Leaf Nutrient Analysis as a Management Tool in Yield Intensification of Oil Palm

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In the BMP trials established in six commercial plantations in Indonesia, the improved nutritional regimes had no consistent effect on leaf nutrient concentrations, and there were no obvious relationships between leaf nutrient status and yield. The authors suggest that Plantation Intelligence™, based on the observation and analysis of farm operations (operational research) and on-farm experimentation principles with data from commercial operations, can be used to adjust critical nutrient levels to fit the particular conditions of commercial blocks.

Leaf analysis is the most common method used to assess the nutrient status of the oil palm crop. Leaf analysis values are usually compared with established critical levels to determine whether a nutrient deficiency exists in the plant. Early researchers defined the critical concentration as not a point, but rather a narrow range of nutrient concentrations that separate the zone of deficiency from adequacy (Ulrich, 1952). Prevot and Ollagnier (1954) gave the critical level a more practical definition as *"the leaf nutrient concentration above which a yield response from fertilizer is unlikely to occur."* From this standpoint, leaf analysis and critical nutrient levels serve as a diagnostic tool to indicate when fertilizer should be applied to the crop.

Various factors affect leaf nutrient concentrations and, hence, critical levels. These include, among others, palm genotypes, soil factors, leaf rank and palm age (Coulter, 1958; Foster and Chang, 1977, Knecht et al., 1977). Some critical levels for N, P and K found in the literature are shown in **Table 1**. Teoh and Chew (1988) provided evidence that rachis K concentration is a better indicator of K nutrient status than leaf K.

Table 1. Critical values for N, P and K in leaf 17 of oil palm.

---- Deficient levels ----			---- Optimum levels ----			
N	P	K	N	P	K	Reference:
2.7	0.15	1.00				Prevot and Ollagnier (1954)
2.5	0.15	1.00	2.6-2.7	0.16-0.17	1.1-1.2	Ng (1969)
2.5	0.15	1.00				Ochs and Olivin (1976)
			2.9-3.0[a]	0.18-0.19	1.1-1.2	Foster and Chang (1977)
			2.6-2.7[b]	0.17-0.18	0.9-1.1	
2.5[c]	0.15	1.00	2.6-2.9	0.16-0.19	1.1-1.3	Von Uexkull and Fairhurst (1991)
2.3[d]	0.14	0.75	2.4-2.8	0.15-0.18	0.9-1.2	
2.6 ; 2.3[e]	0.13		2.5-3.0	0.15-0.19	0.9-1.3	Goh and Hardter (2003)
		1.00[f]			1.3-1.6[f]	Teoh and Chew (1988)

[a]Optimum levels for inland soils of West Malaysia; [b]Optimum levels for coastal soils of West Malaysia; [c]Critical and optimum levels for palms <6 years after planting (YAP); [d]Critical and optimum levels for palms >6 YAP;
[e]Critical level: 2.6 for palms <6 years after planting (YAP); 2.3 for palms >6 YAP; [f]Rachis K

In 2006, the Southeast Asia Program of IPNI evaluated a suite of BMPs for yield intensification of oil palm in large-scale commercial plantations at six sites in Indonesia (**Table 2**). Sites were located in Sumatra (North, South) and in Kalimantan (West, Central and East). The six sites included three with optimal conditions for palm growth and yield (sites 1, 2, 6), and three sites with sub-optimal conditions (sites 3, 4, 5). At each site, five pairs of commercial blocks, each of at least 25 ha, were selected so that each pair was planted in the same year with the same source of planting material and on comparable terrain with similar soil characteristics. In each pair, a block was designated for BMP implementation, while the other became the REF block, where current estate practices were maintained. BMPs related to crop recovery and crop management were implemented in the BMP blocks.

Table 2. General description of oil palm BMP project sites in Indonesia.

			Area, ha		Stand, palms/ha	
Site	Baseline palm age	Annual mean rainfall, mm[a]	BMP[b]	REF[c]	BMP	REF
1	5-12	1,923	266	281	121-140	136-143
2	8-14	3,072	156	160	124-134	122-135
3	15-18	2,782	256	259	127-137	128-135
4	8-9	3,080	143	147	135-149	138-147
5	8-9	3,045	124	121	112-138	128-141
6	3-12	2,509	135	135	133-154	135-146

[a]Climatic variables calculated using long-term averages from WorldClim (Hijmans et al., 2005) by Rhebergen (2012); [b]BMP = best management practices; [c]REF = reference block.

