Analysis of a pineapple-oil palm intercropping system in Malaysia

MSc Thesis Plant Production Systems

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Acronyms & definitions

Johor Department of Agriculture: Jabatan Pertanian Negeri Johor
MARDI : Malaysian Agricultural Research and Development Institute
MISI: Malaysia Institute for Supply chain Innovations
MPIB: Malaysian Pineapple Industry Board
MPOB: Malaysian Palm Oil Board
P&G: Procter & Gamble
UTHM: Universiti Tun Hussein Onn Malaysia

BCR: Benefit-cost ratio
CT: (a pineapple plant) directly next to an oil palm, Close-to-Tree
FFB: Fresh Fruit Bunch
FT: (a pineapple plant) exactly in the middle of three neighbouring palms, Far-from-Tree
MAP: Months After Planting
P_{cs}: Petiole cross-section area
P-density: Pineapple planting density
YAP: Years After Planting

Contractor: A person who manages oil palm fields of clients, in return for a reward per ton FFB production. Most contractors hire workers to carry out the maintenance.

Dealer/oil palm dealer: The middleman who manages collection and transport of FFB from farmers' fields, to his collection centre, to a nearby palm oil mill in return for a reward per ton FFB.

Establishment intercropping: The practice to intercrop immature oil palms with (food) crops.

Farmer: The person deciding on the oil palm and/or pineapple management of a field. The farmer is not necessarily the field owner or the person carrying out the management.

Farming system: A distinctive set of agricultural, economic and social structures and functions at field level, including for example the cropping system, input and output costs and land ownership.

Pineapple dealer: The middleman who buys pineapples from farmers and sells pineapples to the next parties in the supply chain.

Abstract

In Malaysia, the second largest producer of palm oil globally, about a third of all oil palm planted area is managed by smallholder farmers. An increase of the average yields of these smallholders is needed to meet the rising demand for vegetable oil and prevent further loss of tropical rainforest. One strategy to increase yields is to enable timely replanting of aged oil palm fields.

A method to enable replanting as practised by smallholder farmers on peat soil on Johor is pineapple-oil palm establishment intercropping. To assess the potential of this farming system to sustainably increase smallholder yields, this study aimed to understand the environmental, economic and social effects of pineapple-oil palm intercropping and to formulate recommendations for improvement of the sustainability of pineapple-oil palm intercropping on peat soil.

Data on oil palm and pineapple growth and productivity and on agronomic, economic and social aspects of this farming system have been gathered in Johor through field measurements, key informant interviews and farmer interviews. Statistical analysis of crop data and descriptive analysis of farming system information provided an overview of the most important sustainability issues. These issues were used for a Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis.

The results showed that pineapple-oil palm intercropping has large positive economic effects, providing farmers an average income of US$21 000 ha^{-1} over the four-year intercropping period. No significant negative effects of intercropping on oil palm and pineapple growth and productivity could be found. On the other hand, smallholders used practices which increased negative environmental effects of cultivation on peat soil, such as burning of crop residues and suboptimal fertilisation.

It is concluded that pineapple-oil palm establishment intercropping can increase smallholder yields. However, to do so sustainably it is needed to find alternative pineapple removal methods, formulate good agricultural practices and confirm that this intercropping system has no negative effects on palm oil yields throughout the whole palm life cycle.

Contents

1. Introduction

Few products generate such controversy and public debate as palm oil. From being a minor crop in the 1960s, palm oil has become the world's main vegetable oil since 2005. In 2017, global production exceeded 69 million ton, versus 55 million ton for soybean and 27 million ton for rapeseed, the numbers two and three most important vegetable oils (USDA, 2018b). Demand for palm oil, and vegetable oil in general, has been rising due to increased human consumption and increased use of biodiesel. As population and wealth of many developing countries are still growing, demand is projected to keep rising, though at a slower pace than in the previous decades (OECD & FAO, 2018).

Palm oil production has multiple advantages. The oil palm (*Elaeis guineensis* Jacq.) is a highly productive species: its average oil yield (3.68 t ha^{-1} yr^{-1}) is ten times higher than that of soybean (0.36 t ha^{-1} yr^{-1}) (Basiron, 2007). Fruit bunches are harvested year-round and deliver the main products, crude palm oil (CPO) and palm-kernel oil (PKO). It is a profitable crop in industrial plantations and has been adopted by many smallholders as an attractive new income opportunity, leading to increased livelihoods and welfare (Basiron, 2007; Rist et al., 2010; Sheil et al., 2009).

At the same time, palm oil is suffering from a bad reputation among European consumers. Expansion of oil palm planted area is assumed to be a driver of deforestation, especially in Malaysia and Indonesia. Figures are uncertain, but it has been suggested that between 1990 and 2005, over 50% of expansion occurred at the expense of forests (Koh & Wilcove, 2008). As a result, palm oil production is associated with environmental problems such as biodiversity loss, forest fires, peat degradation, water pollution and greenhouse gas emissions. In addition, social injustices linked to palm oil production like land grabbing, exploitation of plantation labourers and market monopolisation are not yet eradicated, despite establishment of certification schemes (Corley & Tinker, 2016b; Kusumaningtyas, 2018; Li, 2015).

What's more, actual yields from oil palm plantations are considerably lower than potential yields, especially among smallholders. While maximum theoretical oil yields of 18.5 t ha^{-1} yr^{-1} have been calculated and peak oil yields of 12 t ha^{-1} yr^{-1} have been achieved, the average productivity worldwide is currently only 3.68 t oil ha^{-1} yr^{-1} (Woittiez et al., 2017). Considering the rising demand for vegetable oil and the negative effects associated with the expansion of oil palm planted area, these yield gaps are an important problem. Reducing these yield gaps in ways that are environmentally sound, can help to increase palm oil production while preventing further loss of tropical rainforests.

1.1 Malaysia and the importance of smallholders

Malaysia is the second largest producer of palm oil in the world, following after neighbouring country Indonesia. In 2017, oil palm production in these two countries accounted for 28 and 56% of the global production (USDA, 2018a). Malaysia and Indonesia have an especially suitable climate for oil palms, characterised by high temperatures and frequent rainfall. In Malaysia, temperatures range between 25 and 33°C year-round. Rainfall is evenly distributed throughout the year and adds up to 2000 mm annually (Basiron, 2007). In 2016, 8.1% of the Malaysian Gross Domestic Product (GDP) was earned by the agricultural sector, with 43% of the agricultural GDP coming from oil palm (Departments of Statistics Malaysia, 2017).

In 2017, 17.7% of the total Malaysian land area was planted with oil palm (FAOSTAT, 2017; MPOB, 2017). Oil palm plantations are either under management of private estates, governmental schemes or independent smallholders. Smallholders are defined by the Roundtable on Sustainable Palm Oil (RSPO) as family-based farms producing palm oil from less than 50 ha of land. Smallholders produce palm oil either in cooperation with governmental schemes or independently, selling their fruit directly to local mills through dealers (RSPO, 2018).

Distribution of oil palm planted area over the different management categories is shown in Table 1. Estimating that at least half of the area under governmental schemes consists of smallholder land, it can be concluded that almost a third of all oil palm planted area in Malaysia is managed by smallholders. Improving smallholder productivity and practices is thus an important step towards a sustainable future for the palm oil industry. Even more so because smallholders often lag behind large plantations in terms of yield (Woittiez et al., 2017) and because there is little empirical evidence about the environmental performance of smallholders (Vermeulen & Goad, 2006). The challenge is to identify, develop and share good practices among smallholders.

Table 1. Distribution of oil palm planted area by management category in Malaysia, 2017. Data source: (MPOB, 2017).

	Area (ha)	Proportion (%)
Private estates	3 543 429	61.0
Governmental schemes	1 287 958	22.1
Independent smallholders	979 758	16.9
Total	5 811 145	100.0

1.2 The potential of intercropping

Compared to large plantations, smallholders have different issues to take into account when making their management decisions. First of all, smallholders have less access to good quality seed stock, sufficient fertilisers and large constructions like drainage canals, dams and flood gates (Woittiez et al., 2017). Furthermore, smallholders are vulnerable to price fluctuations, especially if they rely on palm oil as their main source of income (Vermeulen & Goad, 2006). Last, replanting of aged oil palms can be difficult, as this simultaneously requires investments and deprives smallholders of income from palm oil for a few years (McCarthy, 2010). Still, timely replanting of oil palm is important to maintain high productivity and decrease yield gaps. This challenge is addressed specifically in this research.

One strategy of smallholders to cope with the challenge of replanting is to intercrop immature oil palms with (food) crops. Corley & Tinker (2016b) termed this practice ‘establishment intercropping’. Even though oil palm is generally regarded as a monoculture crop, establishment intercropping is a widespread practice among smallholders (Nchanji et al., 2016). During the first years after planting of oil palm, there is sufficient space and light in between the palm seedlings to grow a second crop. This intercropping ceases when the palm canopy closes, which happens after two to four years.

The effects of such intercropping can be multiple. Negative impacts on growth and future yields of the palms could arise due to competition for nutrients, water and light with the intercrop. On the other hand, intercropping can have positive impacts such as protection of the soil from erosion and reduction of weeding costs. Especially important for smallholders, intercropping was shown to provide significant food and income during the years that the oil palms were not yet producing (Koczberski et al., 2012; Nchanji et al., 2016). In an ideal situation, establishment intercropping would have positive environmental, economic and social effects during the replanting period, and no or positive effects on oil palm productivity during the whole palm life cycle.

Only a few studies have reported the effects of establishment intercropping on the growth of oil palms and results were somewhat mixed. Rafflegeau et al. (2010) compared leaf N and K contents in mature palms on smallholder plantations in Cameroon and found a significant correlation between N-deficiency in mature palms and intercropping with food crops in the immature phase. Similarly, inflorescence sex-ratio (the ratio of female to total inflorescences, an index for productivity) was found to be lower in intercropped than in monoculture palms, three years after planting (Erhabor & Filson, 1999). Interestingly, root distribution patterns of monoculture and intercropping palms were the same when investigated two years after planting (Erhabor et al., 2002). Finally, Okyere et al. (2014) followed the growth and yield of oil palms which had been intercropped with food crops up to thirteen years after planting. Compared to oil palms that had been cultivated with a common leguminous cover crop (*Pueraria phaseoloides*), they found no significant differences in oil palm growth and yield. Together, these results suggest that establishment intercropping can negatively influence palms both in the short and long term, but such a negative influence does not always occur.

1.3 Oil palm and pineapple cultivation on peat

One example of an establishment intercropping system as practised by smallholder farmers is the pineapple-oil palm intercropping system in Johor, the most southern state of Peninsular Malaysia. Farmers plant pineapples as cash crop in-between immature palms while waiting for the palms to come into production (M. Slingerland, personal communication, October 16, 2018). These farmers are situated on peatland, a soil type known for its sensitivity to degradation.

Oil palm cultivation on tropical peatland is a controversial practice. Peatlands are globally important terrestrial carbon pools, storing carbon by preserving C-rich biomass (Page et al., 2011). Conversion and cultivation of peatland involves deforestation and drainage, causing biodiversity loss, oxidation, greenhouse gas (GHG) emissions and soil subsidence. In peatlands located near the coast, continued subsidence can eventually lead to increased occurrence of flooding and salt water intrusion (Schrier-Uijl et al., 2013).

Furthermore, peat soil characteristics constrain oil palm yields and good management practices are required to maintain productivity (Corley & Tinker, 2016h; Woittiez et al., 2017). Ground water level should be kept at 50–75 cm from the peat surface to restrain peat oxidation but provide sufficient rooting depth to prevent leaning (Corley & Tinker, 2016g; Lim et al., 2012). Fertilisation with a large rate of potassium and additional copper and zinc is necessary to compensate the low and unbalanced nutrient content of peat (Lim et al., 2012). The general optimum fixed planting density is 140–160 palms ha^{-1} in a 9 m equilateral triangular pattern (Figure 1A). On peat, optimum planting densities are slightly higher (Woittiez et al., 2017). For more information on oil palm cultivation, morphology and growth, see Appendices 1, 2 and 3.

In Malaysia, pineapple cultivation on peat is a common practice performed both by plantations and smallholders (Ahmed et al., 2001; Hanafi et al., 2009). However, pineapple cultivation on peat brings about similar disadvantages and challenges as oil palm cultivation on peat. Pineapples are relatively well adapted to drought, but require good drainage (Coppens d'Eeckenbrugge & Leal, 2003; Hepton, 2003; Malézieux et al., 2003). Like oil palms, pineapples need a high amount of potassium. Additionally,

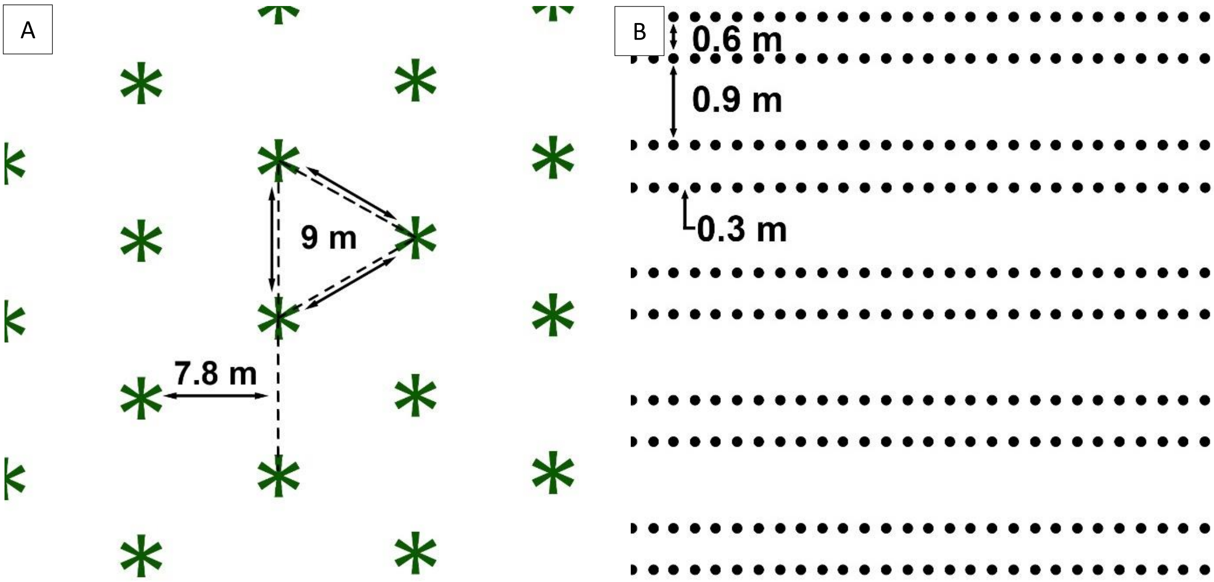

Figure 1. A: 9 m triangular oil palm planting pattern. **B**: Double-row 30x60x90 cm pineapple planting pattern.

zinc, copper and iron sulphates may be applied (MPIB, n.d.). Generally recommended planting density in Malaysia is approximately 43 500 plants ha^{-1}, in a double-row system of 30x60x90 cm (Figure 1B) (Mohd Selamat & Ramlah, 1993; MPIB, n.d.). For more information on pineapple cultivation, morphology and growth, see Appendices 4, 5 and 6.

No previous reports on pineapple-oil palm intercropping could be found. Pineapple has been used successfully as intercrop in coconut plantations, enhancing economic returns and soil fertility without affecting coconut yield (Akus et al., 2001; Sudha & George, 2011; Fangren & Baolong, 1999). Pineapple yields might be affected due to shading as pineapples are said to be most productive in areas with intensive sunlight (Hepton, 2003). However, one study found that pineapple productivity may actually increase under low light intensities compared to high light intensities (Chipungahelo et al., 2007). These results suggest that good yields for both pineapples and oil palms may be reached in a pineapple-oil palm intercropping system. Due to the specific requirements of both crops on peat soil, exact management practices probably have a large influence on the attainable yields and sustainability of the system.

1.4 Sustainability definition and assessment frameworks

To assess and improve the sustainability of oil palm cultivation, a definition of sustainability and an assessment framework is needed. The term sustainability may be one of the most ambiguous terms in the world. Though there is no global consensus on its definition, one definition which is widely used and seems to grasp the basic principle comes from 'The Brundlandt report' of the World Commission on Environment and Development. It states: ''Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs'' (WCED, 1987). In the UN conference known as 'The Earth Summit' of 1992, it was added that sustainable development requires convergence between economic development, social equity and environmental protection. This concept has been generally accepted and implemented in the 2015 UN Sustainable Development Goals (Drexhage & Murphy, 2010; UN General Assembly, 2015).

Following these concepts, sustainability of a given system can be analysed by integrated assessment of its environmental, economic and social features through the use of appropriate indicators (López-

Ridaura et al., 2002). Extensive assessment frameworks have been developed which could be applied to farming systems, such as the GRI Sustainability Reporting Standards, the Sustainability Assessment of Food and Agriculture systems (SAFA) and the Farm Sustainability Indicators (IDEA) method (FAO, 2014; GSSB, 2018; Zahm et al., 2008).

According to the Brundlandt definition of sustainability, human activity on peat soil can in essence never be sustainable due to the negative environmental effects inevitably involved. On the other hand, elimination of all activity on peat soil would be an immense political undertaking probably involving negative social and economic effects. Knowing that, assessment of the sustainability of a farming practice on peat soil will for this study be limited to comparison with other farming practices. Improvement of the sustainability of a farming practice on peat soil will for this study be limited to minimisation of negative environmental effects, while maximising economic and social benefits.

2. Research objective & relevance

This study focused on the pineapple-oil palm intercropping system as practiced by smallholder farmers on peat soil in Johor, Malaysia. As an establishment intercropping system, this practice can help smallholders to gain income during the replanting phase. This would enable smallholders to timely replant and increase palm oil yields, improving the overall sustainability of palm oil production. However, the exact environmental, economic and social advantages and disadvantages of the pineapple-oil palm intercropping system were unknown. This knowledge gap limited the possibility to draw conclusions on the potential of pineapple-oil palm intercropping to improve sustainability of palm oil production. Thus, the aims of this study were to understand the environmental, economic and social effects of this intercropping system and consequently, formulate recommendations for improvement of the sustainability of pineapple-oil palm intercropping on peat soil.

To achieve these aims, in-depth analysis of the pineapple-oil palm intercropping system was necessary. The research questions guiding this analysis were:

1. What are the effects of intercropping on oil palms and pineapples, in terms of vegetative growth and productivity?
2. What are the agronomic, economic and social aspects of the pineapple-oil palm intercropping system in Johor?
3. How does this intercropping system perform in terms of sustainability?
4. How can the sustainability of this pineapple-oil palm intercropping system be improved?

This study was a first, exploratory study on pineapple-oil palm intercropping and helped to identify the potential of this practice for improvement of palm oil sustainability. The findings could guide further research and provide options for smallholders to improve management practices and reduce yield gaps. Such options could be promoted and spread to smallholder famers by governmental institutes like the Malaysian Palm Oil Board (MPOB), companies like P&G or Nestlé, and non-governmental organisations like Proforest or Wild Asia.

3. Materials & methods

In this chapter, information on the study area, measurements and other data collection methods, data analyses and sustainability assessment is presented.

3.1 Partners & study area

In order to collect information on the pineapple-oil palm intercropping system in Johor, a collaboration was established with the Malaysia Institute for Supply Chain Innovation (MISI), the P&G Palm Independent Smallholder Program and the Universiti Tun Hussein Onn Malaysia (UTHM). This collaboration enabled contact with smallholder farmers, access to farmers' fields and access to office and laboratory facilities. Study sites were located in the areas of Rengit, Benut and Pontian. These areas are situated near the west coast of Johor (Figure 2). Benut and Pontian are located in the district of Pontian, which used to be the largest pineapple production area of Malaysia. Rengit is located in the district of Batu Pahat, which is traditionally known for its industry and palm oil production.

Johor has a tropical rainforest climate with high temperatures, rainfall and humidity, and little seasonal variation throughout the year. Average daytime temperature is approximately 31°C, average annual rainfall is 1778 mm and average relative humidity lies around 83% (Jaji, Man, & Nawi, 2018; WorldData.info, n.d.). In the study areas, farmers distinguished three seasons based on the annual rainfall pattern: a rainy season from October to February, a dry season from March to June and a middle season from July to September.

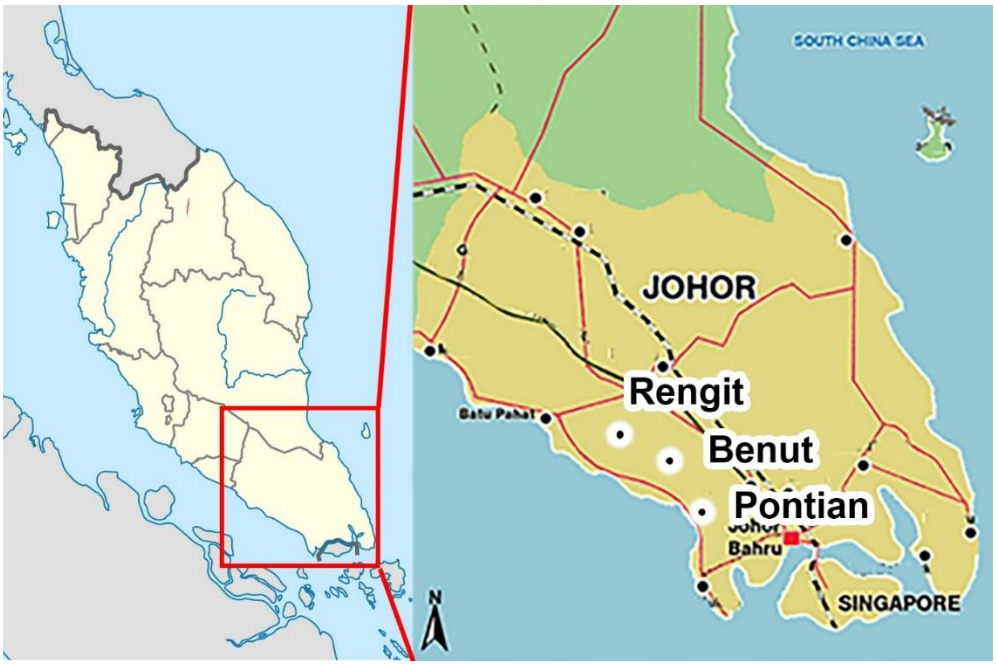

Figure 2. The state of Johor, with the location of the three study areas. The left map shows the position of the state of Johor in Peninsular Malaysia.

3.2 Farming systems

The main focus of this study was the pineapple-oil palm intercropping system. However, to assess the performance of this system, comparisons had to be made with other local farming systems. Systems identified as suitable controls were a pineapple monoculture and an oil palm underplanting system. In short, the pineapple-oil palm intercropping system is a farming system in which farmers grow pineapples in between immature oil palms. In the pineapple monoculture system, pineapples are the sole crop grown per field. In the oil palm underplanting system, immature oil palms are planted and grown underneath old oil palms which are ready for replanting. For this study, analysis of the farming system is defined as analysis of agricultural, economic and social structures and functions at field level. This includes for example crop management practices, inputs, outputs and farmer organisation.

3.3 Information triangulation

Data has been obtained during fieldwork in Johor, from January to April 2019. Two types of data collection have been carried out:

1. Field measurements: to obtain vegetative growth and productivity data of oil palms and pineapples;
2. Key informant and farmer interviews: to obtain general and specific information on agronomic, economic and social aspects of the farming systems and farmers' reasons for intercropping.

These two data collection methods have provided multiple types of information, including quantitative data from field measurements and both quantitative data and qualitative information from key informant and farmer interviews. In addition, qualitative observations have been made by the researcher during both field measurements and interviews. These types of information have been combined and compared to find the answers to the research questions.

3.4 Field & interview selection

Farmers with fields potentially suitable for this study were approached and visited together with the local partners. These first visits allowed to meet the farmers and inspect the fields, followed by field selection based on farming system, soil type, and willingness of the farmer to participate. This resulted in the selection of 20 fields. The intercropping fields were spread over Rengit (n=5) and Benut (n=8), the monoculture fields were located in Benut (n=3) and Pontian (n=1) and the underplanting fields in Rengit (n=3). All fields were located on peat soil, except for the underplanting fields which were located on mineral soil. For an overview of all fields with information such as field size and crops, see Appendix 7.

The farmer of each field was interviewed, except for the farmers of two monoculture and one underplanting field as they were unavailable. Some farmers managed multiple of the selected fields. For this study, the farmer of a field is defined as the person deciding on the field management. Farmers were not necessarily the field owners or the persons carrying out the management. In total, nine different farmers have been interviewed in ten different interviews. For an overview of all farmer interviews, see Appendix 8.

Furthermore, five key informants have been interviewed. Key informants were contacted through the local partners or independently. In literature, key informants have been characterised as members of a community or society who are able to provide more information and a deeper insight into what is going on around them, as a result of their personal skills or position (Marshall, 1996). In this study, key informants included for example downstream supply chain actors and governmental officers. For an overview of all key informant interviews, see Appendix 9.

3.5 Data collection: field measurements

Field measurements aimed at measuring indicators of vegetative growth and productivity of both oil palms and pineapples. Indicators were chosen based on relevance, whether they had been reported in literature and feasibility given the available time and resources. Measurements have been carried out in intercropping, monoculture and underplanting fields. Here, the indicators and corresponding methods of measurement are described.

