Plant Nutrients in Palm Oil

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An apparent knowledge gap concerning the amount of plant nutrients in palm oil motivated a study to determine plant nutrient content in palm oil and assess the impact of fertilizer management on such content.

Export of plant nutrients was low in palm oil extracted by industrial mills; part of the nutrients likely remain in post-milling residues.

Selected nutrients in palm oil were affected by fertilizer application rate, but not timing or frequency.

Research documented nutrient removal from harvested oil palm fresh fruit bunches (FFB). Reports from Southeast Asia and Africa show that each t of FFB contains 3.0 to 5.0 kg N, 0.3 to 0.7 kg P, 3.5 to 5.3 kg K, and 0.5 to 0.9 kg Mg (Tinker and Smilde, 1963; Ng and Thamboo, 1967; Tarmizi and Mohd Tayeb, 2006; Prabowo et al., 2006; Donough et al., 2014). There are reports of nutrient contents in post-milling residues after processing and extraction of palm oil and palm kernels from the FFB. These are for the empty fruit bunches (EFB) and the palm oil mill effluent (POME). The nutrients in the post-milling residue do not fully reconcile with pre-milling values (Prabowo et al., 2006). This suggests that the palm oil and palm kernel may contain some of them, or there could be unaccounted loss in the milling process. In a review of the fate of plant nutrients in palm oil production, Corley (2009) wrote that, "palm oil contains no N or K, and only about 20 g of P per tonne." Beyond this, there is virtually no information for contents of plant nutrients in palm oil.

The International Plant Nutrition Institute (IPNI), received an inquiry about the S content in palm oil in 2014. At the time, the Southeast Asia Program (SEAP) of IPNI sampled FFB in a project in Kalimantan for bunch analysis (BA, procedure shown in **Figure 1**, from Oberthür et al., 2012) to estimate yield of crude palm oil (CPO) and palm kernel. For this paper, the extracted samples of palm oil were analyzed. First, to determine the content of plant nutrients in CPO from BA (referred to as 'BA CPO'). This will show the portion of exported nutrients in FFB that the oil contains. Second, since the Kalimantan project compared different fertilizer managements, the results should also indicate if these had any influence on nutrient contents in the BA CPO. Third, to compare BA CPO with CPO from an industrial mill to make a balance sheet to identify where nutrient losses occur in the palm oil milling process.

