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ABSTRACT

Palm oil has become a leading vegetable oil over the past 30 years and smallholder farmers in Indonesia, with more than 12 million hectare the world's largest producer of palm oil, have massively engaged in oil palm (*Elaeis guineensis*) cultivation. In Sumatra, where more than 60% of Indonesian palm oil is cultivated, smallholders currently cover roughly 50% of the oil palm area. The rapid expansion of palm oil however did not happen without controversy. In current efforts by the Indonesian government, NGO's and private sector to improve sector performance, smallholders are often characterized as the Achilles heel of the oil palm sector due to poor practices and low yields compared to companies. However, 'oil palm smallholders' is a container concept and there has been only limited research into smallholder diversity beyond the organised versus independent farmer dichotomy. This research delves into the implementation of Good Agricultural Practices (GAP) among seven types of independent smallholders in Rokan Hulu regency, Riau province. The research area consisted of a relative established agricultural area on mineral soils and a relative frontier, mostly on peat. Smallholder types ranged from small local farmers to large farmers who usually reside in urban areas far from their plantation and regard oil palm cultivation as an investment opportunity. The underlying hypothesis is that larger farmers have more capital and therefore implement better agricultural practices than small farmers, who are usually more cash constrained. A wide range of methods was applied, including farmer and farm surveys, remote sensing, tissue analysis and photo interpretation by experts. These methods provided data on fertilizer use, nutrient conditions in oil palms, planting material, planting patterns, and other management practices in the plantations. Results show that yields are poor, implementation of GAP are limited and there is much room for improvement among all farmer types. Poor planting materials, square planting patterns, and limited nutrient applications were particularly prevalent. This implies that farmers across different typologies opt for a low-input low-output system for a myriad of reasons and that under current conditions, initiatives such as improving access to finance or availability of good planting material alone are unlikely to significantly improve the productivity and sustainability of the smallholder oil palm sector.

1. Introduction

Palm oil has become the world's most produced and traded source of vegetable oil (USDA, 2016), in large part due to its unrivalled land to oil ratio. The largest palm oil producing country is Indonesia, which covers 54% of global palm oil production. Palm oil is a key foreign exchange earner for Indonesia, with export earnings up to 15.4 billion USD in 2015, and therefore of crucial importance to the country (DJP, 2017b). The sector provides direct employment for an estimated 4.3 million people and indirect employment for another 12 million (BPDPKS, 2017). Oil palm growers in Indonesia are classified into three categories: privately owned companies, state owned companies and smallholders. Companies usually manage several thousand hectares to feed their mill (Byerlee and Deininger, 2013) and cover an estimated 60% of the oil palm area in Indonesia. The remaining 40% of the oil palm area is cultivated by smallholder farmers, mainly in Sumatra and Kalimantan (DJP, 2017b).

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The remarkable expansion of oil palm over the past four decades has been accompanied with controversy. The sector has been associated with deforestation (Gaveau et al., 2016; Abood et al., 2014) and biodiversity loss (Sayer et al., 2012; Obidzinski et al., 2012). Peat fires and associated smoke, which covered large parts of Indonesia, Malaysia and Singapore in 2015, are a major source of GHG emissions and are often linked to oil palm expansion (Gaveau et al., 2014; Purnomo et al., 2017). The oil palm industry has also frequently been criticized for its negative social impacts on local communities (Colchester et al., 2006; Afrizal, 2013), unfair partnerships between local communities and companies (Cramb, 2013; Gillespie, 2010) and land grabbing (Gellert, 2015). These controversies have led to increased demands for sustainability and transparency in the oil palm sector, mainly due to customer demand in Northern countries (Hidayat et al., 2015). Measures are being taken to improve the performance of the industry, notably through certification schemes.

The Round Table on Sustainable Palm Oil (RSPO), a voluntary certification scheme initiated by major buyers and NGOs, is deemed to be one of the most stringent of numerous certification initiatives (Rival et al., 2016; Ivancic and Koh, 2016). It has pushed for better production standards by developing sustainability principles and criteria. Partially in reaction to this non-state actor initiative the Indonesian government launched the mandatory Indonesian Sustainable Palm Oil (ISPO) certificate in 2009. Currently the ISPO framework is being revised and strengthened in order to increase international recognition. In addition to these initiatives, the Indonesian Palm Oil Association (IPOA), the lobby of large scale oil palm producers, strongly advocates the implementation of Good Agricultural Practices (GAP). Whilst debated in academia (Alcott, 2005; Villoria et al., 2013; Byerlee et al., 2014), these actors promote a narrative in which GAP leads to yield increases per hectare so that less land is required to fulfil global demand for palm oil. Thereby the environment is spared whilst farmers receive higher incomes from their plantations. Corley (2009) suggested that the oil palm has a theoretical potential of 18 Mt of oil ha^{-1} $year^{-1}$ and Mathews and Foong (2010) reported best yields for whole estates of 8 Mt of oil ha^{-1} $year^{-1}$. Yet the average productivity in Indonesia in 2015 was only 3.6 Mt of oil ha^{-1} $year^{-1}$, with smallholders producing on average 20% less per ha than private companies (DJP, 2017b). While there is large scope for intensification throughout the sector, the smallholders currently are the weakest link in terms of productivity (Molenaar et al. 2013; Lee et al. 2013).

However, the smallholder segment of the sector is likely to continue to expand over the coming years (Euler et al., 2017) as it becomes more difficult for companies to open up large tracts of land since the most suitable lands are already occupied. Other factors which constrain company expansion through concessions include rising scrutiny towards the social and environmental performance of companies and related impacts on financing (Van Gelder et al., 2017) and the oil palm moratorium which freezes the issuance of new permits for oil palm plantations (Busch et al., 2015). There is also increased recognition of rights of indigenous populations (Forest People Program, 2013), increased scrutiny from the anti-corruption agency and tax authorities (KPK, 2016) and new technologies which allow for easy tracing (and potentially sanctioning) of companies (see eg. https://www.cifor.org/map/atlas/ for an overview of all oil palm concessions and mills in Borneo). The development of roads and mills by large scale oil palm companies has paved the way for smaller actors to access markets more effectively and cultivate remaining patches of available land. This has happened particularly in Sumatra (62% of Indonesia's 11.3 million ha of oil palms in 2015), where the oil palm boom emerged through corporate expansion, but smallholders currently cover 49% of oil palm area (DJP, 2017b; Bissonnette and De Koninck, 2017). In other parts of Indonesia, mostly Kalimantan, large scale expansion started later and smallholders cover only 26% of the oil palm area (DJP, 2017b). Although it can be expected that the smallholder area and share will further increase in the near future, smallholders are in a vulnerable position as they are often included in the value chain on disadvantageous terms. These include but are not limited to poor access to certified planting materials and technological know-how, and a poor bargaining position when selling produce, leading to low prices and being last in line to sell their FFB when supplies are ample (Hidayat, 2017; Cramb and McCarthy, 2016). The RSPO acknowledges the weak position of smallholders and addresses it by working towards redeveloping the certification approach to better accommodate smallholders and by prioritizing smallholder implementation of GAP above certification itself (RSPO, 2017). Nevertheless smallholders are currently prone to exclusion from value chains due to their large numbers, high costs associated with certification, and the current poor cultivation practices (Brandi et al., 2015).

The thin body of literature available on plantation practices of smallholders (see eg. Euler et al., 2017; Lee et al., 2013) usually only differentiates between scheme and independent smallholders. Scheme smallholders cover roughly 40% of the smallholder area (Zen et al., 2015; Hidayat, 2017). They are characterized - despite there being a large diversity in these schemes with respect to support and management configurations (Gillespie 2011) - by a partnership between farmers and companies, where the smallholder plantations are usually planted by the partner company and bunches are sold to the partner mill (Hidayat, 2017). Independent smallholder plantations on the other hand are usually developed autonomously, without resources from - or commitments to - oil palm companies (Hidayat et al., 2015). Scheme smallholders usually perform better than independent farmers as they are better integrated into large company plantation systems and hence often have yields close to corporate actors. Independent smallholder plantations, which cover about 2.8 M ha, are the least productive and it is among these farmers that promotion of GAP appears most important.

Good Agricultural Practices in oil palm have been defined based on extensive research in company plantations, research institutes and universities, and on basic agronomic principles (see Fairhurst and Härdter (2003) and Corley (2009) for a good overview). In short, GAP in plantations centre around soil and weed cover management, canopy management, harvesting, plant nutrition, and pest and disease management (Rankine and Fairhurst, 1998). At planting, GAP include using high-quality planting materials, planting at the right distance and in the right pattern. Good field management includes maintenance of a weed cover with soft weeds (particularly *Nephrolepis* ferns, certain grasses, and legume cover plants), maintaining good plantation access, proper harvesting, and correct palm pruning. Appropriate fertilizer management is crucial for enhancing productivity, reducing negative impacts on the environment and in certain situations reducing input costs when fertilizers are inefficiently used (Goh et al., 2003; Soliman et al., 2016). Smallholders operate in different conditions than company plantations (such as having FFB, rather than oil, as their end product, and having more limitations in access to heavy equipment and inputs), but the same agronomic principles apply in smallholder fields.

In this article we explore the use of GAP by diverse groups of independent oil palm smallholders, including plantations which are on (or beyond) the blurry boundaries between family farms and large scale plantations (Bissonnette and De Koninck, 2017; McCarthy and Zen, 2016). The farmer typology applied is based on the study of Jelsma et al. (2017a), which highlighted that independent smallholders are not a homogenous group. Our objective was to understand the use of GAP among different independent farmer types in Riau, to identify points of improvement, and to support the development of differentiated policies and approaches towards increased productivity. To achieve this, we employed a range of methods such as farmer surveys, field visits, tissue sampling, photo analysis and the analysis of satellite images. Whereas Jelsma et al. (2017a) focused on market linkages, social diversity and legal aspects, this article delves into the implementation of GAP given its centrality in current debates surrounding the sustainability of the smallholder oil palm sector and further explores the hypothesis that larger farmers have more capital and therefore implement better agricultural practices than small farmers, who are usually more cash constrained.

