INCREASING PALM OIL YIELDS BY MEASURING OIL RECOVERY EFFICIENCY FROM THE FIELDS TO THE MILLS

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ABSTRACT: T Oil palm has been commercially cultivated in South East Asia for more than a century to produce crude palm oil (CPO, or oil) and palm kernels (PK, or kernel). The primary products are the fresh fruit bunches (FFB) that are perishable and once harvested must be processed rapidly to extract the oil and the kernel.

In other perishable crops like cassava and sugarcane, which must be processed rapidly after harvesting, the primary products are delivered to the processing plant or mill, weighed and analyzed to determine the amount of extractable final product i.e. starch or sugar. The producers are paid according to estimated final product content of their crop and therefore have a strong incentive to improve it. Furthermore, producers receive information on the product content of individual lots arriving at the mills. Consequently they are able to equate management practices and block characteristics with quality; hence they can improve the quality of the primary product. Similarly, the efficiency of mills in terms of their ability to extract starch or sugar can be evaluated if the quality of the product entering the mills is known.

In oil palm, the FFB received at palm oil mills is graded for ripeness and other criteria that may affect the milling process and oil extraction rate (OER). However, there is no estimate of the oil content of the FFB received. The palm oil mills process FFB of unknown oil content from many sources, and then estimate the OER based on the amount of oil they produce. Thus, in the current system, while FFB yield can be attributed to specific blocks by growers, the OER is not determined for individual blocks or even estates: it is assigned indiscriminately using the average OER of the mill which receives FFB from many sources and blocks. On the basis of "what you cannot measure you cannot manage", oil palm growers can, and do, manage their plantings to maximize FFB yield, but not OER. The International Plant Nutrition Institute's Southeast Asia Program (IPNI SEAP) has shown that when best management practices (BMPs) are implemented in the field to maximize FFB yield, OER may not necessarily be maximized at the same time (Oberthür *et. al.*, 2012). Furthermore, there is no total oil balance at the mill based on total oil arriving in the FFB and oil eventually extracted from the FFB. Hence, milling efficiency is not normally evaluated on an overall balance of oil entering the mill and oil produced, but through estimates of losses in different stages of the process.

IPNI SEA recently showed that by combining bunch analysis (BA) data with harvest audit data, growers can compute their Field Oil Recovery Efficiency (FORE) and the Estimated Oil Content (EOC) of the harvested FFB delivered to the mill. The FORE is of the efficiency with which the oil produced in the field is recovered at harvest. The efficiency would be 100% if all bunches were harvested, the bunches were harvested ripe or mature and there were no losses of loose fruits (Donough *et. al.*, 2013). Thus estimates of FORE provide information on the efficiency of the harvesting operations in recovering oil. The pre-milling EOC of the FFB received for processing will allow mills to measure their Mill Oil Recovery Efficiency (MORE), which is a better indicator of mill performance than OER *per se*. Use of recovery efficiency measures in the field and at the mill will allow a more holistic and inclusive analysis of the overall oil recovery, clearly describing the efficiency of operations managed in the field and at the mill.

Knowledge of EOC will also allow mills to pay growers for the oil content of their crop, which in turn will stimulate growers to improve FORE. A virtuous cycle of estimating potential product contents of individual FFB deliveries and using the information to improve crop recovery in the plantation may thus start.

In this paper, we present the conceptual definitions and framework for assessing oil recovery efficiency (ORE) starting from the field until the mill.

Keywords: palm oil, yield maximization, recovery efficiency

1. INTRODUCTION

Oil palm has been commercially cultivated in South East Asia for more than a century to produce crude palm oil (CPO, or oil) and palm kernels (PK, or kernel). In oil palm the primary product is fresh fruit bunches (FFB) that are perishable and once harvested must be processed rapidly to extract the final products, oil and the kernel. In many perishable crop species, the harvested part of the crop (primary product) must be processed to extract the economically useful part (final product). The standard evaluation of new technology in these crops is normally based on the quantity of final product per unit land area which is the product of primary production and the proportion of final product that is extracted from the primary product (extracted product). This may be valid in terms of biological productivity, but in terms of commercial viability it is not satisfactory. Costs of harvest transport and initial processing of the primary product are normally more closely related to total primary production than to final production. Identical values for final production may be obtained through high primary production combined with low extracted product or vice versa. When primary production is less but the proportion of extracted product is higher, the costs of harvest, transport and initial processing per unit final product will be less (Hugot *et. al*., 1958; Cock *et. al*., 2000). In these types of crop, including oil palm, the industry will tend to be more profitable if the proportion of extracted product is higher with similar levels of final production per unit land area. Hence, we suggest that the industry should provide incentives to both primary produces of fresh fruit and the mills to maximize the levels of extractable product that reach the mills and are processed.