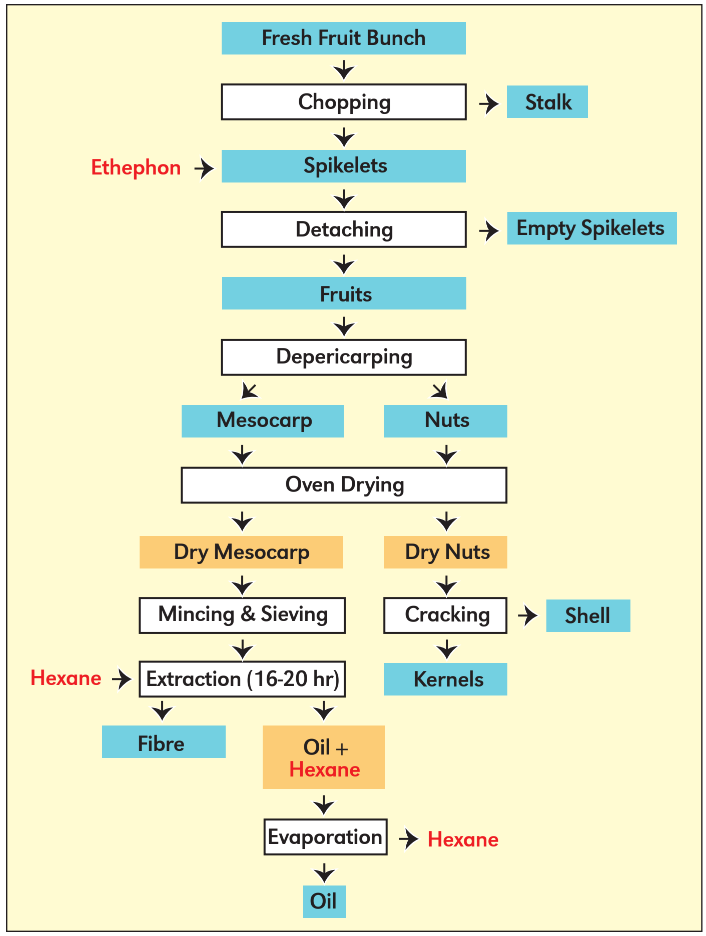

Figure 1. Bunch analysis procedure (Oberthür et al., 2012) implemented by IPNI Southeast Asia Program in Kalimantan, Indonesia.

The Kalimantan Project

The Kalimantan project validated the hypothesis that applying fertilizer more frequently, in line with 4R Nutrient Stewardship, will improve nutrient use efficiency (NUE) on sandy soils, and increase yields. In our project 'nutrient best management practice' (NBMP), the application of fertilizer mixtures supplying N, P, K, Mg, S, and B four times yearly, was compared to standard estate practice (SEP) where single nutrient fertilizers are applied once or twice annually (**Table 1**). The project included a reduced fertilizer rate treatment with 80% of the full rate. There were four treatments in a factorial design of two application frequencies (NBMP and SEP) and two application rates (full and reduced). There were three replicates: full-sized blocks, each 25 ha. Within each block, we embedded two plots each of 36 palms (of which the central 16 palms were recorded). One was fertilized in the same way as the rest of the block, the other left unfertilized.

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; S = sulfur; Ca = calcium; Mg = magnesium; Fe = iron; Zn = zinc; Cu = copper. IPNI Project SEAP-05

Bunch Analysis versus Palm Oil Mill Processing

The BA CPO is obtained directly from individual FFBs (**Figure 1**), whereas the palm oil mill CPO is extracted from large batches of FFB (**Figure 2**). In the BA process, bunches are processed 'fresh', whereas the FFB in the mill is sterilized (cooked) using steam under pressure. BA bunches are chopped to separate the stalk from fruit-bearing spikelets, which are then sprayed with ethrel® (active ingredient is ethephon or 2-chloroethylphosphonic acid, $C_2H_6ClO_3P$, 21% P) to accelerate fruit abscission, and the fruits are separated from the

Table 1. Nutrient Management Practices in IPNI SEAP Kalimantan Project.

Treatment	NBMP[1]			SEP[2]				
Nutrient sources[3]	Urea Gr	Ammophos	Kornkali+B	Urea Pr	TSP	MOP	Kieserite	Borate
N-P-K-Mg-S-B contents	46-0-0-0-0-0	16-9-0-0-12-0	0-0-33-4-4-0.8	46-0-0-0-0-0	0-46-0-0-2-0	0-0-50-0-0-0	0-0-0-16-22-0	0-0-0-0-0-15
Annual frequency of application	4	4	4	2	1	2	1	1
Method of application	Mixed and applied manually			Each type individually applied manually				
Placement	Broadcast outside palm circles onto heaps of pruned fronds			Urea and borate applied onto soil surface inside palm circles; other fertilizers broadcast outside palm circles onto heaps of pruned fronds				
	Approximate[4] annual application rate, kg/ha - Full[5] rates shown							
Nitrogen, N		150		150				
Phosphorus, P		13			12			
Potassium, K		230				230		
Magnesium, Mg		25					26	
Sulfur, S		28			<1		34	
Boron, B		2						1

[1]Nutrient Best Management Practice; [2]Standard Estate Practice; [3]Urea Gr = granular urea, Urea Pr = prilled urea, TSP = triple superphosphate, MOP = muriate of potash or KCl; [4]Values vary slightly (less than +/- 5%) year-to-year; [5]Full rate based on annual FFB yield target = 21 t/ha, calculated for NPKMg only, S rate varies with type of fertilizers used; Reduced rate is approx. 80% of Full rate.