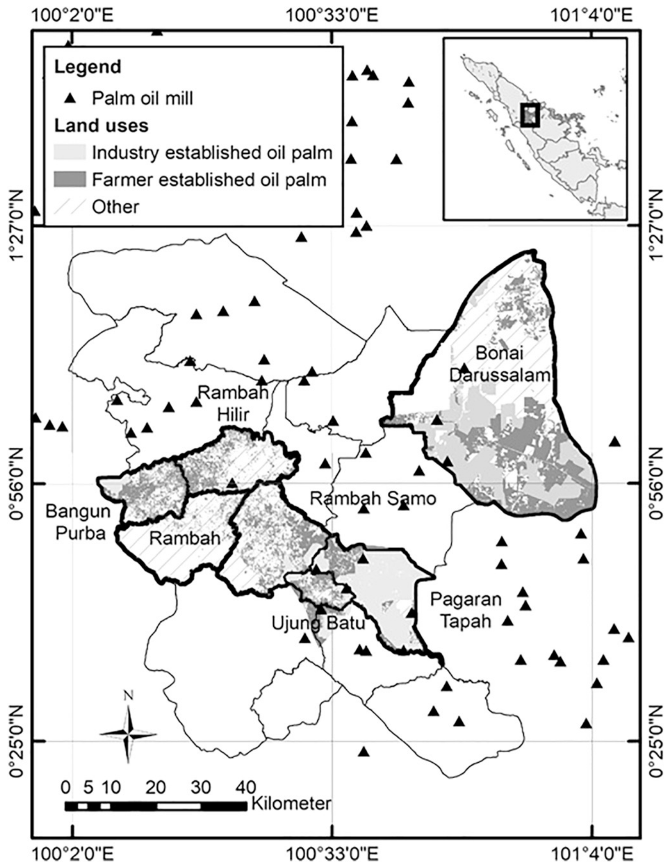

Fig. 1. Overview research area, oil palm mapping and mills in the area (source: CIFOR mill mapping and own data).

2. Background

The research was conducted in Sumatra's Riau province which is the province with the largest oil palm area in Indonesia (2.46 million ha). Approximately 28% of Riau's land area is planted with oil palm, of which 59% is owned by smallholders (DJP, 2015). About 33% of the palm oil processing capacity in Riau comes from independent mills (DIS-BUN Propinsi Riau, 2015), which do not own plantations and usually source from independent smallholders. This indicates the importance of the independent smallholder sector for the Riau oil palm industry. Within Riau our research focused on Rokan Hulu regency (Fig. 1), which with 39 mills - 17 without own plantations - and a total processing capacity of 1,605 Mt of fresh fruit bunches (FFB) per hour, has the largest palm oil processing capacity in the province (DIS-BUN Propinsi Riau, 2015).

The research area consisted of two distinct areas in Rokan Hulu (Fig. 1) which allowed us to capture a diversity of smallholders and landscapes. The first area was Bonai Darussalam (further referred to as BD, 0°52′-1°24′ N, 100°39′-101°05′ E) in the northeast, which is a single sub-district, has a flat topography and largely consists of peat soils (Histosols). The area has experienced considerable deforestation after 2000 and has a low populations density. Peat fires associated with oil palm developments were common in BD, where most land officially falls under the forestry domain. Although this implies that de-jure the majority of land cannot be used for oil palm cultivation, de-facto much of the oil palm expansion in BD has taken place in the forestry domain. BD can be considered a relative frontier in the Riau context.

The other research area was Central Rokan Hulu (comprised of six sub-districts and further referred to as CRH, 0°36′-1°03′ N, 100°05′-100°45′ E) which has a flat to slightly hilly topography in its oil palm growing regions and predominantly consists of mineral soils (mostly Acrisols). The area has been inhabited for a long time with indigenous populations and since the 1980s had a considerable influx of government sponsored and spontaneous migrants. Most land is classified for ‘other use’ (*Areal Penggunaan Lain* (APL)) and hence can be legally planted with palm oil. The forest domain largely covers the forested foothills of the Barisan mountains and a pulp and paper plantation. CRH has a population density of 151 inhabitants km^{-1} (BPS Rokan Hulu, 2015) and can be regarded as a relatively established agricultural area. Both areas have limited forests left (see Table 1 for details on research area).

The smallholder typology was developed by performing a Hierarchical Clustering Analysis (HCA) among 1728 farmers and is described in more detail in Jelsma et al. (2017a). The variables used to develop the typology were inspired by the work of McCarthy and Zen (2016) on rural differentiation through smallholder oil palm developments in Jambi, where they contrasted local and migrant smallholders, resource endowments and farms of different sizes. Key determinants used in developing the typology were: 1) area of smallholder oil palm (proxy for wealth); 2) origin of farmers (locals or migrants); 3) residence (absentees or resident farmers); 4) peat or mineral soils; 5) land status (APL or state forest domain). The seven clusters derived at in Jelsma et al. (2017a) were subsequently used in this analysis as well and Table 2 provides an excerpt from their study to characterize the different farmer types.

3. Methodology

3.1. Sampling

The sampling frame is based on spatial sampling using recent high-resolution Google Maps satellite imagery. From this imagery

Table 1
Research area characteristics.
(Sources: own research and (CIFOR, 2014; BPS Rokan Hulu, 2015; MoA, 2011; MoF, 2014))

	Frontier (BD)		Established agricultural area (CRH)		Total (sampled sub-districts)	
Population density (people^{-1} km^2)	29		151		95.1	
Land use	Area (ha)	Share	Area (ha)	Share	Area (ha)	Share
Deforested between 2000 and 2013	84,739	61%	6,222	4%	90,961	30%
Forest remaining in 2013	7,379	5%	16,743	10%	24,122	8%
Oil palm	75,275	54%	76,302	46%	151,577	50%
Independent smallholder oil palm	39,252	28%	43,133	26%	82,385	27%
Company developed oil palm	36,023	26%	33,169	20%	69,192	23%
Non-state forest land (APL)	51,399	37%	101,050	62%	152,449	50%
Forest domain	87,538	62%	64,367	38%	151,905	50%
Peatland (> 100 cm)	101,635	73%	0	0%	101,635	33%
Total area	138,949	46%	164,321	54%	303,270	100%

Table 2
Farm types and characteristics Jelsma et al. (2017a), and sample sizes[a].

	Cluster	Small Local Farmers (SLF)	Medium Local Farmers (MLF)	Large Resident Farmers (LRF)	Small Migrant Farmers (SMF)	Medium Migrant Farmers (MMF)	Small & Medium Peat Farmers (SMPF)	Large Peat Investors (LPI)
Farm size (ha)	Average plot size	1.1	2.9	52.3	1.4	3.4	4.2	179.2
	Average total area under oil palm	1.7	6.9	94.5	2.3	6.8	5.1	241.0
Primary place of residence	Within sub-district	100%	100%	67%	87%	76%	65%	18%
	Outside regency	0%	0%	15%	6%	8%	29%	78%
Origin	Within sub-district	100%	100%	29%	4%	2%	5%	2%
	Outside regency	0%	0%	67%	90.%	89%	93%	95%
Ethnicity	Malay	62%	48%	22%	10%	7%	7%	3%
	Batak	21%	31%	41%	17%	24%	40%	54%
	Javanese	17%	20%	29%	72%	66%	52%	15%
	Sino-Indonesian	0%	0%	2%	0%	0%	0%	24%
	Other	0%	1%	6%	1%	4%	1%	3%
Soil type	Peat soil	0%	0%	0%	0%	0%	100%	100%
	Mineral soils	100%	100%	100%	100%	100%	0%	0%
Land classification	Outside Forest domain (APL)	74%	56%	59%	83%	74%	26%	26%
	Forest domain	28%	47%	43%	18%	27%	76%	86%
Location	Central Rokan Hulu	95%	96%	80%	87%	87%	0%	0%
	Bonai Darussalam	5%	4%	20%	13%	13%	100%	100%
Prevalence	Share of total farmers in research area[a]	19%	11%	6%	29%	20%	13%	2%
	Share of total research area[a]	7%	8%	18%	10%	14%	13%	31%
Farmer and farm surveys (231)		30	32	34	33	40	30	32
Valid paired surveys and photo interpretations (220)		29	31	33	31	39	29	28
Tissue samples (118)		13	10	19	15	14	23	24

[a] Sampling bias corrected; see Jelsma et al. (2017a) for more details.

smallholder plantations were mapped. The research area was subsequently divided into 25 ha cells from which a random sample of 5% (287 cells containing 4451 ha of smallholder plantations) were visited. Small farmers were relatively prevalent in the established agricultural area whereas the frontier was dominated by large farmers. As especially the frontier area contains more large farmers who occupied several sampled cells, the number of farmer surveys is less than the number of cells visited. A total of 231 farmer and farm surveys were used in this study, including 30–40 farmers per farmer type (see Table 2 for details on sample sizes per farmer type). For all parameters that included expert photo assessments the sample size was reduced to 220, because for some plantations the photo sets were of insufficient quality to be assessed. For more details on sampling and tools applied see Jelsma et al. (2017a).

3.2. Surveys and plantation visits for assessing the implementation of Good Agricultural Practices

Fieldwork was conducted in May–June and August–September 2015. The survey instruments consisted of an in-depth farmer survey and a visual plantation inspection form for surveyors (see Supplementary Material 1). Whereas Jelsma et al. (2017a) focused on developing the typology and their article contains more information on socio-legal and economic aspects such as share of income from oil palm, other sources of income, sources of capital for plantation development and type of land ownership documentation, this article utilizes the agricultural practices component of the survey and highlights aspects such as yields, fertilizer application rates, harvesting frequency and planting materials.