3.5.1 Transect walk and sample size

Upon arrival at a field, a quick walk along the entirety of the field was made to note general characteristics and relevant particularities. These included the number of oil palm rows and lines, planting patterns, slope, ground cover, pest or disease incidence, presence of plant residues or garbage, visible traces of burning, crops in neighbouring fields and presence of drainage ditches. If applicable, the water level in drainage ditches was recorded using a measuring tape. Most fields were divided into smaller pineapple plots with pineapples of different age or cultivar. The distribution of these plots was recorded.

Then, a zig-zag transect walk was made in order to sample min. 12 and max. 15 oil palms (Appendix 10). Per palm, two pineapple plants were sampled: one growing directly next to the palm (close-to-tree, CT) and one growing exactly in the middle of three neighbouring palms (far-from-tree, FT). In four intercropping fields, multiple different pineapple plots were measured. In oil palm underplanting fields, only immature oil palms were sampled. In pineapple monoculture fields, a similar zig-zag transect walk was made, measuring a total of 30 plants.

3.5.2 Oil palm measurements

All measured indicators of oil palm vegetative growth and productivity and their associated units are shown in Table 2. Below, a description of the measurement method of each indicator is given. Apart from these indicators, any relevant particularities of the palms were noted. These included for example pest or disease damage, leaning, signs of deficiencies and presence of birds or insects.

Table 2. Overview of measured oil palm indicators and associated units.

	Name	**Unit**
General parameters	Location	GPS coordinates
	Distances to 6 neighbours	m
Vegetative growth indicators	Number of fronds	-
	Petiole cross-section area	mm^2
	Rachis length	cm
Productivity indicators	Number of inflorescences	-
	Inflorescence sex-ratio	-
	Number of black bunches	-

Location

The location of the sampled palms was recorded to enable tracing back of individual palms, using a handheld GPS receiver (Garmin eTrex 10).

Distances to 6 neighbours

Distances to six neighbouring palms were measured to calculate palm planting pattern and density. For at least three palms per transect, one in each sampled row, the distances to all six neighbouring oil palms were measured using a 10 m measuring tape. In addition, all distances between two consecutive oil palms along the transect were measured. Distances were measured from stem to stem.

Number of fronds

The number of fronds was measured to indicate size of the palm. First, the youngest, fully opened frond was identified. This frond is defined as frond number 1 (Hardon et al., 1969). As oil palm fronds are arranged in eight spirals , all fronds in the spiral of frond 1 were counted and multiplied by eight to obtain the total number of fronds per palm. As exception, in palms of 0 years after planting (YAP), all fronds were counted separately. Fronds were counted if more than half of the leaflets were still green and present.

Petiole cross-section area

The petiole cross-section area (P_{cs}) was measured for its correlation with leaf dry weight (Corley et al., 1971) and leaf area (Gerritsma & Soebagyo, 1999). P_{cs} is the cross-section area at the point of insertion of the lowest leaflet, the junction of rachis and petiole (Figure 3). Width and depth of the petiole at this point are measured using a calliper and multiplied to obtain P_{cs} (Corley et al., 1971).

Both the P_{cs} and the rachis length were measured in two fronds per palm. Preferably, fronds 9 and 17 were sampled. In palms of 0 or 1 YAP which did not have a frond 17 yet, frond 1 was sampled as well. In palms of 3 or 4 YAP where frond 9 could not be reached, frond 25 was sampled additionally.

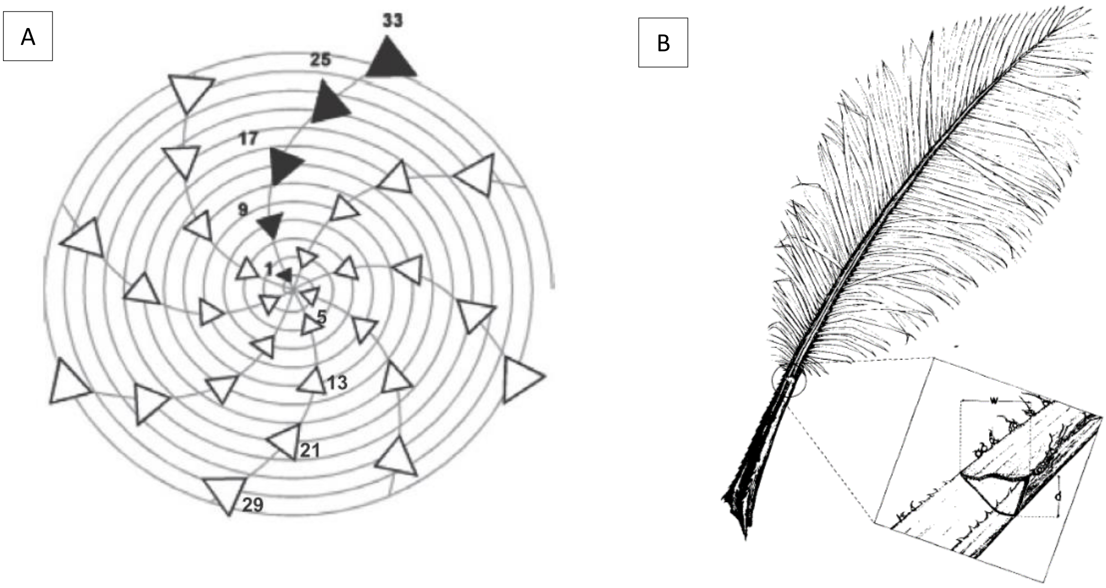

Figure 3. A: Spiral arrangement of fronds in an oil palm crown, with frond numbers indicated. Source: (Aholoukpè et al., 2013). **B:** Position of measurement of the petiole cross-section and close-up of the width (w) and depth (d) which were measured. Source: (Corley et al., 1971).

Rachis length

The rachis length may indicate competition for light, as it has been reported to increase with oil palm planting density (Henson & Dolmat, 2003). Rachis length is defined as the distance from the junction of rachis and petiole (Figure 3) to the point where the final leaflets split. It was measured using a measuring tape.

Number of inflorescences

The number of inflorescences was measured to indicate flowering potential. Female and male inflorescences were counted separately. Decaying male inflorescences or female inflorescences which had partly developed into fruits were not included. Mixed inflorescences were counted both as male and as female inflorescence.

Inflorescence sex-ratio

The inflorescence sex-ratio is the ratio of female to total inflorescences, calculated per palm. This indicator is relevant as sex-ratio has been reported to decrease when palms are under stress, for example from crowding or drought (Corley & Tinker, 2016a; Henson & Dolmat, 2003). Sex-ratio is calculated using Equation 1.

(1) $$Inflorescence\ sex-ratio = \frac{number\ of\ female\ inflorescences}{(number\ of\ male + number\ of\ female\ inflorescences)}$$

Black bunch number

The number of black (unripe) fruit bunches gives an impression of yield in the following 3-4 months. Fruit bunches were counted as black bunches if fruits were coloured black to red, but not if fruits were already turning orange.

3.5.3 Pineapple measurements

In each measured plot, the pineapple growth stage was documented first of all. Five different stages were distinguished (Table 3). Vegetative growth and productivity indicators were only measured if plants were in the vegetative growth or fruit production stage. Planted suckers and plants in the sucker production stage were not indicative for the effects of intercropping, as the size of planted suckers still corresponded to the size of the planting material and as pineapples at sucker production were completely pruned. Based on the growth stage and information given in the farmer interviews, the pineapple age was estimated in months after planting (MAP).

Table 3. Overview of distinctive pineapple stages and their features. MAP = months after planting.

Stage	Features	Estimated age (MAP)
Planted suckers	Recently planted, small vegetative plants, soil visible all around plants	0-4
Vegetative growth	Medium to large vegetative plants, less than one third of all plants bearing fruit, soil not visible in pineapple rows	5-8
Fruit production	Large plants, more than one third of plants bearing fruit	9-12
Sucker production	Large plants, fruits already harvested and plants completely pruned	13-15
Cleared	Sprayed and killed plants, ready for clearing or already cleared	>15

Table 4 gives an overview of the measured pineapple indicators and their units, followed by a description of measurement method for each indicator. Apart from these indicators, any relevant particularities of the plants were noted. These included for example pest damage and leaf colourations.

Table 4. Overview of measured pineapple indicators and associated units.

	Name	Unit
General parameters	Location	GPS coordinates
	Distance to oil palm	cm
	Distances to 3 neighbours	cm
Vegetative growth indicators	Number of leaves	-
	Height of D-leaf	cm
Productivity indicators	Fruit presence	-
	Fruit volume	cm^3

Location

The location of sampled pineapples was recorded using a handheld GPS receiver (Garmin eTrex 10).

Distance to oil palm

In intercropping fields, the distance to the corresponding sampled oil palm was measured, both in CT- and FT-pineapples, using a measuring tape. In addition, its relative position from the oil palm (north, east) was noted.

Distances to 3 neighbours

Distances to three neighbouring pineapples were measured to calculate pineapple planting pattern and density. Distances to one neighbour from the same and two from the adjacent rows was recorded. The measurement was carried out using a measuring tape.

Number of leaves

The number of leaves per plant indicates the growth of the pineapple plant and may indicate competition, as both fertilisation and interplant competition are shown to affect the number of leaves (Mahmud et al., 2018; Zhang et al., 1997). All leaves in one quarter of the plant were counted, distinguishing between immature, mature and pruned leaves. A try square was used to delineate one quarter of the pineapple plant. As exception, in plants with less than 20 leaves, all leaves were counted. The total number of leaves is calculated as the sum of mature and pruned leaves, multiplied by four. Thus, the number of leaves reported represents the potential number of leaves per plant, not the actual number of leaves per plant.

Height of the D-leaf

The height of pineapple plants is measured as the height of the D-leaf and gives and impression of plant size. The D-leaf is defined as the youngest mature leaf and stands nearly straight up, forming the highest point of the plant. Height of the D-leaf was measured with a measuring tape from the ground to the top of the D-leaf, while stretching the leaf.

Fruit ratio

In each plant, it was recorded whether an inflorescence or a developing fruit was present. The difference between an inflorescence and a fruit was defined by the length. Once inflorescences had elongated more than 2 cm, they were defined as fruit. The fruit ratio is defined as the proportion of plants bearing fruit per field and gives an indication of potential yield. It is calculated using Equation 2.

$$(2) \quad Fruit\ ratio = \frac{Number\ of\ plants\ with\ fruit}{Number\ of\ sampled\ plants}$$

Fruit volume

Fruit volume indicates weight and thus grade of the pineapple, influencing profits. Of the present fruits, length and diameter were recorded using a measuring tape and a calliper. Length was measured from the bottom of the fruit to the start of the crown. Diameter was measured at half of the fruit length. Fruit volume was calculated using Equation 3, based on the equation for the volume of a cylinder.

(3) $$Fruit\ volume = \pi * \left(\frac{fruit\ diameter}{2}\right)^2 * fruit\ length$$

3.5.4 Root interaction measurements

If pineapple and oil palm roots are located in the same soil layer, it seems likely that they will compete for nutrients and water. Measurements have been carried out to see if oil palm roots could be found directly underneath pineapple plants. To be able to distinguish between pineapple and oil palm roots, initial root samplings and a description of pineapple and oil palm root morphology have been made (Appendix 11). Presence of oil palm roots underneath pineapple plants has been recorded in three fields of different oil palm ages. In each field, a palm in the centre of the field but next to the field path was picked. Then, three measurements were done: one at the nearest pineapple plant, one at 1 metre from the palm stem and one at 3.5 metres from the palm stem. A square hole of 40 cm wide and 25 cm deep was dug around the centre of the pineapple plant, which was then lifted from the soil. Presence of oil palm roots at the bottom and the sides of the hole was recorded, for each quarter of the hole separately.

3.6 Data collection: interviews

Interviews were aimed at gathering information about agronomic, economic and social aspects of the farming systems. Topics and questions were chosen to obtain both qualitative and quantitative data. The qualitative data, such as reasons for intercropping, served to get a broad understanding of the systems. The quantitative data, such as amounts of fertilisers used, served to calculate economic parameters like benefits, costs and income. Find a description of the interview methods below.

3.6.1 Farmer interviews

Farmers have been interviewed with help from a translator. Interviews were carried out with one to three farmers simultaneously. A questionnaire was followed to structure the interview, to ensure all data would be gathered and to enable the translator to ask the necessary questions (Appendix 12). In short, the interviews covered questions related to field specifics (e.g. crop age, land ownership), farming practices (e.g. fertilisation, harvesting) and farmer background (e.g. education, family composition). All participating farmers signed a consent form to document their agreement with the data collection (Appendix 13). Answers were written on the questionnaires by the researcher and audio recordings were made as back-up. Interviews took between 45 and 75 minutes.

3.6.2 Key informant interviews

Key informants were interviewed with help from a translator or in English by the researcher. All key informants were interviewed separately. The interviews were semi-structured and held in a more conversational way. Which topics were discussed exactly depended on the specialisation and knowledge of the key informant. Notes were made by the researcher in a notebook. Interviews were not officially started or ended, some key informants were met multiple times and provided information in multiple conversations.

3.7 Data analysis: field measurements

The field measurements provided data on vegetative growth and productivity of palms and pineapples of different ages at different fields. These data have been used to investigate effects of intercropping on palms and pineapples. In fields where multiple distinctive pineapple plots were measured, pineapple data was analysed for each plot separately. Statistical analysis was carried out using the program RStudio. As data was gathered on multiple fields in multiple regions, analyses were carried out using a linear mixed model with field and region as random factors. Crop age was always included as fixed factor. Which other parameters were used as fixed factors depended on the specific analysis. As in a multiple regression analysis, using a mixed model allows to test the correlation of a single factor with the outcome variable while keeping other factors constant. Significance of this correlation was evaluated through analysis of variance. For the pineapple analyses, only data from the 'Josapine' cultivar was considered as little data on 'Moris' had been gathered. In all analyses, probability values of $p < .05$ were considered statistically significant.

Pineapple productivity data was measured in one monoculture and five intercropping fields, as these were the only fields with pineapples in the fruit production stage. This rendered statistical comparison between monoculture and intercropping fields impossible. Furthermore, fruit volume turned out to depend strongly on the moment of flower induction. It seemed likely that this moment had been slightly different in every field. This made comparison between intercropping fields equally difficult. Thus, for pineapple productivity, the statistical analysis used was comparison of fruit volume between CT and FT plants of the same field via a two-sample t-test.

Last, data on distances between neighbouring oil palms and neighbouring pineapples were used to calculate planting densities. Find these calculations in Appendix 14.

3.8 Data analysis: interviews

Interview data has been gathered to describe the agronomic, economic and social aspects of the farming systems and the reasons of farmers to perform pineapple-oil palm intercropping. No statistical analysis has been applied to the interview data. The information gathered in the interviews has been read and compared carefully to find general and common practices. This descriptive analysis has been supplemented with observations and pictures made during field measurements and interviews. If necessary, quantitative information was converted to SI-units. Monetary values were converted from the Malaysian Ringgit to US dollars (1 USD = 4.0740 MYR, exchange rate of the 1st of March 2019).

Analysed agricultural aspects were crops and cropping cycles, planting practices, fertilisation practices and other management practices. Analysed economic aspects were oil palm and pineapple yields and prices, benefits, costs, benefit-cost ratio, income and return to labour. Analysed social aspects were the pineapple and oil palm supply chains, farmers' background and organisation and land ownership.

For calculation of the economic aspects, quantities and prices of inputs, labour and outputs were obtained in the interviews. As not all numbers were captured in every interview, estimations and assumptions had to be made to complete the data. Data gaps were filled by using the values of similar farmers (e.g. farmers in the same region or with similar practices), by estimating values based on previous answers of that farmer, or by estimating values based on field observations. To enable comparison between intercropping, pineapple monoculture and oil palm underplanting systems, the following scenario was used when calculating economic aspects:

- All benefits and costs are calculated for one hectare, over a four year period.
- In this four year period, three pineapple cycles are completed.
- All pineapples are 'Josapine'.
- Pineapple planting density is 29 652 plants ha^{-1} for intercropping and 37 066 plants ha^{-1} for monoculture systems.
- 80% of the planted pineapples develop fruits and suckers, 1 fruit and 1 sucker per plant.
- In this four year period, the immature palms in the intercropping and underplanting systems do not give any harvest yet.
- Oil palm planting density is 148 palms ha^{-1} for all types of palms, for all systems.
- Input costs for pest control and flower induction, labour costs for pest control and pineapple sucker harvest or credit costs are not taken into account as there was too little information.

Benefits of intercropping and monoculture farmers were calculated based on sales of pineapples. Benefits of underplanting farmers were calculated based on harvest from old oil palms. Total costs of all famers were calculated as the sum of input costs and hired labour costs. Farmer labour was not included as cost but used to calculate return to labour.

Based on total benefits and costs, the benefit-cost ratio (BCR) is calculated using Equation 4. For simplification, no discount rate is applied. The BCR is a useful indicator to assess the value for money of a system. If the BCR < 1, the costs exceed the benefits. If the BCR > 1, the benefits exceed the costs. Generally, the higher the BCR, the better the investment.

(4) $$BCR = \frac{Total\ benefits}{Total\ costs}$$

In this study, income has been defined as the profit made by the farmer. It is assumed that farmers receive the complete profit from the field they manage. Thus, income is calculated using Equation 5.

(5) $$Income = Total\ benefits - Total\ costs$$

Last, the return to labour is analysed. In this study, return to labour is defined as the reward received by farmers for the labour they invest. As mentioned above, the total reward received by farmers is the income. Thus, return to labour is calculated using Equation 6.

(6) $$Return\ to\ labour = \frac{Income}{Farmer\ labour}$$

It should be noted that some farmers reported to hire all labour needed for field maintenance, while others both hired labour and worked on the fields themselves. Farmer labour was only estimated for farmers working on the fields themselves. As a consequence, the return to labour could be calculated and compared only for this group of farmers. Second, farmer labour is not included as cost. This influences the BCR and income calculation. Farmers who hire all labour are expected to have higher costs and lower BCR and income. This should be kept in mind when comparing the results.

3.9 Sustainability assessment

The last two research questions focus on the sustainability of the pineapple-oil palm intercropping system. Unfortunately, the existing assessment frameworks went beyond the scope of this study. Instead, four simple steps have been followed to identify sustainability indicators and assess sustainability of the pineapple-oil palm intercropping system. These steps are based on work of López-Ridaura et al. (2002) and Mollenhorst & de Boer (2004):

1. Description of the farming system;
2. Identification and selection of critical environmental, economic and social issues;
3. Qualitative assessment of selected issues;
4. Integration of results to formulate conclusions and recommendations.

Results from field measurements and interviews provided a description of the farming system (step 1). Relevant issues are selected by the researcher based on this description and known issues of oil palm cultivation and intercropping, specifically on peat (step 2). A strengths, weaknesses, opportunities and threats (SWOT) analysis is used to order and assess the selected issues (step 3). Integration of results and formulation of recommendations (step 4) allowed achievement of the research objective and form the main content of Chapter 5 (Discussion).

SWOT analysis is a simple, widely-used tool for decision making and strategic planning (Helms & Nixon, 2010). It is based on determination of the internal or external and the positive or negative character of issues (Table 5). In this study, distinction between internality and externality is based on the influence of the farmer (Eilers et al., 2001). Issues within the control of farmers, e.g. fertilisation practices, are internal. Issues beyond farmer control, e.g. market demand, are external. Furthermore, internal issues are identified based on the current situation only. External issues can include the current situation and probable trends (Mollenhorst & de Boer, 2004). As a guideline, four issues in each of the three domains (environmental, economic and social) are selected for the SWOT analysis.

Table 5. Distinction between strengths, weaknesses, opportunities and threats in a SWOT analysis.

	Positive	**Negative**
Internal	Strengths	Weaknesses
External	Opportunities	Threats

4. Results

The results of this study consist of three parts. First, data from field measurements is presented, providing results on the growth and productivity of oil palms and pineapples and root interactions. Second, data collected through interviews and field observations is presented, providing results on the agronomic, economic and social aspects of the pineapple-oil palm intercropping system and farmers' reasons for intercropping. Last, these results are combined to provide a sustainability analysis of the pineapple-oil palm intercropping system.

4.1 Oil palm growth and productivity

In this section, data on oil palms as measured in intercropping and underplanting fields is presented and analysed. Oil palm vegetative growth results are treated first, followed by oil palm productivity.

4.1.1 Oil palm vegetative growth

As indicators for the vegetative growth of oil palms, the number of fronds per palm, the petiole cross-section area (P_{cs}) of fronds 9 and 17 and rachis length of fronds 9 and 17 were measured.

Figure 4 shows the field averages of the number of fronds per palm. As would be expected, the number of fronds was higher in fields with older palms. Furthermore, the number of fronds appeared slightly higher in underplanting fields than in intercropping fields, especially at 2 years after planting (YAP). It should be noted that in both intercropping and underplanting fields, some damaged or diseased palms with a distinctively lower number of fronds were present. These outliers were not removed from the data as they were part of the natural variation in the fields.

Figure 5 shows the field averages for the P_{cs} and rachis length of fronds 9 and 17. Again, these indicators appeared to increase with oil palm age. There are no clear differences between intercropping and underplanting fields. As exception, the rachis lengths in underplanting fields of 2 YAP seemed relatively high compared to the intercropping fields. Only healthy fronds were used to measure P_{cs} and rachis length.

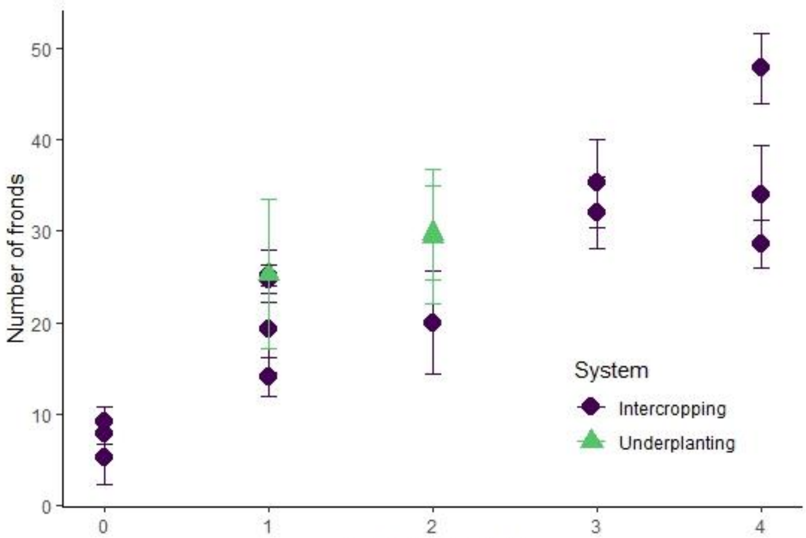

Figure 4. Number of fronds per palm, given as average per field. Error bars indicate standard deviation per field. Sample size is 10–15 palms per field for all fields. YAP = years after planting.

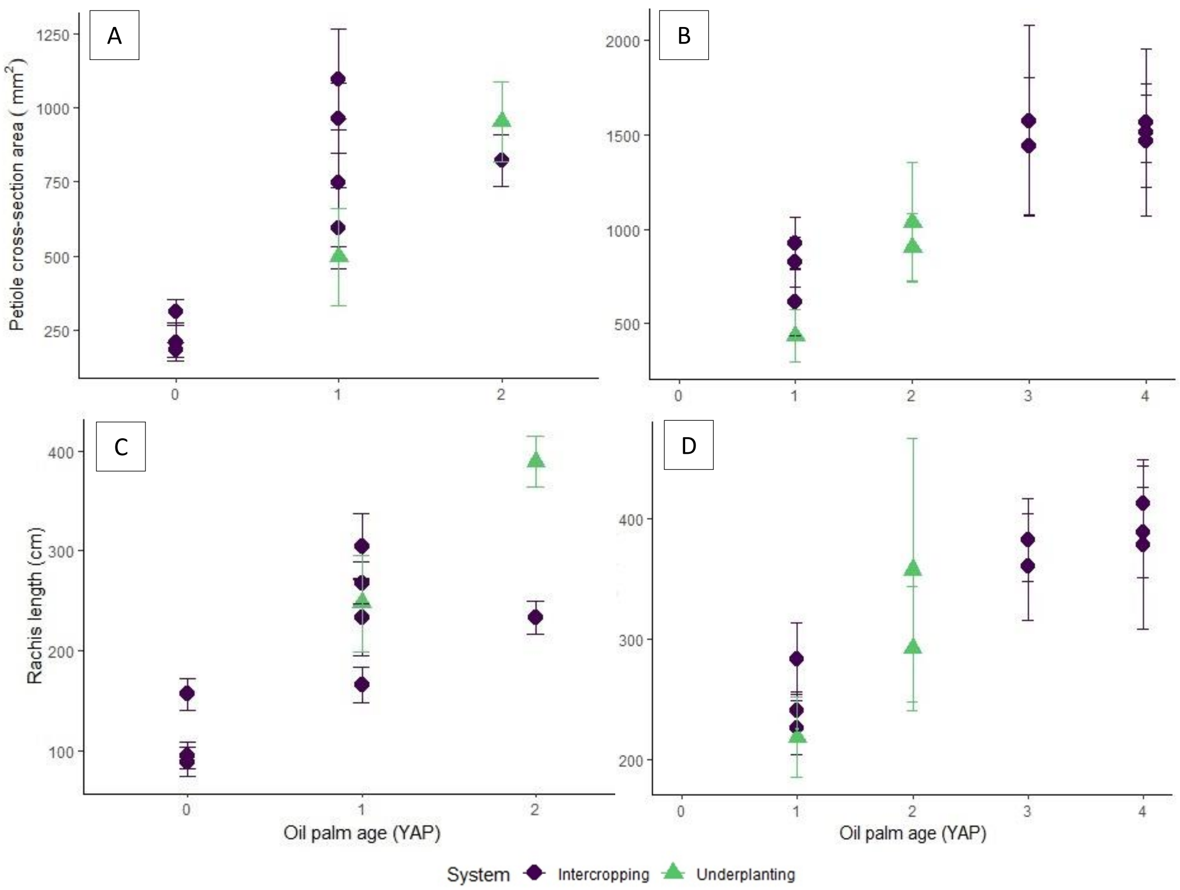

Figure 5. A: Frond 9, petiole cross-section area (P_{cs}). **B:** Frond 17, P_{cs}. **C:** Frond 9, rachis length. **D:** Frond 17, rachis length. For all figures: values are given as average per field. Error bars indicate standard deviation per field. Sample size is 8–15 palms per field for all fields, except for the underplanting field of 2 YAP, frond 9, P_{cs} (n=6) and rachis length (n=4). YAP = years after planting.