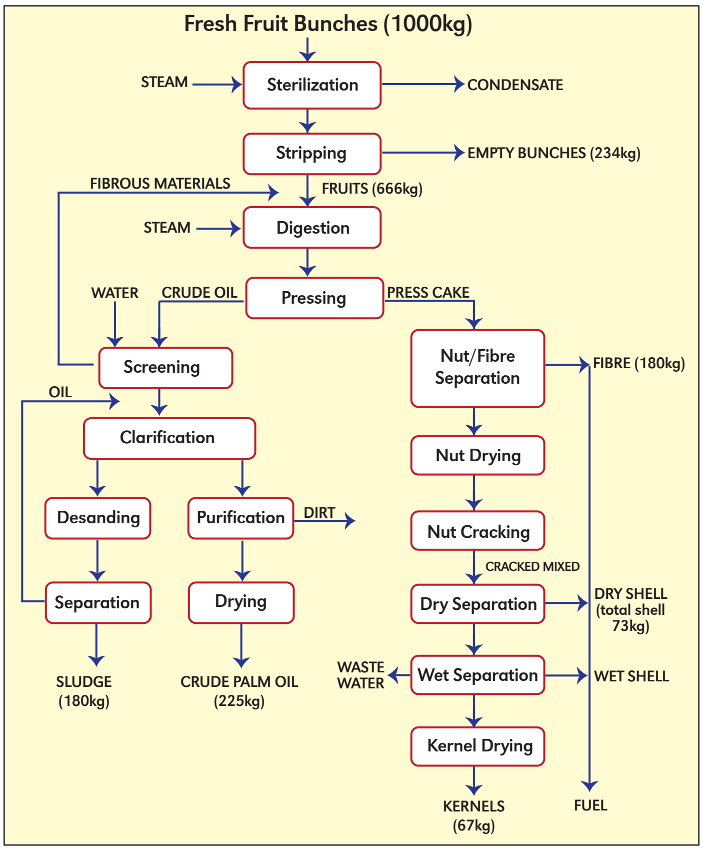

Figure 2. Typical milling process in a palm oil mill receiving fresh fruit bunches (FFB, top of figure) and extracting crude palm oil (CPO, left middle) and palm kernels (PK, right middle). From Siew (2011). Numbers shown for various components are from original author and do not add up.

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Oil palm mill receiving fresh fruit bunches for processing, Kalimantan, Indonesia.

spikelets manually. Each BA sample of 4 to 6 kg is sprayed with 250 ml of a 0.05% v/v solution so the concentration of P applied in ethephon per sample is 4 to 6 mg/kg. A sample will contain (approximately) the following components (expressed as % dry matter): spikelets (13%) and fruits, which consist of mesocarp (69%; containing oil that approximates 75 to 80% of the dry mesocarp), kernel (10%) and shell (8%). Distribution of the P from ethephon between the sample components is not known, but not likely all of the 4 to 6 mg/kg added P will be in the extracted oil. In the palm oil mill, the cooked FFB is fed into a rotating drum thresher that strips fruits from the bunches (**Figure 2**).

In the BA process, the fruits are then manually separated into the mesocarp (that contains the CPO) and the seed nuts (that contain the palm kernels). The BA CPO is extracted from a sample of the (oven-dried and sieved) mesocarp using a soxhlet extractor with hexane (C_6H_{14}) as the solvent. In the palm oil mill, after cooking the fruits are fed into a rotating drum stripper and then into a digester where further heating with steam loosens the mesocarp from the nuts. Stirring arms in the digester help the process. The fruit 'digest' is then fed into a screw press where oil is pressed from the mixture of water, mesocarp fibres and nuts. The oil from the press ('crude oil' in **Figure 2**), is the 'initial crush' CPO, which is still mixed with solids from the 'digest'. The 'initial crush' CPO is screened to remove the larger non-oil particles, and then goes to a

Table 2. Nutrient contents in crude palm oil (CPO) from the mill and bunch analysis (BA), in g per tonne.