Plantation assessments (or 'audits') are common practice in company plantations (Fairhurst and Griffiths, 2014) and were also conducted for this study. Indicators on GAP were based on a diagnostic smallholder survey instrument develop by Aidenvironment (2013) and a smallholder oil palm handbook by Woittiez et al. (2015), which are both richly illustrated with photographic material and provide an extensive set of inspection criteria and guidelines on how to conduct smallholder plantation assessments. Sections from these documents were, with permission, translated into Bahasa Indonesia, used as training materials and shared with surveyors as reference material. For plant nutrition, we looked for the presence of common nutrient deficiency symptoms (particularly P, K, Mg and B) displayed in the foliage and the trunks; occurrence of these symptoms signals lack of GAP implementation. For soil and weed cover management, we looked for a continuous cover of legumes (usually *Mucuna bracteata*) or *Nephrolepis* ferns; absence of bare soils; signs of weeding (but not clear-weeding); and absence of woody weeds. For canopy management, surveyors looked at the retention of two to three fronds below the ripening bunches for palms up to four meters tall and one to two fronds for palms taller than four meters; the absence of dead leaves on the palm; and for the recycling of pruned fronds in stacks within the plantation. For harvesting, we checked for circle weeding practices; ease of access for harvesters in the plantation (based on whether harvesting paths were sufficiently clean and wide, without too many holes and generally accessible, e.g. no major waterlogging); and frequency of harvesting. For planting pattern and density, we looked for planting in triangles through satellite images (further explained in Section 3.3). For planting material, we looked for the presence of thin-shelled Tenera (DxP) fruits by cutting open a sample of 20 loose fruits per farmer; GAP would see an occurrence of > 99% Tenera fruits but for this research we used 95% as a cut of point, allowing one fruit to be Dura. Black bunch counts (BBC) were performed among 20 trees as an alternative method for assessing yields (see section 3.4) to allow for triangulation with other tools for yield assessments such as farmer surveys and expert opinion. In addition to GAP indicators, we also collected basic information about the plantation, such as age of oil palms and quality of the road to the plantation. Criteria for road quality were limited number of holes in the road and no indications of flooding of roads or damaged bridges or other clear obstacles that hinder FFB transport or increase costs due to likely damage to vehicles, as described and illustrated in Aidenvironment (2013).

Tissue sampling was conducted in 118 farms to determine the nutrient content in the leaves and rachis and assess the nutritional condition of the plantation. A minimum of four non-randomly selected palms per plantation were compounded into one sample. Selection criteria for palms were location (at least two rows away from the road and preferably at least five palms away from other sampled palms) and absence of visual abnormalities. Sample collection was performed according to the protocol described in Woittiez et al. (2018) and laboratory analyses were carried out by Central Plantations Services in Pekanbaru.

Due to budgetary constraints and high cost of laboratory testing, we were unable to sample all farms surveyed. Sub-sampling was conducted in a semi-stratified manner in which both CRH and BD sites were proportionally sampled in order to capture both landscapes and soil types. As database analysis or the typology development had not yet commenced during tissue collection it was impossible to proportionally sample farmer types. During sampling it appeared that especially small and medium farmers in the peatlands, which were expected to form separate categories, were only very limitedly captured. It was therefore decided to randomly increase the number of small and medium peat farmers and small farmers at the expense of large farmers, which in absolute numbers still received most tissue sampling (see Table 3). The eventual sample however effectively strikes a balance between geographic spread and covering all farmer types and presence in the landscape, with small and medium peat farmers forming one category and hence being slightly oversampled (see Table 2 and Table 3).

3.3. Photo interpretation of smallholder plantations by experts

In order to allow for expert assessment of plantations without requiring physical field visits, plantations were photographed during the field audit. On average plantations were captured in eight images[1] which showed different aspects of the plantation floor (circle, stack, overview) and canopy, in different angles (see Supplementary Material 2). Three experts audited the plantations based on the sets of photos, and their assessments were used to triangulate the results from the field visits and the survey. The experts estimated oil palm age, bunch weight and yield, and classified plantation condition as poor, reasonable, or good. Yield estimates were given in 5 Mt $ha^{-1} year^{-1}$ intervals (0–5, 5–10, etc.), effectively creating a 'yields up to' average. Bunch weight estimates were also provided with 5 kg ripe $bunch^{-1}$ intervals. Interval averages were subsequently used in calculations to account for lower values within these ranges and avoid overtly positive assessments.[2] Plantation age was estimated in years. For maintenance, the third author separately assessed weeding practices and pruning.

The experts were an academic specialised in agronomic practices in smallholder oil palm plantations (second author of this article), a farmer from Rokan Hulu who is also a representative of the Serikat Petani Kelapa Sawit (SPKS, or Union of Oil Palm Smallholders, a national organisation representing independent smallholder farmers), and an experienced oil palm agronomist working at CIRAD (third author). All three experts have extensively visited smallholder oil palm plantations but did not visit smallholder plantations for this research, nor did they have information about farmers or plantations before completing farmer photo assessments.

Planting density and planting pattern (rectangular or triangular) were determined by tracing the palm row diagonals on high-resolution satellite imagery (see Fig. 2). Average distances between palm crowns were measured in meters using Google Earth from either two or three diagonals depending on whether patterns were rectangular or triangular respectively. From this planting densities per hectare were calculated. Measured rows were preferably over 20 palms long, but less in small plantations.

3.4. Calculations

Seasonal patterns in yield were derived based on data from a nearby company plantation, which showed that the yields are highest in August and lowest in February (see Supplementary Materials 3a and 3b). To account for these patterns when estimating yields, farmers were asked to estimate the yield per harvest in the peak and low season of last year. These yields were averaged, multiplied with the harvesting frequency, and divided by the land size. This approach is justified as yield records are mostly absent with farmers. Yields were benchmarked against a 20 Mt $ha^{-1} year^{-1}$ production curve deduced from Cramb and McCarthy (2016: p. 32) and presented as the share of the benchmark production curve at a given age.

Because farmer estimates are not always reliable, expert assessments and black bunch counts were used to provide additional yield estimates which allow for triangulation of results. Yields based on BBC were calculated by first taking the average BBC from 20 palms per plantation and multiplying this with the estimated average ripe bunch weight, to get the total bunch weight per palm. The ripe bunch weight could not be measured as ripe bunches are only available in the field in the short period between harvesting and transportation. For this reason bunch weight estimates were obtained by averaging expert estimates from photos with surveyor estimates from field observations. Total bunch weights per palm were multiplied with three (assuming that bunches ripen in a four-month period) and with the planting density. Correction factors to compensate for date of surveying were developed based on average productivity curves from monthly yield data provided by three nearby companies (see Supplementary Material 3a). Survey yield benchmarking against the production curve was based on survey yield estimates and survey age data. Expert yield benchmarking was based on expert yield estimates and expert age estimates. For the BBC yield benchmarking the BBC yield estimates were associated with average plantation age from surveys and experts (see Supplementary Material 2).

In order to determine fertilizer practices we calculated nutrient requirements and nutrient balances. Ng et al. (1999) indicate that for a mature plantation on tropical soils of poor fertility, the total demand for producing 20 Mt of FFB $ha^{-1} year^{-1}$ is 112.5 kg N, 14.0 kg P, 202.4 kg K, and 33.2 kg Mg, and for 30 Mt of FFB $ha^{-1} year^{-1}$ 145.5 kg N, 19.2 kg P, 247.5 kg K and 44.4 kg Mg. On peat soils, the quantities of nutrients removed in fruit bunches are similar, but the nutrient balance is different with more N and less K available in the soil (Goh, 2005). In order to compensate for this difference, the estimated N and K requirements on peat are set at 84.4 kg (25% less) and 303.6 kg (50% more), respectively, than the requirements at mineral soils (Ng et al., 1990). A nutrient balance was calculated for each plantation using the following equation:

$$B = (Fe + De) - ((Y \times c) + Tr + Ru + Er + Le)$$

with B = nutrient balance (kg ha^{-1}), Fe = input through fertilizers, De = deposition in rainwater, Y = reported yield, c = concentration of nutrient in the FFB, Tr = nutrients taken up for trunk growth, Ru = loss through runoff, Er = loss through erosion, and Le = loss through leaching (see Supplementary Material 4 for values used).

[1] Instructions were to take pictures of; 1). trunk of a representative palm in the plantation, including crown and fruits; 2). Several palms, showing overall condition and weeds; 3). circle; 4). harvesting path; 5). dead fronds stackings; 6). cut open fruits to determine dura vs. tenera share; 7). Example of leaves with clear nutrient deficiency according to surveyor; 8). Canals and water table if relevant. In some cases however soft and hardware failures limited the amount of pictures that could be taken and assessments were not possible or conducted with less pictures.

[2] Bunch weight categories were thus transformed to values of 3 kg $bunch^{-1}$ (as ripe bunches in this category ranged from 1 to 5 kg), 7.5 kg $bunch^{-1}$, 12.5 kg $bunch^{-1}$, 17.5 kg $bunch^{-1}$ and 22.5 kg $bunch^{-1}$ respectively.

SPSS version 19 was used to calculate differences among farmer type means, using either one-way Analysis of Variance (ANOVA; for scalar variables) or the Chi-Squared Test (for categorical variables). Appropriate post hoc tests such as Tukey and Games-Howell were conducted to calculate pairwise differences between farmer types. Matching letters in Figures and Tables indicate there are no significant differences between types of farmers according to post hoc tests. Where ANOVA revealed statistically significant differences, in some situations the post hoc tests could not indicate where those significant differences were located. This can be attributable to the sample size, a weak global effect, and differences between methods in how Type I errors are dealt with.