In oil palm most attention has been paid to increasing FFB yield through both breeding and management, and raising extraction from the FFB by improvements in the mills. Efforts to increase oil content of the bunches has been principally through breeding for higher oil content and harvesting protocols to manage FFB maturity. With the exception of the varieties planted, little is known about how field management practices adopted to increase bunch yield affect the oil content. Crop husbandry has concentrated on increased oil yield through FFB yield, with minimal emphasis on management practices to increase the potential OER of the bunches harvested.

In other perishable crops, like cassava for starch and sugarcane, which must be processed rapidly after harvesting, the primary products are delivered to the processing plant or mill, weighed and analyzed to determine the amount of extractable final product. Simple procedures have been developed over many years that can be used on a routine basis to determine the quality of the primary product arriving at the mills in terms of the likely yield of the final product. Thus, for example, in sugarcane and sugar beet it is common practice to determine the estimated recoverable sucrose of each wagon of cane or beet that arrives at the mill. Similarly cassava that arrives at starch mills is evaluated for its starch content. Sugarcane fields are often sampled before harvest to see if the sugar content is sufficiently high to warrant harvesting. The producers of the primary product are paid according to quality or estimated extraction rates, and consequently have strong incentives to improve them. Furthermore, individual producers, or plantations receive information on the quality of individual lots arriving at the mills, and consequently they are able to equate management practices and block characteristics with quality, whence they are able to improve the quality of the primary product. Similarly, the efficiency of mills in terms of their ability to extract sugar or starch can be evaluated if the quality of the product entering the mills is known. The producers are paid according to estimated final product content of their crop, and, therefore have a strong incentive to ensure that the crop in the field has a high final product content before harvest, and also to ensure that losses of final product are minimized when harvesting and transporting the harvested crop to the mills.

In oil palm there is no systematic evaluation of the content of final product in the bunches either in the field or when they arrive at the mill. Bunches are harvested according to series of standards that include colour of fruits and loose fruits, but there is no direct estimate of the oil and kernel content in bunches that are harvested. The FFB received at palm oil mills is graded for ripeness and other criteria that may affect the milling process and oil extraction rate (OER). However, there is no estimate of the oil or kernel

content of the FFB received nor of fiber levels or other components such as ash that may reduce the extraction rates in the mill. The palm oil mills process FFB of unknown oil content from many sources, and then estimate the extraction rate based on the amount of oil and kernel they produce. Thus, in the current system, while FFB yield can be attributed to specific blocks by growers, the OER is not determined for individual blocks or even estates: it is assigned indiscriminately using the average OER of the mill which receives FFB from many sources and blocks. Furthermore, there is no total oil balance at the mill based on total oil arriving in the FFB and oil eventually extracted from the FFB. Hence, analysis of the extraction efficiency is not normally carried out on an overall balance of oil entering the mill and oil produced, but through estimates of losses in different stages of the process (Adzmi *et. al*., 2012). Processing losses are normally reported at about 10% (Wood *et. al*., 1987, Adzmi *et. al*., 2012).

On the basis of "what you cannot measure you cannot manage", oil palm growers can, and do, manage their plantings to maximize FFB yield, but not necessarily OER. Cenipalma, the Colombian oil palm research centre, recognized this suggesting that the sector requires a simple, economic, and reliable method to estimate the potential oil in the FFBs processed in the extraction plant from specific wagons that correspond to particular suppliers, blocks, or plantations (Nieto Mogollon *et. al.* 2011). Similarly, the Universiti Malaysia Pahang has been exploring methods to assess oil content of fruits so as to rapidly resolve disputes between the oil mill owners and fruit owners in the fastest possible time (Nurul Aslah, 2010). The need is highlighted by the possibility that management to increase FFB yield may in certain cases decrease oil content. Recently the International Plant Nutrition Institute's Southeast Asia Program (IPNI SEAP) implemented best management practices (BMPs) in the field to maximize FFB yield and found that although overall CPO yield was increased, the OER was slightly reduced (Oberthür *et. al.*, 2012). However, in most cases plantations do not measure oil content and hence they are neither able to quantify the losses nor to evaluate harvesting procedures that may reduce losses or other management practices that may increase oil content.

In general, the industry has paid little attention to palm kernel, and has focused on intensification of production of palm oil. Intensified production of palm oil depends on: increasing the FFB yield; increasing the oil content of the FFB; and extracting more of the oil from the FFB.

IPNI Southeast Asia (IPNI SEA) decided to pay more attention to ensuring that: (i) the oil produced in the field is harvested and taken to the mills; (ii) the extractable oil content of the bunches arriving at the mills is high and (iii) the mills extract oil efficiently. We surmised that this could only be achieved by being able to measure or monitor the oil throughout the processes of harvesting, transporting and processing the fresh fruit bunches. In order to do this the concepts of OER, potential OER and extraction efficiency need to be carefully defined. We have used concepts widely and successfully used in the sugar industry and applied them to oil palm and discuss how they can both be improved and also deployed to improve the efficiency of the palm oil sector. The definitions of the terminology used are presented in Table 1 to facilitate understanding of the procedures.