Nutrient	N	P	K	Mg	Ca	S	Fe	Zn	Cu
Mill CPO[1]	44	18	<10	3	9	11	3	<0.5	<0.5
BA CPO[2]	93	145	20	58	42	37	55	3.0	0.5

[1] Samples from palm oil mill (physical extraction by mechanical presses), taken from production oil tank after clarifying, cleaning and drying. Mean values of 3 samples.
[2] Samples from bunch analysis process (solvent extraction); mean values of 12 composite samples.

clarification tank where much of the remaining non-oil solids settle. The cleaner CPO is skimmed off the top and passes through a centrifuge to remove remaining solids, followed by drying under vacuum. The cleaned crude palm oil passes to a production tank as 'Mill CPO', which then goes on to palm oil refineries. Samples of BA CPO and Mill CPO were obtained for analysis and comparison.

Nutrients in Mill Crude Palm Oil and Bunch Analysis Crude Palm Oil

Samples from the palm oil mill production tank are representative of CPO sold to refineries. The analyses show that there are only very small amounts of plant nutrients exported with the Mill CPO (**Table 2**). The BA CPO values were many times higher than the mill CPO values for all nutrients except Cu (**Table 2**). The difference is likely attributable to differences in the oil extraction methods at the mill (mechanical pressing) and in BA (solvent extraction). An important difference is that in the palm oil mill, FFBs are pressure cooked prior to pressing, so that nutrients may be lost dissolved in the sterilizer condensate (**Figure 2**). In BA, FFBs were not pre-treated.

Further loss of nutrients may occur after pressing in the palm oil mill when the oil is clarified and cleaned to remove dirt and impurities, and dried. Indeed, the nutrients contained in initial crush CPO from the mill were even higher than the BA CPO (**Table 3**). This is likely because the BA process used clean samples of fruit mesocarp and the leachate in soxhlet process contains only solutes. In contrast, the CPO after crushing in the palm oil mill contains much solid materials from the fruit digest.

Influence of Fertilizer Management

Reducing the fertilizer applied to 80% of the full rate affected N and Ca in BA CPO, which increased (**Table 4**). BA CPO from unfertilized plots showed significantly lower contents of P, K, and Mg compared to plots that received the same fertilizers as the blocks (**Table 5**). This suggests that the additional P, K, and Mg in the CPO came from added fertilizers. Other nutrients in the fertilizers did not affect contents of the oil.

The results for P could be slightly increased by 4 to 5% by P added via the ethephon treatment, which added an estimated 4 to 6 g/t to the BA samples.

Removal Rate from Plantations

Contents of N, P, K, and Mg in FFB from the Kalimantan project had been reported earlier (Donough et al., 2014). Those results are reproduced in **Table 6**, with addition of results for Ca and S previously not reported. Each t of FFB removed approximately 3 kg N, 0.4 kg P, 3.8 kg K, 0.6 kg Mg, 0.5 kg Ca, and 0.3 kg S. Assuming a FFB yield of 25 t/ha, this translates to per ha removal of 75 kg N, 10 kg P, 95 kg K, 15 kg Mg, 12.5 kg Ca, and 7.5 kg S. The proportion of total N and K in FFB contained in the BA CPO is <1%, compared with almost 10% of P. In the case of S, about 3% is in the BA CPO. Nutrient removal (per ha) in the oil, assuming the same 25 t/ha FFB yield above, is just 0.6 kg N, 0.9 kg P, 0.1 kg K, 0.4 kg Mg, 0.3 kg Ca, and 0.2 kg S.

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A sample for fresh fruit bunch analysis (main image). Fruit mesocarp is separated from each seed nut (bottom left) and then oil is extracted from the mesocarp by solvent extraction (bottom right).

