Mapping the Potential Use of Peat Land to Formulate a Management Strategy for Smallholder Palm Oil Plantations

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ABSTRACT

By 2030, smallholder plantations will account for 60% of the total oil palm plantation cover. Currently, 40% of smallholder oil palm farms in Indonesia have low productivity and are located in peatlands. The result is that increasing land productivity requires taking into account the maturity, thickness, and depth of the groundwater table. The study's goals were to identify many characteristics of peatlands in smallholder plantations, to create a map of potential peatland use, and to build a strategy for smallholder oil palm farms based on peat potential maps. The peatland mapping units was determined on a combination of soil type maps, peat maturity maps, and peat thickness maps. Observations and extra sampling at each land mapping unit (LMU) were conducted using a random survey method to stratify 20 observation sites and soil physical property samples. The strategy formulation technique employed a SWOT analysis, which was evaluated by key informants. The study found that (1) the characteristics of peat in each LMU show relatively similar properties, namely having low bulk density, high groundwater content, and porous porosity, (2) there were 5 LMUs based on maturity, thickness, and groundwater level, and (3) the strategy consists of efforts to improve the quality of the water management system to overcome the depth of the groundwater level that exceeds the required limit, overcome the depth of irrigation channels that exceed the maximum depth, increase the use of fertilizer according to the recommended dose to increase oil palm production.

Keywords: development strategy, independent palm oil, land mapping unit

INTRODUCTION

In 2021, smallholder oil palm plantations in Indonesia accounted for 35.8% of total planting area. However, these plantations only contributed 34.4% of total national palm oil production. This figure is lower than that of private oil palm plantations, which accounted for 60.6% of total production (from 47.8% of the national oil palm plantation area). Projections for 2023 show that smallholder farms will increase to 37.4% of total oil palm plantation area, resulting in increased productivity. However, data suggest that smallholder oil palm farms produce only 2.5 t/ha, which was lower than the productivity of private oil palm plantations, which is 3.5 t/ha (Direktorat Jenderal Perkebunan Kementan RI 2022).

The low productivity of smallholder oil palm plantations has an impact on the national average, which is much lower than that of numerous other nations, including Malaysia, a major competitor of Indonesian palm oil goods in the worldwide market. To boost oil palm productivity under these conditions,

long-term initiatives are required. One approach to increasing productivity is to create an adequate and coordinated long-term strategy for managing smallholder oil palm estates. Determining the best management strategy necessitates data and information on land characteristics (Goenadi *et al.* 2021, Widiarti & Nurlina 2012), particularly for peatlands, which are home to the majority of oil palm plantations in West Kalimantan, covering 538,106.50 ha.

Several important issues arise while farming oil palms on peatlands, including peat thickness, maturity, and groundwater level, all of which vary greatly and influence the natural fertility of peat soil. To increase productivity, oil palm plantations must be managed based on these three location-specific peat soil features, as soil parameters influence oil palm production (Purnamayani *et al.* 2022). There is still a scarcity of research that measures all three of these traits at once. However, increasing oil palm productivity requires a management approach that incorporates all three of these features. Based on this situation, a peatland map based on measuring peat maturity, layer thickness, and groundwater level in smallholder oil palm farms is required to evaluate peatland potential and develop management plans for smallholder oil palm plantations on peatlands. As a result, the goals of this study were to (1) identify and inventory several characteristics of peatland in smallholder oil palm

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plantations; (2) map the potential use of peatland based on maturity, thickness, and depth of groundwater levels; and (3) develop a management strategy for smallholder oil palm plantations based on peat potential maps.

METHODS

Materials and Tools

The study's materials included village administration maps, soil type maps, observation point maps, and land use maps. Tools utilized included hoes, a Munsell Soil Color Chart, an Eijkelkamp peat drill, GPS, sample rings, knives, plastic bags, measuring tape, label paper, a digital camera, and stationery.

Research Site

The study was carried out in a small-scale oil palm plantation in the border area with Malaysia, specifically in Sijang Village, Sambas Regency. The village had a fairly large oil palm plantation, consisting of 3,121.78 ha of privately owned land and 146.71 ha of small-scale oil palm plantations. However, the average production of small-scale oil palm plantations in this vllage in 2020 was just 1.8 ton/ha (Badan Pusat Statistik Kabupaten Sambas 2021).

