Technological factors associated with oil palm yield gaps in the Central Region in Colombia

Factores tecnológicos asociados a las brechas en el rendimiento en cultivos de palma de aceite de la Zona Central en Colombia

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ABSTRACT

This study builds on the results from a previous study (Ruiz, 2017), aimed to identify and quantify yield gaps in a sample of lots from small and medium scale producers, all suppliers of the same mill. The technical staff from the mill provides technical assistance to the aforementioned growers. This study was aimed at identifying what technological factors are associated with such gaps. Regarding the methodological approach, first, it was used the technology balance index (TBI) in order to quantify technology adoption. The TBI allows for rating technology adoption at oil palm crops by considering five processes (which comprehend 25 cropping practices). The processes evaluated are establishment, weeding and pruning, fertilizing, pests control and harvesting. The TBI assigns a category for each practice: high if it is fully adopted, intermediate if it is partially adopted and low if it is not adopted at all. Secondly, in order to determine those practices affecting yield gaps; we used a multiple correspondence analysis (MCA). MCA allowed to synthesize data into two dimensions with 51% of the variability given by the data gathered (qualification of the adoption of 25 crop management practices). Thirdly, we used cluster analysis in order to group lots according to adoption of technology. Then we related the obtained groups with the yield records. MCA results indicated that proper establishment, harvest and nutrition practices are the ones causing most of the variability in terms of technology adoption. The groups resulting from CA, provided evidence that a greater adoption of technology, leads greater yields (i.e. smaller yield gaps).

Key words: technology balance index, multiple correspondence analysis, cluster analysis, fertilising, palm plantation establishment, harvest cycle.

RESUMEN

Este estudio se basa en los resultados de un estudio previo (Ruiz, 2017), dirigido a identificar y cuantificar las brechas de rendimiento en una muestra de lotes de productores de palma de aceite de pequeña y mediana escala que son proveedores de la misma planta extractora El personal técnico de la planta proporciona asistencia técnica a los productores antes mencionados. Este estudio tuvo por objetivo identificar cuáles son los factores tecnológicos que están asociados a las brechas en el rendimiento. Con respecto a la metodología, en primer lugar, se utilizó el Índice de Balance Tecnológico (IBT) para cuantificar la adopción de tecnología. El IBT permite valorar la adopción de tecnología en cultivos de palma de aceite considerando cinco procesos (que comprenden 25 prácticas de manejo del cultivo). Los procesos evaluados fueron el establecimiento, desmalezado y poda, fertilización, control de plagas y cosecha. El IBT asigna una categoría para cada práctica: alta si es plenamente adoptada, intermedio si se adopta parcialmente y baja si no se adopta. En segundo lugar, con el fin de determinar las prácticas que se asocian a las brechas de rendimiento, se utilizó un análisis de correspondencias múltiples (ACM). Este análisis permite sintetizar en dos dimensiones el 51% de la variabilidad de los datos recogidos (calificación de la adopción de 25 prácticas de manejo del cultivo). En tercer lugar, se utilizó el análisis de conglomerados (AC) para conformar grupos de lotes, según la adopción de la tecnología. Posteriormente, identificamos los rendimientos de cada uno de los grupos conformados. Los resultados del ACM indicaron que las prácticas de establecimiento, cosecha y nutrición adecuadas, son las que causan la mayor parte de la variabilidad en términos de adopción de tecnología. Los grupos resultantes de AC, proporcionaron evidencia en el sentido de que a mayor adopción de tecnología, se encuentran mayores rendimientos (es decir, menores brechas en el rendimiento).

Palabras clave: Índice de balance tecnológico, análisis de correspondencias múltiples, análisis de conglomerados, fertilización, establecimiento de la palma, ciclo de cosecha.

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Introduction

A gap in crop yield is defined as the difference between yields obtained by producers in their own particular conditions and the potential yield. In essence what could be achieved if there were no limiting factors regarding crop management (Fischer, 2015). The importance of studying yield gaps lies in how such studies provide information leading to the identification of factors limiting yield, enabling prioritising aspects which must be improved to close gaps. The forgoing, contributes towards increase efficiency regarding the use of production factors (land, capital and work) and natural resources, thereby, contributing increasing producers net income.

