Opportunities for Research and Development in Oil Palm Fertilization to Support Sustainable Intensification

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The Southeast Asia Program of IPNI (IPNI SEAP) has developed a process to reduce yield gaps in oil palm plantations using Best Management Practices (BMPs). This process appraises the yield that can be obtained with BMPs on a set of commercial production blocks, evaluates the benefits from packages of management improvements, and also assesses the most appropriate BMP for a particular site. Estates can then identify BMPs suitable for yield intensification that work on a small set of commercial plots and use this information to make investment decisions for larger areas with a higher level of confidence.

Palm oil production over the last 50 years has increased mainly through area expansion. With limitations on expansion of agriculture into new areas, a major concern is how to increase productivity in order to meet future demand for palm oil (Corley, 2009). Yet, intensification of oil palm production to obtain higher yields is possible. The Unilever plantations in Malaysia, over a 40-year period, increased crude palm oil (CPO) productivity from 1.3 to 5.4 t/ha through breeding advances and improved management; with better fertilization alone accounting for 29% of the increase (Davidson, 1993).

Best management practices can be separated into those that contribute to *yield-taking* (crop recovery) and *yield-making* (crop management). Yield-making is related to producing more fruit bunches (and therefore more oil) in the field, whereas yield-taking is ensuring that available fruit bunches are effectively harvested and transported to the mill. Yield-taking practices have an almost immediate effect after their implementation. On the other hand, there is a time lag between the implementation of improved agronomic yield-making practices and their impact on yield. Thirty-five to 40 months elapse between floral initiation and fruit bunch ripening (Breure, 2003). Hence, the impact of a BMP that affects floral initiation or other processes related to bunch formation might only manifest themselves in increased yields after periods of several months, with the full effects only observable after 3 to 4 years. Increased yields are due to impacts on the biological processes that drive bunch development. When palms become stressed because of suboptimal growth conditions, complex feedback mechanisms change the sex ratio and also promote abortion (**Figure 1**). Appropriate nutrition and water availability reduce these stresses in the earlier stages after floral initiation; hence the importance of the yield-making BMP in this phase. Later on, nutrition is important for bunch development, with soil fertility BMPs being crucial for yield-making.

The suite of BMPs contains several practices that impact directly or indirectly on plant nutrition. Direct impacts come mainly from providing nutrients for plant growth, whereas indirect impacts may arise from reducing competition for nutrients and by providing a healthy soil medium. While the IPNI SEAP BMP process improves all aspects of crop management, oil palm usually responds to improved nutrient management and adequate nutrition with higher yields. Furthermore, when fresh fruit bunches (FFB) are harvested, nutrients are removed from the field and only partially returned with empty fruit bunches (EFB). Unless supplemental nutrients are added to replace them, oil yields will be low (Chan, 2000). Hence, we present here opportunities for sustainable intensification of oil palm plantations through improved nutrient management. These opportunities have been identified from the analyses and interpretation of results from a large scale, 4-year BMP project in Indonesia (detailed results can be found in Oberthür et al., 2012).

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium. IPNI Project # Southeast Asia SEA06.