Over four years, nutritional status, fertilizer application, yield and other growth indicators were monitored in each block. Treatment pairs of BMP and REF measured at each site were subjected to analysis of variance (ANOVA). The level of significance used was 5% ($p = 0.05$).

Leaf Nutrient Concentrations

Across years, average leaf N levels in the BMP and REF treatments for sites 1, 2, 3 and 4 were below the published optimum range for N (**Figure 1**). Leaf N was similar between

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; BMP = best management practices; REF = reference block; FFB = fresh fruit bunches; EFB = empty fruit bunches. IPNI Project #SEAP-06.

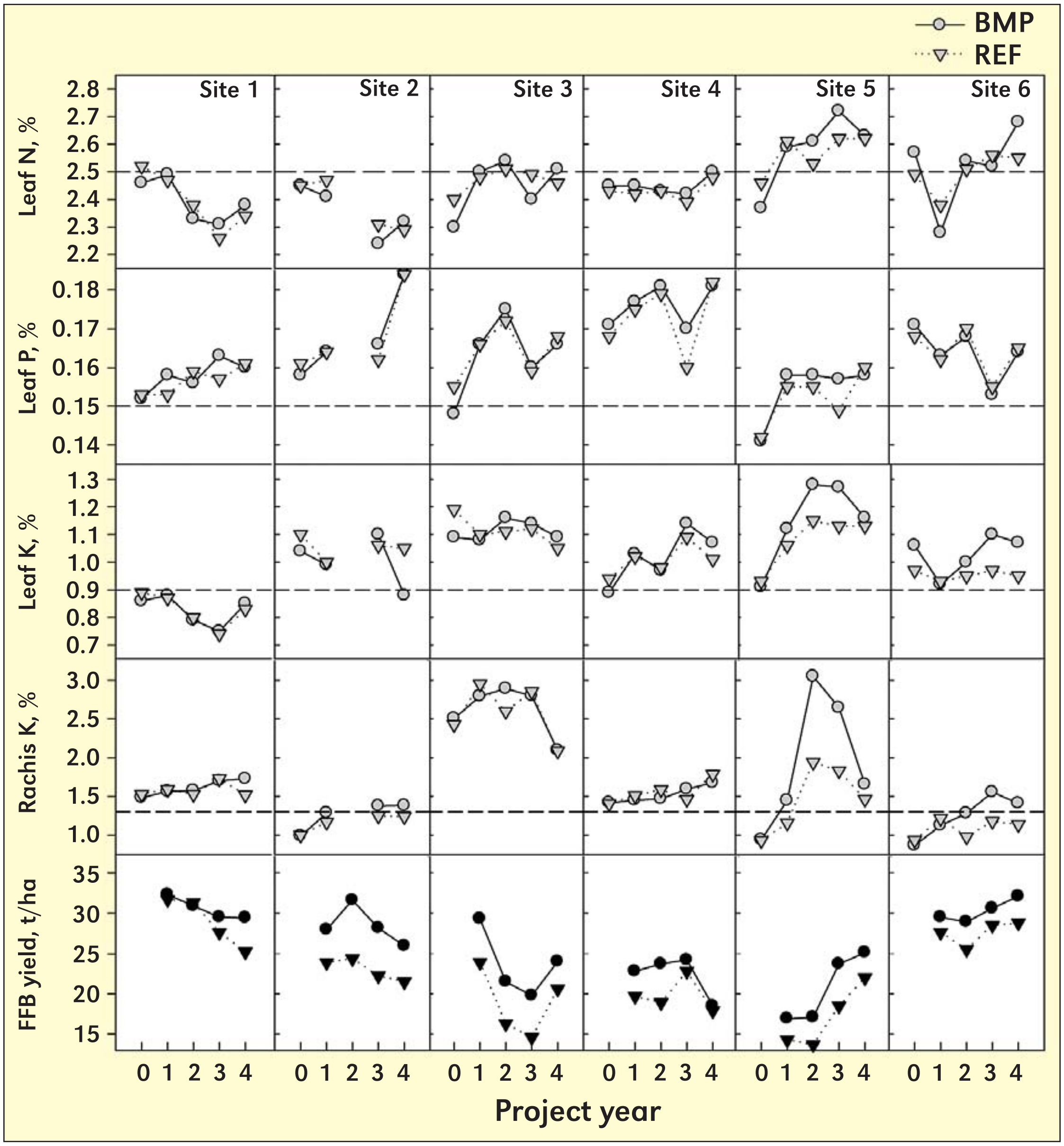

Figure 1. Nutrient concentrations in leaf 17 and rachis, and fresh fruit bunch (FFB) yield in the BMP project. Each data point is the average of five blocks. Broken lines refer to the critical level for N, P and K as given by Goh and Hardter (2003) for leaf 17 and by Teoh and Chew (1988) for rachis. Baseline FFB yield data for all sites and nutrient concentration data for year 2 at site 2 are not available.

BMP and REF in all sites and for most years (**Table 3**). Leaf N levels for both treatments remained fairly constant across years at sites 4 and 6, but declined at sites 1 and 2 and increased at sites 3 and 5.

Leaf P levels for both treatments were mostly within the optimum range (0.15 to 0.19%) at all sites and years. Leaf P levels were similar between BMP and REF treatments, except at sites 4 and 5 where P levels in the BMP were significantly higher than in the REF. In general, leaf P levels increased over time.

Leaf K levels for both treatments were within the optimum range (0.9 to 1.3%), except at site 1 where BMP and REF leaf K values were below the optimum in all years. Leaf K was significantly higher in the BMP treatment at sites 5 and 6, but was similar between the two treatments at other sites. Leaf K levels declined at site 1 during the four years of the project, increased at sites 4 and 5 and remained fairly constant at sites 2, 3 and 6. When averaged across sites, leaf K in the paired blocks were similar at the start of the project; K levels gradually increased in the BMP treatment, but stayed constant in the REF treatment. After the second year of the project, leaf K levels were much higher in the BMP than in the REF.