Data Collecting

Peatland unit boundaries was determined within the cultivation area of an smallholder oil palm plantation in the village. Land units were created by overlaying soil type maps (Peta RBI Lembar Tenggulang No. 1317-62, Riam No. 1417-41, Sambas No. 1317-34, Satai No. 1417-13, scale 1:50.000 (BIG 2017)), peat maturity maps, and peat thickness maps (2020 Spot Recording Imagery and 2022 Field Data Analysis Results). Furthermore, a random system survey was used to stratify 20 observation points based on land units; the distribution was determined using the base map and adjusted to the survey area's field conditions by considering the distribution of smallholder oil palm plantations located on peat land.

At each preset observation point, the physical environmental features of the land were identified, such as peat maturity, thickness, and groundwater depth. Peat maturity was measured using the Von Post method, while peat thickness and groundwater level were determined using field observations with a measuring tape. Furthermore, each observation location was GPS-marked and documented. Soil surveys and environmental observations were used to collect data on the physical properties of the soil and its surroundings. Other parameters that were studied include bulk density, porosity, pyrite in the mineral layer beneath the peat, and soil water content. Measuring bulk density and porosity with ring samples taken at specified observation sites with a random system between oil palm trees at a distance of 1.5−2 m and depth of 0−30 cm. The gravimetric method was used to calculate bulk density, and the three-phase meter method was used to determine porosity. The pyrite layer was determined in the substratum beneath the peat using hydrogen peroxide (H_2O_2).

To investigate soil physical attributes, soil sampling and boring observations were carried out on typical land units made up of intact soil samples. The soil samples were then studied at the Physics and Soil Conservation Laboratory, Faculty of Agriculture, Universitas Tanjungpura. The approach was developed by comparing real field circumstances with the standards for good oil palm production outlined in the Indonesian Ministry of Agriculture Regulation Number 131 of 2013.

Data Analysis

Data processing, analysis, and mapping were three activities that are consistent with the study objectives.

1 The analysis results for peat properties, such as maturity, thickness, groundwater depth, pyrite layer depth, bulk density, porosity, and soil water content, were presented in a tabular format and interpreted descriptively.

2 Peat utilization potential was mapped based on maturity, thickness, and groundwater level using interpolation and the Spline with Barriers tool. Data points were limited by barriers to ensure the distribution pattern did not exceed predetermined limits.

3 The SWOT method was used to develop management strategies for smallholder oil palm plantations by mapping potential peatland exploitation based on maturity, thickness, and groundwater levels. The SWOT indicators were based on oil palm cultivation guidelines that can ensure the sustainability of peatland functions according to Indonesian Ministry of Agriculture Regulation No. 131 of 2013, particularly those related to peat characteristics such as peat maturity, peat thickness, groundwater level depth, depth of pyrite layer under peat, bulk density, porosity, and soil water content. Each measured indication was weighted and rated during the study. The weight (value range 0−1, the higher the number, the greater the influence) represents the relative relevance of each indication, whilst the rating indicates the indicator's influence in the context of SWOT. The weights and evaluations are decided by key informant respondents, which include representatives from Sijang Village and smallholder oil palm producers.

RESULTS AND DISCUSSION

Peatland Characteristics

The survey was carried out using a stratified random sampling system with 20 observation points. The distribution of which was determined using a base map and adjusted to the field conditions of the survey area, considering the distribution of the smallholder oil palm plantation. In this study, the activity area on the peatland of the smallholder plantations in Sijang Village was 146.71 ha.

Variations in peatland properties were discovered at 20 drilling places, including peat depth, maturity level, peat thickness, and groundwater level (Table 1). The findings revealed that the peat depth ranged between 0 and 190 cm, showing that the peat at the survey site was fairly deep, with fibric, sapric, and Hemic maturity types. The peat thickness ranged from 30−240 cm, indicating that a portion of the survey area had deep peat with a groundwater level of 10−75 cm.

