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Palm oil plantation waste handling by smallholder and the correlation with the land fire

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ABSTRACT

BACKGROUND AND OBJECTIVES: From August to October 2019, several provinces in Sumatra and Kalimantan had faced severe forest fires, causing thousands of citizens to suffer respiratory disorders. This study aims to assess waste handling in palm oil plantation manage by smallholders and the correlation palm oil plantation waste handling with the fireland in Sumatera, especially on Jambi province.
METHODS: Primary data collection was conducted in September 2019, and a purposive random sampling method was used to select respondents. Primary data collection was applied for four hundred smallholders in five districts in Jambi using a mixed method.
FINDINGS: Out of 400 correspondents that handle their waste, 50% of respondents handle the residues by stacking the waste on their field, 25% of correspondents stack the waste between trees, 17.25% of correspondents stack the waste on piles, 5% of them bury the posts, and 2.75% incinerate the waste. The average distance from home to the field for 200 correspondents is 8.825 kilometres, and they have the highest harvest quantity with a mean of 1.0940 tons. Most of them are common smallholders and self-subsistent smallholders. The 298 correspondents join a farming association. About 50% of smallholders in Jambi handle the residues by stacking the wastes on their field instead of incinerating the waste.
CONCLUSION: Out of the overall samples collected in this study, only 2.75% smallholders in Jambi incinerate their residues. Hence, the fire breakouts happened on several provinces in Sumatera and Kalimantan in late 2019 did not happen due to crude palm oil waste-handling activities.

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INTRODUCTION

Palm oil is one of the most potential commodities which have made its smallholders also be important on the past and future palm oil industry. Palm oil cultivation is related to land clearing, both from the forestry sector and from grasslands. Land clearing for palm oil plantations takes place in several regions in Southeast Asia (Gatti *et al.*, 2019; Uusitalo *et al.,* 2014). Land conversion also occurs in Brazil. Nearly 47.7% of primary forests were converted, and an increase of forest degradation by 17% in agriculture was reported. There was also an increase in land expansion in the palm oil sector by 11%. Over a 22-year period, 30% of forests in Brazil were converted into palm oil plantations (de Almeida *et al.*, 2019). Palm oil expansion is carried out in primary, secondary forests, and spread to the prairie area, which contributed to 9% of land conversion in Brazil (Benami *et al.,* 2018). The existence of palm oil plantations causes several problems, including land degradation, deforestation, and fires. Unregulated logging activities and land fire affected the degradation of land. The existence palm oil plantations certification is considered to be less than optimal. In some areas, it was found that approximately 40% of the RSPO certified area has the land cleared. Despite being certified, palm oil cultivation still leads to deforestation, hence it is considered less sustainable. There are several types of methods for land clearing, such as through burning or utilising heavy equipment. The burning method is one of the traditional methods used in clearing forests to become agricultural land. This option has a minimum economical impact, but has a negative impact to the environment. Palm oil plantations are always associated with forest fires, a phenomenon that occurs almost every year. This method contributes to the production of GHG, namely, CH4 and CO2 (Uusitalo *et al.*, 2014). Land clearing requires urgent efforts to protect degraded forests by adopting sustainable palm oil plantation strategies (de Almeida *et al.*, 2019). Identifying supporting factors is important in the opening of palm oil plantations to minimise deforestation (Benami *et al.*, 2018). In 2015, a land fire disaster happened with palm oil plantations as the main cause, burning down 16% of the concession area (Purnomo *et al.*, 2018). Incineration cause a lot of damage to the environment, human health, as well as other creatures. According to Purnomo *et al.* (2018), land burning is not necessarily free; it costs USD 15 per hectare to burn land. There are several stages in palm oil cultivation, including seedling, nursery, planting, maintenance, and harvesting. Each stage of cultivation requires different inputs and outputs. Similar to the number the utilised materials, the amount of residue also increases. Palm oil residues come from cultivation on plantations and oil processing industry (Awalludin et al., 2015). which is every year 4.5 tons (t) DM ha/year residue was produce (Bessou *et al.*, 2017). The residue can be solid and liquid. A kg of palm oil contains 0.132 kg of fibre, 0.068 kg of shells, 0.227 kg of empty fruits, 0.053 kg of kernels and 0.684kg of POME (Uusitalo *et al.,* 2014). The extraction plant from FFB produces MF and PKS as waste. After FFB is cooked with pressure from the palm bunches to extract the oil in FFB, it will produce EFB as the by-product. MF is produced during the extraction process, while VFD is obtained after separation from the kernel (Awalludin *et al.*, 2015). Nevertheless, this article does not focus on residue from oil process industry. Palm oil has a vascular (Nair, 2010) and vertical stem (Hosseini and Wahid, 2014) with a crown amounting to 35-60. The height of the palm oil reaches 30 m (Mohammed *et al.*, 2011) with a branch length of about 7 m, the leaf stalk reaches 150 cm, and a rachis contains 250-350 leaflets (Nair, 2010). In 4-5 years, palm oil trees are ready to be harvested for the first time (Jaroenkietkajorn and Gheewala, 2020; Hosseini and Wahid, 2014). Mature plants are harvested annually. Harvesting is done by cutting fruit bunches and cutting the midrib. Some of the parts are not utilised for palm oil production, which then becomes biomass waste. To maintain and protect the growth of palm oil, some leaves that are not healthy and have pests need to cut down (Bessou *et al.*, 2017). Palm oil plants only have 25-30 years before the plants have to be cut down and replaced with new plants (Jaroenkietkajorn and Gheewala, 2020). Cutting down of old palm oil plants will produce solid waste in the form of stems and leaves, which is often also considered as biomass waste. The waste must be treated well; therefore, it does not produce negative impacts on the environment or to humans. Solid wastes produced in the cultivation process include trunk and leaves (Hambali and Rivai, 2017; Mahidin *et al*., 2020). Leaf