Table 1. Definitions of terms and measurements.

Term	Definition	Comment
CPO	Crude Palm Oil	
PK	Palm Kernel	
FFB	Fresh Fruit Bunches	
FFB_{HW}	Harvested fresh fruit bunches	Weight recorded by Estate or Mill
FFB_R	Weight of FFB at the weighbridge	Taken to be equal to FFB_{HW} recorded by Mill
OER	Oil Extraction Rate	Normally expressed as a percentage
OC	Mesocarp oil content	Sometimes referred to as potential OER (%)
EFPO	Estimated Field Potential Oil	Total oil weight that would be produced in the field with solely mature, ripe, bunches and no loose fruit losses. Expressed as weight.
EFRO	Estimated Field Recovered Oil	Estimate of the weight of oil actually harvested or recovered (Estimated Field Recovered Oil, EFRO). Normally expressed as weight
FORE	Estimated field oil recovery efficiency	Percentage of oil produced in the field recovered in the harvested bunches
MORE	Mill extraction efficiency	Percentage of oil delivered to mill recovered.
LF	Loose Fruits	
MRS	Minimum ripeness standard	
EOC	Estimated Oil Content of fruit bunches	
EOC_M	Estimated Oil Content of mature fruit bunches	Percentage obtained from Bunch Analysis
$EFFB_T$	Estimated Total Weight of Mature FFB	Includes Loose Fruits (LF)
EOC_{HF}	Oil content of the harvested fruit bunches	Percentage
$ELFW_{UR}$	Unrecovered loose fruits	Weight
ELF_b	LF lost per bunch	Number recorded by Estate Audit
BNO	Number of bunches harvested	Number recorded by Estate
BNO_{NH}	The bunch number not harvested. is.	Number obtained from harvest audits
LFW_{Av}	Average weight of loose fruits	Weight from Bunch Analysis
ELO_{LF}	Oil lost in the unrecovered LF	Weight
EOC_{LF}	Estimated oil content per fruit	Percentage from Bunch Analysis
$PFFB_{IM}$	Estimated percentage of immature or unripe bunches in the harvest	Percentage from Estate or Mill audits
BWT	Average weight of bunches	Weight (estimated from FFB_R and BNO)
EOC_{IM}	Oil content of immature or unripe FFB	Percentage
EOC_{MF}	Oil content of mature fruits	Percentage from Bunch Analysis
ELO_{UH}	Estimated Loss of Oil in Unharvested bunches	
EOC_{HF}	Oil content of the harvested fruit bunches with the harvested loose fruits	Percentage.
$EOER_P$	Estimated Potential Oil Extraction Rate. Taken as equal to EOC_{HF}	Extraction obtained if the mill recovered all the oil delivered in the FFB. Percentage
TOE	Total oil delivered to the mill in FFB	

2. THE CONCEPTUAL BASE

First the absolute content of a product such as oil or kernel in the primary product is required. We will for simplicity work solely with oil, and define the absolute content of mesocarp oil as the Oil Content (OC), which is simply the percentage of oil in a FFB, on a weight basis, before any harvest (i.e. field) losses occur. In the palm oil industry, OC is sometimes referred to as potential OER (Wood *et. al*., 1987, Chew *et. al*., 1999, Corley and Tinker, 2003).

When sugarcane, sugar beet or FFB are processed, not all the sucrose or oil is extracted, as some is lost in the extraction processes. In sugarcane and sugar beet, the Estimated Recoverable Sucrose (ERS) is a standardized routine measure which is normally determined on each load arriving at the mill. The ERS takes into account factors such as fibre and reducing sugars which influence the losses in processing, however, it does not take into account the losses in the field at harvesting and the post-harvest deterioration of cane between burning or harvesting and arriving at the mill for processing.

In oil palm we develop the concept of Estimated Field Potential Oil (EFPO) and an estimate of the weight of oil actually harvested or recovered (Estimated Field Recovered Oil, EFRO).

EFPO is the total weight of oil that would be produced in the field if:

a. there were no losses of loose fruits (LF), and
b. all harvested FFB fulfilled the minimum ripeness standard (MRS) i.e. all bunches are harvested ripe or mature.
c. no bunches were left in the field unharvested.

The estimate of total oil weight that would be produced in the field with solely mature (i.e. ripe) bunches and no loose fruit losses (EFPO) is the product of:

a) the estimated oil content (EOC) of ripe or mature FFB (EOC_M), and
b) the estimated total weight of mature FFB including LF produced in the field ($EFFB_T$).

Thus: EFPO (*kg*) = $EFFB_T$ (*kg*) x EOC_M (*%*)/100

EFRO is the total oil harvested in the FFB and transported to the mill. The difference between EFPO and EFRO is the losses in oil content due to harvesting immature fruits, loose fruits that are not harvested and FFB that are simply not harvested. The ratio of EFRO/EFPO is the efficiency of recovery of the potential oil produced in the field.