Peatland Mapping Unit

Based on data from 20 drilling points, 5 LMUs were categorized according to soil attributes such as maturity, thickness, and peat groundwater level (Table 2). Peat soil characteristics in each LMU were

Table 1 Observation of drilling on peat land of smallholder oil palm plantation in Sijang Village

Observation point	Depth (cm)	Peat maturity	Peat thickness (cm)	Groundwater depth (cm)	LMU
1.1	0–30	Sapric	180	40	1
	31–70	Hemic			
	71–180	Hemic			
1.2	0–30	Sapric	240	75	3
	31–50	Hemic			
	71–240	Hemic			
1.3	0–30	Sapric	52	42	5
	31–52	Hemic			
2.1	0–70	Hemic	130	20	2
	71–110	Hemic			
	111–130	Hemic			
2.2	0–30	Sapric	160	48	1
	31–70	Hemic			
	71–160	Hemic			
2.4	0–10	Sapric	54	24	5
	11–54	Hemic			
2.3	0–10	Sapric	30	38	5
	11–30	Hemic			
2.5	0–10	Sapric	54	24	5
	11–54	Hemic			
2.6	0–10	Sapric	70	10	5
	11–70	Hemic			
2.7	0–10	Sapric	30	20	5
	11–30	Hemic			
2.8	0–30	Sapric	80	19	5
	31–80	Hemic			
2.9	0–10	Sapric	80	35	3
	11–80	Hemic			
2.10	0–20	Sapric	54	20	5
	21–54	Sapric			
2.11	0–30	Sapric	55	30	5
	31–55	Hemic			
2.12	0–20	Sapric	53	33	5
	21–53	Hemic			
2.13	0–30	Sapric	200	55	3
	31–80	Hemic			
	81–150	Fibrik			
	151–190	Hemic			
2.14	0–10	Sapric	205	68	4
	11–205	Hemic			
3.1	0–40	Sapric	40	19	5
3.2	0–10	Sapric	40	23	5
	11–40	Hemic			
3.3	0–30	Hemic	107	35	2
	31–80	Hemic			

described using color, peat maturity, peat thickness, and peat groundwater level (Figure 1). Soil color observations were evaluated using the Munsell Soil Color Chart color standard, which was divided into three categories: hue, value, and chroma. Table 3 shows the soil color at each LMU and depth. According to Hardjowigeno and Widiatmaka (2007), color represents many soil qualities since soil color is controlled by a variety of elements within the soil. Surface soil color varies according on the amount of organic matter present. The soil color becomes darker as the organic matter concentration increases. The peat in LMU 1−5 was generally dark reddish brown, indicating that it is hemic in maturity, however the upper layers were beginning to change to sapric. Peat hue indicates peat maturity. The more mature the peat, the darker it becomes. Fibric is brown, hemic is dark brown, and sapric is black (Darmawijaya 1990). In damp conditions, the peat color typically darkens.

Peat soil is classified into three categories based on maturity level: fibric (raw), hemic (moderately/slightly decomposed), and sapric (highly decomposed). Fibric peat was detected at depths above 200 cm, hemic peat

at depths between 100−200 cm, and sapric peat at depths below 100 cm. As a result, the peat is less mature as it gets deeper. This condition could be seen in each LMU at varied depths, indicating various levels of maturity, with thicker and deeper peat indicating a semi-mature condition. The condition of peat in the survey region was commonly classified as sapric at a depth of 0−30 cm, hemic (slightly decomposed) with a peat layer depth of 50−200 cm, and hemic (moderately decomposed) at 200−300 cm. The disparities in maturity level show that the survey area's water conditions (drainage) are rather steady, implying that the organic material breakdown process is functioning properly.

The thickness of the peat is a significant issue when utilizing peatland. Hardjowigeno and Widiatmaka (2007) defined shallow (thin) peatlands as those with a thickness of 50−100 cm. The thicker the peat, the less possibilities for crop cultivation. Peat thickness measurements at the research site classified it as shallow, medium, or deep, indicating that its current use for oil palm plantations is appropriate. The thicker the peat, the less potential it has for growing food crops

Table 2 Land mapping unit (LMU)

