leaves were sampled from 20 trees distributed evenly throughout the 42-tree plot. The leaves chosen (2 per tree) were the third leaf of a recently hardened leaf flush at mid-canopy height. Leaves were

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dried, weighed and ground, and a composite sample was prepared for each site. Cocoa pods were sampled from 8 sites. At each site, 10 ripe pods were picked, with no more than one pod being picked per tree within the 42-tree plot. The beans and husks were separated, weighed, dried and weighed again. They were then ground and mixed, and composite sub samples prepared. Soil samples were taken 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 plot. The shallowest depth increments were sampled at 9 trees and the deeper increments at 5 of those trees, and one composite sample was prepared for each depth increment at each site. Plant tissue samples were analysed for macro and micro elemental contents. Assessments of deficiency or otherwise were made using the leaf concentration values noted by Fahmy (1977). These values have only ever been described as 'tentative' because they have not been verified by trials in PNG. Furthermore, it should 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). Soil samples were analysed for field texture and a range of parameters related to chemical fertility. A subset of subsoil samples were analysed for mineralogy by x-ray diffraction and x-ray fluorescence.

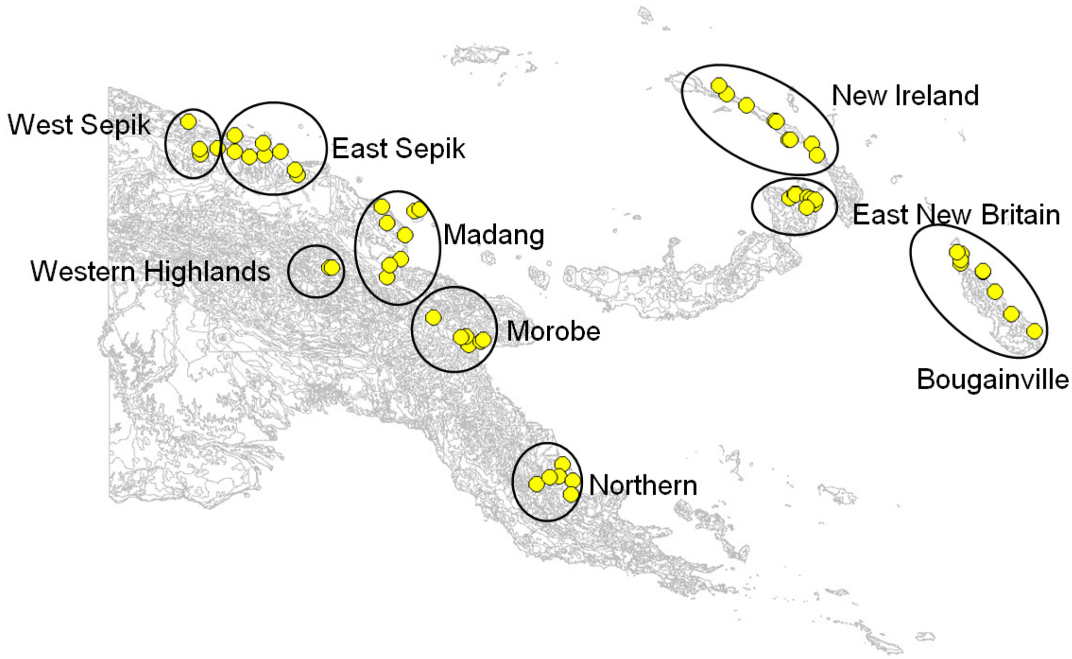

Figure 1. Map of Papua New Guinea showing the sampling locations and province names.

Results and Discussion

Based on leaf analyses, some nutrient deficiencies were widespread (Figure 2). For N, 95 % of sampled blocks fell below the critical level. Leaf N:P ratios were low, with a mean of 10.4, 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 (89%), leaves had deficient or suboptimal Fe concentrations compared to the published tentative critical levels. P deficiencies were encountered in ~ 25% of the blocks sampled and were distributed across all provinces. Leaf Mg concentrations were adequate in most blocks in most provinces, except East New Britain, 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. From leaf measurements, it appeared that leaves expand to near full size early in development and then accumulate dry matter as they mature. Nutrient exports, calculated from pod analyses, were generally within the range measured elsewhere (Hartemink 2005), but N exports were relatively low (18-22 kg/t dry beans) and K exports (11-15 kg/t dry beans) were higher than previously reported values.