Statistical analysis showed that oil palm age had a significant positive correlation with all vegetative growth indicators, except with the rachis length of frond 9. As positive correlations between oil palm age and oil palm size were expected, they have not been analysed further. Farming system (i.e., intercropping vs. underplanting) did not have a significant correlation with any of the vegetative growth indicators, except with the P_{cs} of frond 17 (p=.02). However, this correlation should be considered with caution, as not all model assumptions were met. Analysis of the differences in the P_{cs} of frond 17 showed that the predicted mean for the underplanting system (913 mm^2) was significantly lower than for the intercropping system (1285 mm^2), based on least significant difference (LSD) analysis. All p-values are listed in Appendix 15.

During fields measurements, it was noticed that the distance between the nearest pineapple and the oil palm stem (CT-distance) varied both between and within fields. As can be seen in Figure 6, CT pineapples stood generally quite far away from the palms in older fields, leaving an empty circle around the palm stem. In young fields, CT-distance was more variable, with some pineapples planted very close to the palms. Furthermore, fields differed in pineapple planting density (P-density). If pineapples are standing very close to the palms or if pineapples are planted more densely, competition between palms and pineapples may be larger. To see if pineapple management could have an influence on oil palm growth, correlations of CT-distance and P-density with the vegetative growth indicators have been tested, but no significant correlations were found (for p-values, see Appendix 15).

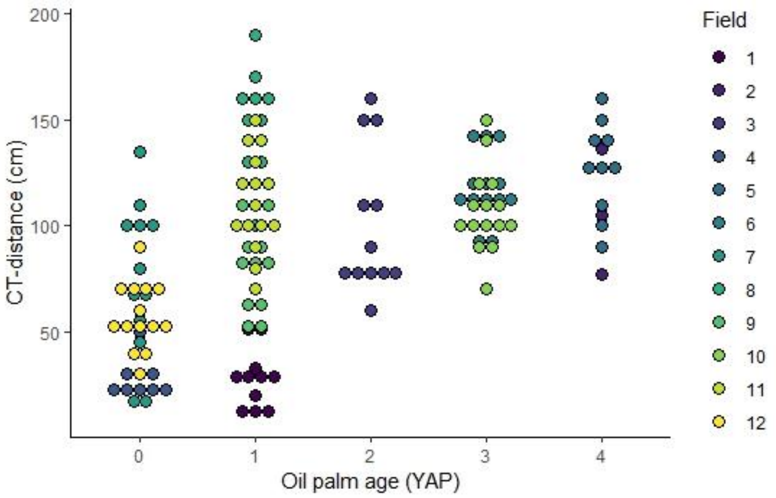

Figure 6. CT-distance per palm, according to oil palm age. Colours indicate fields.
YAP = years after planting.

4.1.2 Oil palm productivity

As indicators for oil palm productivity, the number of inflorescences per palm, the number of black bunches per palm and the inflorescence sex-ratio per palm were measured.

As can be seen in Figure 7A and 7B, number of inflorescences and number of black bunches per palm showed a similar pattern. In palms of 0 YAP, no inflorescences or black bunches were present yet. Overall, there appeared to be a slight increase with age, though variation among and between fields was large. It should be noted, however, that the number of inflorescences ranged from 0 to 4. In absolute numbers, differences were small.

The inflorescence sex-ratio is calculated as the ratio of female to total inflorescences for each palm. As can be seen in Figure 7C, the inflorescence sex-ratio did not show any clear pattern with oil palm age or farming system.

Statistical analysis of the data confirmed that oil palm age had a significant, positive correlation with the number of inflorescences (p=.02). Correlation with the number of black bunches and the inflorescence sex-ratio was not significant. The farming system was not significantly correlated with any of the indicators. Find all p-values in Appendix 15. Test results should be considered with caution, as the model assumptions were not met.

Among intercropping fields, effects of P-density and CT-distance were tested again. A significant, positive correlation of CT-distance with the number of inflorescences was found (p=.02). However, it turned out that there was significant interaction between oil palm age and CT-distance (p=.03) for the number of inflorescences. It seems likely that the positive correlation of CT-distance with the number of inflorescences is the consequence of the interaction with oil palm age.

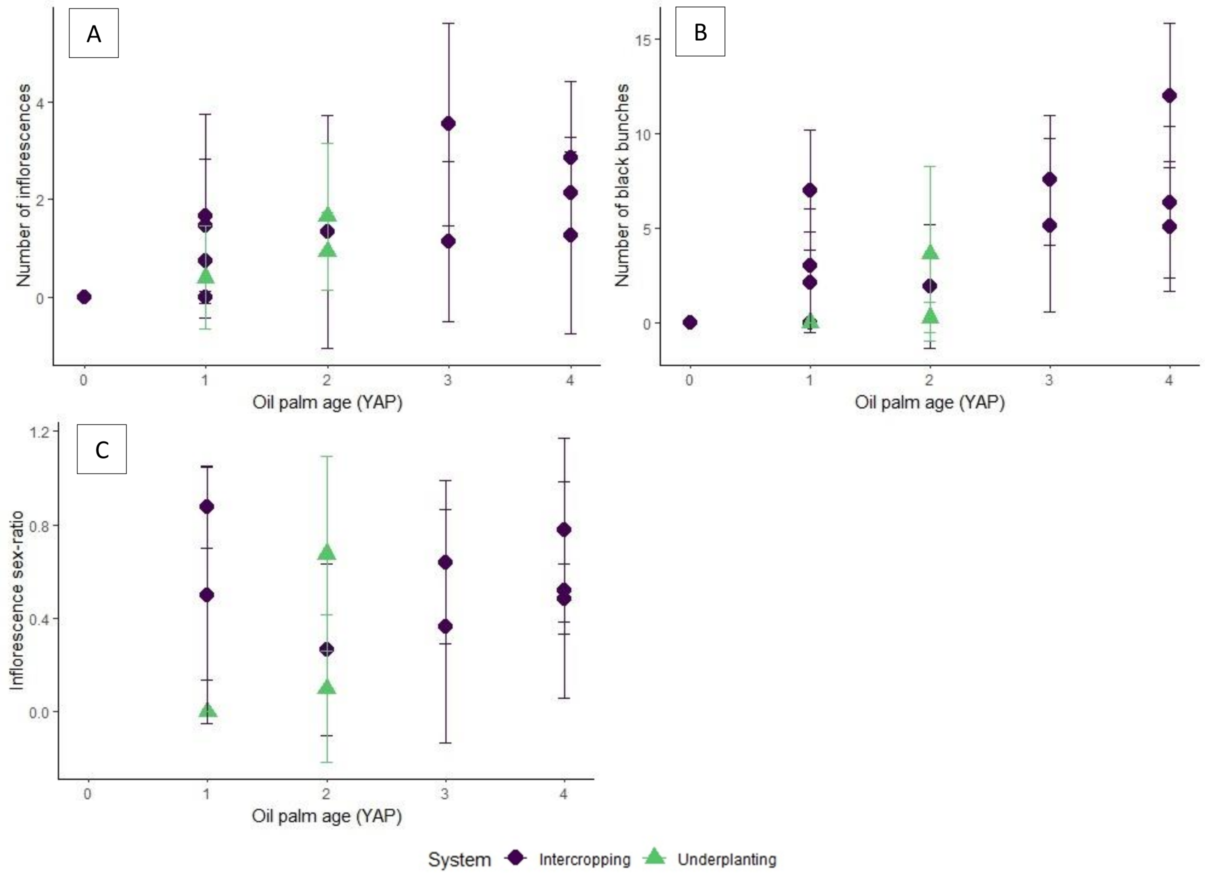

Figure 7. A: Number of inflorescences per palm. **B:** Number of black bunches per palm. **C**: Inflorescence sex-ratio per palm. For all figures: values are given as average per field. Error bars indicate standard deviation per field. Sample size is 10–15 palms per field. YAP = Years after planting.

4.2 Pineapple growth and productivity

In this section, data on pineapples as measured in intercropping and monoculture fields is presented and analysed. Pineapple vegetative growth results are treated first, followed by pineapple productivity.

4.2.1 Pineapple vegetative growth

The vegetative growth of a pineapple plant was indicated by the number of leaves per plant and the height of the D-leaf. Results are shown in Figure 8. All results come from 'Josapine', except for the data points labelled as 'Moris'. Outliers clearly due to pest damage were removed from the data. In intercropping plots, a distinction was made between pineapples growing directly next to a palm (CT) and pineapples growing exactly in the middle of three neighbouring palms (FT).

As can be seen in Figure 8, the plot measured at 5 months after planting (MAP) had relatively low values for both number of leaves and height of D-leaf. From 7 to 11 MAP, there did not seem to be a consistent trend with pineapple age. The monoculture fields of 8 MAP showed distinctively lower leave numbers. This may be due to the relatively high pest and weed pressure in these two fields. Farmers mentioned that flower induction had not yet been carried out in these fields, so a physiological explanation seems unlikely.

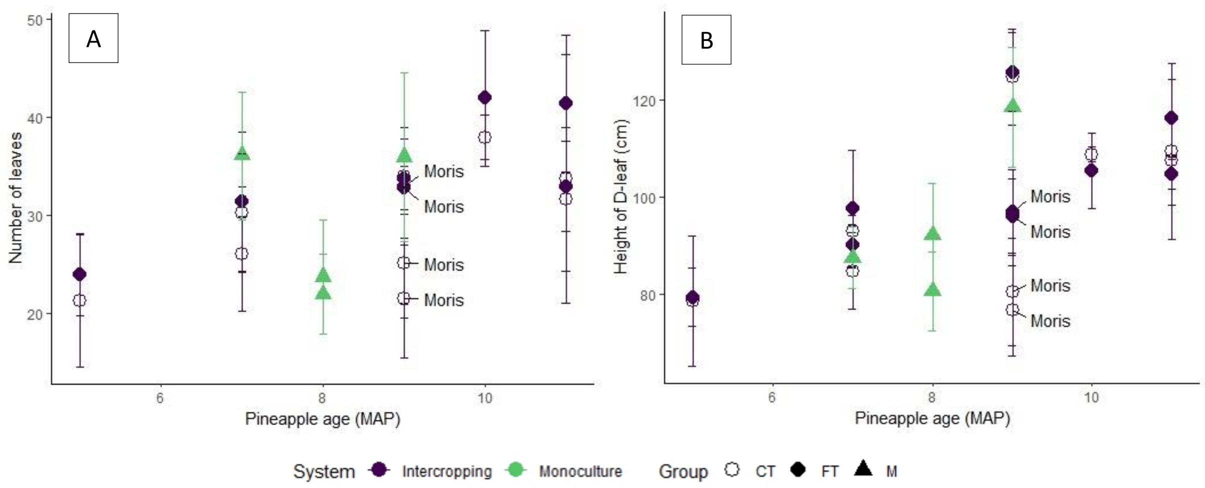

Figure 8. A: Number of leaves per plant. **B:** Height of the D-leaf. For both figures: values are given as average per plot. Error bars indicate standard deviation per plot. Sample size is 30 plants in monoculture plots and 7–15 plants in CT and FT groups, except for the groups at 10 MAP (n=4) and the 'Moris' groups (n=5–8). MAP = months after planting.

Comparing the farming systems, the number of leaves seemed higher in the monoculture system than in both CT and FT plants of the intercropping system. Comparing the height of the D-leaf between farming systems, results were relatively similar. Regarding the intercropping plots, plots with 'Moris' had relatively low results. Studying the CT and FT groups, the number of leaves appeared consistently lower in CT plants. In the data and in the fields, it could be seen that most CT plants were similar in size to FT plants, but some CT plants were remarkably smaller. This explained the low CT averages.

Statistical analyses have been carried out on 'Josapine' data only. Pineapple age had a significant, positive correlation with the number of leaves and height of the D-leaf ($p=.046$ and $p<.001$). Group (CT, FT or monoculture) also had a significant correlation with the number of leaves and height of the D-leaf ($p=.02$ and $p=.046$, respectively). These correlations have been analysed further (Table 6). For the number of leaves per plant, the predicted means showed that CT plants had significantly less leaves than monoculture plants, but FT plants overlapped with both groups. On the contrary, for the height of the D-leaf, the monoculture fields had the lowest predicted means. In this test, the differences in height of D-leaf between groups were not significant ($p=.052$). This is possible as the significance in the first test was small ($p=.046$) and illustrates that this difference should be regarded with caution.

Table 6. Predicted means per vegetative growth indicator per group. Means followed by different letters within one indicator differ significantly ($p < .05$) as established by the LSD-test.

	Number of leaves per plant, predicted means	**Height of D-leaf (cm), predicted means**
CT – Intercropping	27.1^{A}	96.2^{A}
FT – Intercropping	30.6^{AB}	98.3^{A}
Monoculture	33.9^{B}	92.5^{A}

Furthermore, effects of different management practices were analysed. As mentioned, fields differed in pineapple planting density (P-density). If pineapples are planted closer together, they may experience more competition from each other. Checking in monoculture and intercropping fields simultaneously, no significant correlation of P-density was found with either the number of leaves or the height of the D-leaf ($p=.16$ and $p=.30$).

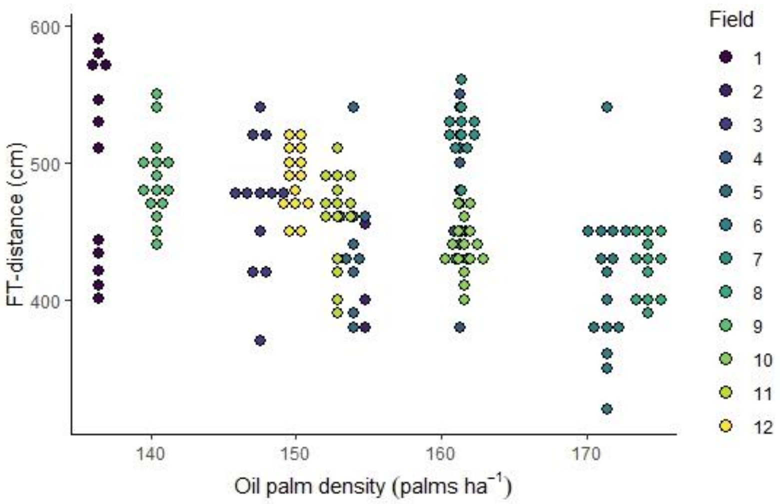

Figure 9. FT-distance per palm, according to oil palm planting density. Colours indicate fields.

In intercropping fields, pineapples may be influenced by the exact distance from the oil palm. As shown in Figure 6, distance between CT-pineapples and the oil palm stem (CT-distance) varied in fields with younger palms. Alternatively, the distance between FT-pineapples and the oil palm stem (FT-distance) can be argued to differ with oil palm planting density: the higher the density, the lower the FT-distance. The data show a corresponding trend (Figure 9). CT-distance and FT-distance have been analysed, but no significant correlation was found with any of the pineapple growth indicators (for p-values, see Appendix 16). It should be noted that in these tests, not all model assumptions were met.

4.2.2 Pineapple productivity

Indicators used to measure pineapple productivity were fruit ratio (the proportion of plants bearing fruit per field) and fruit volume. In one monoculture and five intercropping fields, fruits were present. As fruit presence and fruit volume depend on the moment of flower induction, caution is required when comparing between fields; it is unknown if farmers induced flowering at exactly the same age.

First of all, the fruit ratio per field was calculated (Table 7). Though there was quite some variation among the fields, the monoculture field seemed to have a relatively low fruit ratio. Most intercropping fields had high fruit ratios. In intercropping fields, the same number of CT and FT plants were sampled. However, the division of fruits among CT and FT plants was not exactly 50 – 50: there was a slight trend towards fruits in FT.

Table 7. Fruit ratio (proportion of plants bearing fruit) per field. For the intercropping fields, the distribution of fruits over CT and FT plants is reported. NB: field 5 and 6 were 'Moris', the others 'Josapine'. MAP = months after planting.

System	Age (MAP)	Field #	Plants sampled	Fruit ratio	Proportion fruits in CT	Proportion fruits in FT
Intercropping	9	5	10	0.5	0.40	0.60
		6	16	0.94	0.47	0.53
	10	4	8	1	0.50	0.50
	11	1	24	0.96	0.48	0.52
		12	28	0.71	0.45	0.55
Monoculture	9	15	30	0.43	-	-

Fruit volumes of the present (unripe) fruits have been measured (Figure 10). Interestingly, in intercropping fields 5 and 6 which were the 'Moris' cultivar, FT plants had higher average volumes than CT plants. On the contrary, intercropping fields 4, 1 and 12, which were 'Josapine', average volumes were higher in CT than in FT plants. In general, 'Moris' fruits had relatively high volumes compared to 'Josapine'. This is a known difference between these cultivars. Fruit volumes in the monoculture field were similar to fruit volumes in the intercropping fields. Statistical analyses showed that in none of the intercropping fields, CT and FT plants had significantly different fruit volumes (for p-values, see Appendix 16). Only for field 1, the model assumptions were not met.

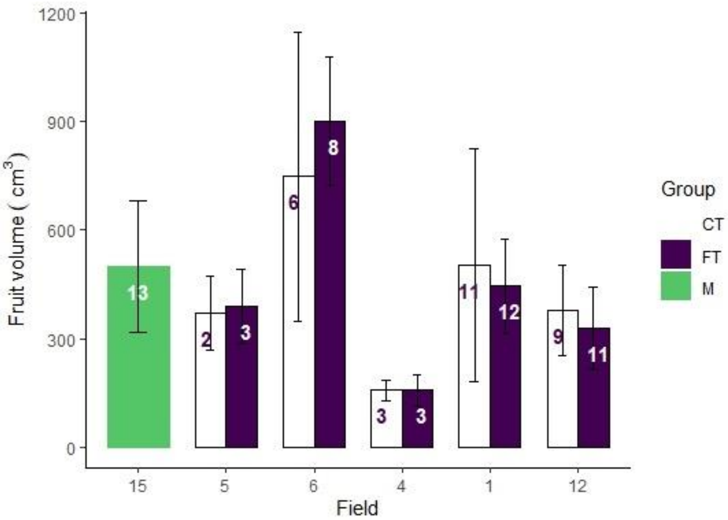

Figure 10. Average fruit volume per plot per group. Error bars indicate standard deviation per field. Numbers indicate sample size. NB: field 5 and 6 were 'Moris', the others 'Josapine'. For pineapple age, see Table 7.

4.3 Root interaction

In three fields, the presence of oil palm roots under pineapple plants was investigated. Three measurements were taken per field: one under the nearest pineapple, one at 100 cm from the palm stem and one at 350 cm from the palm stem. The results are reported in Table 8.

The results indicate that interaction between pineapple and oil palm roots in the top 25 cm of soil can occur. However, this interaction depended on distance from the oil palm and oil palm age. Oil palm roots were present under pineapples plants nearby the palms, but absent under pineapples at 3.5 m from the palms (a typical FT-distance). No oil palm roots were found under any pineapple in field 4, where the oil palms had just been planted. This seems reasonable; the root system of a just planted oil palm will not reach as far as the root system of an established oil palm. Additionally, the palms seedlings were planted in a 30 cm deep planting hole, so their roots had not yet gotten much time to reach the top 25 cm of soil.

Table 8. Root interaction, counted in soil quarters under pineapple plants with oil palm roots present. In field 4 and 9, the nearest pineapple stood at 40 cm from the oil palm stem. In field 5, the nearest pineapple plant stood at 130 cm from the oil palm stem. YAP = years after planting.

Field	Palm age (YAP)	Pineapple stage	Soil quarters with oil palm roots present		
			Nearest pineapple	100 cm	350 cm
4	0	Vegetative	0	0	0
9	1	Seedling prod.	2	2	0
5	4	Seedling prod.	2	3	0

4.4 Agronomic aspects

In this section, basic agronomic aspects, such as crops, cropping cycle, planting, fertilisation and other management practices of the pineapple-oil palm intercropping system are analysed. For comparison, agronomic aspects of the pineapple monoculture and oil palm underplanting systems are given as well. It should be noted that information on intercropping and underplanting was provided solely by farmers. Information on pineapple monocultures was gathered from one farmer (B8), two agronomic officers (P9, K4) and a large pineapple estate manager (K5).

All fields ranged in size from 0.7 to 2.4 ha. Observed pineapple-oil palm intercropping and pineapple monoculture fields were situated on peat soil. Oil palm underplanting fields were situated on mineral soil. For an impression of the different farming systems, see Figure 11.

Figure 11. A: Pineapple oil-palm intercropping field, 1 YAP (field 1). **B:** Pineapple-oil palm intercropping field, 3 YAP (field 6). **C:** Pineapple monoculture field with 'scrap' heaps in between plots (large estate field, not measured). **D:** Oil palm underplanting field, 1 YAP, old palms still present (field 19). YAP = Years after planting.

4.4.1 Crops

In the intercropping system, two crops were grown per field simultaneously: immature DxP oil palms with pineapples of either the 'Josapine' or 'Moris' cultivar. As the name implies, in the pineapple monoculture system, pineapples were the sole crop per field. Monoculture farmers grew a few other pineapple cultivars as well. However, as 'Josapine' was the dominating cultivar in the research areas, only this cultivar is treated here (unless otherwise specified). In the oil palm underplanting system, immature DxP oil palms were planted and grown underneath old oil palms which were ready for replanting.

4.4.2 Cropping cycle

Pineapple-oil palm intercropping was carried out for three to four years after planting of oil palm seedlings. Farmers explained that intercropping was terminated when the oil palms started producing. At that moment, farmers no longer depended on the pineapples for income, pineapples would obstruct oil palm harvesting, and pineapple growth reduced. After intercropping, fields were continued as oil palm monocultures until there was no more significant production and fields needed replanting again.

In pineapple monoculture fields, pineapple cycles were repeated continuously. In underplanting fields, oil palm seedlings were planted when the old palms were 18 to 20 YAP. The old palms were removed gradually, starting with the palms which had lowest production, were diseased, leaning, etc. Two to four years after planting, the young oil palms should have fully spread their fronds and started to produce fruits. Then, all remaining old palms were removed and underplanting was terminated.

In intercropping fields, two to three pineapple cycles could be completed during the intercropping period. One 'Josapine' cropping cycle took typically sixteen months. After planting, vegetative growth lasted eight months. Then, farmers would perform flower induction. After flower induction, it took one month until inflorescences appeared and three months for the inflorescences to grow into mature fruits. Altogether, fruit harvest took place twelve months after planting. After fruit harvest, plants were maintained for another three months to produce vegetative material called suckers. The suckers were harvested to use as new planting material. Last, the field was cleared so it could be replanted, adding one more month to the entire cycle. Find a visualisation of the 'Josapine' cropping cycle in Figure 12. Intercropping and monoculture farmers did not mention differences in the pineapple cropping cycle.

The exact number of cycles that could be completed during intercropping depended on multiple factors such as pineapple cultivar, planting date and oil palm growth. First, pineapple cultivar determined the length of the pineapple cycle ('Moris' cycles being shorter than 'Josapine'). Second, on a field where the pineapples were planted before the oil palms, it was possible that one more cycle could be finished compared to a field where pineapples were planted later than the oil palms. Third, if oil palms started producing early (due to weather or management factors), intercropping would be terminated early as well, reducing the time available for pineapple cropping.