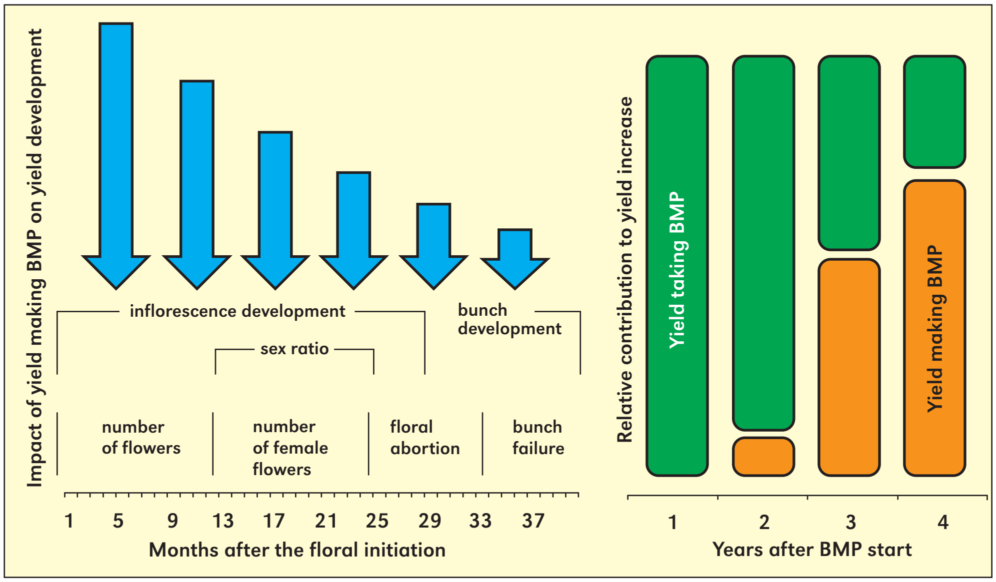

Figure 1. A conceptual description of the contribution from yield-making and yield-taking BMP towards the formation of fresh fruit bunch yield (Source Oberthür et al., 2012).

BMP Case Study for Intensification of Oil Palm Production

In 2006, IPNI SEAP evaluated the BMP concept on 30 commercial blocks, established in partnership with five plantation companies in six sites in Indonesia (Donough et al., 2011). 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, on

Returning empty fruit bunches back to the stand along with supplemental fertilizer nutrients is a critical part of the IPNI SEAP BMP strategy to sustainable intensification.

Table 1. Fresh fruit bunch (FFB) yields from the BMP project under different conditions in Sumatra and Kalimantan.

Location and treatment	Year 1	Year 2	Year 3	Year 4	Average[1]
	---------- Annual FFB yield, t/ha ----------				
Sumatra (Sites 1,2,3)					
Best management practices (BMP)	29.9	27.9	25.7	26.2	27.4
Reference block (REF)	26.6	24.0	21.2	22.4	23.5
Difference (%)	13	17	21	17	17
Kalimantan sites (Sites 4,5,6)					
BMP	23.0	23.6	26.6	25.5	24.7
REF	20.6	20.5	23.5	23.1	21.9
Difference (%)	12	15	13	11	13
Optimal site condition (Site 1,2,6)					
BMP	29.8	30.4	29.2	29.1	29.6
REF	27.8	27.1	25.7	25.2	26.4
Difference (%)	7	12	14	15	12
Sub-optimal site condition (Site 3,4,5)					
BMP	23.1	21.2	23.0	22.7	22.5
REF	19.4	17.3	19.0	20.3	19.0
Difference (%)	19	22	21	12	18

[1]Average values are for the 4-year project duration.
Source: Donough et al., 2011.

comparable terrain with similar soil characteristics. In each pair, the block with historically lower yields was designated for BMP implementation; the other became the reference (REF) block, where current estate practices were maintained. Sites were located in Sumatra (1, 2, 3) and Kalimantan (4, 5, 6). The trials were designed in such a manner that differences in yield-taking and yield-making effects could be separated. However, when plantation managers in most sites observed the benefits of simple measures to improve yield-taking they often adopted these protocols on their REF blocks. Therefore, it has not been possible to determine the relative importance of yield-taking and yield-making effects with absolute precision. Details about the BMPs and the deployment process can be found in the IPNI SEAP series of oil palm books.