4. Results

4.1. Age & yields

Yield is the ultimate product of three factors: genotype, management and environment (see eg. Tester and Langridge, 2010). In perennials yield depends on crop age, and therefore can be presented both in absolute terms and as deviation from a reference production curve (%)'. We used a reference production curve for a full 25-year production cycle, with a peak yield of 20 Mt ha^{-1} $year^{-1}$ as derived from Cramb and McCarthy (2016; p. 32).

Yield estimates from surveys, photo analysis by experts, and BBC provide a fairly uniform pattern (Fig. 3). Limited differences were observed among farmer types, with the majority of significant differences observed between farmers on mineral soils compared to farmer types on peat soils. All three yield assessment methods indicate farmers on peat generally have low yields.

4.2. Applications of fertilizers and nutrient balances

Smallholder fertilizer applications in general were limited, poorly balanced and variable between farmers and farmer types (see Supplementary Material 5 for details on fertilizer use). Nitrogen application rates were on average below expected demand at 20 Mt of FFB ha^{-1} $year^{-1}$, with the exception of migrant and large resident farmers (see Fig. 4). Average P applications appeared sufficient among most farmer types, with small local farmers and large peat investors applying too little on average to reach 20 Mt of FFB ha^{-1} $year^{-1}$. Average K applications were limited among all farmer types, with small local farmers applying only 32.1 kg ha^{-1} $year^{-1}$ on average. Less than 25% of farmers applied enough K to meet the demand for producing 20 Mt of FFB ha^{-1} $year^{-1}$. Average Mg applications were generally insufficient, especially among farmers on mineral soils. Small local farmers were most likely to not to apply any fertilizers but differences between farmer types were not significant (see Figs. 4 & 6; and Supplementary Material 5).

Whereas Fig. 4 highlights the nutrient requirement for producing 20 Mt of FFB ha^{-1} $year^{-1}$ and the actual nutrient applications of farmer types, Fig. 5 provides a nutrient balance, using reported yields by

Table 3
Leaf and rachis analysis average, standard deviation and planting density per farmer type (SLF = Small Local Farmers, MLF = Medium Local Farmers, LRF = Large Resident Farmers, SMF = Small Migrant Farmers, MMF = Medium Migrant Farmers, SMPF = Small & Medium Peat Farmers, LPI = Large Peat Investors). Critical nutrient levels are from Fairhurst and Mutert (1999) for leaves and from Foster and Prabowo (2006) for rachis. The critical values are for palms > 6 year after planting; they are slightly higher for younger oil palms. DM = dry matter. Significance level $p < .05$ and are $p < .01$ are indicated with * and **, respectively.

	Critical Value (units)		SMF	MLF	LRF	SMF	MMF	SMPF	LPI	F Values (ANOVA)
Leaf N	2.3 (% DM)	% DM	2.14_{a}	2.13_{a}	2.17_{a}	2.19_{a}	2.17_{a}	2.22_{a}	2.24_{a}	$2.620_{(6,111)}^{*}$
		Std.dev.	0.09	0.08	0.11	0.11	0.08	0.11	0.12	
Leaf P	0.14 (% DM)	% DM	0.13_{a}	0.14_{ab}	0.14_{ab}	0.13_{ab}	0.14_{ab}	0.15_{bc}	0.15_{c}	$7.063_{(6,111)}^{**}$
		Std.dev.	0.01	0.01	0.02	0.01	0.02	0.02	0.01	
Leaf K	0.75 (% DM)	% DM	0.71_{a}	0.60_{a}	0.66_{a}	0.63_{a}	0.66_{a}	0.71_{a}	0.79_{a}	$1.864_{(6,111)}$
		Std.dev.	0.28	0.18	0.12	0.10	0.07	0.13	0.01	
Leaf Mg	0.20 (% DM)	% DM	0.26_{a}	0.37_{ab}	0.29_{a}	0.34_{ab}	0.33_{ab}	0.39_{b}	0.42_{b}	$5.460_{(6,111)}^{**}$
		Std.dev.	0.11	0.09	0.12	0.10	0.07	0.12	0.11	
Leaf B	8.0 (mg/kg)	(mg/kg)	10.3_{ab}	10.4_{ab}	12.2_{ab}	10.0_{a}	10.6_{ab}	13.4_{b}	13.0_{ab}	$3.102_{(6,111)}^{**}$
		Std.dev.	1.7	2	3.5	1.5	2.2	6.8	3.1	
Leaf Cu	3.0 (mg/kg)	(mg/kg)	3.9_{a}	4.7_{a}	3.9_{a}	4.0_{a}	4.3_{a}	4.0_{a}	2.8_{b}	$5.914_{(6,111)}^{**}$
		Std.dev.	1.1	1.1	0.8	1.0	1.1	1.2	0.7	
Rachis P	0.09 (% DM)	% DM	0.07_{ab}	0.06_{a}	0.06_{a}	0.05_{a}	0.07_{a}	0.08_{ab}	0.13_{b}	$5.673_{(6,111)}^{**}$
		Std.dev.	0.07	0.03	0.03	0.02	0.03	0.05	0.07	
Rachis K	1.1 (% DM)	% DM	0.63_{a}	0.57_{a}	0.58_{a}	0.57_{a}	0.65_{a}	0.61_{a}	0.89_{a}	$1.833_{(6,111)}$
		Std.dev.	0.36	0.23	0.28	0.2	0.29	0.37	0.46	
Planting density		Mean	143.2_{a}	136.6_{ab}	134.0_{b}	142.6_{ab}	140.2_{ab}	137.3_{ab}	135.9_{ab}	$2.643_{(6,224)}^{*}$
		Std.Dev.	14.9	11.6	13.1	11.1	12.5	12.5	9.9	

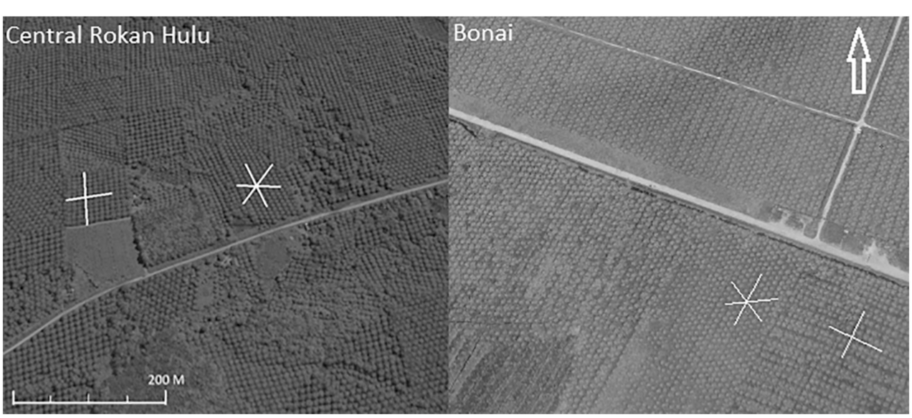

Fig. 2. Example of satellite imagery of smallholder plantations in Central Rokan Hulu and Bonai. Note the differences in planting patterns between smallholders, demonstrating rectangular planting patterns and triangular patterns. The left picture illustrates typical example of a mosaic of smallholder plantations in Central Rokan Hulu. The right picture illustrates straight plantation patterns and a large smallholder in the north of the picture (source: Google Earth, visited 16-12-2017).