Table 1: Palm oil trunk biomass production during plant rejuvenation (Hambali and Rivai, 2017)

Year	Rejuvenation area (ha)	Trunk biomass production (tons)
2002	202,682	15,302,515
2003	211,342	15,956,342
2004	211,389	15,959,863
2005	218,153	16,470,527
2006	263,797	19,916,640
2007	270,673	20,435,845
2008	294,554	22,238,818
2009	314,932	23,777,348
2010	335,416	25,323,890
2011	359,713	27,158,328
2012	382,909	28,909,599
2013	418,601	31,604,360
2014	430,192	32,479,499
2015	452,015	34,127,117

waste comes from pruning of every harvested fruit or two-year care (Chin *et al*., 2019; Mohammed *et al*., 2011). Table 1 summarises the amount of trunk biomass waste produced in Indonesia.

Table 1 describes the mass of palm oil biomass produced by trunk waste. This waste usually comes from the replanting process. Palm oil plantations have a lifespan period of 25-30 years, after that the plants need to be replanted. The process is often called the rejuvenation process. Old palm oil trees are cut down, the trunks from the harvest then become waste for farmers who cannot utilise it. Similar to palm oil leaves, the stems also have greater biomass value. Approximately 6.3 tons of leaf biomass is produced per year. The amount of stem biomass in 2015 was 34.13 million tons, which produce from the replanting or rejuvenation process (Hambali and Rivai, 2017). The amount of stem and leaf waste illustrates the abundance of biomass. That is because waste has excellent potential to retreat. The abundance of biomass from palm oil is an opportunity for oil production and economic improvement, as well as a challenge for most parties as waste (Ahmad *et al*., 2019). The prospect of palm oil has experienced rapid development, both for increasing the area and production. The palm oil plantations in Indonesia amounted to 14,326,350 ha in 2018, with 55.09% managed by large private companies, 40.62% managed by smallholder plantations and 4.29% by large state estates (Directorate General Plantation, 2019). From that number of palm oil plantation have it by smallholder, aside a large private companies, smallholders also have important role to the development of palm oil. The increase in palm oil production affects the amount of biomass waste generated from plantations. For large private companies, waste can be treated with their own technology. However, smallholders have a limited capital that makes them handle their biomass waste in accordance with nature conservation.

Handling of palm oil waste

The issue of palm oil biomass waste presents opportunities and challenges for farmers. Farmers especially feel burdened by waste disposal, because they find it difficult to dispose of. It considers increasing their operational costs (Awalludin *et al*., 2015). Palm oil biomass waste increases proportionally with palm oil production. Therefore, rapid management is required. Minimum treatment for accumulating biomass waste can cause by a lack of technology. Smallholders prefer the utilisation of traditional methods in handling waste. Smallholder usually carries out their waste management by incinerating or piling up waste around the plantation (Zain, 2019; Nusadaily, 2020; Anyaoha *et al*., 2018). This biomass waste is organic waste, which can decompose in plantations. Stacking has been carried out by stacking on a pile, stacking up on fields, mound on the posts, and stacking up between trees. The accumulation method utilises the process of spoilage of waste, however decomposition is done naturally without the addition of chemicals, the required long period becomes the drawback. The incineration process is carried out by releasing heat that comes from burning waste into the air (Awalludin *et al.*, 2015). The mechanical method is done by chopping or cutting the waste using a small cutting machine. If there is no cutting machine, waste is usually burnt for removal (Nusadaily, 2020). The management of biomass waste has not been maximised or less effective (Ahmad *et al.*, 2019) because there are still many smallholders who utilise traditional methods. RSPO and ISPO is sustanaible certification that use in Indonesia, that applied voluntary by smallholder (Hidayat *et al.*, 2018). Waste management is include to the indicator evaluation for both certification even though RSPO has the clearest explanation in term of its environment aspect (Hidayat *et al.*, 2018; Furumo *et al.*, 2019; Nasution *et al.*, 2020). Even though sustainability certification could bring an economic, social, and environment benefits, but still small number smallholder involved in the schemes. That because the financial and knowledge barier and institutional constrain (Saadun *et al.*, 2018; Furumo *et al.*, 2019; Hutabarat *et al.*,2019). However, in this study include RSPO and ISPO as variabel to determine smallholder methods to handle their palm oil plantation. This study aims to assess 1) Agriculture process, productivity and waste-handling for palm oil plantations; 2) Social factor and waste-handling in palm oil plantation; 3) palm oil plantation waste-handling; 4) Palm oil waste handling and fireland. The study has been carried out in five districts in Jambi Province, Indonesia, in 2019.