Different factors originates gaps regarding agricultural crop yields, among them the climatic and soil conditions where the crops are established, planting materials sown and their characteristics, and the adoption of technology by producers. Technology adoption is related to the producers' socioeconomic characteristics, such as their educational level, age, land tenure, access to credit, business organization, technical assistance/advice services, regional infrastructure and prevailing agricultural policies (Ruiz *et al*., 2015).

An example of this can be seen in a study carried out in Indonesia which identified oil palm crop gaps reaching 50% of material´s yield potential; such gaps were related to technology adoption as well as technical assistance/advice and training services received (Euler *et al*., 2016).

Yield gaps in oil palm crops in Colombia have been mainly related to aspects regarding the technological management of crops, especially regarding irrigation, nutrient balance and the sanitary management (Sanz *et al*., 2017). This study was aimed to determining the crop management practices that impact the most on yield gaps. We built on results from a previous work that took place at the Central Region of Colombia. As starting point, the sample of oil palm producers and the yield gaps quantified were used (Ruiz, 2017).

The main goal of this study was aimed at identifying what are the technological factors are associated with yield gaps. In order to do undertake this task we developed a three stages study. In the first stage, we used the technology balance index (TBI) in order to quantify technology adoption. In the second stage we determine those practices affecting yield gaps by using the multiple correspondence analysis (MCA). Finally, we used cluster analysis in order to group the studied lots, according to adoption of technology. Then, we related the groups obtained by CA with yield records.

This paper is organized as follows. After these introductory paragraphs we describe the methodological approach that we used in order to carry out this study. In the second section, we present the results obtained and, they are discussed. In the final section, we provide our concluding remarks.

Materials and Methods

The study region

The field work for this research was carried out in the Central Region of Colombia, at a place known as nucleus[1] which, was interested in closing their fruit supplier´s yield gaps. Specifically, these oil palm growers were located in the municipalities of Sabana de Torres, Rionegro, Tamalameque and Rio de Oro (7°58'54" N and 73°30'46"W). We gathered information in plantations of fruit suppliers (at a lot level), according to the stratified sampling method described below.

Study population – sampling

The nucleus covers 81 farms, with 494 lots, owned by small and medium sized producers (20 to 500 ha). Given the large amount of lots, a stratified design was used, in order to obtain a representative sample of the population involved. The stratification criterion was the oil palm age, since oil palm fruit yield depends upon age (Ruiz *et al*., 2017).

At preliminary stages of this study it was not possible to obtain yield records per lot, so it was necessary to use a variable closely related to yield. One accounted with records of this variable to the desired level (i.e. at lot level) was included. We decided to use bud rot (BR) incidence, because is highly suggested that, in order to avoid BR spread, it is necessary to implement best management practices in oil palm crops (such as, good drainage and balanced nutrition) (Martínez, 2009). Note, these practices are quite related to obtaining high yields (Beltrán *et al*., 2015).

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1 Oil palm grower`s nucleus being understood as an oil palm company usually having a palm oil extraction plant, buying fruit from a cluster of growers located near to the plant and, in some cases, providing facilities for the establishment and maintenance of the suppliers' crops by supporting credit applications, providing technical assistance and input for the crops.

Sample size was estimated with 25% precision and 80% reliability; 33 lots were selected from the 288 aged six years-old and older. Regarding oil palm age stratification, 16 lots were aged 6 to 10 years-old (stratum 1), 10 lots aged 11 to 15 years-old (stratum 2) and 7 lots aged over 16 years-old (stratum 3). The area covered by the whole sample represented 403.4 ha sown with oil palm (Ruiz, 2017).

Yield gaps

Yield potential was taken from Franco *et al*. (2014) (Tab. 1). Once the sample was obtained, it was necessary to gather yield information for each lot. The real yields (obtained) were provided by the administrators of each farm where the lots were located.

TABLE 1. Rating oil palm yields in the Colombian (mature oil palms) in central region.