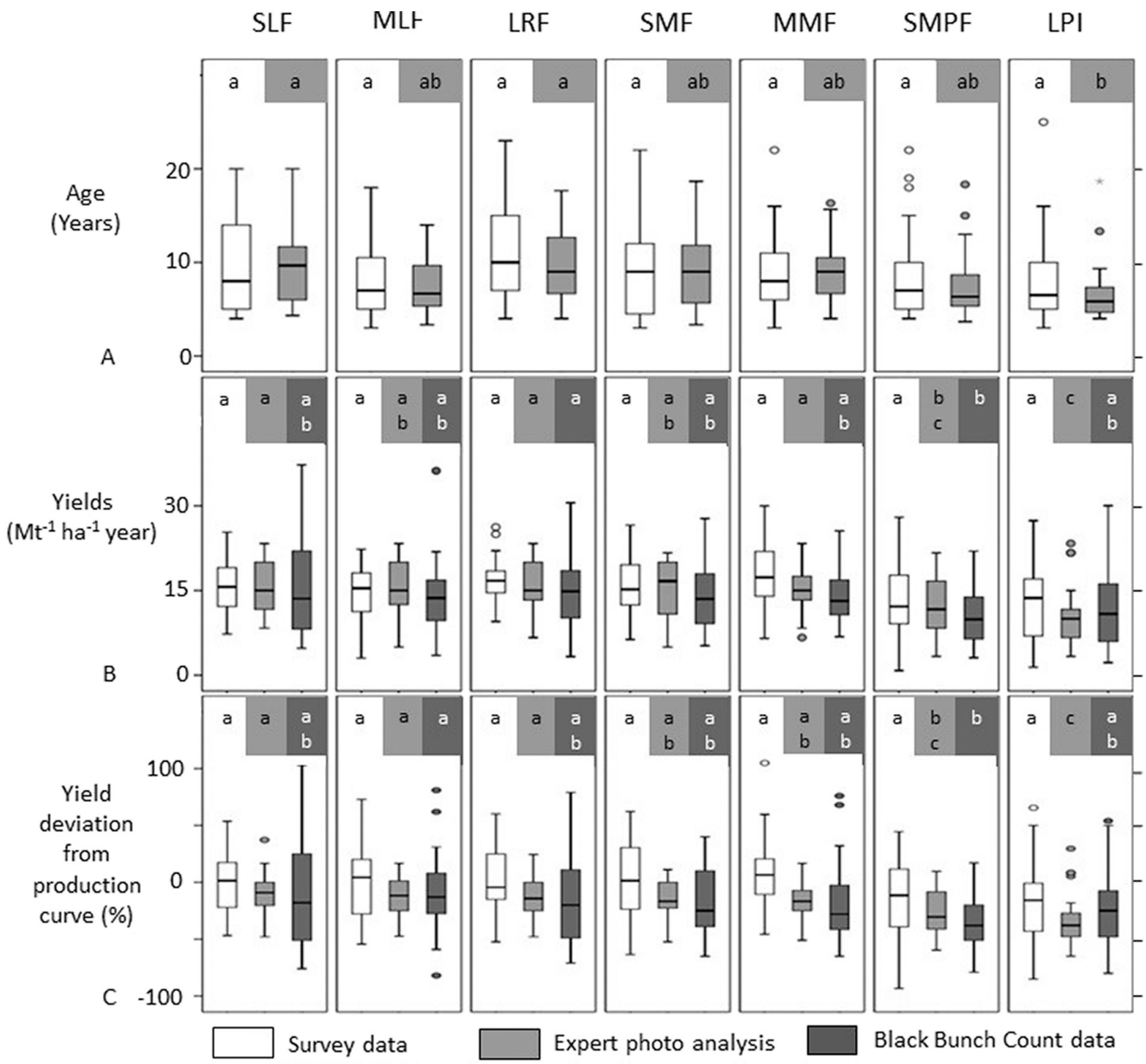

Fig. 3. Age and yield differences between farmer types using three different methods (SLF = Small Local Farmers, MLF = Medium Local Farmers, LRF = Large Resident Farmers, SMF = Small Migrant Farmers, MMF = Medium Migrant Farmers, SMPF = Small & Medium Peat Farmers, LPI = Large Peat Investors). Whiskers show the minimum and maximum values; the box shows the 1st and 3rd quartiles; the line shows the median. Values of > 1.5 interquartile range (IQR) are shown as circles, and > 3.0 IQR are shown as asterisks. Significance level $p < .05$. Pairwise significant differences are indicated per method only and not between methods.

farmers and the estimated offtake rates from Ng et al. (1999) to calculate the nutrient requirement.

The nutrient balances presented in Fig. 5 indicate that especially small local farmers had negative N, P and especially K balances. Potassium shortages were common among all farmer types, and < 75% of farmers applied enough K to sustain their estimated production levels. Peat farmers applied more Mg, mostly as Dolomite which is a cheap form of lime that farmers often believe to neutralize the acidic peat soils. However, the effectiveness of such a practice is probably limited, considering the high buffering capacity of peat soils (Bonneau et al., 1993).

4.3. Leaf and rachis analysis

Leaf and rachis samples from 118 plantations were analyzed to assess nutrient deficiencies. The results are displayed in Table 3.

Although there are some significant differences, our results indicate that the tissue concentrations of the different macro-nutrients (apart from Mg) were below the critical leaf and rachis concentrations on average for all sampled smallholder types, with especially K concentrations in leaf and rachis appearing very low. Peat farmers performed relatively well, and differences among farmers on mineral soils were minimal. Concentrations of micro-nutrients such as copper and boron were on average above critical values, except for copper in the plantations of large peat investors.

4.4. Good Agricultural Practices within smallholder plantations

In company plantations the layout usually entails a harvesting path between every two rows of palms followed by a *pasir mati*, or row with pruned dead leaves, which may be stacked as a row or in a u-shape around the palms, with the open end towards the harvesting paths. Neat rows or u-shapes facilitate easy access in the plantation, increase nutrient recycling and provide ground cover. Neat stacks were encountered more frequently in plantations on mineral soils than on peat soils, but differences between farmer types were not significant ($\chi^2 = 10.911$, df = 6, $p = .091$) (see Fig. 6). Significant differences among farmer types were observed regarding the presence of harvesting paths every second row ($\chi^2 = 13.317$, df = 6, $p = .038$), with small local and medium local and medium migrant farmers less likely to

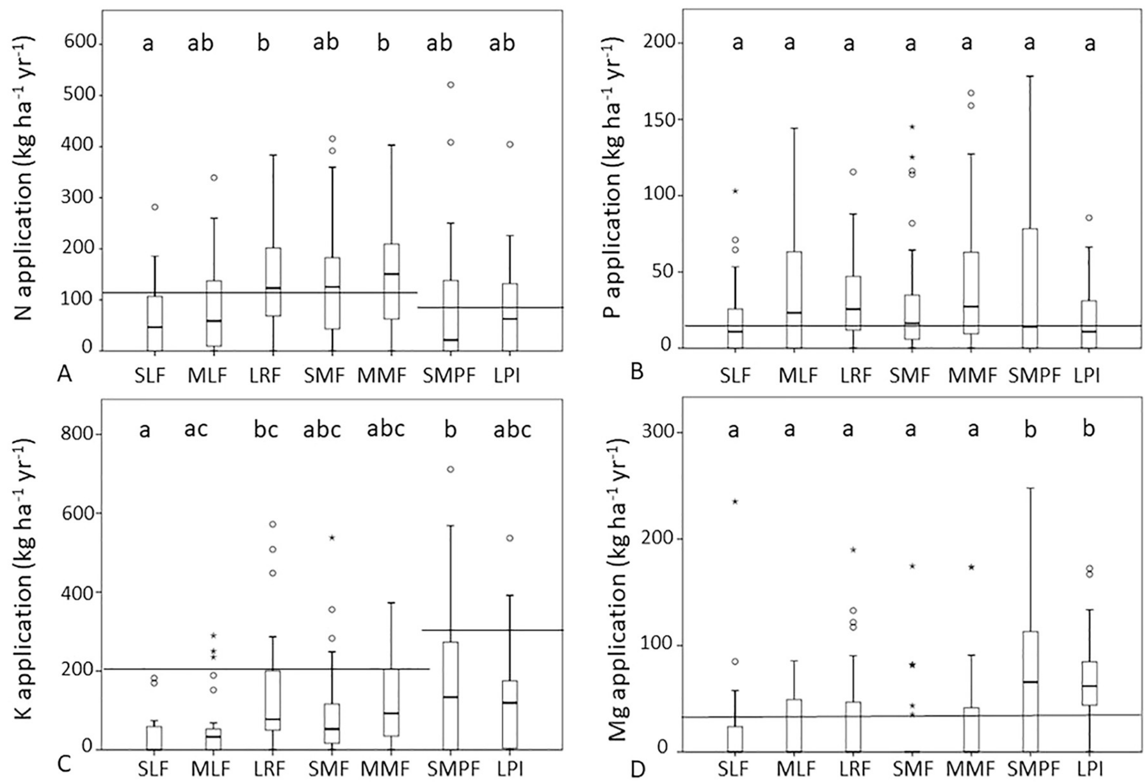

Fig. 4. Nutrient application rates per farmer type (SLF = Small Local Farmers, MLF = Medium Local Farmers, LRF = Large Resident Farmers, SMF = Small Migrant Farmers, MMF = Medium Migrant Farmers, SMPF = Small & Medium Peat Farmers, LPI = Large Peat Investors). Whiskers show the minimum and maximum values; the box shows the 1st and 3rd quartiles; the line shows the median. Values of > 1.5 interquartile range (IQR) are shown as circles, and > 3.0 IQR are shown as asterisks. Nutrient application outliers with values > 3.0 IQR in both combined sample and farmer groups were removed from further analysis. Horizontal lines indicate requirements at 20 Mt of FFB ha^{-1} $year^{-1}$ for mineral soils (first five farmer types) and separately for peat soils (last two farmer types) where N and K requirements are different. Significance level $p < .05$.

have harvesting paths every second row compared to especially small-medium peat farmers and large resident farmers. Although some palms may be less accessible due to lack of structured paths, access for harvesting within the plantations was generally good and there were no significant differences among farmer types ($\chi^2 = 7.743$, df = 6, $p = .258$). Farmers on mineral soils however had slightly better access within their plantations compared to peat farmers (see Fig. 6 for details on implementation of GAP). This was mostly due to problems with waterlogging and excessive weed growth in plantations on peat.

Survey data indicated that bare soils, which are prone to erosion and fertilizer run-off, were absent in 80%–91% of the plots, without significant differences among farmer types ($\chi^2 = 3.369$, df = 6, $p = .761$). This was in line with expert photo interpretations. Legume cover crops, which can fix nitrogen and suppress undesirable weeds such as *Imperata* and *Chromolaena*, were observed only in one farm (large resident farmer). Weeding was common practice among all smallholder types ($\chi^2 = 3.989$, df = 6, $p = .678$). There were differences in weeding methods between farmer types: manual or mechanical weeding were preferred by especially small local farmers and to a lesser extent by the other farmer types on the mineral soils ($\chi^2 = 24.070$, df = 6, $p = .001$), whilst peatland farmers were significantly more likely to implement chemical weeding ($\chi^2 = 33.190$, df = 6, $p = .000$). Absence of woody shrubs was used as an indicator of good weeding practices, but most plantations did contain woody weeds ($\chi^2 = 8.996$, df = 6, $p = .174$). Small local plantations were most commonly infested, with only 24% not having woody shrubs in their fields. In some large peat farms woody shrubs were difficult to spot as non-woody weeds covered everything. Circle weeding was common, and while small local farmers and large peat farmers were least likely to establish weeded circles, the differences among farmer types were not significant ($\chi^2 = 11.292$, df = 6, $p = .080$). Similarly, there were no significant differences in pruning practices among farmer types ($\chi^2 = 5.825$, df = 6, $p = .443$).