MATERIALS AND METHODS

A survey and an in-depth interview were conducted on a field survey to palm oil smallholders in Jambi. The field survey was conducted in July 2019 until September 2019. The districts involved were Merangin, Sarolangun, Muaro Jambi, Tanjung Jabung Barat, and Tebo. The five districts were chosen as representatives from palm oil smallholders across highlands, lowlands, and coastal areas of the East Coast in Jambi. The primary data collection recorded 80 smallholders from each district, resulting in 400 observed samples as the whole sample processed in this study. All of 400 samples were smallholders who own the land and cultivate their field with palm oil. All of the smallholders in this study were chosen from a purposive random sampling method, where only palm oil smallholders who own the field will be recorded on primary data collection. In this study, smallholders were grouped based on their palm oil waste handling procedure as opposed to their farming association, or their affiliated company. As the main indicator for grouping the smallholders, methods to handle waste are divided into five types; i) incineration, ii) stacking up on field, iii) mound on the posts, iv) stacking up between trees, and v) stacking on a pile. The questionnaire was used to understand the waste handling method, where smallholders were asked about their method for palm tree waste treatment. Among smallholders, these five methods of waste handling are common methods among CPO smallholders. Inferential statistic mean and standard deviation were applied to analyse the correlation between agriculture process as well as palm oil productivity and the smallholders' waste handling methods. In this study, inferential correlation has been used to profile whether forest fires in Jambi province are caused by palm fruit smallholders' waste-handling activities. The factors of agriculture process analysed in this research were dosage of fertilisers, the number of seed planted per hectare, and distance from home to the field. The analysed factors for palm oil productivity were harvest quantity per hectare, frequency of harvest, expenditure per capita, and income per capita. Cross tabulations – tables containing methods of waste handling (columns) and observed variables (rows) were utilised to assess the correlation of social factor to waste handling methodology by smallholders. The social factors considered were a type of farmers, whether the smallholders are joining a farming association, how smallholders acquired their field, and whether smallholders use ISPO or RSPO. Based on the inferential statistic, the factor that influences the smallholders' method in handling their waste plantation was determined. A tabular form was prepared to compare the smallholders' waste handling methodology between land clearing waste and general waste on their plantation. The graph and all tables prepared for this study were carried out using a MS Excel. All survey inputs in this study were managed, cleaned and calculated using Stata MP. Calculations, tables and tabulations presented

Table 2: Agriculture process and productivity and waste handling for palm oil plantation

Quantitative variables		(i) Incineration	(ii) Stacked up on field lanes	(iii) Mound on the posts	(iv) Stacked up between trees	(v) Stacked on a pile	Total
Harvest quantity per hectare (Tons)							
	Mean	0.8000	1.0940	0.6800	0.8330	0.8000	0.9493
	S.D.	0.0000	0.1413	0.0616	0.1965	0.0000	0.2042
	Freq.	11	200	20	100	69	400
Frequency of Harvest (times/year)							
	Mean	24	24	24	24	24	24
	S.D.	0	0	0	0	0	0
	Freq.	11	200	20	100	69	400
Dosage of fertilisers (L/ha)							
	Mean	2.1364	2.2950	1.7917	1.6864	2.2500	2.1617
	S.D.	0.3233	0.3985	0.3343	0.2439	0.4287	0.4436
	Freq.	11	200	12	59	69	351
Number of seeds planted per hectare							
	Mean	129.64	130.04	137.10	137.88	130.32	132.37
	S.D.	2.94	1.92	2.71	1.31	2.20	4.00
	Freq.	11	198	20	98	69	396
Distance from home to landfields (Km)							
	Mean	5.818	8.825	6.500	6.818	5.783	7.602
	S.D.	1.471	5.804	1.850	2.771	1.962	4.608
	Freq.	11	200	20	99	69	399
Expenditure per capita (USD/person/day)							
	Mean	7.87	7.76	8.26	8.03	7.68	7.84
	S.D.	1.37	1.53	1.21	1.91	1.39	1.60
	Freq.	10	199	20	100	69	398
The income per capita (USD/person/day)							
	Mean	18.31	17.53	18.91	15.78	14.58	16.67
	S.D.	7.34	7.57	7.69	6.69	5.63	7.14
	Freq.	10	199	20	100	69	398

in this study were calculated and produced by using Stata MP, and then finished by using MS Excel.