The estimated oil recovered in the field EFRO is the oil harvested in the fresh fruit bunches and the loose fruits and delivered to the mill.

EFRO (*kg*) = FFB_{HW} (*kg*) x EOC_{HF} (*%*)/100

where FFB_{HW} is the weight of harvested fresh fruit bunches and EOC_{HF} is the oil content of the harvested fruit bunches.

The losses in unrecovered loose fruits ($ELFW_{UR}$) can be estimated from:

a) the estimated number of LF lost per bunch (ELF_b, obtained from harvest audit reports),
b) the actual total number of bunches harvested (BNO, as recorded by the estate), and
c) the average weight (g) per LF (LFW_{Av}, from Bunch Analysis).

Thus: $ELFW_{UR}$ (kg) = ELF_b x BNO x (LFW_{Av} (*g*))/ 1000)

The weight of oil lost in the unrecovered LF (ELO_{LF}) can then be estimated from:

1. the weight of unrecovered LF ($ELFW_{UR}$) and
2. total estimated oil content per fruit (EOC_{LF}, obtained from Bunch Analysis)

Thus the Estimated Oil Lost in loose fruits ELO_{LF} (kg) = $ELFW_{UR}$ (kg) x EOC_{LF} (%)/100

The weight of oil lost in immature or unripe FFB (ELO_{IM}) is assumed to be due to the difference between the oil content of mature and immature bunches not taking into account any difference in the bunch weights of immature and mature bunches. On this basis ELO_{IM} can be estimated from:

1. the estimated percentage of immature or unripe bunches in the harvest ($PFFB_{IM}$, obtained from estate audits in %),
2. the total number of bunches harvested (BNO, as recorded by the estate),
3. the average weight of bunches (BWT) and
4. the oil content of immature or unripe FFB EOC_{IM} and the oil content of mature fruits EOC_{MF} .

Thus $ELO_{IM}(kg) = (PFFB_{IM}(\%) \times (EOC_{MF}(\%) - EOC_{IM}(\%)) \times FFB_{HW}(kg))/10{,}000)$

As the oil content of immature bunches is not normally measured it is frequently assumed that the oil content of immature bunches is 70% of that of mature bunches.
Thus $EOC_{IM} = EOC_{MF} \times 0.7$ and hence:

$ELO_{IM} = (PFFB_{IM}(\%) \times (EOC_{MF}(\%) \times 0.3) \times FFB_{HW}(kg))/10{,}000)$

An estimate of the FFB that are not harvested is also required as considerable losses may be incurred as harvesters simply miss ripe bunches, or due to labour shortages, heavy rains and flooding the blocks are not harvested with the required frequency. The Estimated Loss of Oil in unharvested bunches (ELO_{UH}) is estimated from the audits of the number of bunches not harvested BNO_{NH}. It is assumed that the oil content, the weight and the loose fruits of the bunches not harvested is the same as mature bunches.
Thus $ELO_{UH} = ((FFB_{HF}(kg) \times EOC_{MF}(\%))/100 + ELO_{LF}(kg)) \times (((BNO + BNO_{NH})/BNO)-1))$

The total oil potentially produced in the field EFPO is given by summing the total weight of harvested fruits assuming that they are all mature and adding the losses due to lost fruits, lower oil content of unripe fruits and the fresh fruit bunches that were never harvested:
$EFPO = (FFB_{HW}(kg) \times EOC_{MF}(\%))/100 + ELO_{IM}(kg) + ELFW_{UR}(kg) + ELO_{UH}(kg)$

and the estimated field oil recovery efficiency, FORE, is:
$FORE(\%) = EFRO(kg) \times 100/EFPO(kg)$

in addition the oil content of the harvested fruit bunches plus the loose fruits (EOC_{HF}) is given by taking the total oil recovered in the field, which is the potential minus the losses divided by the total harvested weight:
$EOC_{HF}(\%) = (EFPO(kg) - ELO_{IM}(kg) - ELFW_{UR}(kg) - ELO_{UH}(kg)) \times 100/ FFB_{HW}(kg)$

The recovered FFB weight (i.e. FFB Recovered, FFB_R) is the actual weight obtained at the weighbridge of the mill receiving the harvested FFB, after field losses have occurred. Hence, assuming no loss in transport, the:
$FFB_R(kg) = FFB_{HW}(kg)$

Similarly the Estimated Oil Content of the harvested FFB (EOC_{HF}) is assumed to be the same as the oil content of the harvested fruit delivered to the mill. EOC_{HF} then becomes the Estimated Potential Oil Extraction Rate $EOER_P$, which provides an estimate of the maximum extraction that could be obtained if the mill recovered all the oil delivered in the FFB. It is of critical importance as it estimates the quality of the FFB arriving at the mill in terms of their oil content.
Thus $EOER_P(\%) = EOC_{HF}(\%)$

At the mill the oil extraction efficiency OEE then becomes the relationship between the total oil entering the mill and the total oil produced. The total oil entering (TOE) the mill is the sum of the oil in the individual batches delivered to the mill:
TOE (*kg*) = $\sum EOER_P(\%)$ x $FFB_R(kg)/100$

And if total oil output is (TOO) then the mill extraction efficiency (MORE) is given by:
MORE(*%*) = TOO(*kg*) x 100/TOE(*kg*).