Regarding harvesting, we observed significant differences among farmer types, with large resident farmers and large peat farmers appearing more likely to adhere to harvesting cycles of 10 days or less compared with all other types (< 7%). Although more frequent harvesting cycles can be an indicator of high yields (see eg. Lee et al., 2013), we did not find significantly better yields among the larger farmer types. It may be that the harvesting frequencies from large farmers were inflated because of misinterpretations as larger farmers usually harvest more frequently due to their larger area, while in fact they are not harvesting the same palms more than once every two weeks. Excluding the large farmers, harvesting frequencies appeared very similar among remaining farmer types, with 97–100% indicating that they harvested every 14 days or twice per month.

Holistic plantation assessments by experts indicated only limited differences in plantation condition between farmer types (see Fig. 6). When averaging the assessments of all three experts for all farmer types, 17% of plantations were assessed to be in poor condition, 66% in reasonable condition and 18% in good condition. Whereas large resident farmers had the highest share of plantations in good condition (22%), they also had the second highest score on plantations in poor condition (21%). Large peat investors were assessed worst with on average 29% of plantations being assessed as in poor condition. Wilcoxon Signed Ranks Tests indicate no significant differences among expert assessment and two of the three experts did not see significant differences among farmer types ($\chi^2 = 9.186$, df = 12, $p = .687$ and $\chi^2 = 12.205$, df = 12, $p = .439$ respectively). Only the farmer expert indicated significant differences between farmer types ($\chi^2 = 27.290$, df = 12, $p = .007$),

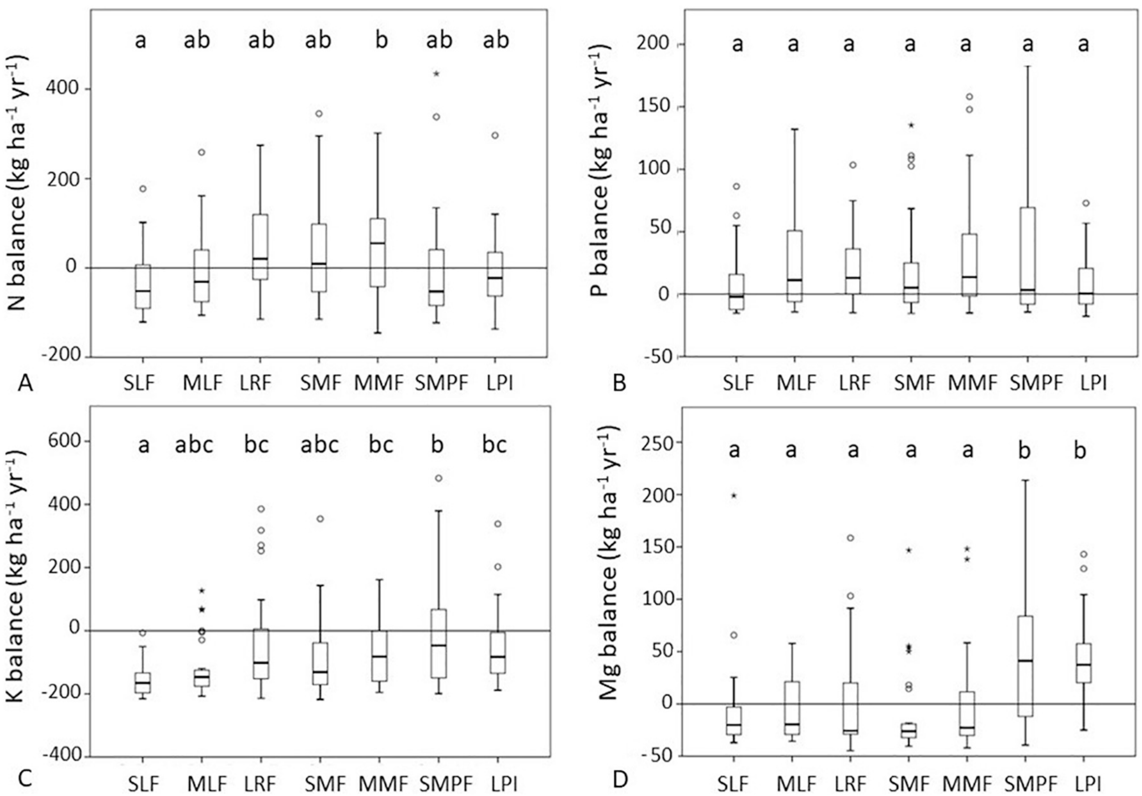

Fig. 5. Nutrient balances based on yield data provided by farmers per farmer type (SLF = Small Local Farmers, MLF = Medium Local Farmers, LRF = Large Resident Farmers, SMF = Small Migrant Farmers, MMF = Medium Migrant Farmers, SMPF = Small & Medium Peat Farmers, LPI = Large Peat Investors). Whiskers show the minimum and maximum values; the box shows the 1st and 3rd quartiles; the line shows the median. Values of > 1.5 interquartile range (IQR) are shown as circles, and > 3.0 IQR are shown as asterisks. Nutrient application outliers with values > 3.0 IQR in both combined sample and farmer groups were removed from further analysis. Significance level $p < .05$.

with conditions in large peat farmers plantations being assessed significantly poorer compared with other farmer types (see Supplementary Material 6).

There are also conditions which are more difficult and costly for individual farmers to correct once the plantation has been established. These conditions and differences among smallholder types are shown in Fig. 7. With regards to topography, the sampled smallholder plantations were fairly similar: most were flat or slightly hilly, with only a few large resident farmers and medium migrant farmers partially operating on steeper slopes. Terraces or other soil conservation measures were not present in the few plantations on steep slopes. Sub-Fig. 7C and D show that feeder roads (linking plantations to main roads) and main roads in the peatlands are of significantly poorer quality than the roads on mineral soils ($\chi^2 = 7.204$, df = 6, $p = .302$ and $\chi^2 = 45.842$, df = 6, $p = .000$ respectively).

There were significant differences in planting patterns between farmer types. The vast majority of large peat farmers implemented correct triangular patterns, compared with only 33% of the small local and small migrant farmers ($\chi^2 = 31.908$, df = 6, p = .000). With 143.2 palms ha^{-1} on average, small local farmers tended to plant fairly densely and significantly denser than large resident farmers, who had the lowest average density with 134.0 palms ha^{-1} (see Table 3). Although we observed some variation in planting densities within farmer types, average planting densities per farmer type were quite similar and in line with commonly recommended planting densities of 136–143 palms per hectare (Uexküll et al., 2003). Monocropping was standard practice among all smallholder farmer types ($\chi^2 = 4.381$, df = 6, $p = .625$), but with some pineapple cultivation observed in peatlands and rubber and cocoa intercropping observed on mineral soils.

Planting material data highlights that Dura palms were common among all farmer types. Most plantations had > 50% Dura palms on average. Smaller and medium farmers on several occasions mentioned Dura fruits desirable as the large kernels are heavy and farmers are paid per kilo by the middlemen, rather than for fruit quality. However, on mineral soils (only) a linear regression model indicated that bunch numbers significantly increase with share of Tenera in plantings (see Supplementary Material 7 for details). The share of farms with > 95% Tenera fruits was low among all farmer types but there were significant differences, with 17% of larger peat farmers and 7% of large resident farmers having > 95% Tenera, while medium local or small migrant farmers never had > 95% Tenera fruits ($\chi^2 = 14.025$, df = 6, $p = .029$). A share of > 50% Dura palms was common among especially small local and small migrant farmers and differences among farmer types were significant, with large farmers performing better ($\chi^2 = 28.283$, df = 6, $p = .000$).

5. Discussion

Our results have shown, through fertilizer application practices, nutrient balances and tissue nutrient concentrations, that fertilizer application rates among the various farmer types were limited, particularly for K. Potassium deficiencies were common in our sample, and have been observed in samples from independent smallholder plantations in Jambi and West Kalimantan (Woittiez et al., 2018). Active knowledge dissemination on the importance and necessity of balanced nutrition for good productivity in oil palm, combined with efforts to make the required fertilizers accessible to, and affordable for independent smallholders, are important measures to improve the nutritional status and productivity of smallholder plantations. Trainings on the specific nutrient requirements of plantations on peat would be an example of a targeted measure to increase efficient use of fertilizers. The application of EFB was uncommon among all smallholder types,