The apparent K deficiency determined by leaf levels of the BMP and REF treatments at site 1 was not reflected in the rachis K results, with K values within the optimum range of 1.3 to 1.6%. Moreover, whilst leaf K levels were within the optimum range, rachis K levels were outside the optimum range in the REF treatment at site 2 and 6. Across years, rachis K levels were significantly higher in the BMP treatment at sites 2, 5 and 6. Except for site 3, rachis K levels generally increased with time in both treatments. Rachis K in the paired blocks was similar initially, but from the second year onwards the K rachis levels were greater in the BMP treatments. The high rachis K values for all years at site 3 and for years 2 and 3 at site 5 were likely due to the removal of the outer green layer of the rachis during sampling prior to nutrient analysis.

Nutrient Concentrations as a Management Tool

Nutrient levels measured in the leaf and rachis of the treatment blocks reflect neither the differences in yield nor the differential nutrient inputs in BMP and REF. The BMP treatment consistently yielded more FFB than the REF across all sites and years (**Table 3**). The greater yields were attributed to yield-taking BMPs (crop recovery) during the first year and to the combined effect of yield-making (principally improved nutrition) and yield-taking BMPs in later years (Oberthur et al., 2013). The mulching with EFB at a rate of 40 t/ha in the BMP blocks of sites 3, 4, 5, and 6 increased the total nutrient input in the BMP treatment as compared to the REF. However, leaf nutrient levels were not significantly different, particularly for N and P, between BMP and REF within and among sites, in individual years, and averaged across time. Leaf nutrient levels varied over time at some sites; however, the patterns and magnitude of this variation was similar in the REF and BMP treatments. Differences in leaf and rachis K levels between BMP and REF were significant only at certain sites. Also, leaf K results did not correspond well with rachis K results. Site 1 had the lowest total K input among the six sites, which were reflected in leaf analysis results, but not in rachis K levels.