Rating	Evidence
Maximum	Productivity greater than 33 t ha^{-1} per year
Intermediate	Productivity 21-33 t ha^{-1}
Minimum	Productivity lower than 21 t ha^{-1}

Source: Franco *et al*. (2014)

Yield gaps were quantified as the ratio from real yield with respect to potential yield, both expressed in terms of tonnes of fresh fruit bunches (FFB) per hectare; and taken as a percentage, as observed in equation 1 (Eq. 1):

$$Gap\ (\%) = \frac{t\ of\ FFB*ha^{-1}\ (obtained)}{t\ of\ FFB*ha^{-1}\ (potential)} * 100 \qquad (1)$$

Technology balance index (TBI)

The TBI (%) index reported by Franco *et al*. (2014) was used for rating the lots' levels of technology; this indicator rates technology adoption, considering five crop management processes (Tab. 2), evaluated according to compliance with practices for each process. Each practice[2] could be rated maximum, intermediate or minimum (see table 5), according to the compliance of criteria reached by experts for each practice (for more information see Franco *et al*., 2014).

Information regarding practices adopted at each lot from the sample was provided by technical assistants from the nucleus and from personal interviews with growers. Once each process had been rated, the TBI (%) was calculated as shown in equation 2 (Eq. 2):

TABLE 2. Processes evaluated and maximum possible rating.

Crop process evaluated	Maximum possible rating
Establishing	20
Crop tasks (managing weeds and pruning)	10
Nutritional management	30
Sanitary management	25
Harvesting	15

Source: Franco *et al*. (2014)

$$\begin{array}{c}Technology\ balance\\ index\ (TBI)\end{array} = \frac{Actual\ rating}{Desirable\ rating} * 100 \qquad (2)$$

Association between yield gaps and TBI – multiple correspondence analysis

SAS statistical software (version 9.4) was used for multivariate analysis for identifying associations between the practices evaluated and yield. Multiple correspondence analysis (MCA) is an exploratory technique which enables a large amount of data to be summarised in a reduced number of dimensions, involving the least loss of information possible. MCA is orientated towards studies in which one accounts with qualitative variables and its goal is to find associations among the variables entering the study (Greenacre, 2008). MCA was thus used for identifying whether there were associations between the categories of the different practices evaluated regarding TBI Pearson's chi-squared test ($P\leq0.05$) was used for evaluating the independence of the categories analysed here. This was followed by conglomerate analysis from the coordinates produced in correspondence analysis to form groups of lots having similar characteristics regarding yield within them; Ward's method was used in the analysis and Euclidean distance was used.

Results and discussion

Rating yield and gaps

As it was mentioned above, the sample was stratified into three groups regarding the age of the lots (i.e. the age of the oil palm trees in each lot). It was found that 50% of the lots in strata 1 and 3 and 20% of stratum 2 lots, were rated as lots with high yields, totalling 136.8 ha. A high percentage of lots, especially in stratum 2, were rated as having intermediate yields (235 ha). A low percentage of lots was rated as having minimum yields (31.7 ha) (Tab. 3).

[2] Practices refers to aspects which must be considered regarding each crop process; for example, practices for assessing nutritional management considered soil analysis, foliar analysis, production surveys, fertilizer subdivision/fractionating, fertilizer application time, measuring fertilisation effectiveness and measuring vegetative growth. Each was rated according to how such process was carried out on a specific plantation.

TABLE 3. Percentage of lots having high, intermediate or low yields.

Stratum	Description	n	High	Intermediate	Minimum
1	Age (≥6-≤10)	16	50%	43%	7%
2	Age (≥11- ≤15)	10	20%	50%	30%
3	Age (≥16)	7	58%	42%	

Source: Ruiz (2017)

Figure 1 gives the gaps found, showing that lots in strata 1 and 3 had lower yield gaps, having zero minimum limit (i.e. no gap) and 10 t ha^{-1} maximum limit. It was also found that the gap was negative regarding lots rated as having high yields (33 t ha^{-1} yield was exceeded) (Ruiz, 2017).

Regarding stratum 2, it was found that lots having a greater yield gap had an average 10t ha^{-1} and maximum 17 t ha^{-1}.