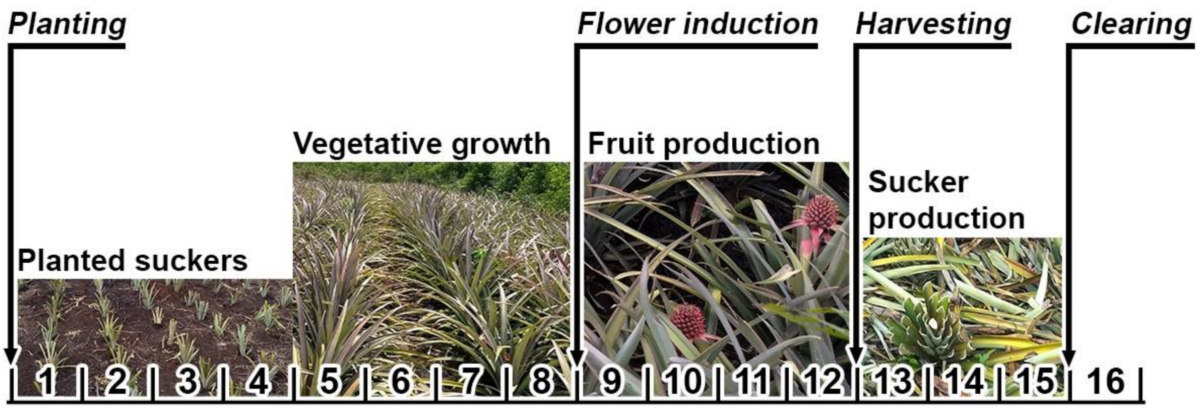

Figure 12. Cropping cycle of 'Josapine' pineapples in Johor, Malaysia. Numbers indicate months after planting.

4.4.3 Planting material, density and pattern

Planting of oil palm and pineapple was done year-round, though one farmer advised against planting of oil palms during the dry season (Mar-Jun). Pineapples and oil palms were not necessarily planted simultaneously. Commonly, farmers performed one or more pineapple monoculture cycles before planting oil palms and starting the intercropping cycle. This was motivated both economically, as these monocultures generated additional income, and agronomically, as disease pressure from the old to the new palms might be reduced.

Oil palms were planted as one-year-old seedlings obtained from MPOB, either directly or via the farmer's oil palm dealer. Normally, the whole field was planted at once. All farmers reported to stick to an oil palm planting density of 148 palms ha^{-1}, which coincides with the 9 m triangular planting pattern. In most fields, a triangular planting pattern could indeed be recognised though the planting distances were not exactly kept, resulting in slightly smaller or non-equilateral triangles. In two intercropping fields, the pattern appeared to be rectangular rather than triangular (Figure 13A). It is unknown if any of these alterations to the pattern were a deliberate choice or caused by inaccuracy during lining and planting. In underplanting fields, young palms were planted in the same rows as the old ones. In two out of three underplanting fields, the old palms stood in a rectangular pattern, and consequently the young palms as well. Based on the measured distances, planting densities were calculated for all fields (Table 9) and ranged between 129 and 174 palms ha^{-1}.

Farmers obtained pineapple planting material from their own sucker harvest or bought suckers from other farmers in their network. In most fields, pineapples were divided over small plots (<0.5 ha) with different age or cultivar. The typical pineapple planting density reported by intercropping farmers was approximately 30 000 plants ha^{-1}. For monocultures, higher densities were reported: either 37 000 or 42 000 plants ha^{-1}. The planting pattern observed in all fields was a double-row system. However, the average spacing in intercropping fields was 45x55x70 cm (Figure 13B), resulting in smaller paths and a lower plant density than when sticking to the recommended 30x60x90 cm spacing (Figure 1B).

In fields with oil palms of 0 or 1 YAP, pineapples would grow directly next to the palm stem. Interestingly, in fields with oil palms of 3 or 4 YAP, more than one meter of empty space was left between the nearest pineapples and the palm stem (Figure 6). This empty space reduced the pineapple planting densities in intercropping fields. In both intercropping and monoculture fields, calculated pineapple planting densities ranged between 28 000 and 43 000 plants ha^{-1} (Table 9). The calculated densities in intercropping fields were higher than the reported densities.

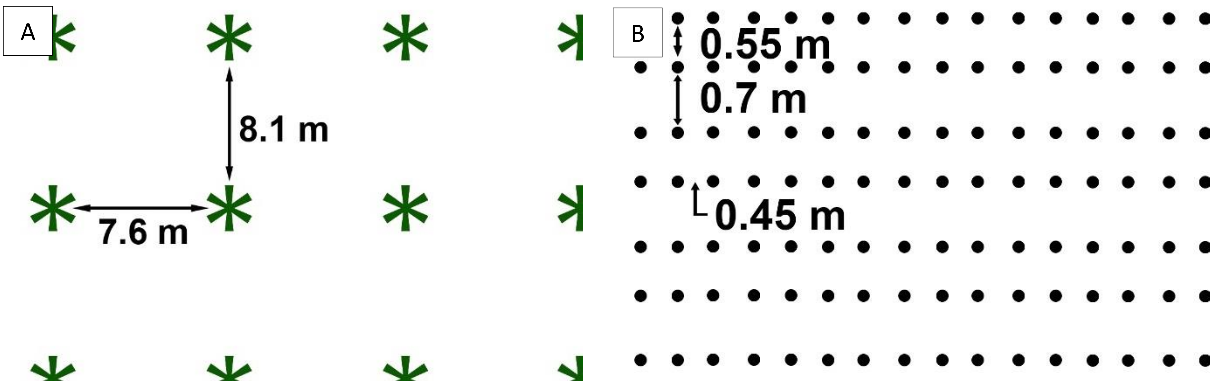

Figure 13. A: Rectangular oil palm planting pattern, as observed in field 4. **B:** Double-row 45x55x70 cm pineapple planting pattern, as observed in intercropping fields.

4.4.4 Fertilisation

Fertilisation in intercropping fields seemed to be adjusted to the requirements of the pineapples. Farmers typically reported to fertilise three times per pineapple cycle, during the vegetative growth stage only. Oil palms were not fertilised separately, but did receive fertilisation along with the pineapples. For example, some fertilisers were mixed with water and sprayed by hand on the pineapple plants. When doing so, the palms would be sprayed just as well. Monoculture farmers would also fertilise three times per pineapple cycle in the vegetative growth phase. Underplanting farmers recommended to fertilise the young palms one to three times per year.

In all interviews, three types of fertiliser were consistently mentioned: NPK fertiliser, urea and hydrated lime. NPK fertiliser is a chemical fertiliser containing a determined ratio of nitrogen, phosphorus and potassium. Three N:P:K ratios were reported in the interviews: 15:15:15, 16:16:16 and 12:12:17. Fertiliser bags found in the fields showed that different kinds of brands were used, some specifically for pineapples, some containing 2 or 3% sulphur and some with a different N:P:K ratio, such as 30:2:32.

Urea, $CO(NH_2)_2$, is a nitrogen fertiliser containing 46% N. Strictly speaking, hydrated lime, $Ca(OH)_2$, is not a fertiliser but a liming material used to increase soil pH. However, farmers themselves regarded it as fertiliser. Bags of both urea and hydrated lime were found in the fields.

Based on amounts, application frequencies and N:P:K ratios reported in the interviews, fertilisation was calculated (Table 9). For comparison, fertiliser recommendations for pineapple monoculture on peat (MPIB, n.d.) and immature oil palms on peat (Woittiez et al., 2016) were added. Table 9 shows that fertilisation reported by intercropping farmers ranged widely. Farmers B5, B6 reported an amount of N eight times and an amount of P and K fourteen times higher than reported by farmer R4. Furthermore, some farmers who reported fertilisation to be the same (like B1, B2, B3, B4 and B7) had very different planting densities of both oil palms and pineapples.

Comparing the fertilisation of intercropping farmers with monoculture and underplanting farmers, some intercropping farmers clearly fertilise little (R1+3, R4, B1 – 4 and B7). The other intercropping farmers (R1, R2, B5 and B6) fertilised similar or more than monoculture farmers, even though monoculture farmers normally had higher pineapple densities. This could mean that the fertilisation of these intercropping farmers was sufficient for both oil palms and pineapples. However, compared to the fertiliser recommendations for pineapples, almost all farmers fertilised too little. On the other hand, the Malaysian Pineapple Industry Board (MPIB) fertiliser recommendations appear high. For the oil palm, farmers fertilised sufficient N but too little K compared to the recommendations.

Farmers themselves believed that oil palms in the intercropping system benefitted from the fertilisation. Furthermore, it was said that oil palms which are replanted in monoculture would not receive fertilisation at all in the first years, as such fields do not provide any income.

Table 9. Per farmer and per field, calculated planting densities and fertiliser amounts (per 16 months). Amount of N is the sum of N from NPK fertiliser and urea; amounts of P and K come from NPK fertiliser and are calculated using the molar masses of P_2O_5 and K_2O. Planting densities and fertiliser amounts in underplanting fields are for the immature palms only. *Farmers R1+R3 managed one field together. **(MPIB, n.d.). ***(Woittiez et al., 2016).

	Farmer	**Field**	**Density (plants ha^{-1})**		**Nutrients (kg ha^{-1})**			
			Oil palm	Pineapple	N	P	K	Lime
Intercropping	R1	1	136	34 487	280	73	139	247
	R2	2	164	-	427	88	197	371
	R1+3*	3	148	28 239	148	65	123	247
	R4	8	174	32 520	94	16	31	247
		9	140	35 299				
	B1	4	156	36 309				
	B2	5	154	41 646				
	B3	6	171	38 773	145	26	49	371
		10	162	29 820				
	B4	7	149	32 965				
	B7	13	153	-				
	B5	11	153	33 119	807	235	443	890
	B6	12	150	32 193				
Monoculture	B8	14	-	35 000	282	49	92	74
	P9	17	-	43 000	364	155	328	237
Underplanting	R1	19	152	-	59	26	49	-
	R4	18	129	-	89	39	74	-
Pineapple recommend**			-	43 500	548	8	486	-
Oil palm recommend***	1 YAP		148	-	73	31	157	-
	2 YAP		148	-	91	39	246	-
	3 YAP		148	-	131	47	393	-

4.4.5 Management practices

All pineapple-oil palm intercropping fields in this study were previously planted with oil palm. Old palms were cut down by chainsaw and burned to enable replanting. In underplanting fields, old palms were removed one by one after young palms were planted. This was done by injecting herbicide (glyphosate) through a cut in the stem made by chainsaw. The oil palm would then die and drop in about six months. This sometimes damaged the young palms, but this damage was not perceived as significant by the farmers. Old palm residues were left on the field (Figure 11D).

Once planted, oil palm seedlings in intercropping and underplanting systems were barely managed, at least until the start of fruit production. Apart from fertilisation, pest control against the Asiatic rhinoceros beetle (*Oryctes rhinoceros*) may be carried out using malathion or pheromone traps. According to farmers, this was rarely necessary. Some intercropping farmers reported to prune the lowest fronds so pineapples underneath could be reached. In underplanting fields, young palms were never pruned and weed control was done three times per year by spraying.

Pineapples required more intensive management. Intercropping and monoculture farmers reported very similar management practices. Pest control would be carried out if necessary and included fencing the field against boars and monkeys, removing diseased plants and spraying pesticide. Amounts of pesticide reported by intercropping farmers for pineapples and palms together were less than 1 litre per pineapple cycle (Appendix 19, Table 35). To simplify activities in the pineapple fields, some intercropping farmers pruned the pineapple leaves once or twice during growth. Interestingly, farmer P9, who kept to the 30x60x90 cm spacing, reported that this planting pattern provided sufficient space to work between the pineapples without pruning the leaves.

Until the pineapple plants fully covered the soil (five to six months after planting), weed control was carried out. On average, farmers performed weeding three times each cycle either manually or by spraying herbicide. Amounts of herbicide reported by intercropping farmers were very small (max. 5 litres ha^{-1} per pineapple cycle), monoculture and underplanting farmers reported larger amounts (11 and 16 litres ha^{-1} per 16 months, equivalent to one pineapple cycle) (Appendix 19, Table 35).

To synchronise fruit production in pineapples, flowering was induced by spraying growth regulators (such as ethephon and 1-naphthaleneacetic acid) around eight months after planting. Once fruits were mature, they were harvested, counted and graded based on fruit weight into categories A (≥1.4 kg), B (~1.2 kg), C (~1 kg) and D (≤0.8 kg)

After fruit harvest, all farmers pruned the pineapple plants to induce sucker production. Once the suckers were harvested, plants were removed completely before a new cycle was started. All intercropping farmers reported to remove pineapple plants by spraying and burning: spraying herbicide to kill and dry the plants, burning to remove the residues (Figure 14). The amount of herbicide used for pineapple clearing was not reported.

Though key informants on pineapple monocultures recognised spraying and burning as the quick and easy method, they used different techniques themselves. Two agronomic officers either took the plants out by hand or cut the plants into pieces by machete or machine. The estate manager had just started to use ‘scrapping’: shoving all the old plants into a heap on the side of the field using a light excavator (Figure 11C). This reduced the available planting space with 20%, but for the estate outweighed the disadvantages of burning, including the need to get permission and the environmental consequences. Additionally, the manager hoped this strategy would provide compost and improve soil quality.

Around fields on peat soils, drainage ditches were present but farmers did not actively control the water level (Appendix 17). All reported that there used to be regional control, but not anymore.

Figure 14. A pineapple-oil palm intercropping field after pineapples have been cleared through burning (field 11, 3 YAP).

4.5 Economic aspects

In this section, yields, benefits, costs, benefit-cost ratio (BCR), income and return to labour of the farming system are presented. These economic aspects are calculated based on the scenario described in Chapter 3 (Materials & Methods). All values are given for one hectare over a four year period, which equals one entire intercropping cycle.

4.5.1 Oil palm yields & prices

Intercropping farmers were asked to estimate oil palm yields after the intercropping period based on their experience. Not all intercropping farmers were able to do so. The ones who did, reported that oil palm yields in the first year of production were still relatively low, but increased in the years after. Yields during the peak (Jul-Sep) and low (Mar-Jun) season were said to level each other out. Find farmer estimates of average yields in Table 10.

Interestingly, most farmers found it difficult to estimate fresh fruit bunch (FFB) price. Farmer R1, who also worked as contractor and dealer, reported that the FFB price fluctuates throughout the year, mostly due to fluctuations in the global market. Find farmer estimates of the average price per t FFB in 2018 in Table 10.

Table 10. Oil palm yields and prices as reported by intercropping farmers. Farmers not shown in this table could or did not estimate these values. NA: Not answered. YAP = years after planting.

	Farmer	First yield (~5 YAP) (t FFB ha^{-1} $month^{-1}$)	Mature yield (≥6 YAP) (t FFB ha^{-1} $month^{-1}$)	Average FFB price 2018 ($ t^{-1})
Intercropping	R1	1	3.0	85.9
	R2	NA	3.2	73.6
	B2	NA	1.2	82.2
	B3	1	NA	82.2
	B7	0.5	3.0	82.2

Underplanting farmers did not report any yield estimates for the replanted palms. During the underplanting period, farmers did harvest the old palms. They mentioned that income from this harvest was important to cover the costs for fertilisation and maintenance of the immature palms. Yield was estimated at 1.2 t FFB ha^{-1} $month^{-1}$, relatively low because of the old palm age and because part of the old palms was removed. Estimated average FFB price in 2018 was $82.2 t^{-1}.

4.5.2 Pineapple yields & prices

For 'Josapine' pineapples, farmers received a price per fruit, depending on fruit grade. Each pineapple plant can develop one fruit. Thus, farmers counted their yield in fruit ratio: the proportion of plants bearing fruit at harvest. Furthermore, farmers reported proportions of grade A, B and C fruits per harvest and prices for grade A, B and C fruits (Table 11). Most farmers reported to harvest mostly grade B. This corresponds to observations in the fields.

Only three farmers reported fruits ratios. Their estimates seemed high. For 'Josapine', farmers mentioned timing of fertilisation to be an especially important factor determining which fruit grade was achieved. Reported fruit prices were similar among farmers, except for farmer P9. However, this was an agronomic officer from a different region. 'Moris' fruit prices were consistently estimated to be $0.074 lower than 'Josapine' prices.

No yield estimates for sucker production were obtained. In the fields, it was observed that plants produced one or two suckers. Reported price per sucker was typically $0.049 for 'Josapine' and $0.025 or $0.037 for 'Moris'.

Table 11. Pineapple fruit ratios, grade proportions and fruit prices for 'Josapine' as reported in interviews. Some farmers reported their answers together. Farmers not shown in this table could or did not estimate these values. NA: not answered.

	Farmer	Fruit ratio	Proportion of fruit grade per harvest			Price per fruit per grade ($)		
			A	B	C	A	B	C
Intercropping	R1	NA	NA	NA	NA	0.44	0.39	0.34
	R4	NA	0.25	0.6	0.15	0.49	0.44	NA
	B1, B2, B3	NA	0.35	0.4	0.25	0.44	0.38	0.28
	B4, B7	0.92	NA	NA	NA	0.44	NA	NA
	B5, B6	NA	0.7	0.2	0.1	0.44	0.34	0.29
Monoculture	B8	0.77	0.6	0.3	0.1	0.47	0.39	0.29
	P9	0.90	0.2	0.45	0.35	0.37	0.25	0.17

4.5.3 Benefits, costs, BCR and income

Mean benefits, costs, benefit-cost ratio (BCR) and income of each farming system are shown in Table 12. These means are based on the values calculated for individual farmers. Find all data and estimated values for individual farmers in Appendices 18, 19, 20 and 21.

Intercropping and monoculture farmers received benefits solely from sales of pineapple fruits and suckers. Underplanting farmers received benefits solely from sales of FFB from old oil palms. As the underplanting farmers reported average FFB yield and price together, their benefits were exactly the same. Comparing benefits between intercropping, monoculture and underplanting, monoculture provided slightly higher benefits than intercropping. This can be explained from the higher pineapple planting densities in pineapple monocultures. Underplanting provided much lower benefits.

Total costs are based on input costs and hired labour costs. Some input and labour costs could not be calculated due to lack of information. Also, it may be that farmers still used other inputs or hired labour for other activities which they did not mention in the interviews. Thus, costs estimated here are probably lower than the actual costs. Comparing between farming systems, underplanting costs were lowest. Intercropping and monoculture costs were quite similar.

BCR of monoculture and intercropping were quite similar and very positive. BCR of underplanting was remarkably lower. Regarding income, monoculture performed slightly better than intercropping thanks to the higher benefits. Income from underplanting seemed negligible. Both monoculture and intercropping systems seemed to provide high incomes, of $5000 to $6000 per year. For reference, the minimum wage in Malaysia was set at $3240 per year as of 2019 (Ministry of Finance Malaysia, 2019). To make the same amount of money from oil palm cultivation, farmers would need to harvest 5 to 6 t FFB ha^{-1} per month, an impossible yield on peat. It should be remembered, however, that BCR and income were overestimated, as costs were probably underestimated. Also, the BCR and income given here do not take into account how much labour a farmer invests to make this income. Surprisingly, differences in amounts of hired labour did not cause large differences in total costs between intercropping farmers, as shown by the standard deviation (Table 12).

Table 12. Mean benefits, costs, BCR and income per farming system, ± the standard deviation, over a four year period.

	Sample size (number of farmers)	Benefits ($1000 ha^{-1})	Costs ($1000 ha^{-1})	BCR	Income ($1000 ha^{-1})
Intercropping	10	31.3 ± 1.0	10.3 ± 1.2	3.09 ± 0.34	21.0 ± 1.1
Monoculture	1	33.9	10.5	3.22	23.4
Underplanting	2	4.2 ± 0	3.7 ± 0.1	1.13 ± 0.04	0.5 ± 0.1

4.5.4 Return to labour

To take into account the amount of labour invested by farmers, the return to labour was calculated. Only for farmers who reported to work on the fields themselves, an estimation could be made of the amount of their own labour that they invested (see Appendix 22). Thus, return to labour was calculated for these farmers only, not for farmers who reported to hire all labour. Average required farmer labour and return to labour are presented in Table 13.

Table 13 shows that estimations of farmer labour are unrealistically low. This is due to the fact that only for pineapple planting, fertilisation, weed control and pineapple pruning an estimation of farmer labour could be made. For activities such as pineapple clearing and pest control, no indications of farmer labour were given. For some activities such as oil palm clearing and planting, farmers hired others. However, they would still need to invest some of their own time in worker management. Required labour for such activities was not reported or asked in the interviews. Furthermore, farmers themselves regarded pineapple as highly labour intensive, also indicating that the farmer labour calculated here is probably an underestimation.

Due to the underestimation of farmer labour and the overestimation of income, the estimated returns to labour are unrealistically high, knowing that wages for hired labour were $10 to $20 man-day^{-1}.

Table 13. Mean required farmer labour and return to labour per farming system, over a four year period.

	Sample size (number of farmers)	Farmer labour (man-days ha^{-1})	Return to labour ($1000 man-day^{-1})
Intercropping	8	37.4 ± 13.3	0.69 ± 0.46
Monoculture	1	54.7	0.43

4.6 Social aspects

In this section, social aspects such as organisation of supply chains, farmers' background and organisation and land ownership in the study area are analysed.

4.6.1 The oil palm supply chain

The farmers approached for this study were all independent farmers. The farmers sold their oil palm produce (FFB) to local 'dealers'. Dealers arranged transport of the FFB to their collection centre ('ram'). At the collection centre, harvest was weighed and gathered for transport to a palm oil mill.

The relationship between dealers and farmers was very important. On one hand, farmers depended on their dealer to sell the FFB to the mill. Additionally, farmers bought oil palm seedlings, fertilisers and other inputs via their dealer. Dealers were trusted to correctly weigh and register the harvests and pay the farmers a fair share of the FFB revenues. On the other hand, dealers depended on the farmers for FFB supply. To gain farmers' trust and bind them to their collection centre, dealers were willing to invest in the relationship with farmers. For example, it was observed that dealers bought their farmers drinks, food or clothes. Informant K1 explained that dealers provided unofficial loans to their farmers. Normally, such loans were repaid by the farmers but if the farmers would switch dealers, this investment was lost. In this research, contact with dealers was crucial as they provided contact with farmers. Farmers were willing to participate because their dealer asked them to.

Little information was obtained about upstream supply chain actors, such as fertiliser or herbicide suppliers. Some farmers obtained their oil palm seedlings via MPOB which could influence their cropping practices in two ways. First of all, the moment of delivery of seedlings determined when palms were planted exactly and which crop was planted first (pineapple or oil palm). Secondly, to apply for free seedlings from the Malaysian Palm Oil Board (MPOB), farmers were obliged to plant oil palms seedlings directly after clearing the old palms. If farmers first performed a few years of pineapple monoculture, which was a common practice, they had to pay for the oil palm seedlings.

4.6.2 The pineapple supply chain

All intercropping farmers reported to sell their pineapples to a pineapple dealer, who arranged transport, counting, grading and all further handling of the fruits. As counting and grading determined the pineapple benefits received by the farmer, the pineapple dealer had an important influence on their income. Unfortunately, attempts to contact pineapple dealers did not succeed.

Interestingly, farmers in Benut reported that the pineapple dealer already played an important roll even before the actual harvest. They contacted a pineapple dealer 1 week up to 4 months before harvesting. Over the phone, they discussed the pineapple development and set a harvesting date. The preference of the dealer and demand on the pineapple market determined harvesting date and amount of pineapples to be harvested. During low demand, harvest might be carried out in multiple times. Farmers in Rengit seemed to have a stronger position, calling their pineapple dealer only shortly before harvest and having more influence in the harvesting process.

The one pineapple monoculture smallholder farmer (B8) did not sell his pineapples to a dealer but directly to customers in his roadside shop. This shop and adjoining roadside restaurant were managed by his wife and daughter. Pineapples produced at the Malaysian Agricultural Research and Development Institute (MARDI) by farmer P9 were counted and graded locally, before being sold to a dealer. The large estate manager (key informant K5) sold only a part of the harvest to local dealers. Most of his pineapples went to a related canning factory or were exported.

No information was obtained about the sources of inputs such as fertiliser or herbicide. Planting material was produced by farmers themselves or bought from farmers in their network. MARDI and the Johor Department of Agriculture, located in the area of Pontian, worked to develop and spread planting material of new pineapple varieties to smallholder farmers.

4.6.3 Farmers' background and organisation

Age, education and gender

Though the exact age of farmers has not been asked, age seemed to range widely. Some farmers still had young children, while others had already adult children. Most farmers had finished secondary school, except for two who had finished primary school only and one who had a degree in IT. This last farmer could communicate in English, the others very little. All interviewed farmers were male, and no female farmers or land workers have been observed. Women did perform other jobs, for example in restaurants, shops or offices.

Source and level of income

Among the farmers in Rengit, only R3 reported to be a full-time farmer, managing and working on fields. R1, R2 and R4 farmed some fields of their own but acted mainly as contractors, employing workers to manage fields of clients. As contractors, R1 reported to manage approximately 600 ha and R4 180 ha. In addition, R1 managed a FFB collection centre and a heavy equipment rental company. As can be expected, these farmers seemed to be well-off, with R1 driving expensive cars and R2 living in a luxurious villa.

In Benut, the situation was slightly different. Five farmers reported to be full-time farmers. For B2, farming was a side job: most of his income was made in construction work. B8, the pineapple monoculture farmer, received additional income from the roadside shop and restaurant. These farmers appeared to manage a limited amount of land and to have small incomes, sometimes supported by income from their wives or children. The exception was farmer B5, who was the son of the oil palm dealer in Benut and worked with his father at the collection centre and as contractor. Their whole family lived in a luxurious villa.