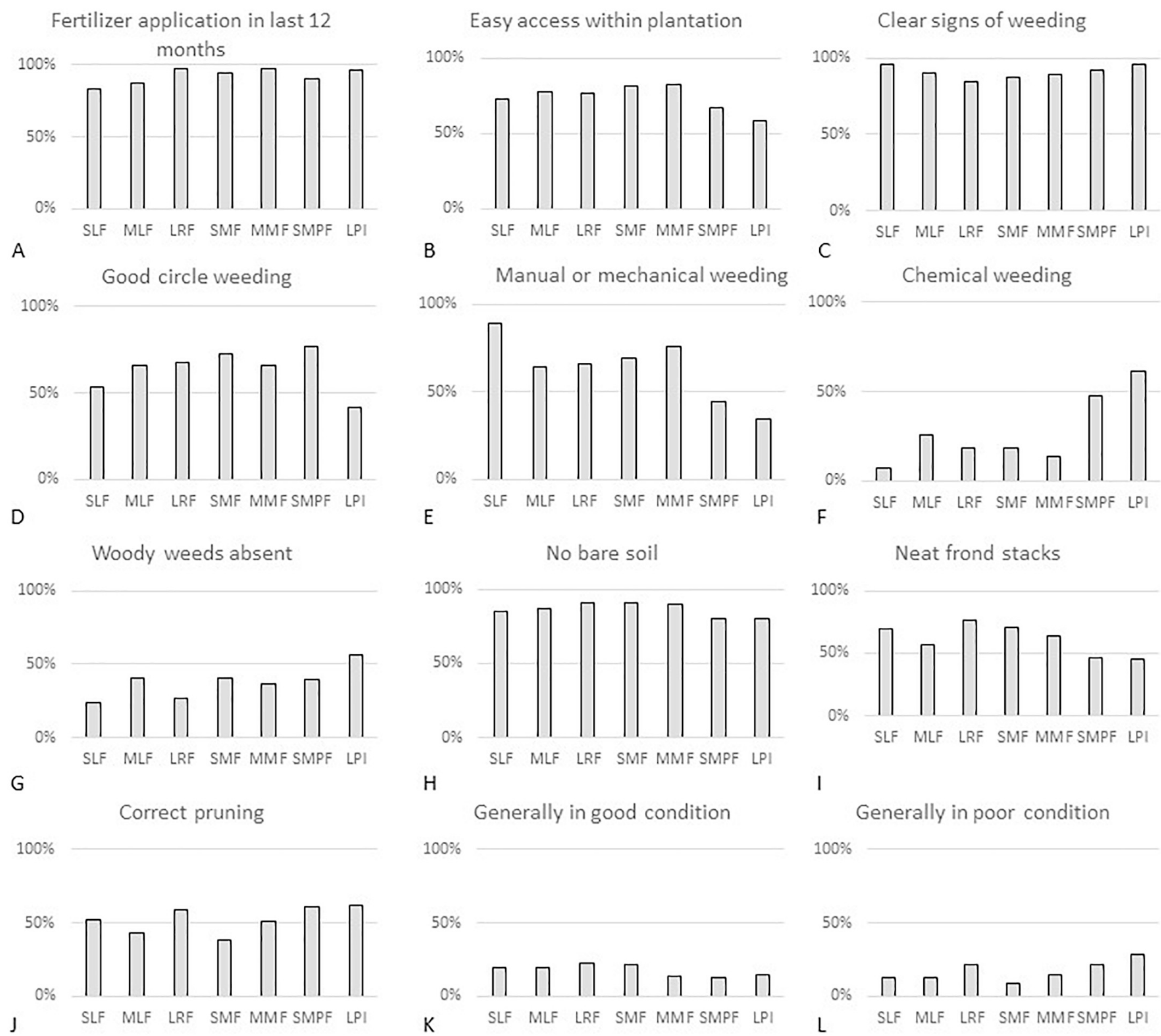

Fig. 6. Share of farmers per farmer type that implement flexible GAP (SLF = Small Local Farmers, MLF = Medium Local Farmers, LRF = Large Resident Farmers, SMF = Small Migrant Farmers, MMF = Medium Migrant Farmers, SMPF = Small & Medium Peat Farmers, LPI = Large Peat Investors). Sub-Fig. 6K and L refer to expert photo assessments of management practices. Y-axis indicate share of farmer, x-axis shows farmer types.

indicating that there is space to improve nutrient cycling and reduce nutrient outflow from smallholder plantations. Besides educating farmers about the well documented advantages of EFB application (Comte et al., 2013; Woittiez et al., 2018), improving linkages between mills and farmers and promoting the return of EFB to smallholders appears a worthwhile strategy to improve nutrient balances and soil management of smallholders. We found it striking that five of the seven farmers who do use EFB were large farmers, who have better direct access to mills compared to small and medium farmers who usually sell to middlemen and have no direct link with mills (Jelsma et al., 2017a). Whereas Soliman et al. (2016) claims that fertilizer usage does not need to increase, based on N application only, results in this study show that N rates on average indeed appear enough for large resident and migrant farmers to produce 20 Mt of FFB ha^{-1} $year^{-1}$, but that in general quantities of nutrients provided are too limited to produce and sustain large yields.

Planting materials were often of substandard quality, limiting the potential for yield increases through the implementation of GAP. Besides limiting FFB yield potential, Dura bunches also contain around 30% less oil (Corley, 2009), thereby reducing oil yields substantially and partially explaining low FFB prices for farmers as middlemen generally do not differentiate in prices for quality or variety differences for individual farmers (Jelsma et al., 2017a). Dura palms were particularly prevalent in plantations of small local and small migrant farmers, often in combination with square planting patterns. These farmers often use uncertified planting materials, which are easily available as either loose fruits or via illicit seedling traders who are not hindered in their activities by the local authorities, whilst large farmers appear to have better access to official seedling producers and have more capital available for planting material. During discussions with leading seed producing companies during the 2018 annual GAPKI meeting, we were informed that efforts of companies to reach out to independent smallholders are limited to providing seeds at a reduced price, while the crucial aspect of easy and local access, including

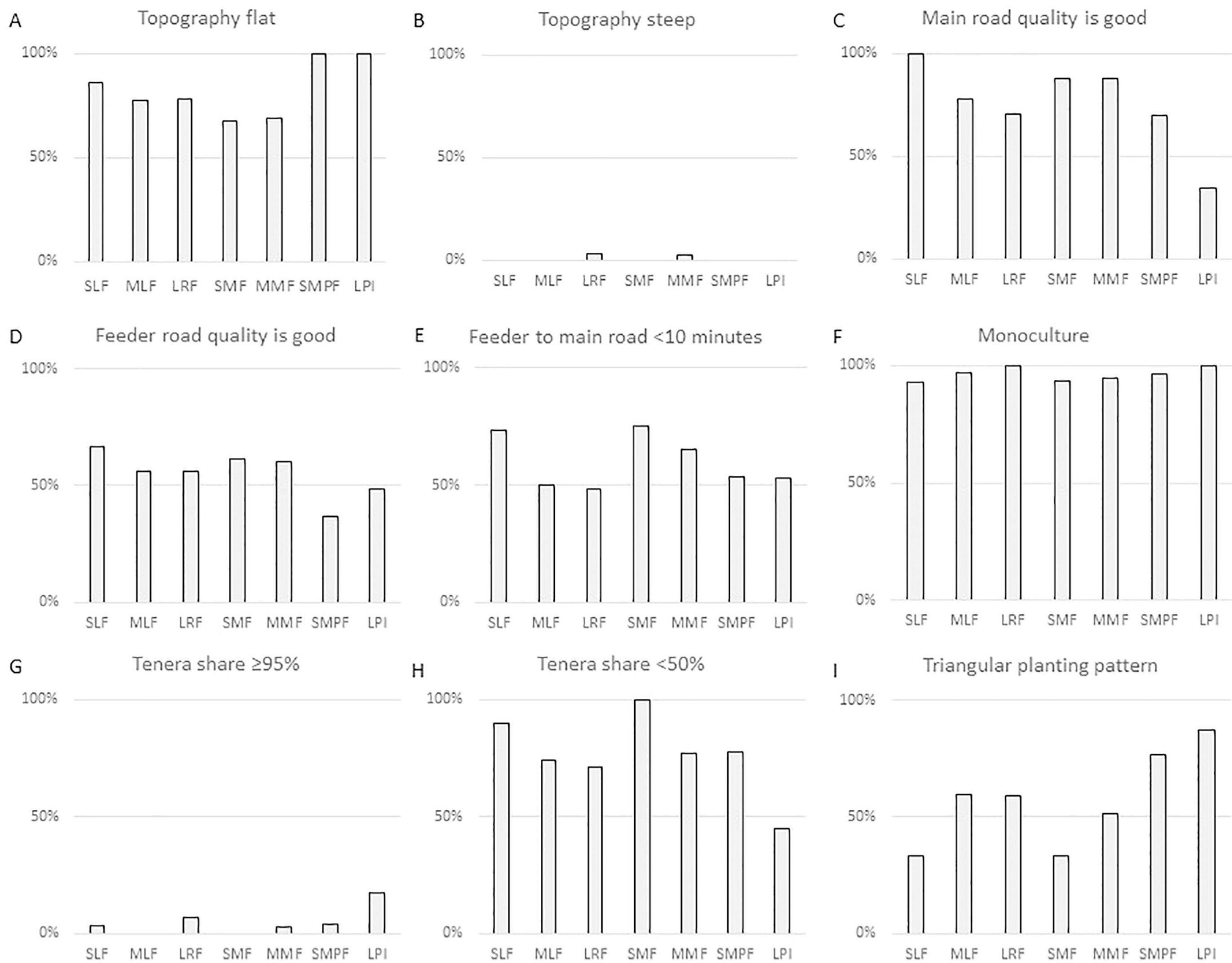

Fig. 7. Semi-permanent plantation conditions among different farmer types (SLF = Small Local Farmers, MLF = Medium Local Farmers, LRF = Large Resident Farmers, SMF = Small Migrant Farmers, MMF = Medium Migrant Farmers, SMPF = Small & Medium Peat Farmers, LPI = Large Peat Investors). Y-axis in sub-figures indicate share of farmers with plantation condition, x-axis shows farmer types.

administrative requirements and costs, remains a key obstacle for smallholders to purchasing certified planting materials. Only the Indonesian Oil Palm Research Institute regularly went to villages with three cars and sold seeds in Sumatra (interviews, 1–3 November 2017). Industrial oil palm producers, banks and the Government of Indonesia, through the CPO fund (DJP, 2017a), do support replanting efforts for smallholders and we recommend to increase awareness campaigns which demonstrate potential yield losses due to poor planting material, correct planting patterns and the relatively limited costs of high-quality planting materials, increase the number of distribution centres with high-quality planting materials in combination with banning non-certified seedling sellers and possibly subsidize proper planting material. However, impacts on current farmers will be limited as palm stands are often young and especially smaller and poorer farmers are unlikely to cut their young palms and accept an additional three years without income until their palms yield again. The negative effects of square planting patterns, which significantly reduce the growth and yield potential of the palms due to reduced availability of sunlight, can be reduced however by selective thinning (Uexküll et al., 2003) and rigorous pruning. Although there is support through the CPO fund, the chairman of the union of smallholder oil palm farmers has expressed its fear of '*plasmafication*' of independent smallholders (SPKS, 2018), referring to being locked into undesirable relations with companies, banks and the bureaucracy; this is a key reason why the previous *Revitalization* policy aimed at supporting smallholder with replanting failed (Zen et al., 2016).