From the above analysis it can be seen that the critical measures of the Field Oil Recovery Efficiency, the Mill Oil Recovery Efficiency and the Estimated Potential Oil Extraction Rate can be determined if the following parameters are evaluated: EOC_M, EOC_{LF}, EOC_{IM}, FFB_{HW}, FFB_R, $ELF_{B,}$ BNO, BNO_{NH}, LFW_{AV} , and FFB_{IM}.

3. BUNCH ANALYSIS AND HARVEST AUDITS AS MEASUREMENT METHODOLOGIES

The variables required to carry out the analysis described in the conceptual base were evaluated. We used bunch analysis as described by Oberthür *et. al.* (2012) as the basis for measurements of EOC_M, EOC_{LF}, and LFW_{AV}. Bunch analysis in simple terms consists of separating bunches into the fruits and the other parts of the harvested raceme and weighing them. Fruits are then analyzed for oil content. Bunch Analysis is carried out on individual bunches including all their LF. Mature, ripe bunches are selected for bunch analysis. Hence, if a representative sample of mature or ripe bunches are harvested bunch analysis provides an estimate of EOC_M. Harvest audits were used to record $ELF_{B,}$ BNO_{NH}, and $PFFB_{IM}$. The oil content of immature bunches was assumed to be 70% of the oil content of mature bunches. Data routinely recorded by the estates and the mills were used to determine the remaining parameters, FFB_{HW}, FFB_R, and BNO.

EOC_{MF}	Bunch Analysis determines the oil content of the mature fruits.
EOC_{LF}	The oil content of the loose fruits is estimated from the bunch analysis.
EOC_{IM}	The oil content of immature bunches is generally not measured directly. It is assumed to be 30% less than of mature bunches. Thus $EOC_{IM} = EOC_M$ x 0.7 but this can be modified if the oil content of immature bunches is measured.
FFB_{HW}	The FFB harvested weight is the weight of fruit delivered to the mill (**FFB_R**) as it is assumed that there are no losses in transport.
ELF_B	The harvest audits report the number of loose fruits per bunch.
BNO	The bunch number harvested is reported by estates.
BNO_{NH}	The bunch number not harvested is obtained from harvest audits.
LFW_{AV}	The average weight of loose fruits is determined in the bunch analysis.
FFB_{IM}	The percentage of unripe fruits is obtained from the from the harvest audits or from the evaluation on delivery at the mill.

All the other variables are derived from these variables.

4. RESULTS AND DISCUSSION

IPNI SEA and partners used a modified BA procedure (Oberthür *et. al.*, 2012) to evaluate the effects of best management practices (BMPs) on EOC_M of ripe bunches from mature oil palms in individual commercial blocks. In order to better monitor the blocks and minimize sampling errors in IPNI SEA projects, the number of bunches analyzed per block was increased several fold compared to the 23 to 65 bunches per block of Wood *et. al*. (1987). Between Dec-2009 and Jun-2011, over 13,750 ripe bunches were sampled from 50 commercial blocks (average 275 bunches per block) at 5 sites in Indonesia (2 sites in Sumatra, 3 sites in Kalimantan) and analyzed according to the procedure described by Oberthür *et. al*. (2012).

BA was chosen rather than batch milling for two reasons. First and foremost, batch milling of individual blocks is extremely difficult to organize. The total production of a block for two or three days is normally not sufficient to keep a mill working for sufficient time to obtain a reasonable estimate of OER and KER. Moreover, it is extremely difficult to coordinate activities at the block level with mills. Secondly, batch milling will include variations introduced by the management of the mill, whereas BA evaluates the EOC_M of the mature bunches with no distortions caused by variation in mill performance, or harvest losses in the field.

The BA procedure adopted by IPNI SEA can be used by any estate using very basic facilities. Only one of the five IPNI SEA project sites had an existing Research Unit with facilities and staff with experience in BA. At the other four sites, BA teams were formed and trained in the IPNI SEA BA procedure, and facilities for BA were established by modifying existing buildings (such as a vacant staff house). However, BA is labour intensive and the Soxhlet extraction processes are time consuming.

BMP blocks were harvested with a short (7-days) harvesting interval (HI) coupled with a low minimum ripeness standard (MRS) of usually 1, and a maximum 5 LF before harvest. The reference (REF blocks) used current estate standard harvesting protocols with 10 day harvesting intervals and the same MRS as the BMP blocks. BMP blocks invariably produced higher yields of FFB than the REF blocks. EOC_M tended to be lower with BMP harvesting protocols. As the harvesting procedures were considered to be better in the BMP plots, the lower EOC_M may reflect a direct affect of the management practices on the oil content with a trade-off between FFB yield and oil content. It was only through BA that we were able to detect the effects of management on EOC_M.