Organisation

No information about farmer cooperatives or other forms of farmer organisation was reported in any of the interviews. Farmers appeared to be organised mostly through their oil palm dealers, as explained above. In Benut, the farmers seemed to form a strong community, who discussed farming practices and exchanged labour. Furthermore, these farmers spoke Javanese among each other, as their parents or grandparents came from Java originally. Such a community was not seen among the farmers in Rengit, though some of these farmers spoke Javanese as well.

All interviewed farmers were contacted via the field officers of MISI, who provide information and training for smallholders as part of the P&G Palm Independent Smallholder Program. It is unknown if and how other farmers received training.

4.6.4 Land ownership

Farmers interviewed in this study were defined as the people deciding over the field management. Farmers did not necessarily own or work on these fields themselves. Three clearly different land ownership situations could be distinguished.

1. Own or family owned land

In the first situation, the land was owned by the farmer himself or close relatives (wife, parents, siblings). Farmers took full responsibility and care over the fields. They received either the full profit or shared (part of) the profit with family. Eight of the intercropping fields, one monoculture field and one underplanting field were owned in this way.

2. Leased land

In the second situation, specifically occurring among intercropping fields, the land was owned by acquaintances (friends, neighbours) but farmers 'leased' it to perform pineapple cultivation in return for oil palm replanting. They did not pay for the use of the land apart from covering the oil palm replanting costs and taking care of the oil palms while growing pineapples. Farmers did not specify whether the land owners were involved in management decisions. After the intercropping period would be finished, some farmers had to move to a new piece of land while others would continue to take care of the oil palms. The exact situation depended on the specific relation between the farmer and land owner. In total, five intercropping fields were leased in this way.

3. Management as contractor

In the third situation, farmers acted as contractor, hiring workers to perform field maintenance on fields owned by clients. Contractors received a reward per produced ton FFB. Which decision were made by the contractor and which by the client, differed per client. Some clients would leave all the management with the contractor, other clients would still make part of the decisions or even did part of the work themselves, for example the fertilisation. Two of the underplanting fields were managed in this way.

4.7 Reasons for intercropping

During the interviews, farmers were asked why they performed pineapple-oil palm intercropping during the replanting period. The main reason mentioned by all farmers was to receive income while waiting for fruit production from the replanted oil palms. In addition, farmers perceived the FFB prices at time of study as low, making pineapple cultivation more attractive. Farmer B6 reported that the pineapple income allowed him to make savings. However, farmers still preferred oil palm cultivation in the long-term because they perceived pineapple cultivation as highly labour intensive (though this could not be confirmed by the labour estimations made in the previous section). Another disadvantage mentioned is the fact that pineapples provided income only once every 1.5 years. Farmers reduced this disadvantage by dividing their fields in plots, but this made management more complex.

Based on the differences in farmers' background, it may be hypothesized that the replanting period is a larger economic challenge for farmers in Benut than for farmers in Rengit. Indeed, when asked, farmer R2 reported not to perceive the investments needed for oil palm replanting as problematic.

Some agronomic reasons for intercropping were reported. Multiple farmers believed that the fertilisers used for pineapples, also benefitted the palms. Farmer R2 added that the pineapple cover protected the soil and that pineapples ashes improved fertility. According to farmers R1 and R4, the pineapple cover helped to reduce weed control costs and herbicide use. Last, farmers R2 and R4 mentioned that burning all old palms and growing pineapple monocultures before replanting could reduce occurrence of basal stem rot caused by *Ganoderma boninense*. On peat fields with *Ganoderma*, they would specifically choose intercropping.

The only social reason mentioned for pineapple-oil palm intercropping was regional preference. Though pineapple-oil palm intercropping was carried out in both Rengit and Benut, Benut farmers appeared to have a stronger affiliation with pineapple cultivation. This is in accordance with the regional history.

Underplanting farmers were asked why they performed underplanting instead of intercropping. As these farmers acted as contractors, they reported that the choice between underplanting and intercropping depended on their client. However, they themselves linked the advantages of intercropping to peat soils. On peat, pineapples were easy to plant and performed better than other crops. Furthermore, leaning of old palms occurred more strongly on peat, making underplanting difficult. From his experience, farmer R1 concluded that on peat, intercropped palms grew better and produced earlier than underplanted palms. On mineral soils, underplanting or intercropping with other crops (banana, cassava) were easier and more lucrative alternatives.

4.8 Sustainability analysis

Based on the data presented in the sections above, four sustainability issues were identified per domain. These issues have been qualitatively assessed and classified as either a strength, weakness, opportunity or threat of the pineapple-oil palm intercropping system in Johor. This provided the SWOT-analysis shown in Table 14. The four issues identified as most important or most influential are given in bold and discussed.

Income formed the major strength of the intercropping system. Pineapple cultivation in between the young oil palms could not only cover the replanting investments and costs of oil palm maintenance, it provided income during the period that oil palms did not yet produce fruit bunches. The income from intercropping seemed substantial, even when taking into account that the income as calculated in this study was probably overestimated. Replanting could otherwise be a very difficult phase for smallholders, even forcing farmers to sell their land (McCarthy, 2010; Nchanji et al., 2016).

The residue management was the largest weakness of the intercropping system. All intercropping farmers removed the old pineapples by burning. Burning on peat soil has serious negative consequences. Environmental consequences include greenhouse gas emissions and soil erosion (Schrier-Uijl et al., 2013; Smith et al., 2018). In the long-term, soil erosion negatively impacts yields, directly affecting farmers. Air pollution (haze) from peat fires has been found to increase mortality caused by respiratory diseases (Sahani et al., 2014). Peat fire smoke could be smelled almost constantly in the research areas and farmers carried out burning without any protection.

Logically, land use is more efficient in a pineapple-oil palm intercropping field than in a field with only immature palms. However, for a fair comparison, land use efficiency should be calculated over the whole life cycle of an oil palm field (approx. 25 years). Though the growth and productivity data and the yields reported by farmers did not show negative effects of intercropping, the current study did not provide information on oil palm yields after intercropping. This is an important knowledge gap which can pose a threat to the system, if for example sustainability certifications would assume that intercropping negatively affects yields in later palm stages and condemn the practice. Of course, use of peat soil for agriculture leads to high greenhouse gas emissions. This general disadvantage of peat soil is acknowledged but not further discussed here.

The land ownership situations could have different influences on the system. Adoption of sustainable practices is more common on fields owned by farmers than on rented or borrowed plots (Kassie et al., 2013). The leasing arrangement could make farmers prioritize short-term interests, especially if they lease the field only during the intercropping period. At first glance, it did not seem like farming practices were influenced by the land ownership situation. For example, suboptimal oil palm planting patterns occurred both in own and leased fields. Still, this potential conflict of interests can pose a threat to the system.

Table 14. SWOT analysis of identified sustainability issues.

	Sustainability issue	Strength	Weakness	Opportunity	Threat
Environmental	Fertilisation practices	Young palms receive fertiliser	Fertiliser not adjusted to intercropping		
	Residue management	Low labour requirement	**Use of herbicide, burning of pineapples**		Future regulations may ban this practice
	Herbicide & pesticide use	Small amounts	Dependency on chemical inputs		
	Land use	High efficiency in intercropping years	Greenhouse gas emissions from peat soil		**Whole life cycle efficiency unknown**
Economic	Benefit-cost ratio	High BCR			
	Income	**High income**			
	Return to labour	High return to labour	Labour perceived as very intensive		
	Product & market diversification	Farmer dependency on palm oil reduced on short-term	Farmer and land owner dependency on palm oil in long-term		No diversification on regional scale
Social	Supply chain organisation			Easy access to oil palm & pineapple market via dealers	Influence of suppliers/dealers on practices, harvest & grading
	Farmers' organisation	Exchange of knowledge between farmers		Strengthening of farmers' position via dealers	High dependency on dealers
	Access to information & training			Existing network via MISI officers / P&G project	No pineapple information or training available
	Land ownership	Own land or contracting: long-term income and interests		Leasing: Additional land for low cost	Leasing: Short-term income, **conflict of interests palm vs. pineapple**

5. Discussion

The aims of this study were to analyse environmental, economic and social effects of pineapple-oil palm intercropping and formulate recommendations for the design of a sustainable pineapple-oil palm intercropping system. To achieve these aims, the following research questions have been posed:

1. What are the effects of intercropping on oil palms and pineapples, in terms of vegetative growth and productivity?
2. What are the agronomic, economic and social aspects of the pineapple-oil palm intercropping system in Johor?
3. How does this intercropping system perform in terms of sustainability?
4. How can the sustainability of this pineapple-oil palm intercropping system be improved?

First, strengths and limitations of the current study are discussed. Second, the answers to these research questions are formulated and their implications assessed.

5.1 Strengths & limitations of the current study

The design and methodology used for this research had notable advantages and disadvantages, which should be considered when assessing the results.

Field measurements have been carried out in intercropping fields and in local alternative farming systems as control groups. This strategy ensured that outcomes of this study were relevant for farmers in the local context. When making comparisons between such fields, it should be kept in mind that results are influenced by differences in management and environment. Differences in crop growth or productivity may be caused by other factors than the farming system of the field. Another pitfall of the field measurements was the sample size and selection. Especially of the control groups, only few fields have been visited. These fields were not evenly spread over regions and underplanting fields were located on a different soil type. Though field differences have been taken into account in the analyses, the small sample size reduced the potential to identify significant differences between systems. If differences would have been found, it would have to be checked if these were not the result of confounding factors. Still, the current results provide a first impression of the farming systems and help to identify interesting targets and necessary sample sizes for future studies.

Farmer interviews formed an important part of this study, providing both qualitative and quantitative information on local practices and farmers' insights in a time- and resource-efficient manner. However, it has to be noted that especially some of the quantitative interview information seemed inaccurate. For example, estimations of fertiliser use ranged widely and oil palm yield estimations were unrealistically high. Some methodological shortcomings may have increased inaccuracy. First, interviews took relatively long (45–75 minutes). Second, a part of the interviews were held with multiple farmers at the same time, making farmers copy each other's answers. Third, interviews were conducted via a translator. In future studies, adjusted design and planning of the interviews and training of the translator could reduce these limitations (Kapborga & Berterö, 2002). Here, answers have been compared between interviews and triangulated with field observations to increase accuracy as much as possible.

Sustainability assessment is an almost controversial topic by itself. Sustainability is a complex concept with many definitions and measuring sustainability is notoriously difficult. In any sustainability assessment, choice of indicators affects the assessment. Here, indicators were selected based on the description of the intercropping system and then assessed qualitatively. For this exploratory study and for the formulation of recommendations, this approach was sufficient and feasible. However, a more standardised and quantitative analysis would be necessary if the intercropping system is to be assessed or compared in a broader context (Schader et al., 2014).

5.2 Effects of intercropping on oil palms and pineapples

The data collected in this study did not show any effects of intercropping on vegetative growth and productivity of oil palms, compared to oil palms in underplanting systems. Furthermore, no correlations were found between pineapple planting density and oil palm growth or distance between the oil palms and the nearest pineapples (CT-distance) and oil palm growth in intercropping fields. This can indicate that intercropping farmers had adapted their management so that palms would not be affected by the pineapples.

Values for vegetative growth of young oil palms measured in this study were relatively similar to the few values that could be found in literature (Table 15). Only one study found much higher numbers of fronds per palm in monoculture (Gerritsma & Soebagyo, 1999). Of the productivity indicators, only values for inflorescence sex-ratio could be found in literature. These sex-ratios fell within the range measured in this study (Erhabor & Filson, 1999; Henson & Dolmat, 2003) but variation in this study was large. Though sex-ratio has been used as indicator of productivity before and was shown to decrease with different types of stress (Corley & Tinker, 2016a; Erhabor & Filson, 1999), it may be that at such young age, inflorescence sex-ratio is too variable to use as productivity indicator.

Altogether, it can be concluded that the oil palms in intercropping fields showed good growth. Field observations confirmed this conclusion: though some palms were diseased, overall growth seemed vigorous. There are potential explanations why intercropping would not affect vegetative growth and productivity. Competition for water seemed unlikely as water levels were not far from the optimal 50–75 cm and oil palm roots can reach depths that pineapples do not (Jourdan & Rey, 1997). In contrast to underplanted palms, intercropped oil palms stood in full sunlight which is beneficial for their growth (Corley & Tinker, 2016b).

Table 15. Reported values for vegetative growth indicators of young oil palms. Values are estimated from figures or tables in the referenced articles and converted to the units used in this study.

	Number of fronds	**P_{cs} (mm^2)**	**Rachis length (cm)**
(Nake & Simin, 2013)			
Volcanic soil, Papua New Guinea			
Intercropped, 2 YAP:	33	830	234
Underplanted, 2 YAP:	39	880	266
(Henson & Dolmat, 2003)			
Peat soil, Malaysia			
Monoculture, 3 YAP:	49	-	350
Monoculture, 4 YAP:	49	-	400
(Gerritsma & Soebagyo, 1999)			
Volcanic soil, Indonesia			
Monoculture, 3 YAP:	60–70	-	-
Monoculture, 4 YAP:	55	-	470

Results for the pineapples proved slightly different. The collected data show that intercropping negatively affected the vegetative growth of pineapples nearest to oil palms (CT plants), but not the pineapples far from palms (FT plants). However, the low average CT values were caused by some CT plants with remarkably smaller size. Most CT plants were similar in size to FT plants. This would suggest that oil palms did not have an overall effect on nearby pineapples, only on some specific pineapples. An explanation could be that some CT plants got severely damaged during oil palm maintenance. This corresponds with the finding that there were no differences in productivity between CT and FT pineapples.

No effect of differences in distance between palms and pineapples was detected. For the CT pineapples, it should be noted that this distance increased with oil palm age. This can be one of the reasons why no competition effects were found. Secondly, no effect of pineapple planting density was detected. This can be explained from the relatively low planting densities used in intercropping fields (30 000 plants ha^{-1}). Though evidence in literature showed that fruit weight does decrease with increasing planting density, the effect is relatively small and typical commercial planting densities range up to 80 000 plants ha^{-1} (Hepton, 2003). and distance between palms and pineapples

Values for vegetative growth and productivity of pineapples measured in this study are slightly different from values reported in literature (Table 16). Numbers of leaves per plant in this study were relatively low, while heights of the D-leaf were higher than reported for 'Josapine'. Fruit volumes were clearly lower than in literature, but this can be due to the moment of measurement. Fruit volumes in in this study were measured no later than 11 MAP, while values in literature were measured at harvest. Fruit weights from literature correspond to fruit grade B, the grade most reported by farmers in this study as well.

Overall, it can be concluded that pineapple growth and productivity in intercropping fields seemed good. This can be partly explained. Competition for water seems unlikely, as rainfall in Johor is sufficient to reach the pineapples' minimal requirement (5 cm of water per month). CT plants under older oil palms (3 to 4 YAP) surely experienced shading, but it has been found that pineapple productivity may actually increase under low light intensities compared to high light intensities (Chipungahelo et al., 2007).

Table 16. Reported values for vegetative growth and productivity indicators of pineapples. Values are estimated from figures or tables in the referenced articles and converted to the units used in this study.

	Number of leaves	**Height of D-leaf (cm)**	**Fruit volume (cm^3)**	**Fruit weight (kg)**
(Mohd Selamat & Masaud, 2005)				
Sandy soil, Malaysia				
'Josapine', 9 MAP:	52	81	-	-
'Josapine', 13 MAP:	-	-	484	1.22
(Razzaque & Hanafi, 2001)				
Peat soil, Malaysia				
'Gandul', 10 MAP:	55	110	-	-
'Gandul', 15 MAP:	-	-	622	1.15
(Mohd Selamat & Ramlah, 1993)				
Peat soil, Malaysia				
'Gandul', 9 MAP:	-	99	630	1.35

The fertilisation by intercropping farmers remains a point of discussion. Comparing the amounts of fertiliser reported by intercropping farmers with the fertiliser recommendations (Table 9), it would be expected that the oil palms and pineapples did not receive sufficient nutrients in some of the fields. However, this can't be seen in the results on oil palm and pineapple growth and productivity. Here, the management practices and soil type should be taken into account. Though burning of pineapple residues brings negative environmental effects such as greenhouse gas emissions and soil loss, fires do enhance nutrient availability in peat soil (Knicker, 2007).

It might be that negative effects of competition for nutrients would have been visible in the yields of pineapples and oil palms. These yields, however, have not been measured in this study. Farmers did report fresh fruit bunch (FFB) yields in the interviews. Estimations for the first year of harvest were 6 and 12 t FFB ha^{-1} yr^{-1}. Similar yields were measured in intercropped palms of 4 YAP in Ghana (Okyere et al., 2014). This would indicate that intercropped yields are not depressed. Strangely, mature yields reported by farmers were either relatively low (14.4 t ha^{-1} yr^{-1}) or very high (36 t ha^{-1} yr^{-1}) compared to yields in well-managed plantations (25–30 t ha^{-1} yr^{-1}) (Woittiez et al., 2017). This suggests that this interview information may be inaccurate and validation through objective measurements is necessary.

5.3 Agronomic, economic and social aspects of the intercropping system

The agronomic, economic and social aspects of the pineapple-oil palm intercropping system in Johor have been thoroughly described in Chapter 4.4, 4.5 and 4.6. To summarise, the pineapple-oil palm intercropping system emerges as a farming system which can provide good income but still requires further improvement regarding agronomic practices and environmental effects.

Intercropping farmers applied agronomic practices which are mostly targeted at the pineapples. Though there was no evidence for negative effects of intercropping on oil palm and pineapple growth and productivity, the suboptimal planting patterns and fertilisation reported for some fields may cause suboptimal yields. It should be noted that the intercropping system does provide farmers with the possibility to apply fertilisation, which is not the case if oil palms would be grown in monoculture.

Pineapple cultivation in both intercropping and monoculture systems provided good income and a higher income than oil palm cultivation would do. For the income calculated in this study, farmers invested different amounts of labour. Unfortunately, labour requirements could not be realistically estimated in this study, so the actual return to labour remains unknown. Farmers themselves perceived pineapple cultivation as highly labour intensive, which was their main reason for continuation of oil palm cultivation.

Socially, there proved to be strong relationships between oil palm dealers and farmers. Interestingly, farmers also managed land under a leasing arrangement or as contractor. This indicates that part of the land owners in Johor are no longer interested in farming by themselves, and the remaining farmers may be managing areas larger than their own fields. These social aspects could also help explain why oil palm cultivation is still popular.

Compared to underplanting, intercropping can bring higher income and similar oil palm growth. Based on the results in this study, intercropping would be a better replanting strategy.

5.4 Sustainability assessment and recommendations for improvement

From the summary above and the SWOT analysis, it can be concluded that the intercropping system had both sustainable and unsustainable aspects. Though this study did not enable weighing of the strong economic advantage of increased income against the environmental disadvantage of pineapple removal by burning, the implication of these findings is that the sustainability of the intercropping system can be improved by finding an alternative for pineapple burning which does not significantly decrease income. Additional recommendations focus on improving pineapple and oil palm yields without causing trade-offs in other sustainability aspects.

5.4.1 Alternative pineapple removal

Alternatives ways of pineapple removal are used already by the MARDI and Johor state research institutes and a large pineapple estate. Methods of the research institutes were to take plants out by hand or to chop by machete or machine. The large estate scrapped old plants into heaps by excavator. Other removal methods combine spraying or chopping with incorporation of the residues into the soil, once sufficiently desiccated (Hepton, 2003). In organic pineapple cultivation, residues are composted (Hengsdijk & Elbersen, 2019).

Any method involving heavy machinery, i.e. chopping, scrapping and soil incorporation, has two large disadvantages. First, machine rental increases costs and may be difficult to access for smallholders. Costs could be reduced if farmers rent together or via their oil palm dealers. However, the second disadvantage remains: use of heavy machines is harmful for peat soil structure as it causes compaction and tillage increases peat decomposition. These effects can lead to reduced yields and cause additional greenhouse gas emissions.

Manually taking out plants or chopping by machete requires more labour than spraying and burning, as confirmed by the agronomic officers. This means that these methods are realistic only if the costs from increased labour are compensated somehow. This may be possible through valorisation of the plant residues. Proposed approaches of pineapple residue valorisation include use as animal feed or production of biogas or bioethanol, bromelain or paper (Hengsdijk & Elbersen, 2019; Hepton, 2003; Seguí & Fito Maupoey, 2017). In the long-term, such valorisation chains could be established, for example in collaboration with large pineapple estates, pineapple dealers and government institutes like MPIB. On shorter term, composting or small-scale biogas production could be solutions though no literature on the success of pineapple plant residues for composting or small digesters could be found.

Until pineapple residue valorisation has been developed, spraying without burning could be tried. Regrowing plants could be taken out during normal subsequent weeding activities. The last, radical solution would be to intercrop with other crops which can be removed more easily. Unfortunately, few crops grow as well as pineapples on peat soil (Andriesse, 1988). Cassava or paludiculture crops could have potential, provided that there is sufficient demand and market opportunities.

5.4.2 Good agricultural practices

Recommendations that improve pineapple and oil palm yields bring both environmental and economic advantages in the form of improved land use and increased income, under the condition that there are no significant increases in soil depletion, pollution, costs or labour. Such recommendations can be summarised as 'good agricultural practices' and include improvement of planting patterns, fertilisation practices and disease control. Peat soil characteristics should especially be taken into account when formulating such recommendations, so negative environmental effects are minimised. Some of the current management practices of intercropping farmers did seem beneficial for the performance of the intercropping system, such as the increasing distance between pineapples and oil palms with increasing palm age. Such good practices should be identified and maintained.

In underplanting systems, any inconsistencies in the old palm planting pattern will remain with the young palms. The intercropping system has as advantage that the planting pattern can be corrected. Still, observed oil palm planting patterns deviated from the 9 m equilateral triangular pattern to non-equilateral or even rectangular patterns. Though a slightly increased planting density of 150 to 170 palms ha^{-1} may be beneficial on Malaysian peat soil (Corley & Tinker, 2016b; Woittiez et al., 2017), it is important to maintain an equilateral triangular pattern for optimal light interception. More precise lining would not significantly increase labour, as it is done only once in 20–25 years, while influence on the cumulative yield over this period can be substantial. Any other alterations to the planting pattern, such as maintenance of wild seedlings or additional palms in field edges, should be discouraged.

All pineapples were grown in a double-row pattern, though intercropping fields followed different plant spacing than advised for monocultures. Advantages of the 30x60x90 cm planting pattern used in monocultures are increased planting density and wider paths, eliminating pruning operations. Switching to this planting pattern can both increase yield and reduce labour, as long as the increased planting density does not cause negative competition effects on the oil palms.

Farmers reported widely ranging fertilisation rates. Both under- and over-fertilisation have negative consequences. Optimisation of fertiliser rate and application methods help to increase yields and resource use efficiency and reduce negative effects such as leaching and volatilisation. When formulating fertilisation recommendations, peat soil characteristics and other management practices (such as residue management) should be taken into account.

Basal stem rot, caused by the fungi *Ganoderma boninense,* is a common palm disease in Malaysia which causes severe yield losses (Woittiez et al., 2017). Farmers suggested that performing pineapple monoculture cycles before replanting can reduce the spread of *Ganoderma* from old to young palms. Similarly, a one-year fallow was shown to reduce infection rates (Virdiana et al., 2010). If such an effect can be proven for pineapple monoculture, and reduced disease incidence can compensate the yield loss from delayed replanting, it improves sustainability.

5.5 Suggestions for further research

This study was the first to investigate pineapple-oil palm intercropping on peat soil. As such, it served to see if pineapple-oil palm intercropping has potential to improve palm oil sustainability and if so, to identify topics requiring further research.

Pineapple-oil palm intercropping already has sustainable aspects, but would benefit still from implementation of the recommendations mentioned in the previous paragraph. Further research is needed to strengthen and specify these recommendations. This includes research on pineapple removal, fertilisation requirements and *Ganoderma* occurrence. In addition, effects of the (improved) intercropping system on oil palm productivity in later life stages still need to be studied. Though this research suggest that intercropping has no influence on palm productivity, this has not been measured in older palms due to time and resource constraints.

A possibility to overcome such constraints is to make use of models. A suitable model for intercropping systems is WaNuLCAS, which describes Water, Nutrient and Light Capture in Agroforestry Systems (van Noordwijk & Lusiana, 1999; van Noordwijk et al., 2011). WaNulCas has already been adapted to the specific properties of oil palm (van Noordwijk et al., 2001). To enable modelling of the pineapple-oil palm intercropping system, a crop library with all necessary input parameters of pineapple will have to be developed. This may be possible using values for pineapple growth and productivity reported in literature (Hanafi et al., 2009).

If pineapples could be maintained throughout the whole palm life cycle, income and position of smallholders could be improved permanently. WaNuLCAS has been used previously to study permanent intercropping of oil palm with cacao, rubber, cassava, groundnut, mucuna and black pepper in the so-called 'double-row avenue system' (Migeon, 2018; Stomph, 2017). This system allows permanent integration of crops in an avenue between palm rows, while maintaining a similar planting density (138 palms ha^{-1}). Pineapple has been proposed as suitable intercrop, but the productivity of this combination has not yet been studied and results with other intercrops were mixed (Ashraf et al., 2018; Migeon, 2018; Stomph, 2017; Suboh, Norkaspi, & Raja Zulkifli, 2009). The performance of pineapple-oil palm intercropping in the double-row avenue system and willingness of farmers to adopt this practice are valuable topics for further research.