Foster (2003) indicated that nutrient concentrations alone may not be a very good indicator of oil palm nutrient requirements. The lack of a clear association between plant nutrient levels, yield and soil nutrient supply support this view (**Table 3 and Figure 1**). It is possible that increased availability of nutrients increases leaf (or rachis) nutrient content up to a certain level under given conditions, and that beyond that level the plant responds by increased growth with no change in nutrient levels. If this occurs with increased leaf growth leading to greater light interception then yield could increase with no change in nutrient status. This would then suggest that an estimation of the total nutrient content of the fronds, or the total cation content, would be a better indicator of nutrient status as it takes into account both the nutrient concentration and the total growth of the fronds.

Fairhurst and Mutert (1999) suggested that effective fertilizer recommendations are usually the result of combining the results of leaf analysis with field knowledge and common sense. Improvement of field knowledge to relate yield to nutrient contents can be obtained from carefully designed field trials (see, for example, Prabowo et. al., 2010). However, other options exist that may well be less costly but equally effective. The recently developed concept of Plantation Intelligence™ (Cook et al., 2013) as a mechanism to implement operational research and on-farm experimentation is designed to reduce decision uncertainty. This is achieved through a learning process based on the observed performance of individual management blocks in estates. The concept may provide a means to adjust leaf nutrient concentration indicators to suit local conditions. Advances in information technology make it possible to apply operational research principles and on-farm experimentation to agricultural production systems in which record keeping is the norm. If data from commercial operations are routinely collected on leaf nutrient contents, yield, weather and soil conditions on a large number of blocks over a period of time, it should be possible to deduce useful relations between leaf nutrient contents and yields under a particular sets of conditions. Guidelines can then be derived to use leaf nutrient concentrations as a means to determine nutrient requirements adjusted to specific conditions that vary in both space and time. The cyclic nature of the plantation intelligence process of observation, interpretation, evaluation, change etc. provides a built in feedback loop to assess the performance of indicator values and continually improve them in a real production setting.

Due to the large variation in uncontrollable factors that affect production and the multiple management responses required to manage crops within a constantly varying scenario, a large number of data sets for individual blocks

Table 3. Effect of BMP on yield, leaf and rachis nutrient concentrations at six Indonesian plantations (2006-2011).

		Treatment					
Parameter	Levels[a]	BMP	REF	Δ[b]	$P>\lvert t \rvert$[b]	Effects[c]	$P>\lvert F \rvert$[c]
FFB yield, t/ha	All	26.0	22.6	3.4	<0.001	Site	0.020
	Site 1	30.5	29.0	1.5	0.017	ProjYr	0.845
	Site 2	28.4	23.0	5.4	<0.001	Site x ProjYr	0.005
	Site 3	23.7	18.9	4.8	<0.001		
	Site 4	22.3	19.8	2.5	0.000		
	Site 5	20.7	17.1	3.6	<0.001		
	Site 6	30.2	27.5	2.7	<0.001		
	Yr 1	26.5	23.5	3.0	<0.001		
	Yr 2	25.6	21.7	3.9	<0.001		
	Yr 3	26.0	22.4	3.6	<0.001		
	Yr 4	25.8	22.6	3.2	<0.001		
Leaf N, %	All	2.46	2.46	0.00	0.834	Site	0.655
	Site 1	2.40	2.40	0.00	0.946	ProjYr	0.021
	Site 2	2.35	2.39	-0.04	0.151	Site x ProjYr	0.864
	Site 3	2.45	2.47	-0.02	0.544		
	Site 4	2.45	2.43	0.02	0.252		
	Site 5	2.58	2.57	0.01	0.556		
	Site 6	2.52	2.50	0.02	0.522		
	Baseline	2.43	2.46	-0.03	0.206		
	Yr 1	2.45	2.47	-0.02	0.434		
	Yr 2	2.49	2.47	0.02	0.324		
	Yr 3	2.44	2.44	0.00	0.878		
	Yr 4	2.50	2.46	0.04	0.048		
Leaf P, %	All	0.163	0.162	0.001	0.043	Site	0.445
	Site 1	0.157	0.156	0.001	0.472	ProjYr	0.447
	Site 2	0.167	0.166	0.001	0.549	Site x ProjYr	0.691
	Site 3	0.163	0.164	-0.001	0.502		
	Site 4	0.176	0.173	0.003	0.013		
	Site 5	0.155	0.152	0.003	0.018		
	Site 6	0.164	0.164	0.000	0.938		
	Baseline	0.157	0.158	-0.001	0.617		
	Yr 1	0.165	0.163	0.002	0.125		
	Yr 2	0.168	0.167	0.001	0.703		
	Yr 3	0.162	0.157	0.005	0.004		
	Yr 4	0.169	0.169	0.000	0.823		
Leaf K, %	All	1.03	1.00	0.03	0.001	Site	0.044
	Site 1	0.83	0.83	0.00	0.974	ProjYr	<0.001
	Site 2	1.05	1.05	0.00	0.925	Site x ProjYr	0.794
	Site 3	1.11	1.11	0.00	0.871		
	Site 4	1.02	1.00	0.02	0.312		
	Site 5	1.15	1.08	0.07	<0.001		
	Site 6	1.03	0.95	0.07	0.001		
	Baseline	0.98	1.00	-0.02	0.193		
	Yr 1	1.01	1.00	0.01	0.498		
	Yr 2	1.04	1.00	0.04	0.027		
	Yr 3	1.08	1.02	0.06	0.001		
	Yr 4	1.05	1.00	0.05	0.006		
Rachis K, %	All	1.72	1.59	0.13	<0.001	Site	<0.001
	Site 1	1.61	1.58	0.03	0.504	ProjYr	0.037
	Site 2	1.26	1.16	0.10	0.022	Site x ProjYr	0.524
	Site 3	2.61	2.58	0.03	0.582		
	Site 4	1.52	1.55	-0.03	0.153		
	Site 5	1.94	1.46	0.48	<0.001		
	Site 6	1.25	1.09	0.16	0.033		
	Baseline	1.37	1.37	0.00	0.916		
	Yr 1	1.61	1.60	0.01	0.601		
	Yr 2	2.05	1.73	0.32	0.002		
	Yr 3	1.95	1.72	0.23	0.005		
	Yr 4	1.66	1.54	0.12	0.094		