Harvest audits were carried out to estimate the number of LF uncollected per bunch, and the number of unripe bunches in the harvested crop. FFB harvested from BMP blocks had fewer LFs per bunch, but as the total number of bunches recovered per hectare was higher with the BMP package, the total quantity of LFs was sometimes greater in the BMP blocks. Nonetheless, overall the absolute LF loss was less in BMP blocks compared to the REF blocks. There was no difference in the percentage of unripe bunches between the BMP and REF blocks. The lower losses in loose fruits increased the FORE with BMP harvesting procedures.

The BA data generated from the IPNI SEA projects provides insights into the variation in EOC_M in FFB from and within individual blocks. Our observations on commercial blocks showed a weak positive correlation between the number of LFs per bunch and the EOC of individual bunches (Figure 1). The variation in EOC of individual bunches was so large that the notion of a higher LF number as a reliable indicator of higher EOC is questioned. In fact, an excessive focus on increasing actual OER by increasing the MRS, as indicated by more LFs in the field, may be counter-productive, leading to lower FFB yields as a result of increased crop losses as loose fruits with little or no compensation in higher oil content.

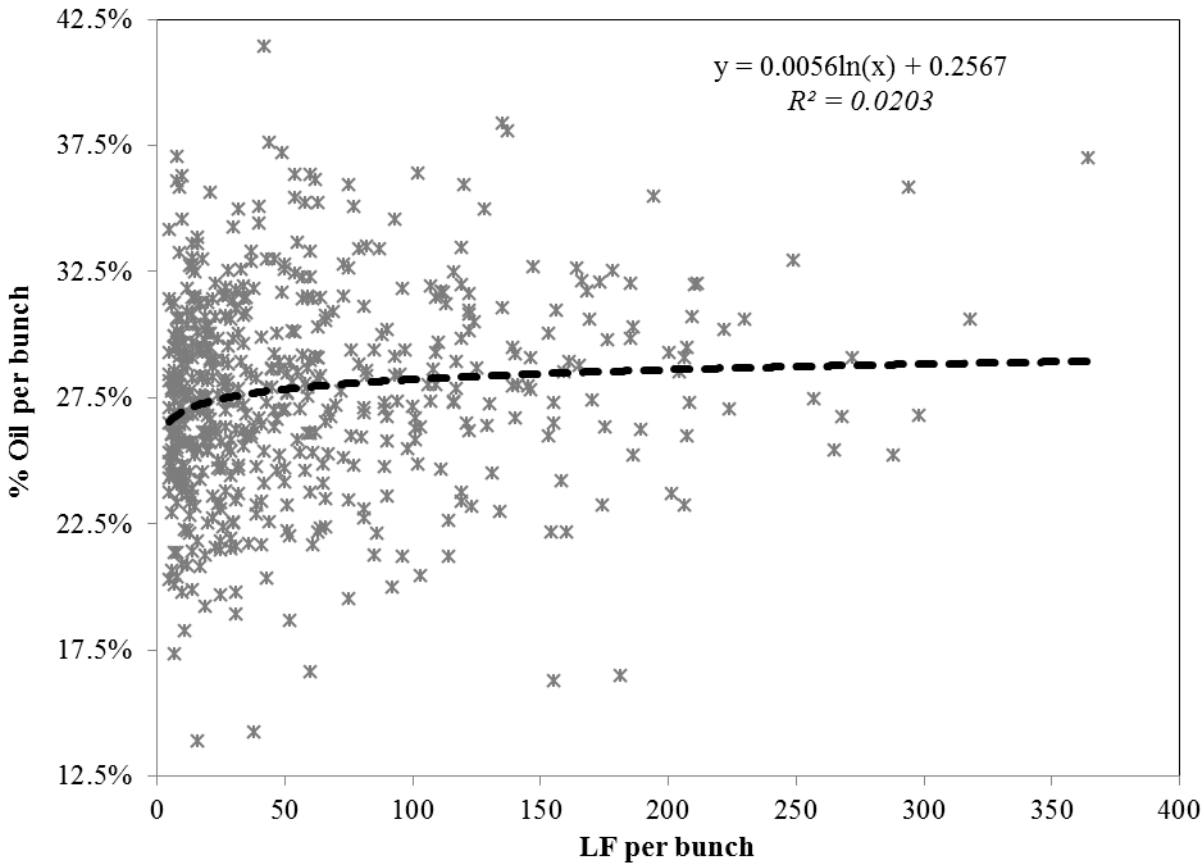

Figure 1. The relationship between oil per bunch and the number of loose fruits per bunch (from Oberthür *et. al*. (2012). *Note*: *Total number of samples: 557 (BMP & REF combined)*.