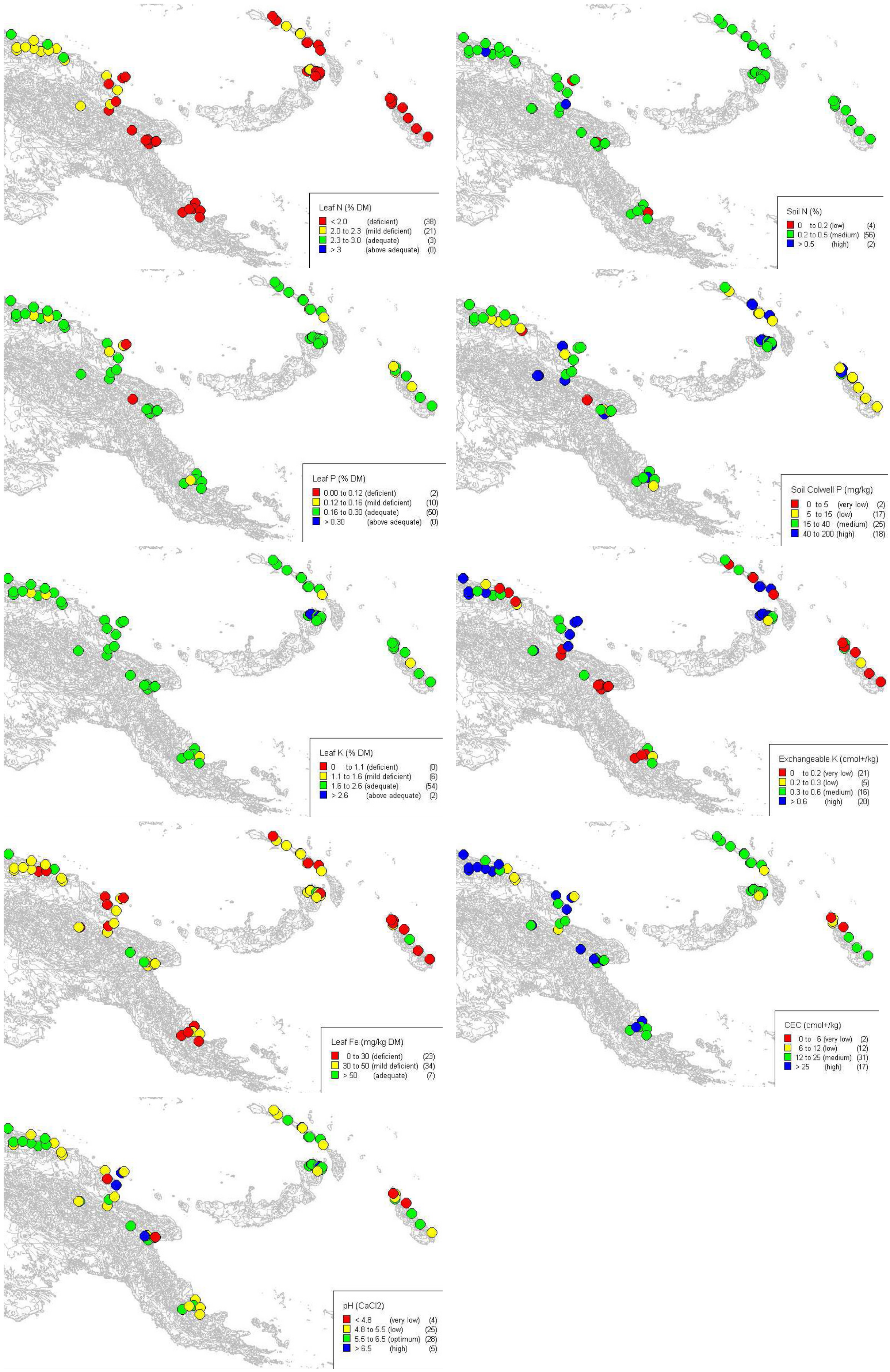

Figure 2. Map of Papua New Guinea showing leaf nutrient contents and soil properties (0 – 0.15 m depth).

Virtually all soil profiles sampled in this survey progressed from loam topsoil to sandy loam or clayey loam subsoils. Soil mineralogy was diverse, from little weathered profiles dominated by glass or feldspar to highly weathered profiles dominated by halloysite. Allophane content was <11% over all sites and was significantly correlated with phosphate buffer index. Most sites had reasonably high soil CEC, pH and organic C contents. Sites with high soil exchangeable K content had high leaf K contents and sites with high CEC and exchangeable Ca had high leaf Ca and B contents. 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.

There was a wide range of crop species cultivated in the surveyed cocoa blocks, although *Gliricidia* was the most common shade tree. However, no relationships were evident between cocoa nutrition status and management factors, including shade and the presence of legumes as shade trees or cover crop.

Conclusions

Nutrient deficiencies in cocoa, especially N, are common in PNG and are partly related to soil properties and geographical location. 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. The current assessment is based on tentative critical levels for leaf nutrient concentrations and there is a clear need to produce reliable critical levels based on manipulative trials.

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