[a] All: Combined data averaged for all sites and years.
[b] Δ = BMP – REF; $P > |t|$: probability of a significant mean difference between BMP and REF.
[c] Source of variation of ANOVA of the difference between BMP and REF; $P > |F|$: probability of a significant *F*-value.

must be available to make sense of the trends and tendencies underlying the response of the crop to both management and uncontrollable variation. A direct consequence of this requirement for large data sets are the massive benefits that are obtained from sharing information with peers in other plantations, rather than using it in isolation. To an extent, the success of Plantation Intelligence™ depends on collaboration between various producers. BC

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Global Partnership on Nutrient Management

The accelerated use of N and P is at the center of a complex web of development benefits and environmental problems. They are key to crop production, but excess nutrients from fertilizers, fossil fuel burning, and wastewater from humans, livestock, aquaculture and industry lead to air, water, soil and marine pollution, with loss of biodiversity and fish, destruction of ozone and additional global warming potential. The problems will intensify as the demand for food and bio-fuels increase, and growing urban populations produce more wastewater.

The Global Partnership on Nutrient Management (GPNM)—a partnership of governments, scientists, policy makers, private sector, NGOs and international organizations—is a response to this 'nutrient challenge' of how to reduce the amount of excess nutrients in the global environment consistent with global development. The GPNM recognizes the need for strategic advocacy and cooperation at global level in order to communicate and to trigger actions by governments and other stakeholders in lowering N and P inputs from human activities. It provides a platform for governments, industry, science community, UN agencies and civil society organizations to dialogue and forge a common agenda, mainstream best practices and integrated assessments, so that policy-making and investments are effectively 'nutrient-proofed'.

GPNM's new website is a place where information about this worldwide nutrient challenge is shared with the wider audience. GPNM news items, upcoming events and publications, as well as interesting movies, links to Twitter and LinkedIn accounts and information about ongoing projects. The website also hosts all the results of the UNEP/GEF project "Global foundations for reducing nutrient enrichment and oxygen depletion from land-based pollution, in support of Global Nutrient Cycle" and other initiatives of GPNM Partners. BC

The GPNM website can be found at:
http://www.nutrientchallenge.org

Abbreviations and Notes: N = nitrogen; P = phosphorus; UNEP/GEF = United Nations Environment Programme/Global Environment Facility.