These findings have important implications for the industry. Firstly the use of standard procedures which are not routinely checked for accuracy may lead to poor decisions. Secondly, in an industry facing severe labour shortages, the possibility of easing restrictions on MRS which may facilitate harvest operations, and increase the FORE with negligible effects on MORE is an attractive option. Thus, the industry may need to revise FFB ripeness or maturity grading definitions based on rigorous quantitative field observations and measurements of the $EORE_P$, rather than continuing unproductive arguments between mills and plantations based on opinions. However, in order to adopt such practices it would be wise to have a means of constantly monitoring $EORE_P$, MORE and FORE.

In the BMP trials the number of bunches simply missed was not recorded in either the BMP or the REF blocks. However, data collected on commercial blocks in the Plantation Intelligence project (Cook *et. al.*, this conference) indicate an association between the FFB harvested and the harvest labour intensity. This data suggests that, particularly at peak production times, mature FFB may be missed and not harvested. Consequently, we have introduced into the conceptual base the bunch number not harvested (BNO_{NH}). In Colombia, Mosquera *et. al.* (1997) developed system with skilled workers who identified ripe bunches and marked the palms for harvest. They do not mention any effect on the number of bunches harvested per unit area; however, they do incorporate the idea of removing the coloured markers each time a bunch is harvested, thus offering the possibility to audit un-harvested bunches by observing the number of coloured markers that remain in the field. We suggest that routine audits of the number of bunches not harvested should be made so as to assess the real losses due to simply missing bunches in the harvesting process, or due to lack of access to fields as a result of flooding, labour or other problems. The Colombian method of

flagging bunches that are ready for harvest described by Mosquera *et. al.* (1997) could form the basis for such a system.

Combining BA and harvest audit data allows plantations to estimate the FORE as a measure of the efficiency of their crop recovery process (Donough *et. al.*, 2013). The recovery efficiency of oil in the field (FORE) represents losses in the field caused by both loss of LF, loss of quality (i.e. maturity or ripeness) of the bunches harvested and losses due to simply not harvesting bunches. Furthermore, the estimate of the oil content of the harvested fruit, EOC_{HF}, which is assumed to be same as the Estimated Potential Oil Extraction Rate ($EORE_P$) of the FFB arriving at the mill, provides the basis for the mills to determine their real extraction efficiency based on the total oil in the fruits delivered to the mill as compared to the oil output from the mill, that is to say MORE.

In their early work Wood *et. al*. (1987), used batch milling of FFB to determine the OER, which is similar but not the same as the $EOER_P$ as OER includes losses in the industrial process. They used BA to estimate the total amount of oil in the FFB, that is to say EOC_M (or what is occasionally referred to as the potential OER). This estimate is based on ripe bunches and does not include immature bunches. Wood *et. al*. (1987) showed a close relationship between the potential OER as determined by BA and the OER estimated from processing batches. This is not surprising as the batches were done in the same mill and one would not expect great differences between the mill extraction efficiency with different batches. At the same time, although there is a close relationship between potential OER and the OER obtained by the mill, this relationship does not provide an accurate estimate of the true extraction efficiency of the particular mill.

On the other hand the $EOER_P$ is an estimate of the oil content of the bunches arriving at the mill. The $EOER_P$ is a characteristic of the FFB and is not affected by the mill processing. Comparing the total oil output produced by the mill TOO with oil delivered to the mill in the fruits $\sum EOER_P \times FFB_R)/100)$ or TOE gives the MORE, which provides a true estimate of the efficiency of the mill in terms of extraction of oil from the specific material which it receives. These estimates of MORE provide information to the mill on how it compares with other mills, and it also allows it to evaluate how its efficiency varies with varying quality of the deliveries of FFB from various sources. *A priori* one would expect mill efficiency to be greater with higher oil contents in the incoming material.

Currently the small size of individual batches of bunches and current methods of evaluating mill performance make it difficult to associate milling efficiency with individual batches of fruits from particular blocks. CENIPALMA has developed an interesting approach to this problem (Nieto Mogollon *et. al.* 2011; Yanez & Garcia, 2009). A time and motion study determines how long it takes from the moment of discharging a wagon to when the press liquor comes out of the press for a particular mill. The press liquor flow is measured using a rectangular notch weir. Samples of the press liquor are taken periodically and the oil content is estimated by separation. From the measurement of the volume of press liquor and its oil content they estimate the oil content in the original bunches assuming the following: bunches enter the plant at the factory capacity; standard loss factors which include the losses in the empty fruit bunches including fruits attached to them, losses in condensates, and losses in the "mud" that comes out of the clarification process. Although the method probably requires further refinement, particularly in the estimates of losses and flow rate that may vary according to the composition of batches, the overall approach of monitoring milling performance and relating it to particular batches or wagons of incoming bunches is interesting. However, on its own it does not resolve the problem of evaluating MORE unless there is an evaluation of $EOER_P$.