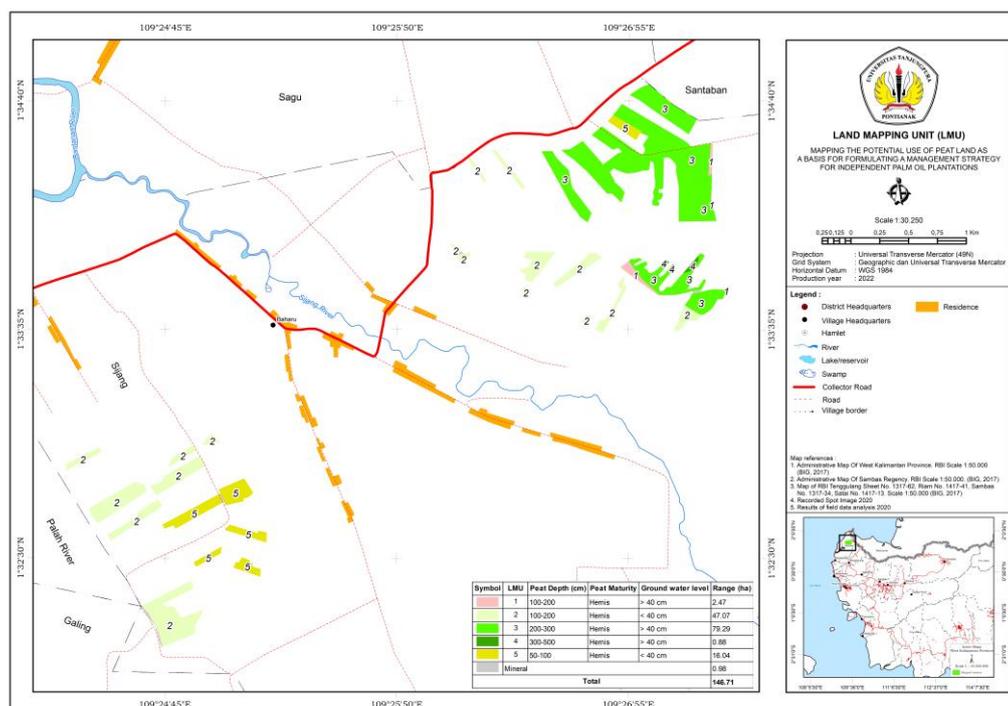| LMU	Peat depth (cm)	Peat maturity	Groundwater depth (cm)	Area (ha)
1	100–200	Hemic	> 40	2.47
2	100–200	Hemic	< 40	47.07
3	200–300	Hemic	> 40	79.29
4	300–500	Hemic	> 40	0.88
5	50–100	Hemic	< 40	16.04
	Mineral			0.98
	Total			146.71

Figure 1 Peatland unit map on the smallholder oil palm plantations of Sijang Village.

Table 3 Peat soil characteristics at the research site

LMU	Peat depth (cm)	Peat color		Maturity		Peat thickness		Groundwater depth	
		Color	Description	Level	Description	cm	Description	cm	Description
1	0–30	5YR 3/4	Dark reddish brown	Sapric	Well decomposed	160	Moderately deep	48	Shallow
	31–60	5YR 2/2	Dark reddish brown Blackish red	Hemic	Moderately decomposed				
	61–160	2,5YR 2/2		Hemic	Slightly decomposed				
2	0–10	5YR 3/2	Dark reddish brown	Hemic	Moderately decomposed	110	Moderately deep	20	Very shallow
	11–70	5YR 2/3	Dark reddish brown	Hemic	Slightly decomposed				
	71–110	2,5YR 2/2	Dark reddish brown	Hemic	Slightly decomposed				
3	0–30	2,5YR 2/2	Dark reddish brown	Sapric	Well decomposed	240	Deep	75	Moderately deep
	31–50	5YR 3/3	Dark reddish brown	Hemic	Moderately decomposed				
	71–240	2,5YR 2/3	Dark reddish brown	Hemic	Slightly decomposed				
4	0–10	2,5YR 2,5/2	Blackish red	Sapric	Well decomposed	300	Deep	68	Moderately deep
	11–50	5YR 2/2	Dark reddish brown	Hemic	Moderately decomposed				
	51–300	5YR 2/3	Dark reddish brown	Hemic	Slightly decomposed				
5	0–10	5YR 2/2	Dark reddish brown	Sapric	Well decomposed	54	Shallow	24	Very shallow
	11–54	5YR 2/3	Dark reddish brown	Hemic	Moderately decomposed				

and horticulture (Arifin & Hardjowigeno 1997). According to the Malaysian Palm Oil Board (MPOB), thick peat can still be cultivated for plantation crops as long as land management adheres to sustainability guidelines. Annual crops, such as rice and secondary crops, are not appropriate for growing on thick peat. Specifically for oil palm plants, Othman *et al*. (2011) observed that there is no significant difference in generating fresh fruit bunches (FFB) of oil palm on thin or thick peat. Meanwhile, Page and Hooijer (2016) and Sabiham and Sukarman (2012) found no significant correlation between peat thickness and subsidence or carbon emissions. These researchers also concluded that carbon loss from subsidence and flow measurements (closed chamber method) have a strong correlation with groundwater table depth.