The BMP blocks consistently out-performed the REF blocks (**Table 1**). Under optimal site conditions (sites 1, 2, 6), annual FFB yields with BMPs were close to 30 t/ha, and equivalent to about 6.5 t CPO/ha. The difference in annual FFB yields between the REF blocks and the BMP blocks increased from 2 t/ha in the first year to almost 4 t/ha in the fourth year in the optimal sites (**Table 1**). If we assume that the yield-making factors had little effect in the first year, then the yield-taking factors provided 2 t/ha extra FFB yield. By the fourth year, supposing that yield-taking factors remained constant, the yield-making factors were providing a similar gain of about 2 t/ha in addition to the yield-taking factors. At site 1, where harvesting was well managed from the beginning, the main gain in productivity occurred in years 3 and 4, indicating the yield-making gains from BMP.

The yield decline in the optimal sites in the REF blocks is largely explained by lower rainfall in the two Sumatran sites during the project period. It is noteworthy that the yield decline was very small in the BMP blocks in the same period, suggesting that if rainfall had not been limiting, yields in year 4 would have increased substantially in the BMP blocks. In the sites with sub-optimal conditions (sites 3, 4, 5), using similar reasoning, the yield-taking effect of BMPs could be as high as 3.7 t/ha of FFB yield as seen from the first year data. One would have expected the difference in FFB yield between the BMP and the REF blocks to be larger and total yield to increase further in the BMP blocks as yield-making effects kicked in. Neither of these effects was observed. However, the plantations on these sites had rapidly adopted the yield-taking BMPs in the REF blocks, skewing results, so that the substantial yield advantage of 4 t/ha in year 3 and 2.4 t/ha in year 4 in BMP blocks was essentially due to yield-making factors like changed fertilization.

Nutritional Status and Growth Indicators

Over the four years fertilizer budgets for BMP blocks were, in most sites, only slightly higher than those in the REF blocks (**Table 2**; site 2 data are not available). Site 1 had higher P inputs in the BMP blocks. In years 3 and 4, inputs were higher in the BMP than in the REF blocks. Nutrient inputs from inorganic fertilizers applied over four project years in the BMP blocks ranged from 414 to 586 kg/ha for N, 68 to 183 kg/ha for P, and from 430 to 881 kg/ha for K (**Table 2**).

Furthermore, the practice of mulching with EFB at a target rate of 40 t/ha, implemented only in the BMP blocks of sites 3, 4, 5, and 6, effectively contributed additional nutrients over and above those supplied via fertilizers. The target rate was not always achieved, and mulching was most complete at sites 5 and 6, where EFB was estimated to essentially triple the total supply of nutrients (**Table 2**). At the other sites mulching was done only in those BMP blocks that were close to palm oil mills. Hence, highest total nutrient inputs over four years from inorganic and organic sources were recorded at site 6 for N (1,268 kg/ha), P (273 kg/ha), and K (3,016 kg/ha), followed by site 5. Therefore, as discussed above, increased FFB yield in the BMP blocks in the later years of the project relative to REF blocks is attributable to yield-making, and we suggest that most of these increases are due to nutrition-related BMP.

However, the additional nutrient supply in BMP blocks did not appear to have any marked effect on the plant tissue content relative to the REF blocks. In both treatments, nutrient content in plant tissue was in the suggested optimal ranges (in our blocks, around 2.5% for N, around 0.16% P, around 1.2% K). Generally there were no significant differences in the percentage of nutrient contents between BMP and REF blocks among the sites. Only in site 1 where nutrient deficiencies were detected for K values (0.75 to 0.89% in both treatments). Furthermore, there was no clear effect on growth indicators, such as petiole cross-section area (Oberthür et al., 2012). The lack of a clear relationship between indicators such as plant tissue nutrient content and growth parameters on one hand, and the relative yields on the other, suggests that these conventional indicators may not be sufficient for nutrient management, as already discussed elsewhere (Foster, 2003). Amongst other factors, Breure (2003) linked canopy efficiency to cultural practices, particularly nutrition. While our data are not conclusive, there is an indication that there may indeed be a positive relationship between improved canopy efficiency, increased yields and yield-making nutrition-related BMPs that provide additional nutrients to the crop. This effect may not be easily uncovered in small-scale research trials and should be further evaluated at a commercial scale.