RESULTS AND DISCUSSION

Agriculture process, productivity and waste handling for palm oil plantation

An analysis was undertaken to understand smallholder's condition based on the relationship between smallholders' agriculture process and productivity and their waste management method. That correlation is tabulated from the datasets and summarised in Table 2.

Table 2 shows that smallholders have the same number of harvests per year (24 times) since farming associations schedule palm fruit harvesting seasons. The highest dosage of fertilisers is utilised by smallholders who stacked their waste on the field. The data also indicate that the number of seeds planted by the smallholders is affected the waste handling for CPO waste. Smallholders who stack the waste between trees or mound on the posts have more space to plant seeds, where on average, they plant approximately 137 seeds per hectares, compared to other waste handling methods. The distance of their home to the field makes they tend to stack the waste instead of incinerating it. Therefore, the distance might drive their behaviour to choose the most efficient waste handling method. In regards to the economic aspect, the waste handling method is unlikely to provide a direct effect on their income or expenditure per capita. Table 2 also indicates that smallholders with the highest harvest quantity per hectares are smallholders who stacked their waste on the field. Stacking up waste on the field is still the most efficient method to harvest palm fruits. However, it is more expensive when compared to incineration. The quantity of harvest per hectares is also affected

Table 3: Social factors and palm oil plantation waste handling

Qualitative and Categorical Variables	(i) Incineration	(ii) Stacked up on field lanes	(iii) Mound on the posts	(iv) Stacked up between trees	(v) Stacked on a pile	Total
Types of Farmers						
Core Smallholders	0	0	0	75	0	75
Common Smallholders	11	120	20	25	69	245
Self-subsistent Smallholders	0	80	0	0	0	80
Total	11	200	20	100	69	400
Member of Farming Association						
No	1	86	0	6	9	102
Yes	10	114	20	94	60	298
Total	11	200	20	100	69	400
How the land field was earned						
Buy and sell	0	91	16	89	0	196
Given	1	28	0	0	10	39
Legacy	10	81	4	11	59	165
Total	11	200	20	100	69	400
ISPO Certification						
No	11	113	20	60	69	273
Yes	0	87	0	40	0	127
Total	11	200	20	100	69	400
RSPO Certification						
No	11	200	4	87	69	371
Yes	0	0	16	13	0	29
Total	11	200	20	100	69	400

by waste handling since waste handling also takes time on their post-production activities. The method of the mound on the post gives the smallest outputs since it needs longer waste-handling time when compared to the other handling method. Agroecological practices in agriculture have a more traditional view of agricultural practices or activities. Agroecological practices utilise waste or agricultural products to maintain or improve soil quality (Bessou *et al.*, 2017). Smallholders' general waste handling method is by accumulating biomass waste around the plantations. EFB or OPF biomass waste is usually left for composting at the mill or plantation (Chiew and Shimada, 2015). Male inflorescences and abscised frond bases are cut down when it becomes two years, then left on the plantation for mulching or rotting (Truckell *et al.*, 2019). Biomass decomposition includes composting, which naturally requires little human energy (Chiew and Shimada, 2015). The problem of nutrient impoverishment on plantations can be managed by palm oil residual composting (Truckell *et al.*, 2019). Composting of biomass waste reduces waste volume by 50% -75% (Chiew and Shimada, 2015). Waste is placed on the plantation will supply potassium to the soil, which improves fertility in the soil that originally depletes due to the cultivation process (Bessou *et al.*, 2017). Biomass can be utilised to replace K/Mg for nearly 10% of plantations and can increase nitrogen and phosphate in the soil, therefore maintain better soil permeability (Arvind *et al.*, 2019). Utilisation of biomass waste is less optimal because it causes the wet condition while composting and recovery of methane is considered to be more environmentally friendly compared to other technologies in terms of measured GHG (Chiew and Shimada, 2015). Palm oil cultivation requires fertiliser that contains potassium to maintain soil fertility and plant development. These chemical contents can be obtained by utilising biomass (Bessou *et al.*, 2017). Stacking has several objectives that can facilitate waste management or cultivation activities. Biomass waste placed around the plantations will decay over time. Decaying leaves are intended to control erosion in the area. However, in the long run, these decaying leaves will become additional nutrients for plantation soils. (Mohammed *et al.*, 2011). OPF and OPT waste that has been left to decompose at the plantation site is utilised for land cover and do not require additional expenditure (Chin *et al.*, 2019). Biomass waste can be utilised to increase crop yields, enrich soil nutrient content, reduce pollution, increase income, and become energy savings for farmers as well as factories (Anyaoha *et al.*, 2018).