Groundwater levels (GWL) at 5 LMUs were observed to range from 20 to 75 cm, indicating that they are very shallow to moderate. This variation in groundwater levels is controlled by rainfall, micro-water management in oil palm plantations, and the distance between drainage canals in smallholder oil palm fields at the research site. Groundwater level influences peat content, whereas rainfall influences peatland water level (Murdiyarso 2015). Peat has distinct characteristics and serves multiple functions, including water management, flooding control, habitat for various types of living things, and carbon storage, all of which contribute to global climate stability (Harrison *et al*. 2009, Hooijer *et al*. 2012, Wibowo 2009).

Physical Characteristics of Each LMU

The documented physical features of peatland include bulk density, water content, soil porosity, and the mineral layer underlying the peat (Table 4). Bulk density is the most commonly studied soil physical parameter because it can predict other soil qualities such as porosity, bearing capacity, and water retention potential. The analytical results suggest that the bulk density in all LMUs in the research site is rather low, placing them in the Hemic peat group. Soil with a low bulk density has a high porosity, which increases its ability to absorb and channel water. However, if the bulk density is too low, the soil's load-bearing ability is reduced. The higher the bulk density, the more mature the peat (Nugroho and Widodo 2001, Masganti 2003).

Table 4 Physical characteristics of peat land

LMU	Bulk density		Soil water content		Porosity	
	(g/cm^3)	Criteria	(%)	Criteria	(%)	Criteria
1	0.15	Low	78.19	High	91.09	Porous
2	0.15	Low	78.19	High	91.09	Porous
3	0.19	Low	75.79	High	87.82	Porous
4	0.11	Low	84.44	High	92.40	Porous
5	0.15	Low	78.19	High	91.09	Porous

Fibric peat typically has a bulk density of <0.10 g cm^3, sapric peat >0.20 g cm^3, and hemic peat 0.10−0.20 g cm^3.

The study found that the soil water content in percentage volume in the 5 LMUs ranged from 75−84%, which was significantly higher than that of mineral soil. According to Elon *et al*. (2011), the water content in peat soil can reach 300−3,000% of its dry weight, which is significantly higher than that of mineral soil, which has a water absorption capability of approximately 20−35%. Mutalib *et al*. (1991) observed peat water content in a lower range, 100−1,300%, indicating that peat may absorb 1 to 13 times its weight. The porosity of peat, which can reach 95%, is one of the factors that contribute to its great ability to hold water. Functional groups formed during the peat breakdown process are also active soil components that aid in water absorption. The average water content of peat in its natural state (flooded) is determined by its level of maturity. At the fibric maturity stage (extremely raw peat), the peat is highly permeable, therefore water fills the crevices between the peat masses. However, because the water is primarily held in the macropores, it is quickly lost when the peat is drained. Water is kept at a higher absorption level in mature peat, where micropores and mesopores occur. Gravity is insufficient to discharge the water trapped in micropores and mesopores.

Soil porosity investigation at 5 LMUs yielded findings ranging from 87 to 92%, indicating porous conditions. However, the water-holding capacity of peat varies due to intricate interactions between peat soil features. As organic matter decomposition progresses, total porosity and soil permeability decrease. Driessen and Rohimah's (Kyuma 1987) investigation on peat porosity measured using soil density and specific gravity yielded findings ranging from 75 to 95%. Peat's high water retention capacity is closely related to soil porosity. The larger the porosity, the greater the water retention capacity of the peat. The level of decomposition determines peat porosity. Fibric peat is more porous than hemic and sapric peat. The increase in peat temperature reduces porosity. The results of field observations at the five LMUs indicate that the substratum is a mineral layer beneath the peat.

Smallholder Oil Palm Plantation Management Strategy

The approach for managing smallholder oil palm farms employs indicators based on sustainable peatland oil palm farming criteria, as outlined in Indonesian Minister of Agriculture Regulation Number 131 of 2013, which are based on maturity, thickness, and groundwater level, and employ the SWOT method. The SWOT analysis scores based on weighting and rating are shown in Table 5. Both internal and external factor scores have negative values. This determines the design of a plan for quadrant 4 of the SWOT matrix. The internal factor analysis results demonstrate that the weaknesses score exceeds the strengths score, indicating that flaws dominate the internal conditions of smallholder oil palm plantations.