In such follow-up studies, previously mentioned limitations of the current study regarding sample size, interview methodology and sustainability assessment should be taken into account and improved upon.

6. Concluding remarks

This study on pineapple-oil palm establishment intercropping on peat soil showed that this practice can provide good income for smallholder farmers during the oil palm replanting phase without significant negative effects on oil palm growth and productivity. Under the condition that there is demand and marketing opportunity for pineapples, adoption of this practice can make it easier for smallholders to timely replant oil palms. As timely replanting improves average oil yields, intercropping has the potential to increase sustainability of palm oil production in terms of land use efficiency.

To fully exploit the advantages of pineapple-oil palm intercropping, three important steps still need to be taken. First, a sustainable method for pineapple removal on peat soil needs to be developed to replace the current burning method. Second, establishment of good agricultural practices is required. Last, it should be verified that this intercropping system does not affect productivity of oil palms in later life stages. Once these steps are completed, the pineapple-oil palm intercropping system can be considered an agricultural practice which is relatively sustainable for a human activity on peat soil.

Some suggestions for sustainable pineapple removal and good agricultural practices are provided, but extensive research on these issues went beyond the scope of this exploratory study. Governments, NGOs and other institutes are recommended to take an active role in the creation of viable alternatives for crop burning, as smallholder farmers will not be able to make the required investments by themselves. From this research, it can be concluded that the pineapple-oil palm intercropping practice has sufficient potential to deserve additional attention.

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8. Appendices

1. Oil palm morphology

The oil palm is a large palm with a columnar stem, covered with old leaf sheaths. Large inflorescences are produced in the leaf axils which are normally either male or female. The female inflorescences develop into compact fruit bunches (Figure 15). The leaves, called fronds, are pinnate and consist of multiple leaflets along the rachis (Figure 16). It has been estimated that oil palms produce one new frond every three weeks, each frond adding 4.5 cm to the trunk height. This adds up to a height increase of 80 cm per year, or 20 m in 25 years. Rachis can reach lengths of 8 m. Roots extend from the base in a vertical or horizontal direction (Figure 17) (Corley & Tinker, 2016e).

Figure 15. Mature oil palm morphology. Adapted from (Cirad, 2010). © C. Bessou

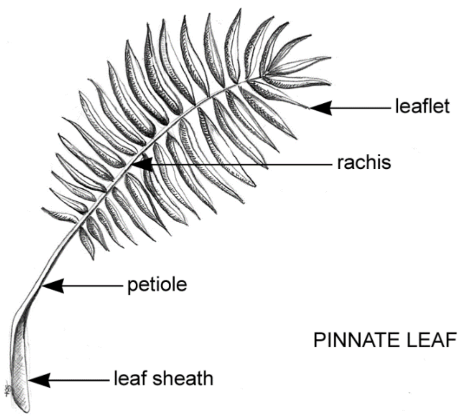

Figure 16. Oil palm leaf morphology. Source: (idtools.org, 2014).

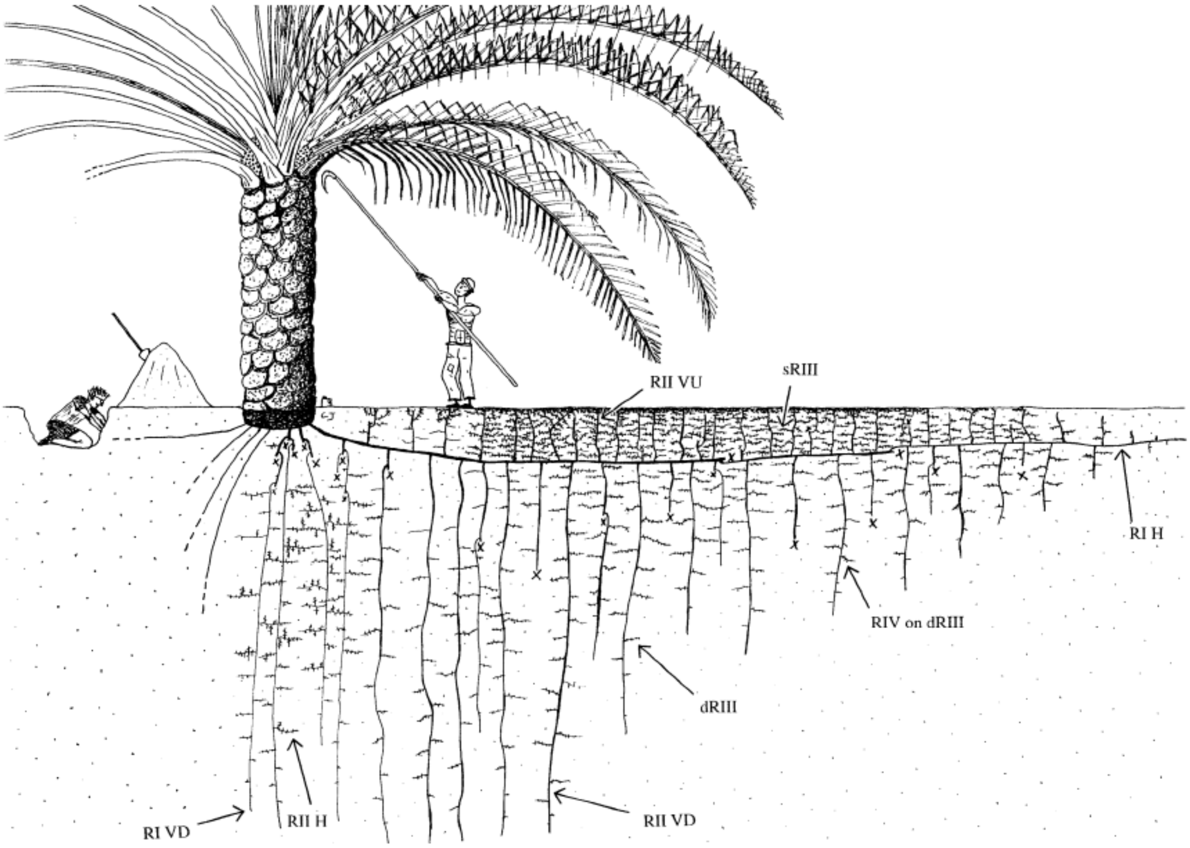

Figure 17. Oil palm root distribution, from one vertical and one horizontal primary root in a 10-year-old palm. The harvesting pole measures 3.5 m. The codes for the root types are as follows: RI: primary; RII: secondary; sRIII: surface tertiary, usually highly branched; dRIII: deep tertiary, less branched; RIV: quaternary; VD: vertical descending; VU: vertical, ascending; H: horizontal (R. H. V. Corley & Tinker, 2016e). Source: (Jourdan & Rey, 1997).

2. Oil palm classification

Currently, the two accepted oil palm species are *Elaeis guineensis* and *Elaeis oleifera*, the African and the American oil palm, respectively. However, as *E. guineensis* is the principal source of palm oil and the commonly grown species in Malaysia, this will be the only species described here. The African oil palm is indigenous to the humid lowland tropics of West Africa. It now exists in a wild, semi-wild or cultivated state in the tropics of Africa, South East Asia and Central America (Corley & Tinker, 2016g).

Oil palms are classified based on their fruit form. Three distinctive fruit forms can be recognised based on differences in the internal anatomy. Fruits consist of fruit pulp (mesocarp) surrounding a nut, which is composed of a shell (endocarp) and a kernel (endosperm). *Dura* are thick-shelled, *tenera* are thin-shelled and *pisifera* are shell-less (Figure 18). It has been found that the *tenera* form is obtained by crossing *dura* with *pisifera* (DxP). As *tenera* has superior oil content, DxP seed is preferred for palm oil production (Corley & Tinker, 2016c).

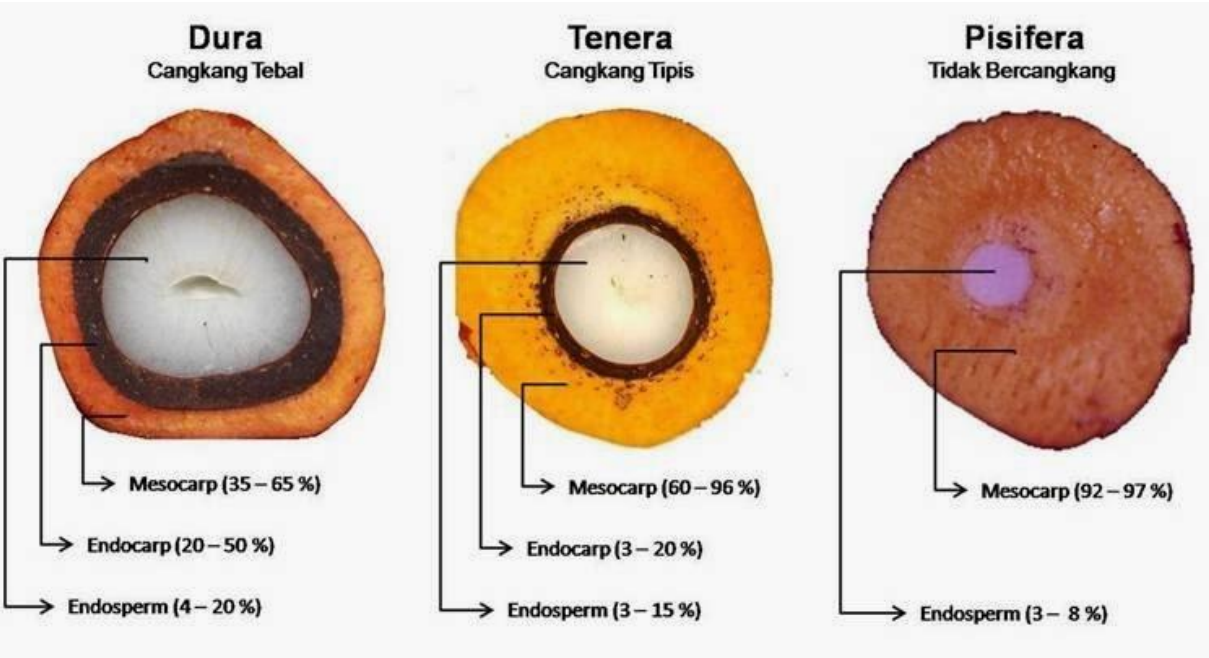

Figure 18. Oil palm fruit morphology and forms. Source: (Malangyudo, 2014).

3. Oil palm cultivation & development

Typically, oil palm plantations use a triangular planting pattern with 9x9 to 9x7.8 m spacing, resulting in a planting density of 110 to 150 stems per ha. Oil palm seedlings are raised in a nursery for about one year before they are ready for transplanting (Sheil et al., 2009). Fruit can be harvested already 30 months after transplanting, but trees are most productive when they are 9-15 years old (Basiron, 2007). Generally, after 25 to 30 years, trees become too tall to harvest, yields decrease and trees are replaced (Sheil et al., 2009).

The growth, development and productivity of mature oil palms is relatively well-documented, for example in (Corley & Tinker, 2016e, 2016a). However, detailed information and data on the development of oil palms during the first years after replanting seems scarce. For young palms, most vegetative growth data is available on leaf parameters, especially number of fronds, frond area and Leaf Area Index (Gerritsma & Soebagyo, 1999; Hardon et al., 1969; Henson & Dolmat, 2003; Nake et al., 2015; Nake & Simin, 2013; Okyere et al., 2014; Perez et al., 2016). Only one study reported root data (Erhabor et al., 2002). Variation in reported values can be caused by many factors, such as climate, soil, fertilisation, planting density, irrigation and management. Most relevant for this study were values from trees grown on peat soils. These are only reported in (Hardon et al., 1969; Henson & Dolmat, 2003). Still, to get an impression of available data, parameters and values for young palm growth as reported in the abovementioned studies are summarised in Table 17.

After two or three years after planting, oil palms start to become productive. Productivity parameters include yield, number of fresh fruit bunches (FFB), single FFB weight, number of female and total inflorescences and inflorescence sex-ratio (ratio of female to total inflorescences). Planting density should be taken into account when comparing productivity parameters that are reported per hectare. Reported values for young palm productivity are summarised in Table 18.

Table 17. Reported values for vegetative growth parameters of young oil palms; values are estimated from figures or tables in the referenced articles.
1: (Nake & Simin, 2013). 2: (Henson & Dolmat, 2003). 3: (Gerritsma & Soebagyo, 1999). 4: (Nake et al., 2015). 5: (Hardon et al., 1969). 6: (Okyere et al., 2014)

Years after planting	Number of fronds	Petiole cross-section (cm^2)	Rachis length (m)	Leaf area per frond (m^2)	Leaf Area Index	Single frond dry weight (kg)	Trunk height (m)
2	39[1]	8.3[1]	2.34[1]	2.4[1]	0.7[1]		
	33[1]	8.8[1]	2.66[1]	2.7[1]	1.2[1]		
				3.8[3]			
				3 – 4[5]			
3	49[2]	10.6[4]	2.83[4]	2[2]	0.5 – 1.4[6]	0.6[2]	0.2[2]
	60-70[3]		3.5[2]	2.6[4]	3.5[3]	0.8 – 1.4[6]	0.3[6]
				2.5 – 3.5[6]	8.7[4]		
				5[3]			
4	49[2]		4[2]	3.3[2]	0.7 – 1.4[6]	1.3[2]	0.4[6]
	55[3]		4.7[3]	3 – 4[6]	4.5[3]	1 – 1.5[6]	0.7[2]
				7[3]			
5				3.5 – 4.5[6]	1.1 – 1.5[6]	1.4[2]	0.5[6]
				5[5]	5.5 – 6.5[3]	1.5 – 2[6]	1[2]

Table 18. Reported values for productivity parameters of young oil palms; values are estimated from figures or tables in the referenced articles.
1: (Henson & Dolmat, 2003). 2: (Erhabor & Filson, 1999). 3: (Nake et al., 2015). 4: (Okyere et al., 2014). 5: (Hardon et al., 1969).

Years after planting	Female inflor. numbers (per palm year^{-1})	Male inflor. numbers (per palm year^{-1})	Inflorescence sex-ratio (%)	Single FFB weight (kg)	Number of FFB (per palm year^{-1})	FFB yield (t ha^{-1} year^{-1})	Oil yield (t ha^{-1} year^{-1})
2			47[2]				
3				2.9[3]	6 – 11[4]	2 – 4[4]	0.67[3]
				3[4]			1[1]
4	37[1]	3[1]		5[4]	10 – 14[4]	4 – 11[4]	3 – 4[1]
					17[5]	14[5]	
5	28[1]	3[1]		7[4]	6 – 9[4]	6 – 11[4]	4 – 6[1]
						16[5]	

4. Pineapple morphology

Main morphological structures of the pineapple plant are the roots, suckers, leaves, peduncle, fruit and crown (Figure 19). The adult plant is 1–2 m high and 1–2 m wide. Leaves grow in a dense rosette around the stem. Due to their crescent shape, leaves help to collect water in the rosette, where it can be taken up by aerial roots or the sheath epidermis (Coppens d'Eeckenbrugge & Leal, 2003). The soil root system can advance up to 1–2 m laterally and 0.85 m in depth, under ideal circumstances. However, pineapple roots are sensitive to soil compaction or poor drainage and roots normally do not extend further than the tilled area (Coppens d'Eeckenbrugge & Leal, 2003; Hepton, 2003; Malézieux et al., 2003).

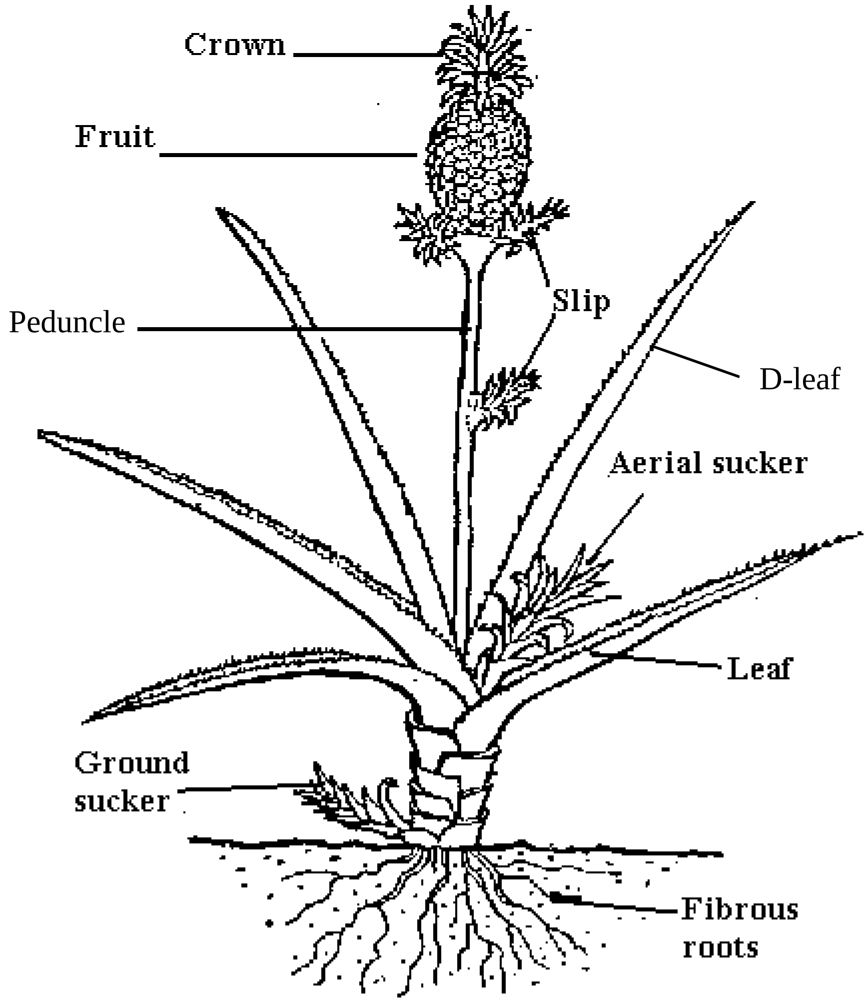

Figure 19. Simplified pineapple morphology. Adapted from (Elfick, 2018).

5. Pineapple classification

Pineapple (*Ananas comosus*) is a perennial, herbaceous crop of the *Bromeliaceae* family, indigenous to the lowland tropics of South America. Important cultivars are 'Smooth Cayenne' (also called Cayenne Lisse) and 'MD-2' (also called Amarilla, Gold or Dorada). 'MD-2' was introduced in 1983 by Del Monte and dominates the fresh-pineapple market (Vagneron et al., 2009). In Malaysia, pineapple is grown mainly on peat soils which influences the cultivars used. The main cultivar used for the canning industry is 'Gandul'; for fresh fruit production, other cultivars such as 'Moris', 'N-36' and 'Josapine' are cultivated as well (Hanafi et al., 2009).

6. Pineapple cultivation & development

Pineapples are grown both in smallholder (agroforestry) systems and large scale monocultures. In monocultures, tillage operations are carried out to obtain a permeable soil profile. A usual planting arrangement is that of the double-row planting system. The planting density is influenced by the variety or cultivar being planted, cultivation practices and the planned use of the fruit.

Pineapples are adapted to hummingbird pollination and produce abundant nectar. In commercial plantings, flowering is induced by applying a solution of ethephon to achieve simultaneous flowering and a steady supply of fruits (Bartholomew et al., 2003). Plants can grow up to two or three fruit cycles, but normally farmers replant after the first harvest due to a reduction in fruit size and uniformity (Coppens d'Eeckenbrugge & Leal, 2003; Hanafi et al., 2009).

To report on the vegetative growth of pineapples, parameters found in literature include D-leaf dry weight, D-leaf width or length, number of leaves and plant height. Productivity parameters include parameters on quantity and quality of fruit, such as yield, fruit length, fruit diameter, fruit weight, core diameter, total soluble solids (TSS) and acidity (Mahmud et al., 2018; Selamat & Masaud, 2005; Selamat & Ramlah, 1993; Noorman Affendi & Rozlaily, 2016; Razzaque & Hanafi, 2001; Soloman George et al., 2016). It should be taken into account that variety has important influence on the values for these parameters. Reported values have been found for cultivars 'Gandul', 'Sarawak', 'Josapine', 'N-36' and 'MD2' on different soils in Malaysia, including some peat soils.

The reported data on growth and productivity of 'Gandul' on peat soils are summarised in Tables 19 and 20. Common yields for 'Gandul' on peat soils in Malaysia were stated to be 45 to 65 t ha^{-1} for smallholders and 60 to 80 t ha^{-1} for plantations. Smallholders who practice intercropping may have pineapple yields of about 20 t ha^{-1} (Selamat, 1997).

Table 19. Reported values for vegetative growth parameters of 'Gandul' pineapples on peat in Malaysia; values are estimated from figures or tables in the referenced articles.
1: (Razzaque & Hanafi, 2001). 2: (Mohd Selamat & Ramlah, 1993).

Months after planting	Number of leaves	Height of D-leaf (cm)	D-leaf dry weight (g)
3		49.5[2]	1.75[2]
6		86[2]	3.8[2]
9		99[2]	3.5[2]
10	55[1]	110[1]	

Table 20. Reported values for productivity parameters of 'Gandul' pineapples on peat in Malaysia, at harvest; values are estimated from figures or tables in the referenced articles.
1: (Razzaque & Hanafi, 2001). 2: (Mohd Selamat & Ramlah, 1993).

Fruit weight (kg)	Fruit length (cm)	Fruit diameter (cm)	Core diameter (cm)	Fruit acidity (%)	Total soluble solids (%)
1.15[1]	16.3[2]	12[1]	1.9[2]	0.6[2]	10.7[2]
1.35[2]	16.5[1]	12.4[2]		0.63[1]	

7. Field characteristics

Table 21. Overview of all fields selected for field measurements. First letter of 'Farmer' indicates the region in which the field is located: R = Rengit, B = Benut, P = Pontian. In field 4, 5, 6 and 7, multiple different pineapple plots were sampled.
YAP = Years after planting. MAP = Months after planting.
Pineapple cultivars: Jos = 'Josapine', Mor = 'Moris'.
Pineapple stages: P = Planted suckers, V = Vegetative growth, F = Fruit production, S = Sucker production, C = Cleared.
*: Field 3 was managed by two farmers: R1 managed the oil palms, R3 managed the pineapples.
**: Field 15 was a monoculture plot within field 7.
***: Field 17 was a field at the Malaysian Agricultural Research and Development Institute (MARDI) Research station.

	Field	Farmer	Size (ha)	Oil palm age (YAP)	Oil palm sample (n)	Pineapple cultivar	Pineapple stage	Pineapple age (MAP)	Pineapple sample (n)
Intercropping	1	R1	1.6	1	12	Jos	F	11	24
	2	R2	1.2	4	15	Mor	C	14	-
	3	R1+R3*	2.0	2	12	Jos	V	5	24
	4	B1	0.7	0	11	Jos	V	7	14
						Jos	F	10	8
	5	B2	2.4	4	15	Mor	F	9	10
						Jos	S	14	-
	6	B3	2.0	3	15	Mor	F	9	16
						Jos	V	7	14
	7	B4	2.0	0	14	Jos	S	14	-
						Jos	V	9	8
						Mor	P	1	-
	8	R4	1.2	1	12	Jos	P	1	-
	9	R4	2.0	1	15	Mor	C	14	-
	10	B3	1.2	3	15	Jos	S	14	-
	11	B5	2.0	1	15	Mor	C	14	-
	12	B6	2.0	0	14	Jos	F	11	28
	13	B7	2.0	4	15	-	C	-	-
Monoculture	14	B8	0.8	-	-	Jos	V	8	30
	15**	B4	<0.5	-	-	Jos	F	9	30
	16	-	<0.5	-	-	Jos	V	7	30
	17***	P9	<0.5	-	-	Jos	V	9	31
Underplanting	18	R4	1.4	2	14	-	-	-	-
	19	R1	1.2	1	15	-	-	-	-
	20	-	1.6	2	15	-	-	-	-

8. Farmer interviews

Table 22. Overview of all farmer interviews.

	Interview	Interviewed farmers	Associated fields	Comments
Intercropping	1	R1, R3	3	These farmers managed one field together thus reported their answers together.
	2	R2	2	
	3	B7, B4	7, 13	
	4	B1, B2, B3	4, 5, 6, 10	This interview was cut off and finished later that day with each farmer separately.
	5	R1	1	
	6	R4	8, 9	
	7	B5, B6	11, 12	
Monoculture	8	B8	14	
	9	P9	17	This farmer was an agronomic officer at the MARDI Research station.
Underplanting	10	R1, R4	18, 19	

9. Key informant interviews

Table 23. Overview of all key informant interviews.