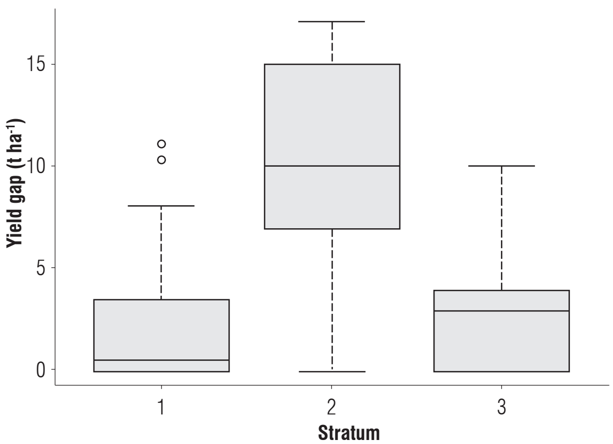

FIGURE 1. Yield gaps for lots (t ha^{-1} in 2014).

Technology balance index (TBI)

Table 4 shows the percentages for the 33 selected lots having a determined rating. It was observed crop establishment was one of the phases during which technology was least adopted (76% of the 33 lots were rated deficient); the pertinent literature refers to gaps caused by failures regarding establishing crops and how it can hardly be closed due to the presence of oil palms on the lots (Fairhurst, 2015).

Equally important was low technology adoption concerning nutritional management; all lots had lower than acceptable ratings (less than 70%). This phase is one of the most critical regarding productivity and one of those which could be intervened, effects on yield being observed three or four years after implementing practices for improving them (Fairhurst, 2015).

Regarding crop tasks, the TBI for the suppliers' lots in this nucleus was rated 45 to 100% and concerning sanitary management, lots had 60-95% TBI (i.e. a high percentage of healthy lots had a good rating); the sanitary aspect of suppliers from the nucleus was rated highly for criteria regarding quality concerning aspects such as surveys for detecting diseases and establishing criteria for them to be handled promptly. However, it was suggested that the initiative for establishing industrial surveys for pests/plagues should be transferred to the suppliers, since these are important for adopt assertive control measures.

Regarding harvesting, it was found that this practice could be improved in all lots, as none of them received an excellent rating; this is an aspect where immediate measurements can be performed with the benefit that yields improvement can be observed in the short-term.

Associations among crop management practices

In order to carry out the MCA, we considered the scores that were obtained for each evaluated practice (Tab. 5). The scores were given according to the TBI methodology for each crop management practice. With the aim of running the MCA, we considered crop management practices related to crop establishment, crop nutrition and harvest.

TABLE 4. Rating lots regarding different processes (percentage lots per rating).

Process	Deficient <50%	Regular 50–60%	Acceptable 60-70%	Good 70-90%	Excellent >90%
Establishing	76%	3%	6%	9%	6%
Crop tasks	9%	12%	27%	39%	12%
Nutritional management	27%	52%	21%	0%	0%
Sanitary management			27%	61%	12%
Harvesting	27%	33%	12%	21%	6%
Overall TBI (%)	27%	21%	36%	15%	0%

TABLE 5. Components evaluated for scoring/rating technology level on oil palm plantations (after Franco *et al*., 2014).

Crop phase evaluated	Desirable rating	Practice evaluated during each phase	Score			
			Abv.	High	Intermediate	Low
Establishing the crop	20	Soil and climatological characterisation studies	SCC	2	-	0
		Topographic studies	TS	2	1	0
		Design of irrigation and/or drainage systems	DID	6	3	0
		Design of agronomic management units	AMU	3	1.5	0
		Soil preparation	SP	4	2	0
		Establishing leguminous cover crops	LCC	3	1.5	0
Crop maintenance tasks	10	Cleaning plots	CP	3	1.5	0
		Cleaning between plots	CBP	1	0.5	0
		Pruning	P	2	1	0
		How leaves from pruning are used	LU	2	1	0
		Infrastructure maintenance	IM	2	1	0
Nutritional management	30	Taking foliar samples	FS	4	2	0
		Taking soil samples	SS	5	2.5	0
		Production survey	PS	5	2.5	0
		Fertilisation effectiveness	FE	6		0
		Fractionation of fertilisation	F	4	2	0
		Fertilisation time	FT	4	--	0
		Measuring vegetative growth	VG	2	--	0
Vegetal health management	25	Surveys and follow-up of diseases and plagues	SDP	10	5	0
		Opportunity regarding disease and plague control	ODPC	10	5	0
		Foliage quality	FQ	2.5	1.24	0
		Foliar area	FA	2.5	--	0
Harvesting and production	15	Harvesting criteria and cycle	HCC	3	1.5	0
		Fruit collecting	CF	3	1.5	0
		Harvested fruit quality	HFQ	3	1.5	0
Total score	100			100		