Table 3. Nutrient contents in crude palm oil (CPO) from different milling stages, g per tonne.

Nutrient	N	P	K	Mg	Ca	S	Fe	Zn	Cu
Mill CPO[1]	44	18	<10	3	9	11	3	<0.5	<0.5
Initial crush CPO[2]	853	81	1,103	286	342	144	52	2.0	1.1

[1] Samples from palm oil mill (physical extraction by mechanical presses), taken from production oil tank after clarifying, cleaning and drying. Mean values of 3 samples analysed by IMS.
[2] Samples from palm oil mill crude oil tank immediately after pressing, results are average values from determinations by two laboratories (SRC and A&L), except for the N result from SRC only.

Table 4. Effect of nutrient management on nutrient contents in bunch analysis crude palm oil, in g per tonne.

Nutrient	N	P	K	Mg	Ca	S	Fe	Zn	Cu
NBMP[1] blocks	102	145	20	56	40	34	52	2.5	<0.5
SEP[2] blocks	85	145	20	60	44	39	58	2.9	<0.5
Full-rate blocks	73	142	19	55	36	42	54	3.3	<0.5
Reduced-rate[3] blocks	113	148	21	61	48	32	56	2.6	<0.5

[1] Nutrient best fertilizer management = nutrients mixed and applied 4 times a year (i.e., high frequency for every nutrient).
[2] Standard estate practice = nutrients applied singly, 1 to 2 times a year.
[3] 80% of full rate.

Table 5. Nutrient contents in bunch analysis crude palm oil - with and without fertilizers, in g per tonne.

Nutrient	N	P	K	Mg	Ca	S	Fe	Zn	Cu
Fertilized[1] plots	79	142	22	61	45	33	55	2.6	0.5
Unfertilized[2] plots	77	128	17	50	45	35	57	2.6	0.5

[1] Embedded plot in each block receiving the same fertilizer treatment as rest of the block.
[2] Unfertilized plot in each block.

Table 6. Nutrient contents in fresh fruit bunches (FFB) and in bunch analysis crude palm oil (BA CPO), in kg per tonne.

Nutrient	N	P	K	Mg	Ca	S
Whole FFB[1]	3.07	0.38	3.84	0.62	0.51	0.28
Proportion in BA CPO[2]	0.02	0.04	0.01	0.01	0.01	0.01
Proportion in BA CPO in %	0.8	9.5	0.1	2.3	2.1	3.3

[1] Contents in whole bunches, including CPO still in mesocarp. Mean of all four treatments.
[2] Contents in the oil extracted from whole bunches (bunch analysis CPO) and assuming an oil content of 25% in FFB.

Conclusions

This work closes a significant gap in oil palm relevant nutrient management knowledge, by clarifying the nutrient content in CPO.

CPO obtained from the palm oil milling process contains few plant nutrients (**Table 2**), indicating that most of the nutrients in FFBs reaching the mills must remain somewhere in the mill system. Therefore, recycling nutrients from the mills back to plantations is an opportunity for better nutrient use efficiency in palm oil production. Decision models on alternative uses for post-milling residues (e.g., for power generation) must factor in the opportunity cost of such nutrient recycling, as prices of fertilizers and fuel fluctuate.

Nutrient content in BA CPO was higher than that in Mill CPO (**Table 1**), most likely due to the difference between extraction by mechanical pressing of whole bunches and leaching with a solvent. While useful for monitoring at the experimental or plantation level, costly solvent extraction is not used at the industry level.

Fertilizer management, in this case different frequency of application and rates, had no effect on most plant nutrients in the extracted CPO. The contents of N and Ca fell when the rate of applied fertilizer increased from 80% to 100%. Explanations are uncertain without further investigation.

Applying fertilizers compared with no fertilizer increased P, K, and Mg in the CPO, indicating that some of the applied nutrients ended up in the oil component of FFB.

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