Interview	Key informant	Informant function	Interview topic
11	K1	MISI field officer	Regional farmer and supply chain organisation
12	K2	Oil palm dealer	Regional farmer and supply chain organisation, replanting possibilities
13	K3	Oil palm contractor	Oil palm cultivation on mineral soil, replanting possibilities
14	K4	Agronomic officer at the Johor Department of Agriculture	Pineapple monoculture cultivation
15	K5	Pineapple estate manager	Pineapple monoculture cultivation

10. Transect walk

The transect walk has been designed to fit the size and shape of the fields. Fields were small (max. 3 hectares) and rectangularly shaped, with few palm rows but many lines. In any field, the outer rows and lines and lines along the middle path were excluded from the transect to avoid possible edge effects. In fields of only three or four palm rows, the transect walk covered the middle rows only (Figure 20). In fields of more than four palm rows, the transect crossed three palm rows (Figure 21). In fields with a rectangular instead of a triangular planting pattern, the transect was slightly adapted (Figure 22).

If possible, the starting palm was picked using a random line number. However, if fields were distributed in multiple pineapples plots with different ages or cultivars, the transect walk was made preferably in a plot with pineapples in the vegetative growth or fruit production stage, of the 'Josapine' cultivar. Per palm, two pineapples were sampled, both either on the north or on the east side. This was done to account for differences in shade. Direction of pineapple sampling was decided per palm by tossing a coin.

In pineapple monoculture fields, a similar zig-zag transect walk was made along the middle of the field. One pineapple was sampled in every third row, every three meters (Figure 23).

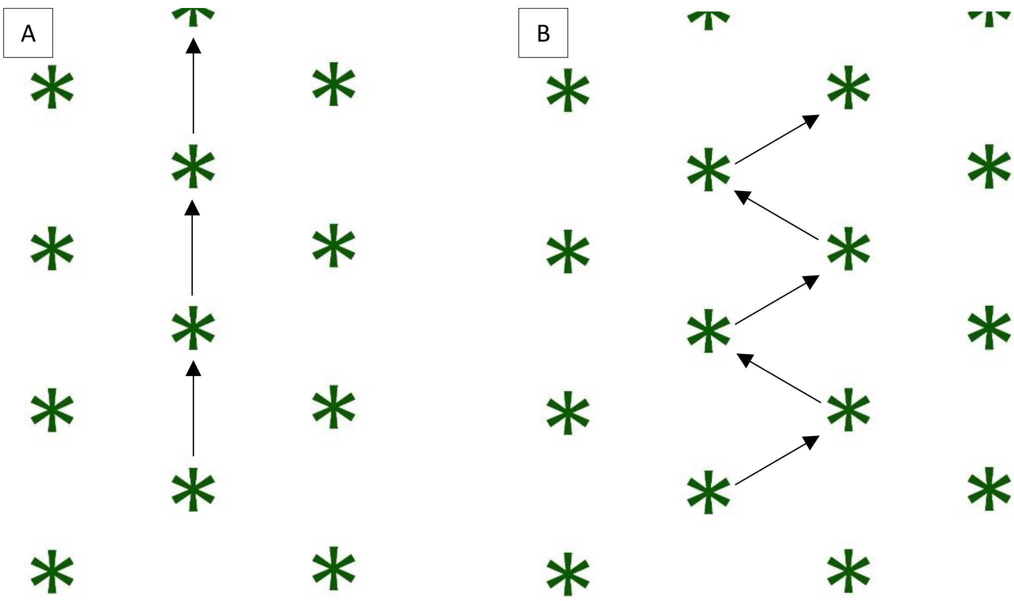

Figure 20. A: Transect walk in an oil palm field with 3 rows and triangular planting pattern. **B**: Transect walk in an oil palm field with 4 rows and triangular pattern.

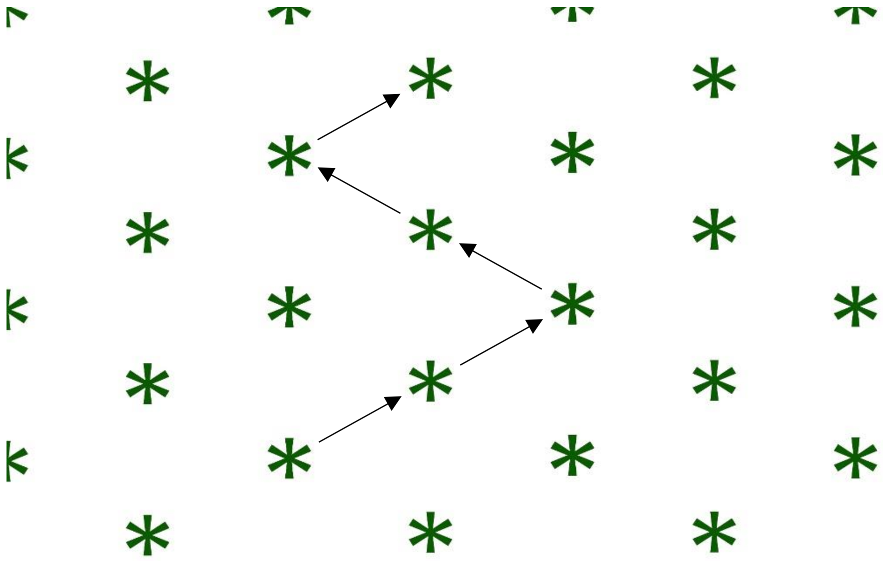

Figure 21. Transect walk in an oil palm field of more than 4 rows and triangular planting pattern.

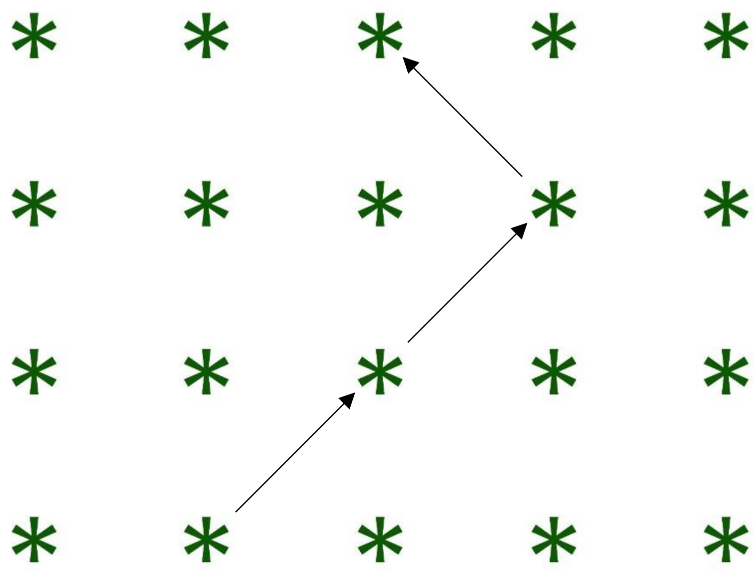

Figure 22. Transect walk in an oil palm field with rectangular planting pattern.

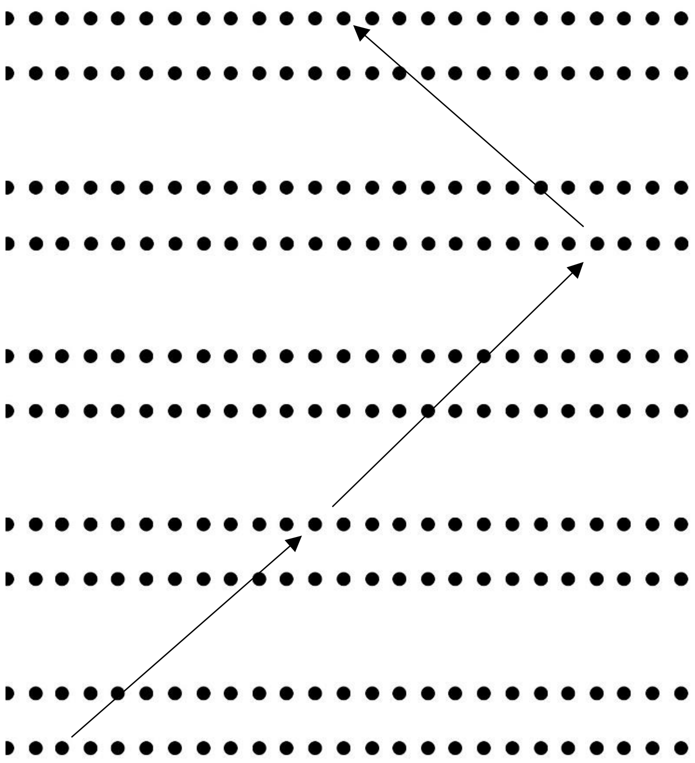

Figure 23. Transect walk in a monoculture pineapple field.

11. Pineapple & oil palm root morphology

Multiple initial root samplings have been carried out to investigate the morphology of pineapple and oil palm roots. The aim of these samplings was to find a clear distinction between pineapple and oil palm roots, to be able to investigate root interaction.

Figures from literature on pineapple root morphology show no more than 'fibrous roots' (Figure 19, Appendix 4). Five intercropped pineapples plants were uprooted to investigate root morphology, three plants in the vegetative growth stage and three in sucker production stage. There were no clear differences between root morphology at these different stages. All root samplings showed that pineapple stems continued a few centimetres underground. From this underground stem, a large number of fibrous roots grew in all directions (Figure 24A). These primary roots did not branch and had a diameter of approximately 1 to 2 mm and lengths up to 50 cm. Short and thin secondary roots and tertiary roots grew from the primary roots (Figure 24B). After washing, pineapple roots coloured yellow/orange.

The root system of oil palm has been studied by Jourdan & Rey (1997). As shown in Figure 17 (Appendix 1), the top 25 cm of soil can contain secondary, upwards growing roots and surface tertiary roots, which are usually highly branched. Such roots were indeed present in the surface soil surrounding oil palms. They could be distinguished from pineapple and weed roots by their branching pattern and lignified structure (Figure 25). In addition, most of these roots had a diameter larger than 2 mm and a vertical growing direction.

Figure 24. A: Pineapple root system, fibrous protruding from the underground part of the pineapple stem. B: Close-up of primary, secondary and tertiary pineapple roots.

Figure 25. Oil palm root as present in surface soil (0-25 cm deep). Note the lignified texture and particular branching pattern.

12. Farmer interview questionnaire

Questionnaire farmers / field managers

Date:
Location:

Personal details

1.	What is your name?	Name: Male / Female	DK	NA
2.	Do you own farm land? If yes, how much and in which area?	A. Yes. Ha / ac: Area: B. No	DK	NA

Field description and management (if necessary, fill in for each field separately)

3.	What is the size of the field?	Ha: Ac:	DK	NA
4.	What is the soil type?	A. Peat B. Clay C. Other:	DK	NA
5.	Is the field your own land, or is it leased from someone? If leased, for what price?	A. Own land B. Leased. Price:	DK	NA
6.	Who manages the land?	A. Him/herself B. Other:	DK	NA
7.	Which operations are carried out by a contractor?	A. None B. Pruning C. Fertilising D. Pest/weed control E. Harvesting F. Other	DK	NA

(Inter)cropping and replanting practices

8.	What is grown on the field?	A. Oil palm monoculture B. Oil palm + pineapple intercrop C. Pineapple monoculture D. Other:		DK	NA
9.	In what year and month did you plant the crops?	Oil palm:	Pineapple:	DK	NA
10.	What is the planting density?	Oil palm:	Pineapple:	DK	NA

11.	Where did you buy the planting material (seedlings)?	Oil palm:	Pineapple:	DK	NA
12.	Did you get a certificate with the seedlings?	Oil palm:	Pineapple:	DK	NA
13.	Which variety of oil palm / pineapple do you grow?	Oil palm: A. Dura B. Pisifera C. DxP hybrid (Tenera)	Pineapple: A. Moris B. Josepine C. MD2 D. Other:	DK	NA
14.	What is the average price per seedling?	Oil palm:	Pineapple:	DK	NA
15.	In what time of the year (season) is replanting carried out?	Oil palm: A. Rainy (Oct-Jan) B. Hot (Feb-Jun) C. Middle (Jul-Sep) D. Year-round	Pineapple: A. Rainy (Oct-Jan) B. Hot (Feb-Jun) C. Middle (Jul-Sep) D. Year-round	DK	NA
16.	Is planting of pineapple carried out simultaneously with replanting of oil palm?	A. Yes B. No:		DK	NA
17.	If carried out by the farmer himself, how much time and how many persons were needed for replanting this field (lining+digging planting holes+ planting)?	Oil palm:	Pineapple:	DK	NA
18.	If carried out by a contractor, how much did the replanting operations (lining+digging planting holes+planting) cost?	Oil palm:	Pineapple:	DK	NA
19.	What was grown on the field before replanting?	A. Oil palm B. Other:		DK	NA
20.	How has the previous crop been cleared to enable replanting of oil palm?	C. Chemically treated & left on field D. Chipped E. Burned F. Other:		DK	NA
21.	If carried out by the farmer himself, how much time and how many persons were needed for clearing this field?			DK	NA

22.	If carried out by a contractor, how much did the clearing operations cost?		DK	NA
23.	How long does one pineapple cycle (planting-harvest) take?	A. <1 year: B. 1 year C. >1 year:	DK	NA
24.	How many cycles of pineapple can be completed before terminating the intercropping?	A. 3 B. 4 C. 5 D. Other:	DK	NA
25.	How old are the oil palms when you terminate the intercropping with pineapple?	A. 3 YAP B. 4 YAP C. 5 YAP D. Other:	DK	NA
26.	What are you reasons for intercropping with pineapple?	A. Income during replanting period B. Weed control C. Other:	DK	NA

Harvest practices

27.	How often do you harvest?	Oil palm: A. Every 10 days B. Every 14/15 days C. Every 30 days D. Other:	Pineapple:	DK	NA
28.	Last year, during which months has the harvest been the highest (peak season), average and lowest? How much was the harvest from this plot per harvesting round during these seasons?	Oil palm: Peak: Average: Lowest:	Pineapple: Peak: Average: Lowest:	DK	NA
29.	Last year, what was the price per harvest unit during the different seasons?	Oil palm: kg FFB Peak: Average: Lowest:	Pineapple: piece or kg Peak: Average: Lowest:	DK	NA

30.	Who do you sell your harvest to?	Oil palm:	Pineapple:	DK	NA
31.	If carried out by the farmer himself, how much time and how many persons are needed for harvesting this field?	Oil palm:	Pineapple:	DK	NA
32.	If carried out by a contractor, how much do the harvesting operations cost?	Oil palm:	Pineapple:	DK	NA

Pruning practices

33.	Do you prune? If yes, how often?	Oil palm: A. Yes: B. No	Pineapple: A. Yes: B. No	DK	NA
34.	What is pruned away exactly?	Oil palm:	Pineapple:	DK	NA
35.	How much time and how many persons are needed for pruning this field?			DK	NA
36.	If carried out by a contractor, how much do the pruning operations cost?			DK	NA

Fertilisation practices

37.	Which fertilisers do you use, and how much do you apply per fertilisation round?	Synthetic fertilisers Brand: Amount: N-P-K content:	Organic fertilisers: A. Manure B. Empty fruit bunches C. Other:	DK	NA
38.	How many fertilisation rounds do you make per year with each fertiliser?			DK	NA
39.	What is the average price of each fertiliser per bag? How much kg is one bag?			DK	NA
40.	How do you spread each fertiliser?			DK	NA

41.	If carried out by the farmer himself, how much time and how many persons are needed for fertilising this field (per round)?		DK	NA
42.	If carried out by a contractor, how much do the fertiliser applications cost (per round)? What is included in this price (labour or inputs)?		DK	NA
43.	Do you add any other amendments to your soil (e.g. residues, compost)? If yes, how often, how much and what?	A. Yes: B. No	DK	NA
44.	What happens with plant residues (e.g. palm fronds, old pineapple plants)?		DK	NA

Weed control

45.	What are the main types of weeds on your field?		DK	NA
46.	How do you control weed?	A. Manual B. Spraying C. Other:	DK	NA
47.	With which frequency do you carry out the weed control?		DK	NA
48.	If spraying against weeds, which herbicides do you use, and how much?	Type/brand: Amount:	DK	NA
49.	What is the average price of each herbicide?		DK	NA
50.	If carried out by the farmer himself, how much time and how many persons are needed for spraying this field?		DK	NA
51.	If carried out by a contractor, how much do the spraying operations cost? What is included in this price (labour or inputs)?		DK	NA

Pest management

52.	What are the main types of pests/diseases on your field?		DK	NA
53.	How do you control pests and diseases?	A. Preventive cultural practices B. Regular monitoring C. Mechanical control D. Spraying (synthetic / biological) E. Other:	DK	NA
54.	With which frequency do you carry out the pest control?		DK	NA
55.	If spraying against pests, which pesticides do you use, and how much?	Type/brand: Amount:	DK	NA
56.	What is the average price of each pesticide?		DK	NA
57.	If carried out by the farmer himself, how much time and how many persons are needed for spraying this field?		DK	NA
58.	If carried out by a contractor, how much do the spraying operations cost? What is included in this price (labour or inputs)?		DK	NA

Income and background

59.	Do you have a job besides the farm? If yes, what do you do and how much is the income?		DK	NA
60.	What is your background and education level?		DK	NA
61.	How many family members do you have? How many are adults and how many are children below 18 year?		DK	NA
62.	Which farm operations are carried out (partly) by family members?		DK	NA
63.	Do family members bring income from a job outside of the farm? If yes, how much?		DK	NA

Other information (for example:)

- Challenges/opportunities during replanting
- Peat depth
- Water management
- License/certification
- Value chain
- Labour availability
- Training/extension services
- Community structure
- Role of women

		DK	NA

13. Farmer consent form

CONSENT FORM
BORANG PERSETUJUAN

Title: Analysis of a pineapple-oil palm intercropping system in Malaysia
***Tajuk**: Analisis sistem penanaman antara nenas-kelapa sawit di Malaysia*

Investigator: Sanne K. van Leeuwen, MSc student Organic Agriculture, Wageningen University & Research (WUR), the Netherlands
***Penyelidik**: Sanne K. van Leeuwen, Pelajar MSc Pertanian Organik, Wageningen University & Research (WUR), Belanda*

Supervisor: Dr. Ir. M. A. Slingerland, Wageningen University & Research (WUR), the Netherlands
***Penyelia:** Dr. Ir. M. A. Slingerland, Wageningen University & Research (WUR), Belanda*

Cooperating Institutes: P&G Chemicals Asia Pacific - Procter & Gamble International Operations SA Singapore Branch (P&G); Malaysia Institute for Supply Chain Innovation (MISI); Universiti Tun Hussein Onn Malaysia (UTHM)
***Institusi Kerjasama**: P&G Chemicals Asia Pacific - Procter & Gamble International Operations SA Singapore Branch (P&G); Malaysia Institute for Supply Chain Innovation (MISI); Universiti Tun Hussein Onn Malaysia (UTHM)*

Purpose: This study aims to explore the pineapple-oil palm intercropping system as currently used by smallholder farmers on peat land in Johor, in order to optimise the intercropping practices regarding yields and income and to describe the sustainability aspects of this system for peat soil.
***Tujuan**: Penyelidikan ini bertujuan untuk mengkaji sistem penanaman antara kelapa sawit dan nenas sebagaimana yang sedang dijalankan oleh pekebun-pekebun kecil di tanah gambut di negeri Johor, untuk mengoptimumkan hasil dan pendapatan melalui amalan penanaman antara pokok serta menggambarkan aspek kemapanan oleh sistem ini untuk tanah gambut.*

Procedures: Farmers will be recruited through the P&G Smallholders Program - an initiative of the Procter & Gamble Company and affiliated dealers. First, one-on-one interviews will be conducted with these farmers about their farming practices (for example, planting density and fertilisation) and the costs involved. The interview will take between 45 to 60 minutes. Answers will be recorded on paper. In addition, the interview will be audio-recorded. A translator will assist these interviews. Secondly, the principal investigator will carry out non-destructive measurements on the oil palms and pineapples in the field. Photographs may be taken during any part of the study.
***Prosedur**: Pekebun-pekebun akan dilantik melalui Program Pekebun Kecil P&G - sebuah inisiatif Syarikat Procter & Gamble dan pengedar yang bekerjasama. Pertama, temu bual perseorangan akan dijalankan bersama pekebun untuk mengetahui amalan pertanian mereka (contohnya, kepadatan penanaman dan pembajaan) dan kos-kos yang terlibat. Temu bual tersebut akan mengambil masa antara 45 hingga 60 minit. Jawapan-jawapan akan direkodkan di atas kertas. Untuk makluman, sesi temu bual tersebut turut direkodkan dalam bentuk audio. Seorang penterjemah akan membantu ketika sesi temu bual berlangsung. Kedua, penyelidik utama akan melakukann satu pengukuran yang tidak merosakkan di tapak tanaman kelapa sawit-nenas. Pengambilan gambar turut dijalankan semasa penyelidikan berlangsung.*

Confidentiality: The participant's names and other identifying information will not be used in any documents. The data collected during the study may be published (may include photographs). A report of the project outcomes will be provided to the cooperating institutes (P&G, MISI, UTHM and WUR) before publishing for review and comments if any. Any information, which will identify the participant, will not be used, except for photographs. All personal data will be protected according to the Malaysia Personal Data Protection Act 2010.
Maklumat kerahsiaan: *Nama peserta dan maklumat lain yang berkaitan tidak akan digunakan dalam mana-mana dokumen. Data yang dikumpulkan semasa penyelidikan berlangsung akan diterbitkan (termasuk gambar-gambar). Satu laporan hasil penyelidikan akan diberikan kepada institusi kerjasama (P&G, MISI, UTHM dan WUR) sebelum ianya diterbitkan untuk tujuan semakan dan ulasan jika perlu. Sebarang maklumat yang akan mendedahkan identiti peserta tidak akan digunakan kecuali untuk tujuan gambar. Segala maklumat peribadi akan dilindungi mengikut Akta Perlindungan Peribadi 2010 (Akta 709).*

Compensation: For this study, there is no compensation.
Pampasan/Ganti-rugi*: Tidak ada sebarang pampasan/ganti-rugi yang akan diberikan dalam penyelidikan ini.*

Freedom to withdraw: There is no penalty if I decide to withdraw from participating in this study. If I decide to give permission today, and then decide to withdraw from the study at a later date, or should I have any pertinent questions about this research or its conduct, and research participants' rights, and research-related injury, I should contact:
Kebebasan untuk mengundur diri*: tiada sebarang penalti/denda dikenakan jika saya membuat keputusan untuk mengundurkan diri dari menyertai penyelidikan ini. Jika saya memberikan keizinan pada hari ini dan bertindak untuk mengundurkan diri dari penyelidikan ini pada masa akan datang, atau saya mempunyai sebarang soalan penting mengenai kajian dan cara pengendaliannya, hak peserta kajian, dan kecederaan berkaitan penyelidikan, saya perlu menghubungi:*

Sanne van Leeuwen
Phone: 017-6194946
Email: sanne.vanleeuwen@wur.nl

Participant's Permission: I have read and understand the consent form and the conditions of this study. I have also had all my questions answered. I hereby acknowledge the above and give my voluntary consent.
Keizinan Peserta: *Saya telah membaca dan memahami Borang Persetujuan ini serta syarat-syarat yang dikenakan dalam penyelidikan ini. Segala persoalan berkaitan penyelidikan juga telah diberikan jawapan yang jelas. Saya dengan ini mengakui semua perkara di atas dan dengan sukarela memberi persetujuan saya untuk penyelidikan ini.*

____

Name of Participant
Nama Peserta

______________________________ ______________________________

Date *Tarikh* — Signature *Tandatangan*

14. Calculation of oil palm & pineapple planting densities

Oil palm planting density has been calculated for each field separately using Equation 7 (Corley & Tinker, 2016f). This equation has been used as the planting pattern in most fields was not exactly equilateral.

$$(7)\quad D = \frac{10\ 000}{(x_1 * x_2)}$$

where *D* is oil palm planting density (in palms ha^{-1}), x_1 distance between palms within the same row and x_2 distance between rows (in m) (Figure 26). However, as distances between palms were measured from stem to stem, measured distances had to be corrected for the palm radius to obtain x_1 and x_2. Oil palm radii have been estimated by oil palm age based on measurements in the fields (Table 24). For fields with triangular planting patterns, x_1 and x_2 have been calculated using Equations 8 and 9. For fields with rectangular patterns, x_1 and x_2 have been calculated using Equations 8 and 10.

$$(8)\quad x_1 = \bar{y}_1 + 2 * r_i$$

$$(9)\quad x_2 = \bar{y}_2 + r_i$$

$$(10)\quad x_2 = \bar{y}_2 + 2 * r_i$$

where $\bar{y}_1$ is the average measured distance between palms within the same row, $\bar{y}_2$ the average measured distance between rows and r_i the palm radius by age *i* (in m).

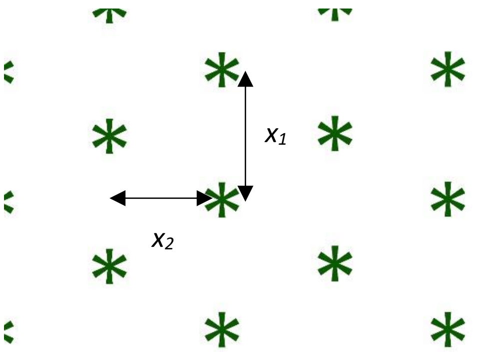

Figure 26. Distances x_1 and x_2 in an equilateral oil palm planting pattern.