Specifically we considered 15 crop management practices (i.e. 15 variables). Otherwise, variables related to practices such as pruning, weed control, pests control, roads maintenance and canal maintenance were not included in the MCA because they did not contribute to the variability (they do not exhibit any differences among lots, with respect to crop management)

The analysis allowed collect in two dimensions 51% of the variability given by categories analysed (Fig. 2). The first dimension explains the 36.6% of the variability, and this show a separation of the categories from strong range of weak ones (high marks of casualties) in establishment and harvest practices. A high score means practices are being adopted with adequate quality standards, while a low grade leads into a non-adoption of the practice or an adoption with inadequate criteria.

When considering dimension 2 (Fig. 2), is evident that there is a difference respect to the adoption of practices related to the nutrition of oil palm crops. Specifically, at the top of the map where some categories are associated to low adoption of technologies, such as: performing various applications of fertilizers along the year (Fint), determination of the soil moisture condition before applying fertilizers (FTLow) and, the estimation of the efficiency of the applications of fertilizers (FELow).

At the bottom of the map (Fig. 2), there is a practice that sticks out from the rest. It is the performance of analyses to determine physical properties of the soil and its chemical contents (SSint). These practices are highly required in order to prescribe fertilizers and, to determine the number of times, in which the prescribed doses of nutrients should be applied (during a year).

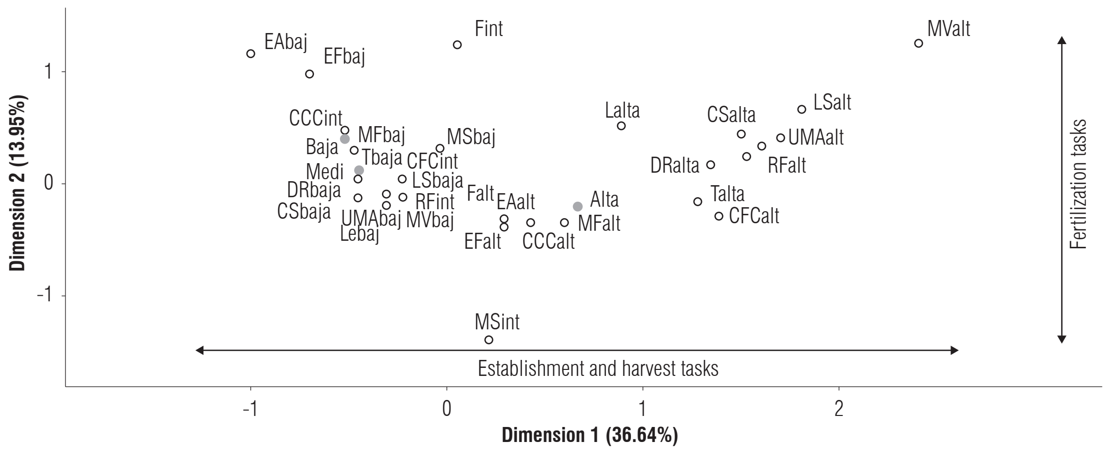

FIGURE 2. Graphical representation of MCA performing the association between the categories analysed here (for abbreviations see table 5).