Peatland in the 5 LMUs with a Hemic maturity level and a mineral substratum layer has the highest strength indication (0.17). Meanwhile, the indicator with the highest vulnerability score is plantation land with a groundwater level greater than 40 cm (0.28). This condition indicates that the depth of groundwater in peatlands is a critical issue for farmers in these places. The external factor analysis results suggest that the opportunity score is lower than the threat score, totaling −0.01. This disparity suggests that negative conditions for farmers outweigh external considerations.

According to the analysis results, the final score of the internal factor is −0.23, which is the *X* coordinate point, and the final score of the external factor is −0.01, which is the *Y* coordinate point (−0.23; −0.01). The SWOT analysis matrix contains negative *X* and *Y* coordinate values, indicating a defensive strategy. The coordinates are in quadrant IV, indicating that smallholder oil palm plantations have weak internal and external conditions. The strategy formulation can be described by the following SWOT matrix.

Table 6 illustrates the SWOT analysis technique for overcoming weaknesses and threats. According to the strategic approach of smallholder oil palm plantations, the following strategies might be developed:

1 Oil palm farmers, especially those with single farms, collaborated to plan and build integrated irrigation canals across their plantations. This endeavor could involve building canal barriers to keep groundwater levels below 40 cm and regulating the drainage of deeper drainage systems.

2 A technique to build and activate farmer groups to address low fertilizer doses. Farmer groups can address fertilizer shortages by procuring fertilizer while also providing a platform for farmers to improve their knowledge and skills in practical farm management, such as building functional irrigation channels and utilizing organic materials derived

from plantation waste. This technique aims to boost farm productivity and profitability.

Smallholder Oil Palm Plantation Management Strategy Based on LMU

Furthermore, a location-specific smallholder oil palm plantation management strategy was developed based on an analysis of the physical characteristics of peatlands in five LMUs as well as the overall smallholder oil palm plantation management strategy. Table 7 demonstrates how the strategies developed through SWOT analysis were combined with the conditions at each LMU.

Table 5 IFAS and Matrix for smallholder oil palm plantations

No.	Indicator	Relative weight (a)	Rating (b)	Score (a × b)
Strength				
1	The proportion of land area with peat thickness of less than 3 m reached 98% of the land cover, exceeding the requirement of 70%	0.07	1.8	0.12
2	The peatlands in the 5 LMUs have a Hemic maturity level with a substratum layer consisting of minerals	0.07	2.4	0.17
	Total strength (c)			0.29
Weakness				
1	The groundwater level is more than 40 cm at the plantation area	0.09	3	0.28
2	The water management system is not suitable for the peatland conditions at the location (drainage channel depth >80 cm)	0.09	2.80	0.25
	Total weakness (d)			0.52
	Internal factor score (c – d = coordinates on the X axis)			**–0.23**
Opportunity				
1.	Availability of organic material from plantation waste that can be utilized as fertilizer	0.11	2.60	0.28
	Total opportunity (e)			0.28
Threat				
1	Fertilizer application in oil palm plantations is lower than ideal conditions due to the limited availability of fertilizer	0.12	2.40	0.29
	Total threat (f)			0.29
	Eksternal factor score (e – f = coordinates on the Y axis)			**–0.01**

Table 6 SWOT ma for smallholder oil palm plantations

INTERNAL FACTORS \ INTERNAL FACTORS	**STRENGTH** 1 The proportion of land area with peat thickness of <3 m reached 98% of the land cover, exceeding the requirement of 70% 2 The peatlands in the 5 LMUs have a Hemic maturity level with a substratum layer consisting of minerals	**WEAKNESS** 1 The groundwater level is >40 cm at the plantation area 2 The water management system is not suitable for the peatland conditions at the location (drainage channel depth >80 cm)
OPPORTUNITY 1 Availability of organic material from plantation waste that can be utilized as fertilizer	**S–O strategy**	**W–O strategy**
THREAT 1 Fertilizer application in oil palm plantations is lower than ideal conditions due to the limited availability of fertilizer	**S–T strategy**	**W–T strategy** 1 Improving the water management system, especially for the groundwater levels that exceed the established limits, and improving irrigation channel depths that exceed the maximum depth (W1, T1) 2 Increasing fertilizer use according to recommended dosages to increase palm oil production (W2, T1)