Social factor and waste handling in palm oil plantation

Other than agriculture process and productivity, another analysis was used to determine the correlation between social factors, such as type of farmers, participation in the farming association, how the land was acquired, and whether the farmers hold ISPO and RSPO Certification, and palm oil plantation waste. The correlation is shown in Table 3

Table 3 shows that the smallholders that incinerate their waste are fewer compared to the others (core and self-subsistent smallholders) that tend to stack their waste. Mostly common and self-subsistent smallholders stack up their waste on the field, while core smallholders stack their waste between trees. According to the farming association, most of the associated smallholders stack their waste on lanes, while only a few of them incinerate the waste. The source of land ownership also does not have a direct impact on waste handling. In terms of certification aspects, all of ISPO (Indonesia Sustainable Palm Oil) certified smallholders stack the residues either on the field lanes or between trees. None of ISPO certified smallholders incinerates their waste. Uncommon findings are also found in RSPO certified smallholders since only a few of them are RSPO certified. Therefore, the likelihood of RSPO certified smallholders on waste handling could not be concluded.

Palm oil plantation waste handling

Table 4 reports the frequencies and percentage of each palm oil plantation waste handling by

Table 4: Summary of palm oil plantation waste handling method

Methods	Frequencies	Percent	Cumulative (%)
(i) Incineration	11	2.75	2.75
(ii) Stacked up on field lanes	200	50	52.75
(iii) Mound on the posts	20	5	57.75
(iv) Stacked up between trees	100	25	82.75
(v) Stacked on a pile	69	17.25	100
Total	400	100	

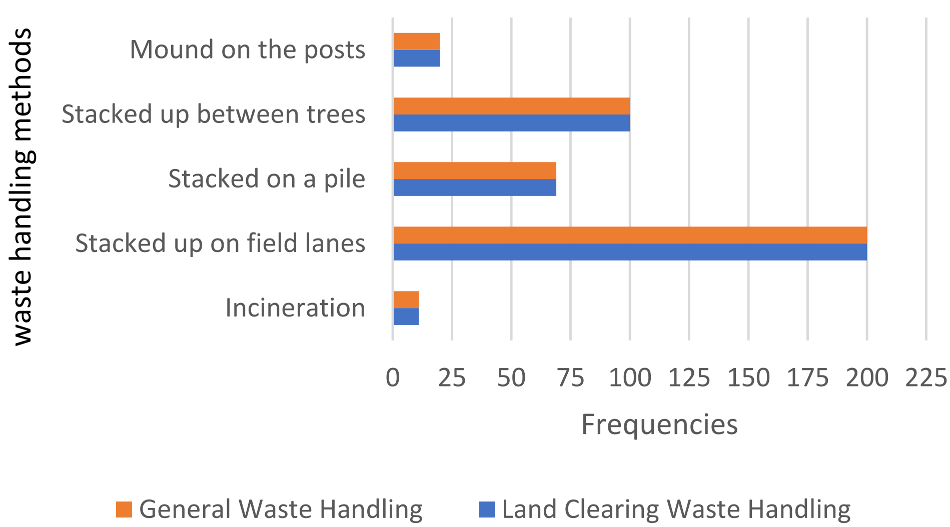

Fig. 1: Comparison of waste handling

smallholders. It was found that the waste handling method distribution are as follows: 50% stack up the waste on the field, 25% stack the waste up between trees, 17.25% stack the waste on a pile, 5% mound the waste on the posts, and 2.75% incinerate their waste for land clearing. The table shows that the method with the highest percentage is stacking up on the field and the lowest percentage incineration. Therefore, Table 4 shows general waste incineration is not preferred by most of the smallholders.

Fig. 1 shows a comparison between smallholders' general and land clearing waste handling on their land plantation. It was found that the similar waste handling process was undertaken for both general and land clearing waste. Out of 400 correspondents, 200 correspondents handle both general and land clearing waste by stacking up on the field lanes.