Good planting and nutrient application practices need to be accompanied by other GAP if intensification of the smallholder sector is to be achieved. Our results show that pruning, weeding, use of legume cover crops, and frond stacking practices are similar among all farmer types, and generally require improvement. Knowledge transfer to smallholders on good practices in oil palm cultivation has been limited in our research areas, with farmers receiving very little formal training, and with most knowledge coming from their input suppliers and their fellow farmers (Woittiez et al., 2018; Jelsma et al., 2017a). Although the organisation of smallholders into cooperatives or groups is a key condition for RSPO or ISPO certification, and while there is evidence that organized oil palm smallholders can maintain high-input high output systems (Jelsma et al., 2017b), there are many barriers to improving practices. In Indonesia the extension services are weak, knowledge on GAP and certification is not widely available, and strong institutional structures through which knowledge can be readily distributed among smallholder farmers are rarely in place (Brandi et al., 2015; Hidayat, 2017). To add to this complexity, strategies need to be tailored to specific types of farmers in order to be effective. Ideally this would constitute easy access to quality information via local farmer training centres run by companies in collaboration with government to support small and medium farmers who mostly reside locally. Large peat investors might require a different approach as the scale of their activities is much larger and their environment poses different challenges. Yields in peat plantations were significantly less, which may be attributable to higher degrees of absenteeism, speculative investment decisions, difficulties in collecting FFB due to flooding in the rainy season and other agro-ecological difficulties of peat soils relative to mineral soils for cultivating oil palm.

Although a straight comparison is difficult due to different methodologies, there are clear similarities in the types of farmers identified by McCarthy & Zen (2016) and the types used in our study. The "prosperous farmers" identified by McCarthy & Zen (2016) appear similar to the large farmer types identified in Jelsma et al. (2017a) as they have considerable land holdings and considerable capital but still use poor planting materials as they lack access to proper planting materials. The poor farmers mentioned by McCarthy are mainly local Melayu farmers who are '…*trapped between their on-farm activities and work as labourers, with little time to invest in improving their plots*', and indeed especially small local farmers appear to use least fertilizers or herbicides. Medium local and medium migrant farmers could be associated with progressive farmers mentioned by McCarthy & Zen (2016), as they have larger oil palm holdings compared to poor farmers, frequently have other jobs as e.g. civil servants and hardly work as labourers (Jelsma, et al. 2017a). However, although McCarthy claims that prosperous farmers invest more in fertilizers and labour, and thus have relatively better yields than poor or progressive farmers, we did not find evidence for this. For this reason, we believe that improving enabling conditions for implementation of GAP is relevant for all farmer types.

The lack of technical and institutional support regarding the management of smallholder plantations needs to be placed in a broader framework of constraints hindering the implementation of GAP and yield intensification. Poorly developed and maintained infrastructure such as roads and waterworks hamper intensification. Among large peat farmers the lack of coordinated drainage systems was problematic. For the more remote farmers on (hilly) mineral soils the infrastructure was especially poor. These areas were relatively often occupied by larger farmers and during surveys and interviews, caretakers indicated that during the rainy season not all fruits were harvested due to poor accessibility of parts of their plantations. Besides flooding, the frequent occurrence of fire in peatlands increases the risks for farmers on loss of investments (Gaveau et al., 2014; Purnomo et al., 2017). Such major risks do not provide a conducive environment for investments in GAP. Measures such as infrastructure development and fire prevention are relevant prerequisites for the implementation of GAP and for yield intensification.

Labour is known as a key constraint for intensive smallholder oil palm cultivation (Soliman et al., 2016) and appears to be a key reason why farmers prefer oil palm over rubber (Euler et al., 2017; Feintrenie et al., 2010). Whereas sufficient well-trained labour force is a requirement for the implementation of GAP, labour issues are also a concern for companies, with rising labour costs being the 'silent killers' of profitability as productivity barely increased over the past 20 years (Liwang, 2017). Labour costs are relevant for smallholder oil palm farming as many of the surveyed farmers employed labourers as well (Jelsma et al., 2017a). As workers are paid at a piecemeal rate, their interest is in harvesting or pruning as many palms as possible in the shortest possible timeframe rather than in performing activities well. For this reason, the implementation of GAP would require considerable monitoring by farmers. Benefits associated with smallholder farming, such as ease of monitoring the fields and having a direct interest in production (Hazell et al., 2010; Hayami, 2010; Bissonnette and De Koninck, 2017), appear to be only of limited relevance for certain smallholder oil palm farmer types. This highlights the grey area between smallholders as family farmers and as company plantations (Bissonnette and De Koninck, 2017). The grey area was strongly observed in the peatlands, where managers of large farmers often complained about the limited number of workers (mostly migrants who were housed in barracks on the plantation). With peat farmers often residing outside the district (Jelsma et al., 2017a), labour and monitoring appear issues in the frontier, complicating the implementation of GAP.

We believe that further research is required to determine to what extent smallholder oil palm is cultivated for income from yields or for speculative purposes as transforming 'empty lands' into oil palm plantations provides profits for many actors (see eg. Purnomo et al., 2017; Prabowo et al., 2017). Many plantations in the peatlands are located within the forestry domain and neither companies nor government are legally allowed to support farmers in these illegally obtained lands. Land documentation among especially peat farmers and local farmers, and to a lesser extent migrant farmers, are often not fully recognized by the State (Jelsma et al., 2017a). This creates risks for the owners and reduces the interest in yield intensification measures, which take time before the investments pay off. Intensification is especially relevant when populations are increasing, and land is scarce, but this is not the case in large parts of the Indonesian outer islands. In Rokan Hulu logging and oil palm companies recently developed the infrastructure necessary to open new lands, and land is now more easily available than labour (Feintrenie et al., 2010). Although for large companies opportunities for expansion are limited nowadays, there still are plenty of smaller 'empty' lands which appear to be grabbed by relatively small scale investors (Bissonnette and De Koninck, 2017; Susanti and Maryudi, 2016). Whilst the goal of intensification for land saving appears worthwhile, a Jevon's paradox lurks as intensification makes it more interesting to transform land into oil palm. Intensification programs therefore need to be accompanied with proper land use regulations, monitoring and enforcement, if the aim is to improve sustainability of the sector.

In this research, multiple methods were used to assess performance of the different types of smallholders. Uncertainties associated with surveys are that farmers often do not maintain farm records, and true plantation sizes are often slightly different compared to what smallholders mention. Yield estimates based on BBC are prone to errors in field assessments (it is known ripe bunches were included, slightly inflating yields), and other assumptions, all impacting yield calculations. Nutrient balances and leaf and rachis analysis are common methods to assess nutrient conditions in company oil palm plantations. However, although the single critical values can provide indicators for the nutritional status of palms, in fact these thresholds are not static as nutrient concentrations vary with palm age, conditions and environment. Commonly used critical values are often developed in older planting materials and should therefore be taken as indicative only and interpreted together with yield and fertilizer application data and visual symptoms in the field (Fairhurst and Mutert, 1999; Corley, 2009). However, as the main objective of this study was to compare performance of different types of smallholders and not to develop targeted fertilizer regimes, the values provided are sufficient to use as a benchmark. Photo interpretations allowed different experts to share their expertise and assess plantations but cannot replace field visits. The diversity of tools applied in this study proved sensitive enough to detect differences among a broad range of smallholder types and landscapes in which they operate and provide a fairly consistent overview of smallholder plantation conditions. Results indicate much space for improvements in independent smallholder practices and are in line with previous publications (Soliman et al., 2016; Woittiez et al., 2018; Molenaar et al., 2013).

6. Conclusion

The independent smallholder oil palm sector can be portrayed as the Achilles heel for the oil palm sector's sustainability. Although our research included a wide variety of farmer types, differences between farmers types in the adoption of GAP was limited, and we observed poor yields among all independent smallholder types in this study. Our results suggest that the notion that larger, more capitalized farmers are significantly more likely to invest in GAP does not hold. The underlying reasons are plentiful. Small local and migrant farmers are locked in a system that is not amenable to investment and can have limited yield potential due to poor planting patterns and materials. Recent programs aimed at increasing access to finance for purchasing proper planting materials or fertilizers could increase yield potential with these groups. However, seeing that larger farmers for whom financial capital is comparatively accessible are not more likely to invest in GAP than smaller less capitalized farmers, it is uncertain that enhancing access to finance will lead to significant changes in practice. Farmer choices are informed by a complex amalgam of factors including, but not limited to, access to labour and knowledge, alternative crops and livelihoods, quality of infrastructure, fire threats, legal status of plantations, land markets, government policies and changes therein, market access and price uncertainty of produce, and other risk assessments farmers make. While we acknowledge the limitations of our research (e.g. sample size, limited geographical coverage), our results show that under current conditions smallholders across the board prefer a low-input low-output strategy, for various reasons. This poses a significant challenge for initiatives such as ISPO, RSPO and other promotors of GAP, and could result in increased marginalization of independent smallholders if sustainability thresholds are raised. In order to support further GAP implementation, we recommend future research to identify and quantify farmer aspirations and strategies as they relate to intensification, and to employ approaches that acknowledge farmers' diversity and the environments in which they operate, but also acknowledge that certain types of farmers e.g. poorly performing peat farmers who operate in the forestry domain on recently deforested land, might have to be excluded from the value chain to improve sector sustainability. Linking performance to land reclassification and legalization in peatlands might be a pathway to increase sector sustainability as well. Meanwhile, policy makers should increase efforts to make proper planting materials and knowledge on GAP available to smallholders, as a first requirement for intensification. Government bodies and NGOs should look for support from industry partners who have the technical expertise and who can be an important source of investment into the sub-sector. If sustainability of the sector is to be improved, it is imperative however to look beyond implementation of GAP and there is a clear need to acknowledge the broader context in which farmers operate.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.agsy.2018.11.004.

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