Table 7 Smallholder oil palm plantation management strategy matrix based on LMU

LMU	Characteristics	W–T strategy	
		Initiating/maintaining farmers' groups through:	Collective movement of farmers in one area:
LMU 1	Peat depth of 100–200 cm, Hemic maturity, and groundwater depth > 40 cm require water management with canal blocking to maintain the groundwater level not exceeding 40 cm. Fertilization recommendations: Urea 7.5 kg/tree/year, SP–36 0.5 kg/tree/year, KCL 1.75 kg/tree/year	− Improving farmers' knowledge and skills in water management by constructing canal barriers to maintain groundwater levels below 40 cm. − Procuring agricultural inputs, especially fertilizers, and improving knowledge of fertilizer use according to recommendations.	Constructing water management infrastructure through canal barriers to maintain the groundwater level at a level not exceeding 40 cm
LMU 2	Peat depth of 100–200 cm, Hemic maturity level, and groundwater depths of less than 40 cm necessitate additional inputs to enhance production through age-appropriate fertilization and consideration of soil nutrient availability. Furthermore, incorporating organic matter from local resources within the surrounding environment is essential. The recommended fertilization rates are as follows: urea at 9.5 kg/tree/year, SP-36 at 1.1 kg/tree/year, and KCL at 4.5 kg/tree/year.	Acquisition of agricultural inputs, particularly fertilizers, and enhancing understanding of recommended fertilizer usage.	Processing of palm oil plantation waste available in the surrounding environment as additional organic material for the growth of palm oil plants.
LMU 3	Peat depth of 200–300 cm, Hemic maturity, and groundwater depth > 40 cm require water management with canal blocking to maintain the groundwater level not exceeding 40 cm, as well as additional input to increase production through fertilization according to plant age and the addition of organic materials from local resources in the surrounding environment. Recommended urea fertilization 2.75 kg/tree/year, SP-36 0.35 kg/tree/year, KCL 3.75 kg/tree/year	− Improving farmers' knowledge and skills in water management by constructing canal barriers to maintain groundwater levels below 40 cm. − Procuring agricultural inputs, especially fertilizers, and improving knowledge of fertilizer use according to recommendations.	− Constructing water management infrastructure through canal barriers to maintain the groundwater level at a level not exceeding 40 cm − Processing of palm oil plantation waste available in the surrounding environment as additional organic material for the growth of palm oil plants.
LMU 4	Peat depth of 300–500 cm, Hemic maturity, and groundwater depth > 40 cm require water management with canal blocking to maintain the groundwater level not exceeding 40 cm. Fertilization recommendations: Urea 7.5 kg/tree/year, SP-36 0.5 kg/tree/year, KCl 1.75 kg/tree/year	Improving farmers' knowledge and skills in water management by constructing canal barriers to maintain groundwater levels below 40 cm.	Constructing water management infrastructure through canal barriers to maintain the groundwater level at a level not exceeding 40 cm.
LMU 5	Peat depths of 50–100 cm, Hemic maturity, and groundwater depths of <40 cm require additional inputs to increase production through fertilization appropriate to plant age and soil nutrient availability. Adding organic matter from local resources in the surrounding environment is necessary. Fertilization recommendations: urea fertilization 9.5 kg/tree/year, SP-36 1.1 kg/tree/year, KCl 4.5 kg/tree/year	Procuring agricultural inputs, especially fertilizers, and improving knowledge of fertilizer use according to recommendations.	Processing of palm oil plantation waste available in the surrounding environment as additional organic material for the growth of palm oil plants.

CONCLUSION

This investigation led to the following conclusions: Peat qualities in each LMU are similar, including low bulk density, high soil water content, and high porosity. There are five Land Mapping Units (LMU) categorized by maturity, thickness, and groundwater level: LMU 1: 2.47 ha of peatland with a thickness of 100−200 m, Hemic maturity, and groundwater levels over 40 cm. - LMU 2: 47.07 ha of peatland with a thickness of 100−200 m, Hemic maturity, and a groundwater level of <40 cm. LMU 3: 79.29 ha of peatland with a thickness of 200−300 m, Hemic maturity, and groundwater levels greater than 40 cm. - LMU 4 refers to peatland with a thickness of 300−500 m, Hemic maturity, and a groundwater level above 40 cm, encompassing 0.88 ha. - 16.04 ha of

LMU 5 peatland with 50−100 m thickness, Hemic maturity, and groundwater level < 40 cm.

To improve groundwater levels and irrigation channel depths, strategies should be developed based on peatland characteristics and LMU management. Fertilizer application should be increased to recommended doses to boost palm oil production. These initiatives could be carried out by forming/activating groups and farmer collective movements within a single plantation region.

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