Based on Table 4 and Fig. 1, most palm oil smallholders in Jambi stack up their waste on-field lanes as opposed to incineration. Stacking waste, whether in field lanes, posts, piles, or between trees, are generally a common method to handle palm oil plantation waste in Jambi. At the same time, the rest (2.75%) of the respondents incinerate the waste. Management of biomass to become bioenergy and biomaterial is driven by energy supply security and pollution reduction purposes (Awalludin *et al.*, 2015). Biomass is an abundant renewable resource and has a neutral carbon cycle (Mohammed *et al.*, 2011). Biomass (plants) plays a role in preventing the release of carbon into the atmosphere because this type of plant is able to produce carbon. If biomass waste is incinerated, then carbon will be released into the atmosphere to mix with oxygen and ultimately produces CO_2 (Hosseini and Wahid, 2014). Burning of biomass will result in the release of carbon into the environment (Awalludin *et al.*, 2015). When biomass is turned into biofuel, the increase of carbon in the environment is lower. Where 60% of the biomass originates from OPT and OPF (Sulaiman *et al.*, 2010). More pollution and fog will develop if biomass waste is incinerated (Awalludin *et al.*, 2015). The incineration process can produce methane gas (CH4) as well as increasing CO2 and CH4, which are contributors to GHG, therefore inducing an increase in the earth's temperature (Cooper *et al.*, 2019; Prosperi *et al.*, 2020). The biggest GHG emissions are CO_2 and methane (Wu *et al.*, 2017). The process of cultivating plantations also produces GHG. However, palm oil plantations are more environment friendly compared to rapeseed and jatropha in terms of GHG emissions (Uusitalo *et al.,* 2014). The reason is that the nitrogen fertiliser and N2O utilised in the cultivation process are released (evaporated) in the air. Burning biomass cause a lot of pollution and low energy efficiency. Burning of palm oil biomass is carried out using a stove, which is a furnace that converts biomass into chemicals and converts into heat (Mohammed *et al.*, 2011). In electricity generation, direct combustion induces evaporation and other waste such as water and CO2 (Awalludin *et al.*, 2015). Ending the practice of incineration and replacing with making use of stems as organic fertiliser that can reduce the consumption of inorganic fertiliser. In the first four years, 20-30% of savings can be made for fertiliser consumption by relying on potassium contained in EFB waste (Nair, 2010). Incineration issues in plantation sector can be managed through coercion, giving or eliminating incentives as well as providing information. stakeholders, rules and good governance practices can be carried out with assistance from the central government, local government, and processing plants (Purnomo *et al.*, 2018). Incineration of biomass waste must be avoided in order not give an impact on the environment (Bessou *et al.,* 2017). Waste management must be done properly to avoid diversity and promote the sustainability of palm oil plantations (Awalludin *et al.*, 2015). The government does not recommend the incineration of biomass waste because it has provided higher economic value when reprocessed (Sulaiman *et al.*, 2010). Biomass waste will be more economical when processed into biofuels (Chin *et al.*, 2019). Processing biomass into other oil products can also be a solution to reduce and mitigate GHG (Wu *et al.*, 2017). Due to an increase in pollution awareness, an increase in fertilisation costs will result in a change in the waste handling method, which shifts from burning waste to processing biomass to fertilisers (Bessou *et al.*, 2017). Based on Table 5 and Fig. 1, waste handling through combustion is at a small percentage. That means the waste handling method contributes to the GHG emitting from CO2 at a low level and therefore contributes to the minimum amount of haze. In relation to the events of land fire in Jambi, the fire did not originate from incineration as waste handling for palm oil waste by smallholders. Palm oil plantations' existence will have an impact on the development of the local area. Increasing infrastructure to support plantations has started to be built, therefore causes pressure on the surrounding area even on the plantation itself. In the harvesting process, large trucks will often pass through plantation land, as such the amount of pressure applied by the trucks will have an impact on compaction of the trajectory land, which may cause land subsidence. The utilisation of OPF can help to relieve compaction pressure by placing OPF in the truck lane, in addition to reducing soil compaction (Truckell *et al.*, 2019). Biomass waste can be used as organic mulch. Mulch is used to condition soil content, maintain soil moisture, and reduce erosion (Chiew and Shimada, 2015). In addition to OPF and OPT, EFB can also be used on the plantation for mulch (Bessou *et al.*, 2017). This mulch is also able to increase chemicals and nutritional content for palm oil production. The use of biomass waste for mulch is affected by labour costs, weight, and volume ratios (Anyaoha *et al.*, 2018). The use of biomass for mulch by smallholders can increase the water content in the soil (Anyaoha *et al.*, 2018). While the use of EFB for mulch in palm oil requires additional costs because it has to be transported from the mill to the plantation (Chiew and Shimada, 2015). Mulch is able to prevent erosion (Shojaei *et al.*, 2019). Using biomass for mulch will help to retain moisture and increase soil fertility and reduce weed growth (Awalludin *et al.*, 2015). However, mulch has a negative side of attracting pests on plantations, such as beetle Oryctes rhinoceros and the bacterium *Ganoderma sp,* as well as causes diseases that attack palm oil, (Anyaoha *et al.*, 2018; Nair, 2010; Chung, 2012). Biomass waste left on plantations to decay is generally on a moist condition and rich in bacteria (Anyaoha *et al.