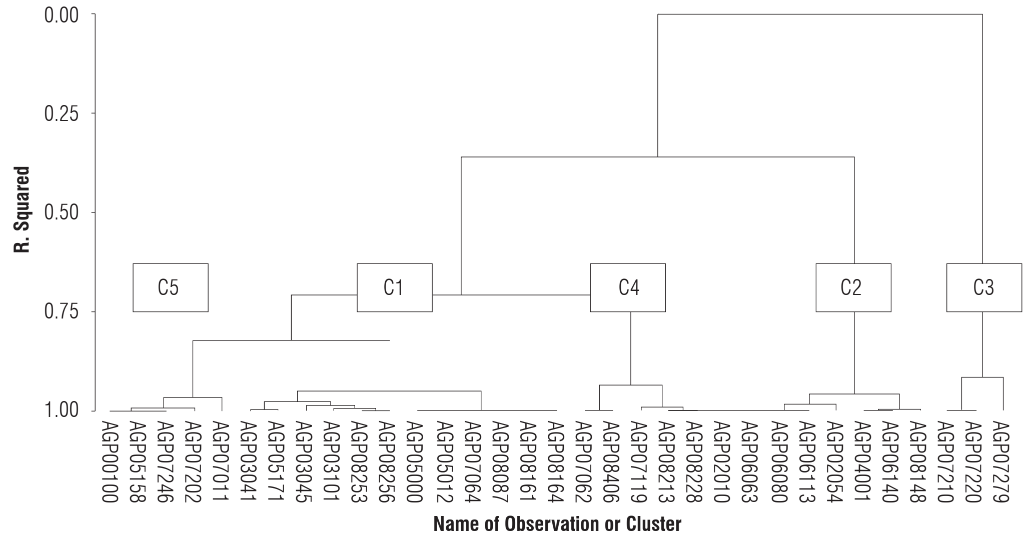

FIGURE 3. Cluster analysis on the sampled lots, according to adoption of oil palm cropping practices.

Technological practices that explain the yield differences among lots – cluster analysis

The first two MCA dimensions were used for conglomerate analysis, explaining around 51% of inertia (Fig. 3). Five conglomerates were selected, explaining 84% of total variability ($R^2 = 0.84$) (represented in the dendrogram in Fig. 3). The groups were described according to the variable´s descriptive statistics (Tab. 6-9).

Table 6 shows the conglomerate´s characteristics. Lots having yields greater than 30 t ha^{-1} on average were grouped in conglomerates 3, 4 and 5, the highest yields occurring in conglomerate 3 having 34.2 t ha^{-1} average yield; regarding reference gaps, it was found that lots in these groups had no gaps or, if they did, they were 2 t ha^{-1} on average. Lots having 25 t ha^{-1} average yields and 6.8 t ha^{-1} gaps were grouped in cluster 1 whilst lots having lower yields (21.5 t ha^{-1} on average) and 8.12 t ha^{-1} gaps were placed in group 2. It should be noted that the TBI for some conglomerates having higher yields were above 64% on average while those having lower yields were 40% on average (deficient).

Table 7 shows how rating was low regarding aspects related to establishing crops in conglomerates 1 and 2, whilst rating was high for all practices in conglomerate 3. The criteria to be considered when establishing crops should be the study of the land in which oil palms are going to be establish (topographic, altimetry, hydraulic, soil characterisation), thereby, identifying suitable practice such as soil preparation and designing the necessary irrigation and drainage work according to conditions in the farms. Lots with high yields also had a high rating regarding aspects related to irrigation design and drainage work, these being very necessary regarding the study region's conditions, where the main limitations concerning soil are associated with moderate capacity for water storage and moderate oxygen availability.

It was found that suitable soil preparation is relateds with the characteristics of lots having high yields. Dredging, hoeing and preparing the subsoil were necessary steps allowing suitable conditions in soil to support the crop throughout its productive cicle. It should be pointed out that legume coverage was established in conglomerate 3 leading high yields, this being a little used practice in the rest of the groups. This is an important aspect considering nutritional return and this species contribution towards biological equilibrium (Ruiz and Molina, 2014).