Table 2. Nutrient applications in the BMP and REF blocks from inorganic and organic fertilizer sources.

Treatment[3]	Nutrient inputs (kg/ha) over four project years[1,2] Site 1	Site 3	Site 4	Site 5	Site 6
BMP IN	463	586	558	478	414
BMP IP	183	68	84	152	136
BMP IK	721	881	884	430	600
BMP ON	-	448	150	790	877
BMP OP	-	54	18	95	137
BMP OK	-	1,348	453	2,376	2,416
BMP TN	463	1,034	708	1,268	1,291
BMP TP	183	122	102	247	273
BMP TK	721	2,229	1,337	2,806	3,016
REF IN	469	583	552	483	404
REF IP	79	68	80	153	132
REF IK	621	882	924	435	571
REF ON	-	-	32	18	382
REF OP	-	-	4	2	115
REF OK	-	-	97	55	655
REF TN	469	583	585	501	785
REF TP	79	68	84	155	246
REF TK	621	882	1,021	489	1,226

[1]Average values from 5 blocks in each treatment for the 4-year project duration.
[2]Site 2 data are not available.
[3]BMP = Best Management Practices; REF = Estate Management Practice; I = Inorganic nutrient source (i.e. various commercial fertilizers); O = Organic nutrient source (i.e. compost or empty fruit bunches).

Opportunities for Fertilization to Support Intensification

R&D in Full Commercial Blocks

Our experience with these large-scale trials clearly demonstrates that it is possible to improve management practices, even on relatively well-managed mature plantations, and increase yield. We suggest that these commercial large scale trials (i) cost no more than conventional smaller-scale plot trials, (ii) require relatively little modification of commercial operations, (iii) do not cause major disruptions in the day-to-day management, and (iv) provide information that reflects real commercial conditions rather than extrapolating from small plot data. The full commercial scale evaluation of BMPs

Dr. Oberthür inspecting harvested fresh fruit bunches.

provides excellent information from applying a set of BMPs at a particular site, but provides little information on the specific contribution of individual factors such as nutrient applications. Thus the approach is excellent for looking at combinations of management practices that managers would like to test, but proves ineffective in determining how individual factors influence productivity. However, if the approach is implemented to develop an improved overall system, operational research principles can be used to test one factor at a time, including nutrient management options. Taking these ideas into account, one can conceive a process we call *Plantation Intelligence™*. Plantation intelligence involves a series of companies, estates and growers evaluating practices at the commercial block level, followed by information sharing to compare results across whole regions, rather than using only data generated within one estate.

Nutrient Rate Management

There is anecdotal evidence that plantations that are highly productive apply more fertilizer than standard recommended rates. Yet, there is little experimental evidence to support or reject the hypothesis that significantly higher rates of fertilizers increase yields sustainably at commercial scale. This is also due to the fact that most fertilizer recommendations are made based on the results of small, carefully managed experiments. There are large variations in the yield response to fertilizers, both within plantations and within single blocks. As a result we suggest that it may be better to over-fertilize than under-fertilize due to this high variability and associated asymmetry of risk (Corley and Tinker, 2003). Assuming a block is one-third low, one-third medium and one-third high fertility, applying fertilizer at a lower rate would run the risk of reducing FFB yields. This conclusion is consistent with the observed results from the BMP project sites analyzed earlier, where in spite of a lack of evidence of nutrient deficiencies in most of the REF blocks, and essentially no significant differences in plant tissue nutrient levels between BMP and REF blocks, there was a strong yield response to yield-making BMPs. Over-fertilizing parts of the commercial blocks will raise costs, but will likely provide higher pay-offs, particularly when CPO prices are high. The concept of 4R Nutrient Stewardship as promoted by IPNI is highly relevant to ensuring that intensified oil palm nutrition is implemented in an environmentally sustainable and yet profitable way (IPNI, 2012).

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