*, 2018). These conditions attract the beetle *Oryctes rhinoceros* to breed in rotten stems or leaves (Chung, 2012; Bessou *et al.*, 2017). The fallen palm tree becomes a reservoir for stag beetle (Nusadaily, 2020). These beetles eat palm crowns and their tops and damage palm oil trees, even cause death to plants. Harvest yields can decrease by 10% due to the presence of these beetles (Arvind *et al.*, 2019). The beetle is capable of causing the death of 3-4 years old palm oil trees that have not been productive yet (Bessou *et al.*, 2017). On the other hand, *Ganoderma sp.* is the cause of basal stem root (BSR) disease. The bacterial infection in palm oil will cause stunted plant growth, pale yellow or green leaves, and rotting stems (Nair, 2010). Waste handling for palm oil biomass waste then needs to be reconsidered. Waste management through combustion and mulch use is less positive impact than the higher value of biomass waste (Sulaiman *et al.*, 2010). Burning waste creates pollution, and using waste as mulch can attract pests. Therefore, farmers need additional effort to handle pests, such as the additional use of pesticides or pheromone traps (Arvind *et al.*, 2019). That can increase the expenditure of pest eradication. However, it will affect the yield of palm oil production. Management control is needed to manage palm oil biomass waste. Waste reduces the sustainability of cultivation (Awalludin *et al.*, 2015) and a challenge if placed on a plantation. However, these challenges can be changed into opportunities for utilisation that can add their economic value (Anyaoha *et al.*, 2018). Hence, in contrast to only leaving the waste to decompose in the plantation, further processing is needed. This waste will have higher economic value if it is reprocessed into biofuels (Awalludin *et al.*, 2015). Other aspects to consider for processing biomass waste into biofuel or materials are the main characteristics of waste, treatment practices, and the available amount of waste (Mahidin *et al.*, 2020). The main characteristics of waste vary, since the form of physical or chemical characteristics of the waste is different, such as shell thickness. The climate and soil conditions are considered to be the cause of these differences (Anyaoha *et al.*, 2018). Processing biomass waste into biofuels is more profitable (Hosseini and Wahid, 2014). Biomass waste has the potential for oil production and can be a replacement for fossil oil. The shell has less water content compared to EFB, hence it is preferred for boiler fuel. Furthermore, this type of waste also has the potential to produce hydrogen (Wu *et al.*, 2017). Lignocellulose content in biomass also has a high potential to produce methane gas for biogas in high levels (Chiew and Shimada, 2015). Therefore, this material can be considered as raw materials for other materials such as cardboard, paper, road paving, briquettes (Awalludin *et al.*, 2015). Biomass waste can be processed into fertiliser or roasted kettle fuel (Wu *et al.*, 2017). The biomass waste can also be considered as raw materials for pulp and paper production. However, this process requires a large amount of energy due to the conversion of fibre into raw materials (Chiew and Shimada, 2015). High water content in biomass needs to be dried off prior to processing to reduce the produced emissions (Sulaiman *et al.*, 2010). The utilisation of biomass as bioenergy requires high costs. However, the processing costs will be replaced by the utilisation of bioenergy itself. In addition, biofuel can provide additional income to improve farmers' economy (Hosseini and Wahid, 2014). Biofuel management faces issues in terms of storage as it requires a large space due to the high mass of waste (Truckell *et al.*, 2019). Processing of biomass waste into biofuel depends on technology, knowledge, interests, and motives of farmers (Chin *et al.*, 2019). Some of the factors that become obstacles in having smallholders' participation in biomass processing include the area of the garden owned by the smallholder, the lack of information regarding biofuel processing, the type of land ownership, processing experience and labour. Other than an obstacle, there is a benefit for biofuel processing, such as the opportunity to increase farmers' income through biofuels. Smallholders prefer the utilisation of traditional methods because they put more trust in experience (Chin *et al.*, 2019). Smallholders tend to adopt practices that have been recognised and proven successful by other farmers. If the surrounding farmers have not applied the method, it is unlikely for them to use the method. Other than that, sending FFB to collectors is the reason why they do not use EFB. At the replanting stage, old plants will be replaced by new plants. This stage requires a high cost for cutting plants into small pieces and cleaning the stumps (Nusadaily, 2020). These costs can be covered by using biofuels as additional income for farmers. The utilisation of biomass to biofuel will also reduce dependence on fossil materials (Awalludin *et al.*, 2015; Idris *et al.*, 2012). According to Hosseini and Wahid (2014), the water content in biomass waste also inhibits the processing of waste into biofuels. High water content complicates the waste collection process. Moreover, this increase the transportation cost. Hence many smallholders still prefer traditional methods. Processing of biomass (stumps) is influenced by the knowledge that will affect the perception of farmers (Rahman *et al.*, 2017). That knowledge includes knowledge about the benefits of the biomass. Additional income can be used as a persuasive argument to attract smallholders. Other than gaining profit, it can also reduce the cost of preparing a new location. Reducing the ecological impact of palm oil plantations can be done by improving agricultural practices, appropriate land utilisation, and appropriate waste management.