Table 24. Oil palm radii by age, used to calculate planting distances.

Oil palm age (YAP)	Estimated radius (m)
0	0
1-2	0.275
3-4	0.425

Pineapple planting density has been calculated for each field separately using Equation 11, which approaches planting density in fields with a double-row pattern.

$$(11)\quad P = 2 * \frac{10000}{((z_1 + z_2) * z_3)}$$

where *P* is pineapple planting density (in plants ha^{-1}), z_1 the distance between rows, z_2 the distance between double rows and z_3 the distance within rows (in m) (Figure 27).

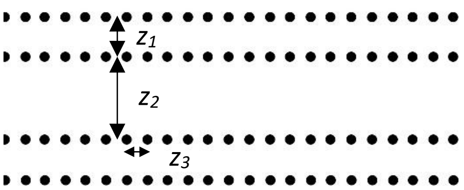

Figure 27. Distances z_1, z_2 and z_3 in a double-row pineapple planting pattern

In intercropping fields, oils palms take up a part of the field, decreasing the actual number of pineapples that is planted per hectare. The actual number of pineapples planted in intercropping fields is calculated using Equation 12.

$$(12)\quad P_{cor} = P - N * D$$

where P_{cor} is the pineapple planting density corrected for oil palm presence (in plants ha^{-1}), N the number of pineapples removed per palm and D the oil palm planting density (in palms ha^{-1}). For each field, N is calculated using Equation 13.

$$(13)\quad N = \pi * (r_i + \bar{c}_1) * \frac{P}{10\,000}$$

where r_i is the palm radius by age i (in m), $\bar{c}_1$ the average measured distance between the nearest pineapple and the oil palm stem (in m) and P the calculated pineapple density based on pineapple planting distance (in plants ha^{-1}).

15. Oil palm data analyses, p-values

The influence of different parameters on oil palm development has been analysed using a linear mixed model with Field and Region as random factors. Oil palm age was included as fixed factor in every analysis. Which other parameters were used as fixed factors depended on the specific analysis. Find the p-values for the influence of the fixed factors on the different indicators per analysis in Tables 25 and 26.

Table 25. p-values for the influence of different factors on different indicators of oil palm vegetative growth, in the complete dataset or among intercropping palms only. * if significant (p < .05). P-density: calculated pineapple planting density. CT-distance: measured distance between the nearest pineapple and the oil palm stem.

	Intercropping and underplanting		**Intercropping only**		
	Oil palm age	Farming system	Oil palm age	P-density	CT-distance
Number of fronds per palm	.001*	.16	.02*	.97	.20
Petiole cross-section area, FR9	.01*	.36	.02*	.21	.36
Petiole cross-section area, FR17	<.001*	.02*	<.001*	.26	.54
Rachis length, FR9	.053	.27	.09	.40	.10
Rachis length, FR17	.002*	.40	.06	.70	.12

Table 26. p-values for the influence of different factors on different indicators of oil palm productivity, in the complete dataset or among intercropping palms only. * if significant (p < .05). P-density: calculated pineapple planting density. CT-distance: measured distance between the nearest pineapple and the oil palm stem.

	Intercropping and underplanting		**Intercropping only**		
	Oil palm age	Farming system	Oil palm age	P-density	CT-distance
Number of inflorescences per palm	.02*	.71	.57	.11	.02*
Number of black bunches per palm	.07	.46	.42	.83	.09
Inflorescence sex-ratio	.97	.43	.50	.62	.20

16. Pineapple data analyses, p-values

The influence of different parameters on pineapple vegetative growth has been analysed in the 'Josapine' data using a linear mixed model with Field and Region as random factors. Pineapple age was included as fixed factor in every analysis. Which other parameters were used as fixed factors depended on the specific analysis. Find the p-values for the influence of the fixed factors on the different indicators per analysis in Tables 27 and 28.

Table 27. p-values for the influence of different factors on different indicators of pineapple vegetative growth, in the complete dataset. * if significant (p < .05). Pineapple group: monoculture, CT or FT pineapples. P-density: calculated pineapple planting density.

	Intercropping and monoculture		**Intercropping and monoculture**		
	Pineapple age	Pineapple group	Pineapple age	Pineapple group	P-density
Number of leaves per plant	.046*	.02*	<.001*	.01*	.16
Height of the D-leaf	<.001*	.046*	<.001*	.052	.30

Table 28. p-values for the influence of different management practices on pineapple vegetative growth in intercropping fields. * if significant (p < .05). CT- and FT-distance: measured distance between the oil palm stem and the nearest pineapple (CT) or the pineapple in the middle of three oil palm neighbours (FT).

	CT pineapples		**FT pineapples**	
	Pineapple age	CT-distance	Pineapple age	FT-distance
Number of leaves per plant	.01*	.74	<.001*	.66
Height of the D-leaf	<.001*	.73	.11	.27

The statistical analysis used for pineapple productivity was comparison of the pineapple fruit volume between CT and FT plants of the same field via a two-sample t-test. Find the p-values for the difference in fruit volume of CT and FT plants per field in Table 29.

Table 29. p-values for the difference in fruit volume between CT and FT plants per field, as obtained by a two-sample t-test.

Field	p-value
1	.59
4	.98
5	.86
6	.41
12	.36

17. Measured water levels

Table 30. Measured water level per field, in cm from the soil surface. '-' indicates that the measurement could not be taken, for example if there was no drainage ditch present or if the water could not be reached.

	Field	Water level (cm)
Intercropping	1	104
	2	49
	3	102
	4	-
	5	50
	6	-
	7	60
	8	50
	9	120
	10	-
	11	80
	12	60
	13	75
Monoculture	14	-
	15	-
	16	-
	17	70
Underplanting	18	-
	19	-
	20	-

18. Yields and prices used for benefit calculations

Total benefits are calculated based on sales of pineapples for intercropping and monoculture farmers and sales of oil palm fresh fruit bunches (FFB) for underplanting farmers. Farmers R1+R3 managed one field together, thus reported their answers together. Monoculture farmer P9 is not included as this was an agronomic officer at MARDI, not an independent farmer. Yields and prices determining the benefits are presented in Tables 31 and 32.

Table 31. Benefits of intercropping and pineapple monoculture farmers, based on pineapple yields and prices for 'Josapine'. Assumed planting densities are 29 652 plants ha^{-1} in intercropping and 37 066 plants ha^{-1} in monoculture. 80% of the plants was assumed to yield fruits and suckers. NA: not answered. *In italic*, estimated values used if farmers did not report a (precise) answer.

	Farmer	Proportion of fruit grade per harvest			Price per fruit per grade ($)			Price per sucker ($)
		A	B	C	A	B	C	
Intercropping	R1	NA	NA	NA	0.44	0.39	0.34	0.06
		0.25	*0.6*	*0.15*				
	R2	NA	NA	NA	NA	NA	NA	0.05
		0.25	*0.6*	*0.15*	*0.44*	*0.39*	*0.34*	
	R1+3	NA	NA	NA	NA	NA	NA	0.05
		0.25	*0.6*	*0.15*	*0.44*	*0.39*	*0.34*	
	R4	0.25	0.6	0.15	0.49	0.44	NA	0.05
							0.39	
	B1	0.35	0.4	0.25	0.44	0.38	0.28	0.05
	B2	0.35	0.4	0.25	0.44	0.38	0.28	0.05
	B3	0.35	0.4	0.25	0.44	0.38	0.28	0.05
	B4	NA	NA	NA	0.44	NA	NA	0.05
		0.35	*0.4*	*0.25*		*0.38*	*0.28*	
	B5	0.7	0.2	0.1	0.44	0.34	0.29	0.05
	B6	0.7	0.2	0.1	0.44	0.34	0.29	0.05
	B7	NA	NA	NA	0.44	NA	NA	0.05
		0.35	*0.4*	*0.25*		*0.38*	*0.28*	
Monoculture	B8	0.6	0.3	0.1	0.47	0.39	0.29	NA
								0.05

Table 32. Benefits of underplanting farmers, based on old palm yields and FFB prices.

	Farmer	Yield (t FFB ha^{-1} month^{-1})	Average price 2018 ($ t FFB^{-1})	Benefits per year ($)
Underplanting	R1	1.2	73.6	1 060
	R4	1.2	73.6	1 060

19. Input amounts and prices used for cost calculations

Input costs form part of the total costs for famers. Input costs reported in this study include costs for planting material, fertilisers, herbicides and pesticides. Farmers R1+R3 managed one field together, thus reported their answers together. Monoculture farmer P9 is not included as this was an agronomic officer at MARDI who did not report all input information. Amounts and prices of inputs used to calculate input costs are presented in Tables 33, 34 and 35.

Table 33. Prices for planting material. NA: not answered. *In italic*, estimated values if farmers did not report a (precise) answer. *: Free oil palm seedlings were received from MPOB. **: Farmers B5 and B6 paid for pineapple suckers through the labour reward for planting (Table 19).

	Farmer	Oil palm seedling price ($)	Pineapple sucker price ($)
Intercropping	R1	4.17	0.056
	R2	3.19	0.052 – 0.056
			0.054
	R1+R3	0*	0.049
	R4	3.19	0.049
	B1	2.95 – 3.68	
		3.31	0.049
	B2	2.95	0.049
	B3	0*	0.049
	B4	0*	0.049
	B5	0*	0**
	B6	0*	0**
	B7	0*	0.049
Monoculture	B8	-	NA
			0.049
Underplanting	R1	3.07	-
	R4	3.07	-

Table 34. Amounts of fertiliser used over a four year period and prices per fertiliser. *: Copper sulphate. **: Zinc. NA: not answered. *In italic*, estimated values if farmers did not report a (precise) answer.

	Farmer	NPK fertiliser (kg ha^{-1})	NPK price ($ kg^{-1})	Urea (kg ha^{-1})	Urea price ($ kg^{-1})	Lime (kg ha^{-1})	Lime price ($ kg^{-1})	Other fertiliser (kg ha^{-1})	Other price ($ kg^{-1})
Intercropping	R1	3 336	0.54	741	0.44	741	0.79	NA *0*	NA
	R2	4 448	0.49	1 483	0.42	741	0.10	30*	0.10
	R1+R3	2 965	0.42	0	NA	1 112	0.12	111*	1.18
	R4	741	0.58 – 0.60 *0.59*	371	0.42 – 0.44 *0.43*	741	0.49	NA *0*	NA
	B1	1 112	0.59	556	NA *0.39*	1 112	0.39	44**	2.75
	B2	1 112	0.66	556	NA *0.39*	1 112	0.39	44**	2.75
	B3	1 112	0.66	556	NA *0.39*	1 112	0.39	44**	2.75
	B4	1 112	0.66	556	NA *0.39*	1 112	0.39	44**	2.75
	B5	10 675	0.66	1 779	0.39	2 669	0.15	36*	1.72
	B6	10 675	0.66	1 779	0.39	2 669	0.15	36*	1.72
	B7	1 112	0.66	556	NA *0.39*	1 112	0.39	44**	2.75
Monoculture	B8	2 224	0.59	1 112	0.39	222	0.49	67*	4.17
Underplanting	R1	3 558	0.39 – 0.42 *0.41*	NA *0*	NA	NA *0*	NA	NA *0*	NA
	R4	3 558	NA *0.41*	NA *0*	NA	NA *0*	NA	NA *0*	NA

Table 35. Amounts of herbicide and pesticides used over a four year period and associated prices per herbicide or pesticide. NA: not answered. *In italic*, estimated values if farmers did not report a (precise) answer.

	Farmer	Herbicide, active ingredient	Herbicide amount (litre ha^{-1})	Herbicide price (\$ $litre^{-1}$)	Pesticide, type or active ingredient	Pesticide amount (units ha^{-1})	Pesticide price (\$ $unit^{-1}$)
Intercropping	R1	Not any	0	NA	Beetle pheromone traps	NA *0*	1.23 $trap^{-1}$
	R2	Glyphosate	15	6.14	Malathion	0.074 litre	44.18 $litre^{-1}$
	R1+R3	Not any	0	NA	Beetle pheromone traps	24 traps	2.45 $trap^{-1}$
	R4	Glyphosate	12	7.98	Not any	0	0
	B1	Ametryn	1.3	5.03	Malathion	0.74 litre	12.27 $litre^{-1}$
	B2	NA	3	1.23	Beetle candies	NA *0*	2.70 – 4.42 kg^{-1}
	B3	Glyphosate	1.9	4.45	Not any	0	NA
	B4	Glyphosate	1.9	4.45	Malathion	0.37 litre	12.27 $litre^{-1}$
	B5	NA	NA *8.9*	7.36	Not any	0	NA
	B6	NA	NA *8.9*	7.36	Not any	0	NA
	B7	Glyphosate	1.9	4.45	Malathion	0.37 litre	12.27 $litre^{-1}$
Monoculture	B8	Ametryn	33	7.06	Not any	0	NA
Underplanting	R1	NA	47	3.38	Malathion	1.2 litre	NA *7.98 $litre^{-1}$*
					Beetle pheromone traps	NA *0*	2.95 $trap^{-1}$
	R4	NA	47	3.38	Malathion	7.0 litre	7.36 – 8.59 $litre^{-1}$ *7.98 $litre^{-1}$*

20. Labour requirements and rewards used for cost calculations

Hired labour costs form part of the total costs for famers. Hired labour costs reported in this study include costs for clearing, planting, fertilising, weed control, pruning and harvesting. Farmers R1+R3 managed one field together, thus reported their answers together. Monoculture farmer P9 is not included as this was an agronomic officer at MARDI who did not report all labour information. Labour requirements and rewards used to calculated hired labour costs are presented in Tables 36, 37, 38, 39 and 40.

Table 36. Clearing methods, labour requirements (over a four year period) and labour rewards for oil palm and pineapple clearing. For pineapple clearing, all farmers used the spraying & burning method. Farmers paid for clearing either per day, per plant or per area. NA: not answered. *In italic*, estimated values if farmers did not report a (precise) answer.
*: Chipping would normally involve additional renting costs for an excavator (RM2471 ha^{-1}), but farmer R1 owned an excavator himself.

	Farmer	**Oil palm clearing**				**Pineapple clearing**			
		Method	Hired labour (man-days ha^{-1})	Worker wage ($ man-day^{-1})	Worker reward ($ unit^{-1})	Farmer labour (man-days ha^{-1})	Hired labour (man-days ha^{-1})	Worker wage ($ man-day^{-1})	Worker reward ($ unit^{-1})
Intercropping	R1	Chipping*	3.7	19.64	NA	0	3.7	NA *19.64*	NA
	R2	Chipping & burning	NA	NA	1.23 palm^{-1}	0	NA *4.0*	NA *14.73*	NA
	R1+3	Chipping	9.9	NA *19.64*	NA	NA	NA *4.0*	NA *9.82*	NA
	R4	Cutting	9.9	NA	1.96 palm^{-1}	NA	NA	NA	91.07 ha^{-1}
	B1	Cutting & burning	6.2	NA *9.82*	NA	NA	7.4	NA	72.90 ha^{-1}
	B2	Cutting & burning	6.2	NA *9.82*	NA	NA	7.4	NA	72.90 ha^{-1}
	B3	Cutting & burning	6.2	NA	60.63 – 121.26 ha^{-1} *91.07 ha^{-1}*	NA	7.4	NA	72.90 ha^{-1}
	B4	Cutting & burning	NA	NA	1.47 – 1.72 palm^{-1} *1.60 palm^{-1}*	NA	15	8.59	NA
	B5	Cutting & burning	5.9	12.27	NA	NA	15	NA *9.82*	NA
	B6	Cutting & burning	5.9	12.27	NA	NA	15	NA *9.82*	NA
	B7	Cutting & burning	NA	NA	1.47 – 1.72 palm^{-1} *1.60 palm^{-1}*	NA	15	8.59	NA

Monoculture	B8	-	-	-	-	56	0	NA	NA
Underplanting	R1	Injecting	2.5	NA	1.96 palm^{-1}	-	-	-	-
	R4	Injecting	2.5	NA	1.96 palm^{-1}	-	-	-	-

Table 37. Labour requirements (over a four year period) and labour rewards for oil palm and pineapple planting. Farmers paid for planting either per day or per plant. NA: not answered. *In italic*, estimated values if farmers did not report a (precise) answer. *: Farmers B1, B2 and B3 paid separately for digging of planting holes. This is added to the oil palm planting reward. **: Worker rewards included price of pineapple planting material.

	Farmer	**Oil palm planting**			**Pineapple planting**			
		Hired labour (man-days ha^{-1})	Worker wage ($ man-day^{-1})	Worker reward ($ palm^{-1})	Farmer labour (man-days ha^{-1})	Hired labour (man-days ha^{-1})	Worker wage ($ man-day^{-1})	Worker reward ($ plant^{-1})
Intercropping	R1	15	17.18 – 19.64	NA	0	NA	NA	0.0037
			18.41					
	R2	NA	NA	1.23	0	NA	NA	0.037
	R1+3	NA	NA	NA	NA	44	NA	NA
		15	*18.41*				*9.82*	
	R4	3.1	NA	1.23	NA	30	NA	0.012
	B1	NA	NA	3.68*	NA	NA	NA	0.033
	B2	NA	NA	3.68*	NA	NA	NA	0.033
	B3	NA	NA	3.68*	NA	NA	NA	0.033
	B4	11	9.82 – 12.27	1.47 – 1.72	15	30	NA	NA
				1.60			*9.82*	
	B5	6.9	NA	1.23	NA	NA	NA	0.074**
	B6	6.9	NA	1.23	NA	NA	NA	0.074**
	B7	11	9.82 – 12.27	1.47 – 1.72	15	30	NA	NA
				1.60			*9.82*	
Monoculture	B8	-	-	-	19	19	NA	0.037
Underplanting	R1	NA	NA	1.96	-	-	-	-
	R4	NA	NA	1.96	-	-	-	-

Table 38. Labour requirements (over a four year period) and labour rewards for fertilisation and weed control. It was assumed that intercropping farmers fertilised oil palms and pineapples simultaneously. Farmers paid for fertilisation and weed control either per day or per area. NA: not answered. *In italic*, estimated values if farmers did not report a (precise) answer.

	Farmer	**Fertilisation**				**Weed control**			
		Farmer labour (man-days ha^{-1})	Hired labour (man-days ha^{-1})	Worker wage ($ man-day^{-1})	Worker reward ($ $unit^{-1}$)	Farmer labour (man-days ha^{-1})	Hired labour (man-days ha^{-1})	Worker wage ($ man-day^{-1})	Worker reward ($ $unit^{-1}$)
Intercropping	R1	0	44	19.64	NA	0	44	NA	NA
								19.64	
	R2	0	22	14.73	NA	0	5.6	14.73	NA
	R1+3	13	27	NA	NA	NA	67	NA	NA
				9.82		*0*		*9.82*	
	R4	11	11	0	NA	NA	NA	0	NA
						10	*10*		
	B1	11	11	NA	NA	22	0	NA	NA
				9.82					
	B2	11	11	NA	NA	NA	NA	NA	NA
				9.82		*10*	*10*	*9.82*	
	B3	11	11	NA	72.90 ha^{-1}	9.3	0	NA	NA
	B4	11	11	NA	NA	9.3	0	NA	NA
				9.82					
	B5	27	27	12.27	NA	13.3	13.3	12.27	NA
	B6	27	27	12.27	NA	13.3	13.3	12.27	NA
	B7	11	11	NA	NA	9.3	0	NA	NA
				9.82					
Monoculture	B8	11	11	17.18	NA	NA	NA	NA	NA
						10	*10*	*17.18*	
Underplanting	R1	0	9.9	NA	116.35 ha^{-1}	0	7.4	NA	255 – 327 ha^{-1}
									291 ha^{-1}
	R4	NA	9.9	NA	116.35 ha^{-1}	NA	7.4	NA	255 – 327 ha^{-1}
									291 ha^{-1}

Table 39. Labour requirements (over a four year period) and labour rewards for oil palm and pineapple pruning. Farmers paid for pruning either per day or per plant. NA: not answered. *In italic*, estimated values if farmers did not report a (precise) answer.

	Farmer	**Oil palm pruning**			**Pineapple pruning**			
		Hired labour (man-days ha^{-1})	Worker wage (\$ man-day^{-1})	Worker reward (\$ palm^{-1})	Farmer labour (man-days ha^{-1})	Hired labour (man-days ha^{-1})	Worker wage (\$ man-day^{-1})	Worker reward (\$ plant^{-1})
Intercropping	R1	0	NA	NA	0	0	NA	NA
	R2	0	NA	NA	0	NA	NA	NA
						0		
	R1+3	0	NA	NA	0	0	NA	NA
	R4	NA	0	NA	8.9	8.9	0	NA
		4						
	B1	9.9	NA	2.95	7.4	0	NA	NA
	B2	9.9	NA	2.95	7.4	0	NA	NA
	B3	9.9	NA	2.95	7.4	0	NA	NA
	B4	NA	NA	NA	7.4	3.7	NA	NA
		4	*9.82*				*9.82*	
	B5	0	NA	NA	12	12	12.27	NA
	B6	0	NA	NA	12	12	12.27	NA
	B7	NA	NA	NA	7.4	3.7	NA	NA
		4	*9.82*				*9.82*	
Monoculture	B8	-	-	-	111	0	NA	NA
					15			
Underplanting	R1	NA	NA	NA	-	-	-	-
		4	*19.64*					
	R4	NA	NA	NA	-	-	-	-
		4	*14.73*					

Table 40. Labour requirements (over a four year period) and labour rewards for oil palm and pineapple harvesting. Farmers paid for harvesting per t FFB, per day or per plant. NA: not answered. *In italic*, estimated values if farmers did not report a (precise) answer. *Farmers B4 and B7 reported to pay for transport and grading separately. This is added in the harvesting price.

		Oil palm harvesting			**Pineapple fruit harvesting**		
	Farmer	Hired labour (man-days ha^{-1})	Worker wage ($ man-day^{-1})	Worker reward ($ $unit^{-1}$)	Hired labour (man-days ha^{-1})	Worker wage ($ man-day^{-1})	Worker reward ($ $plant^{-1}$)
Intercropping	R1	-	-	-	578 *12*	19.64	NA
	R2	-	-	-	NA	NA	0.0037
	R1+3	-	-	-	44	NA *9.82*	NA
	R4	-	-	-	NA *12*	NA *0*	NA
	B1	-	-	-	NA	NA	0.052
	B2	-	-	-	NA	NA	0.052
	B3	-	-	-	NA	NA	0.052
	B4	-	-	-	9.3	9.82 – 12.27	0.085*
	B5	-	-	-	36	NA	0.022
	B6	-	-	-	36	NA	0.022
	B7	-	-	-	9.3	9.82 – 12.27	0.085*
Monoculture	B8	-	-	-	56	17.18	NA
Underplanting	R1	NA	NA	17.18 t^{-1}	-	-	-
	R4	NA	NA	12.27 – 14.73 t^{-1} *13.50* t^{-1}	-	-	-

21. Benefits, costs, BCR and income per farmer

Based on the data presented in Appendices 18, 19 and 20, total benefits, total costs, benefit-cost ratio (BCR) and income have been calculated per farmer (Table 41). Farmers R1+R3 managed one field together and are thus reported together.

Table 41. Total benefits, total costs, BCR and income as calculated per farmer, over a four year period. *: Results of farmer R4 are not taken into account for the calculation of average benefits, costs, BCR and income of the intercropping system. His costs are very low and his BCR is very high because he did not pay for hired labour, but split his income 50-50 with one permanent worker. This is accounted for in the income.

	Farmer	Benefits ($ ha^{-1})	Costs ($ ha^{-1})	BCR	Income ($ ha^{-1})
Intercropping	R1	32 316	10 862	2.98	21 454
	R2	32 142	10 286	3.12	21 856
	R1+3	31 792	8 221	3.87	23 571
	R4*	35 286	6 811	5.18	14 238
	B1	30 351	10 125	3.00	20 227
	B2	30 351	10 156	2.99	20 195
	B3	30 351	9 620	3.16	20 731
	B4	30 351	9 482	3.20	20 870
	B5	32 491	12 169	2.67	20 322
	B6	32 491	12 169	2.67	20 322
	B7	30 351	9 482	3.20	20 870
Monoculture	B8	33 889	10 512	3.22	23 377
Underplanting	R1	4 242	3 841	1.33	1 249
	R4	4 242	3 656	1.39	1 434

22. Farmer labour and return to labour per farmer

Based on farmer labour requirements presented in Appendix 20, required farmer labour was calculated. Return to labour is the income received by the farmer, divided by required farmer labour.

Table 42. Required farmer labour and return to labour, calculated per farmer, over a four year period. *Farmer R1 and R2 acted as contractors and did not report own labour requirements. **Farmer R4 did not report own labour requirements for underplanting fields.

	Farmer	Farmer labour (man-days ha^{-1})	Return to labour ($ man-day^{-1})
Intercropping	R1*	NA	NA
	R2*	NA	NA
	R1+3	13.3	1 767
	R4	41.1	346
	B1	40.8	496
	B2	28.5	708
	B3	27.8	746
	B4	42.6	490
	B5	51.9	392
	B6	51.9	392
	B7	42.6	490
Monoculture	B8	54.7	428
Underplanting	R1*	NA	NA
	R4**	NA	NA