All of the necessary corrections could not be made regarding all aspects related to establishment (conglomerates 1 and 2) on lots having a low rating. In fact, the presence of oil palms on the lots must be considered as improving drainage and irrigation canals, establishing leguminous cover and fixing roads becomes a more expensive investment than if there had been suitable initial planning. Other practices such as soil characterisation and the design of Agronomic Management Units (AMU) could be carried out and contribute towards site specific crop management.

Yield gaps were also associated with the adoption of the practices evaluated here, regarding nutritional management. Table 8 shows that the lots having high yields had high ratings regarding practices related to the diagnosis of the amount of fertilizers to be applied (foliar and soil sampling, measuring vegetative growth), application criteria (application and fractioning times), as well as the evaluation of fertilisation efficiency. Conversely, rating was low regarding these practices on conglomerates having low yields.

TABLE 6. Overall characteristics regarding the conglomerates. Percentage of lots for each conglomerate in a determined municipality.

Category		Cluster				
		C1	C2	C3	C4	C5
Yield ($t\ ha^{-1}\ yr^{-1}$)	average	25.1	21.5	34.2	31.6	30.9
	range	(18 - 39)	(16 - 30)	(33 - 35)	(22 - 35)	(22 - 42)
Gap ($t\ ha^{-1}\ yr^{-1}$)	average	6.8	8.12	0	2	0.6
	range	(0 – 15)	(0 – 17)		(0 – 10)	(0 – 3)
TBI (%)	average	59	40	82	66	64
	Range	(48 – 67)	(33 – 49)	(75 – 87)	(61 – 73)	(52 – 71)

TABLE 7. Characteristics of crops establishment per conglomerate (% of lots having a determined rating, H = high rating, L = low rating).

Category	Cluster				
	C1	C2	C3	C4	C5
Soil and climate characterisation studies	100% L	100% L	100% H	100% H	100% H
Topographical studies	92% L	100 % L	100% H	60% L	60% H
Designing drainage and irrigation work based on studies	92% L	100 % L	100% H	80 % L	60% L
Establishing AMU	100% L	100 % L	67% H	100% L	60% H
Suitable soil preparation	100% L	100 % L	100% H	100 % L	60% L
Planting legumes	75% L	87% L	100%H	100 % L	60% L

TABLE 8. Characteristics regarding nutritional management of lots per cluster concerning suppliers from nucleus A (% of lots having a determined rating).

Category	C1	C2	C3	C4	C5
Foliar sampling	50% H	100% L	67 % H	60% H	80% H
Soil sampling	100% L	100% L	100% H	100% H	80%L
Fertilisation effectiveness	100% H	100% L	100% H	100% H	80% H
Fertilisation time	100% H	87% L	100 % H	100% H	100% H
Vegetative growth	100% L	100% L	100% H	100 % B	100% B
Amount of fertilizer (kg/palma)	7.25[2] (4 – 13.3)	3.35 (1.8 – 5)	10.3 (9 – 11)	8.48 (6.5 - 11)	7.7 (5 – 10)
% Fertilizer application[1]	80% (60 – 100)	51% (20 – 80)	100%	92% (80 – 100)	76% (60 – 80)

[1] Amount of fertilizer which has been applied regarding the amounts which should be applied to oil palms according to their requirements.
[2] Mean and range.

It was found that following-up the soils nutritional state was not a common practice in lots with low yields. It is thus recommended that technologies related to this aspect should be transferred, as following-up soil state enables ascertaining difficulties interfering with nutrient absorption and thus proposing solutions.

Regarding the amount of fertilizer applied, it was found that average amounts of fertilizer over 7.7 kg/palm were applied on conglomerates with resulting yields higher than 30 t ha^{-1} (3, 4, 5), reaching 10.5 kg/palm on conglomerate 3. Real fertilizer application percentage in these groups was more than 76% and 100% in group 3. However, 3.35 kg/palm average applied amount, 50% application, was found in the group having the lowest yield (2).

Fertilisation has repeatedly been found to be one of the factors associated with yield gaps, as found in the present study. Studies carried out in the prevailing conditions in Indonesia have shown low fertilizer application rates are determinant regarding yield gaps among small-scale oil palm growers and that low fertilizer application rates are mainly related to limited access to supplies/input and credit restrictions (Woittiez *et al*., 2015).