Wood *et. al.* (1987) comment on the surprisingly large differences in potential OER and our data supports this observation. This suggests that routine measurement of potential OER or $EOER_P$ could guide the industry to improved performance. BA is probably the only reliable method currently available for estimating $EOER_P$, but it is labour intensive and has not been adopted as a routine procedure. We suggest that it should be possible to develop a simple but effective sampling procedure to determine $EOER_P$ of

FFB arriving at the mill. The sugar industry has developed various means of estimating the recoverable sugar in the incoming cane. Methods take into account the large variation that exists within cane batches coming into the mills: this variation is also a major concern with oil palm. One of the most effective methods in the sugar industry is the core sampler coupled with Near Infra Red Spectroscopy (NIR). This consists basically of a cylinder with a cutting edge which is driven into the individual wagons at a predetermined angle to take a sample. The sample can be analyzed by several means. Currently, many in the sugar industry simply grind up a sample and then directly analyze the sample using NIR (see for example Edye and Clarke, 1996). There are many reports of the effectiveness of NIR to determine the oil content and quality of oil palm samples (Kasemsumran *et. al*., 2012; Nurul Aslah, 2010; Panford and deMan, 1990). We suggest that a system similar to the core sampler coupled to NIR analysis could rapidly be developed by the palm oil industry: we note that Nurul Aslah (2010) indicated that she had developed a NIR based system to analyze fruit bunches but have not been able to access her work.

Once calibrated a NIR system should be able to determine the content mesocarp oil content, kernel oil content, fibre, moisture, as well as stearic acid and oleic acid content of ground samples of fresh fruit bunches or loose fruits. We suggest that this information could then be used to determine the all important levels of EOC in the FFB delivered to the mill, EOC_{HF}, from core samples taken from wagons arriving at the mill. This would allow both mills and growers to know exactly what they are receiving and delivering in terms of quality. Similarly, growers and millers could grind up immature bunches and determine their oil content: this information could then be used to revise the ripeness standards based on a quantitative assessment of the association of ripeness standards with oil content.

A further possibility with this type of analysis would be to determine the kernel content of the fruit. At a minimum it should be possible to distinguish between kernel oil and CPO and hence the content of both in the bunches.

If a core sampler system were not implemented, both the current Bunch Analysis and the CENIPALMA system could be facilitated by using direct NIR analysis on the fruits and the press liquor. In the CENIPALMA system one could even have continuous reading of the press liquor with NIR. Currently in other industries such as brewing beer and making paper continuous monitoring of process is facilitated by NIR systems.

Even if both NIR techniques and something similar to the core sampler were to be used on a routine basis, harvest auditing would still be necessary in order to determine the number of unharvested bunches and the loose fruits that are not recovered. This information is essential to determine the FORE.

5. CONCLUSIONS

There is much variation in the percentage oil in the bunches ($EOER_P$) leaving the plantations and arriving at the mills. The variation is related to differences between blocks and harvesting procedures. The mills have little idea of the quality of the material they receive and the growers little knowledge of the intrinsic quality of the bunches they deliver. With little knowledge on the variation in quality there are few incentives to increase quality. The mills are not able to measure their efficiency if they do not know the quality of the bunches arriving at the processing plant. Growers are not rewarded for improved quality, but they may have their deliveries downgraded according to highly subjective quality assessment such as those based on the Maturity Ripeness Standards. According to our data, the MRS are poorly correlated with $EOER_P$. This obviously leads to discord and poor relations between growers and mills. Similarly, mills may receive bunches that have low oil content from certain grower or blocks, however they are not currently able to identify those blocks or growers that provide them with higher quality bunches.

Currently in the industry the only viable means of determining the $EOER_P$, the single the most important quality trait of the FFB, is through bunch analysis (BA). However, BA is not used as a routine practice.

BA could be facilitated by replacing the Soxhlet process with NIR technology. We suggest that NIR technology coupled with sampling systems similar to those used in the sugarcane industry could be developed and used to determine $EOER_P$ on a routine basis.

Furthermore, harvest audits in the estates, coupled with analysis of mature and immature bunches and loose fruits with NIR technology would provide the industry with a means of evaluating the efficiency with which the sector recovers the oil produced in the field, the FORE. The routine determination of $EOER_P$ would provide growers with information on the quality of the product they deliver to the mills, and would open up the possibility of payment for quality. The information on the both the $EOER_P$ and the weight of FFB of each delivery would provide the mills with a sound basis for determining how efficient they are at extracting oil from bunches.

A more focused monitoring of the two components, plantation and mill, of the overall oil recovery process based on measurements rather than dubious standards will reduce friction between the two and foster better overall achievement.

Clear estimates of the $EOER_P$ of incoming FFB will permit valuations and payments based on product contents to growers, thereby encouraging them to further improve both FORE and $EOER_P$. A virtuous cycle of estimating potential product contents of individual FFB deliveries and using the information to improve crop recovery in the plantation may thus start.

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