Palm oil waste handling and fireland

Land fires can be caused by climate (Hamilton *et al.*, 2019), land-use change (Adrianto *et al.*, 2019) and waste management (Ibrahim, 2020). According to the data of fireland area in Jambi from 2015-2020, Jambi occured the highest number of fireland areas in 2015, which was around 115,634.34 ha land was burnt. The second highest happened in 2019, which was around 56,593 ha land was burnt and the smallest was happen in 2017, which is around 109.17 ha was burnt (MenLHK, 2020). That data was consistent with data from other literature, which stated that in 2015, Indonesia encountered the most significant land fires since the 1997 land fires. That land fire released some carbon (C) into the atmosphere, which affected to the neighbouring countries (Huijnen *et al.*, 2016). However, from the data in Table 4, only 2.75% of smallholders do the incineration process of their plantation waste, which can be driven to the land fire. The palm oil plantations in Jambi amounted to 1,032,145 ha in 2018, with 34.92% managed by large private companies, 63.14% managed by smallholder plantations and 1.94% by large state estates (Directorate General Plantation, 2019). Thus, how smallholders cultivated their plantation and manage their waste, its will give big impact to the environment, including to the fireland driven since smallholders is the biggest stakeholder that manage palm oil plantation in Jambi. The process of incineration waste can be one of the causes of land fires. Variable water levels, flammable surface vegetation, socio-political phenomena, and biophysical conditions allow for an increase in landscape susceptibility to annual fires that are sustained and uncontrolled (Goldstein *et al.*, 2020). Because of that, the smallholder methods of handling their waste becomes important.

Knowledge, their environments, and local wisdom may affect their decision to treat their waste. Whereas if waste incinerated done by smallholders becomes the causes of land fires due to palm oil plantations area owned by smallholders, since their plantation is spread across Indonesia and they have around 40% of palm oil plantations in Indonesia (Jelsma *et al.*, 2019). Table 4 showing the waste handling by smallholder is the least or does not of land fire-driven, especially in the study area. Since in this study show that only 2.75% palm oil plantation smallholder incinerated their plantation waste.

CONCLUSION

Waste handling on plantation process by smallholders influenced by their economic and social condition, which is affecting their decision to how they are handling their waste. The decision waste handling by smallholder influenced by their harvest productivity and the distance between their plantation and their house. That because they have low capacity to bring their waste to another area. Most of the common smallholders and self-subsistent smallholder has been handling their palm oil plantation waste through stacking the wastes on their field. The method to handle the waste also has been used by smallholder that joint a farming association. According to the survey, only 2.75% of total smallholders, handle their waste by incineration. The other 50% of smallholders stack up their waste on the field lane, including both general and land clearing waste. The smallholders might be aware that incineration will cause negative effects. Moreover, their methods of handling their palm oil plantation waste helps to minimise the probability to start land fires. If most of the smallholders still chose incineration as their preferred waste handling method, the probability of land fire to happen will be higher since smallholders are the biggest stakeholder that manage palm oil plantation in Jambi. Therefore, there is a strong argument that waste handling by smallholders does not the cause of that land fires. Moreover, there are possibilities that land-opening activities were the main cause of severe land fires since burning down the trees is the most cost-effective solution to reopen new lands. Hence, it was recommended for undertaking an analysis to understand the cause of forest fire. Aside from proper waste-handling, that most smallholders comply with the environmental preservations, regardless of their certifications. This study also found that not many palm oil smallholders are ISPO-certified. Hence, in order to exhalate sustainable operations of palm oil productions, ISPO and RSPO socializations are needed to the smallholders in order to decrease incineration activities, regardless of waste-handling or field-opening activities. ISPO and RSPO certifications can be a tool for the government and environmentalists to keep maintaining economic growth and minimize the negative impact of palm oil activities on the environment.

AUTHOR CONTRIBUTIONS

H. Herdiansyah performed the literature review, experimental design, analyzed and interpreted the data, prepared the manuscript text, and manuscript edition. E. Frimawaty performed the experiments and literature review, compiled the data and manuscript preparation.

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CONFLICT OF INTEREST

The authors declare no potential conflict of interest regarding the publication of this work. In addition, the ethical issues including plagiarism, informed consent, misconduct, data fabrication and, or falsification, double publication and, or submission, and redundancy have been completely witnessed by the authors.

ABBREVIATIONS

%	*Percentage*
BSR	*Basal stem root*
C	*Carbon*
CH_4	*Methane*
cm	*Centimeter*
CPO	*Crude palm oil*
CO_2	*Carbon dioxide*
DM	*Dry matter*
EFB	*Empty fruit bunch*
FFB	*Fresh fruit bunch*
Fig.	*Figure*
GHG	*Green house gasses*
Ha	*Hectares*
ISPO	*Indonesian Sustainable Palm Oil*
K	*Potassium*
kg	*Kilogram*
L	*Liters*
m	*Meter*
Mg	*Magnesium*
MF	*Mesocarp Fibre*
N_2O	*Nitrous Oxide*
OPF	*Oil Palm Fronds*
OPT	*Oil palm trunk*
OPL	*Oil Palm Liquid*
PKS	*Palm kernel shell*
POME	*Palm oil mill effluent*
RSPO	*Roundtable on sustainable palm oil*
Sp.	*Species*
S.D.	*Standard deviation*
(t)	*Thousand*
ton	*Tonne*
USD	*United States Dollar*
VFD	*Variable frequency drive*

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