A study regarding rice crops found that production was limited by factors such as fertilisation and affected by factors limiting producers regarding suitable technological management. It was found that such restrictions ranged from being underfunded for acquiring supplies/input to producers lacking knowledge regarding the impact of practices related to their businesses profitability (Nhamo *et al*., 2014). Another study in the Soviet Union has shown that yield gaps for many crops (i.e. potato and corn) are related to decreased fertilizer use (cultivator management), in turn related to the removal of subsidies for fertilisation and increased fertilizer prices (macroeconomic environment) (Licker *et al*., 2010). Identifying associations between fertilisation and the yield obtained by oil palm growers is a source of information enabling factors associated with the low application rate for this product to be identified and thus facilitate policies being put into operation in the nuclei favouring the adoption of such practice.

Aspects observed in table 9 were evaluated concerning the harvest of fruit bunches, mainly related to harvest criteria and cycles. A 10 to 12 day fruit cutting time (harvest cycle) was found during the rainy season and around 15 d in the dry season on conglomerates having high yields. A 10 d harvest cycle means that harvesters enter the same lot every 10 d. Note that a mature oil palm produces around 14 bunches per year on a properly managed plantation, However, palms do not produce fruit bunches at the same time, but they do at different times along the year.

Deciding on the proper harvest cycle, implies a balance between optimal ripeness (more oil to be extracted) and logistics (transportation cost). The optimal harvest cycle, favours the amount of oil extracted, as well as it aims at lowering fruit collection costs. The harvest cycle has been reported as being a factor associated with oil palm yield gaps. The explanation lies on the fact that long cycles reflect an extremely large loss. The latter relates to the ripeness of the bunch. The fruits from a bunch tend to become loose as they mature. When the bunch is cut after the optimal time, at the moment it hits the ground, the fruits disperse all over the field. In consequence, collecting fruits becomes a very difficult task. Let alone the fact that not all of them may be collected (Euler *et al*., 2016; Castillo *et al*.,2017).

Gaps caused by poor harvesting practices could be closed completely in the short-term by using suitable logistics regarding labour. Production surveys could provide the necessary information for avoiding problems concerning recruiting people for the harvest, the lack of vehicles for transporting the fruit and the lack of extraction plant capacity (Fairhurst and Hardter, 2012).

Conclusions

This work has led to identifying yield gaps in the group of fruit suppliers from the nucleus being studied. Regarding

TABLE 9. Crop characteristics per conglomerate on suppliers' lots.

Category	Cluster				
	C1	C2	C3	C4	C5
Crop cycle and criteria	58% I	75% I	100% H	100% H	80% H
Fruit collection	91% I	100 % I	66% H	100% I	60 % I
Fruit quality	100% I	100% I	66% H	60% I	80 % I

H = high rating; I = intermediate rating.

potential for the region, the gaps found were below 10 t ha^{-1} on most lots, thereby, indicating good technological management of crops; however, gaps reached 17 t ha^{-1} on a few lots, meaning that alternatives must be sought for increasing yields.

The yield gaps found were mainly associated with aspects concerning establishing crops, nutrition management and FFB harvesting.

Suitable crop establishment is extremely significant due to the crop's long-term horizon and, as once oil palms have become established in the field, it becomes difficult and costly to employ practices which must be considered regarding planning oil palm planting/growing.

Regarding crop nutrition management, it was found that high yield lots had clear criteria and suitable tools for effective diagnosis concerning needs related to the fertilizer to be applied as well as making the application of this costly product much more efficient and following-up application efficiency. The amount of fertilizer applied was also found to be a factor associated with gaps; a high yield plantation applied more than 7 kg/palm of fertilizer on average, this being important for future studies aimed at identifying the reasons for low fertilizer application rate on lower yield lots.

Harvesting involving suitable cycles is a characteristic of high yield lots. This is an important task as a flaw in such process could cause problems in crops which have had a good level of technology previously.

Identifying factors associated with yield gaps enables technology transfer programmes focused on the main limitations thereby optimising technology adoption and diffusion, consequently increasing yields and closing gaps.

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