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Analysis of limiting factors for food agriculture development in peatland areas

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Analysis of limiting factors for food agriculture development in peatland areas

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Abstract. This study aims to determine the main limiting factors in agricultural development on peat lands and the agricultural input to improve it. The study was conducted in peat land of the Sriwijaya Botanical Gardens, Bakung Ogan Ilir Village, South Sumatra, Indonesia. A detailed survey was designed based on a map scaling of 1: 5,000 and analyses of peat samples were carried out in the Soil Science Department Laboratory of Sriwijaya University. The Soil Map Unit (SMU) was then generated based on peat depth and its maturity. The indicator of agricultural food crops is corn. The results showed that the maturity of the peat was dominated by sapric, the depth was divided into two classes, namely 1.5-2m and >2m. The actual land suitability of the site was unsuitable (Nrc, nr) with the limiting factors, i.e. nutrient retention and root media. The limitation of nutrient retention was on low soil pH and low potassium. Whereas, Nitrogen and Phosphorus content were considered as high and medium. By giving agricultural input, the potential land suitability class improve to S3rc (less suitable) with the limiting factor including peat depth. There were some areas considered as permanently unsuitable (Nrc) due to peat depth. Drainage control is essential management to ensure crop water availability.

1. Introduction

Land and forest fires are continuously occurring every year. Human activities and climate change intensify fire occurrences particularly in dry season when soil moisture is somewhat low. The fire rate of South Sumatra Province was relatively high covering of 336,798 hectares in 2019 [1] or 428,356 hectares in 2020 [2]. Ogan Komering Ilir District suffered the largest fire covering of 233,546 hectares and mostly occurred in peat land.

Land clearing for plantation using excessive drainage system is a major cause of peatland fire. Deep and wide drainage system caused water table drawdown so that capillary water movement is inadequate to keep surface soil humidity condition [3]. This dry condition causes land to be flammable. Utilizing land to cultivate productive food crops such as pineapple has successfully maintained soil humidity (moisture) and inhibits land fire. Land protection from fire hazard intensifies when profitable plants are cultivated. To have more alternative cultivation, land suitability assessment for various food crops should be conducted. Corn is a marketable food and feed crops. Cultivating corn with high agricultural input at peat land was capable to yield 5.25 ton/ha [4]. Moreover, sweet corn could produce 7.530 kg/plot (16.73 ton/ha) on micro scale experiment [5]. To allow the production level in peatlands, maintaining the ground water table under 40-50 cm is required to supply water for crop evapotranspiration [6].

Land suitability is essential in designing land management that balancing between the profit and environmental conservation or protection [7]. Land evaluation is assessment process specified to assess land form, soil, vegetation, climate and other land aspects for comparing the developmental effect and selecting optimal land use that minimize land degradation [8]. Additional aspects such as existing network condition, potency of water flow rate and soil maturity level should also be evaluated for peatland. Agricultural development at degraded peatland requires some improvement such as rewetting, fertility improvement and planting [9]. Drainage factor [10] such as water level condition up to 60 cm of channel is an important parameter. Meanwhile, the economic factors should be considered in peat land clearing [11] such as the profit [12]. Agricultural input at peatland is relatively costly in addition to environmental degradation hazard, especially as a result of land drainage that may increase CO_2 gas emission [13].

It is expected that environmental degradation can be minimized by using the above processes. Therefore, it is essential to characterize and assess land suitability of peatlands and its relationship with soil properties and hydrological condition toward the potential of maize cultivation.

2. Methodology

2.1. Location and period

This study was conducted at peatland of Kebun Raya Sriwijaya, Bakung Village, Indralaya Utara Subdistrict, Ogan Ilir District, South Sumatra. Soil analysis was carried out at Laboratory of Soil Chemical, Biological and Fertility, as well as Laboratory of Soil Physics and Conservation, Soil Department, Faculty of Agriculture, Sriwijaya University. Study was conducted from March to April 2021. The location map is shown in Figure 1.

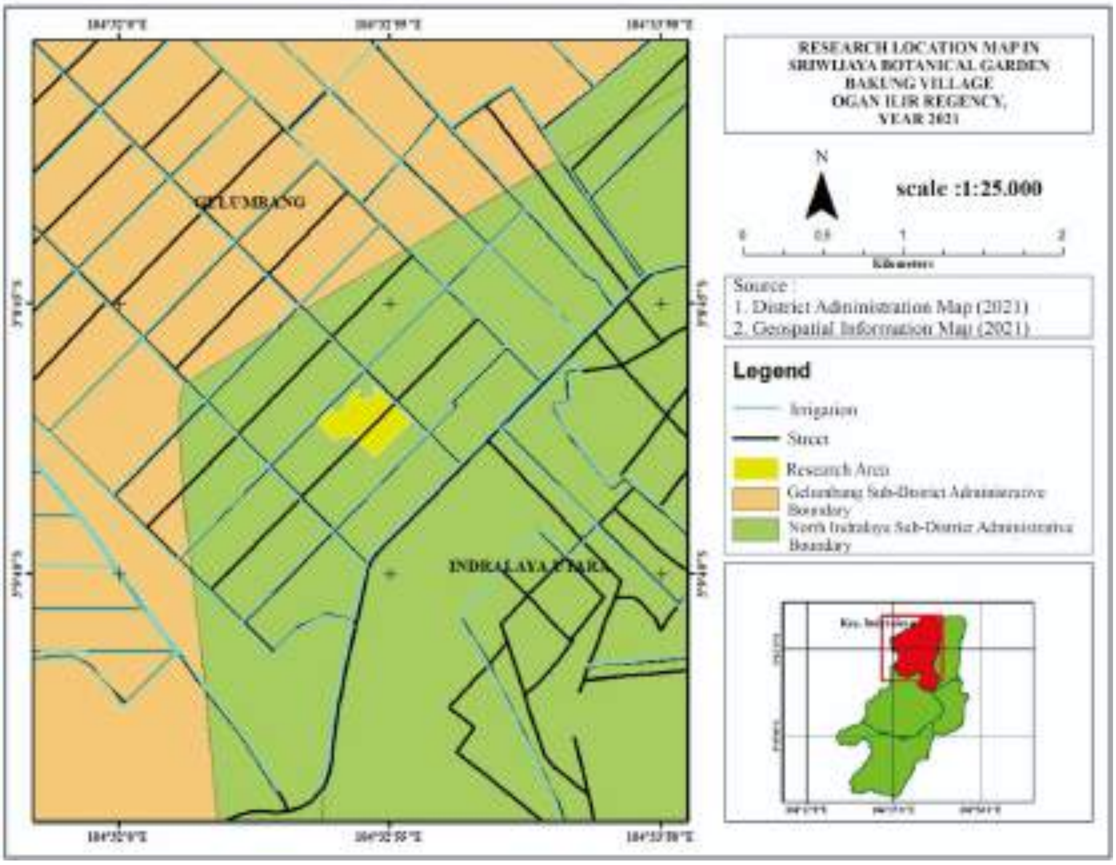

Figure 1. The study location map.

2.2. Equipment and material

Equipment for this study are consisted of laboratory equipment, writing utensils, peat auger, hoe, GPS, camera, rubber bracelet, computer, wrench, mattress, tape measure, Piscal board, transparent plastics, and weel pipe.

A few materials being used were chemical materials, rainfall data from BMKG, observation form, study location map, sample points map, soil samples, and land suitability criteria for corn.

2.3. Method

Land suitability was assessed by matching between land characteristics and specific criteria to cultivate corn. Samples were taken based on map scale of 1: 5.000. Systematic sampling was implemented by using grid and purposive number of samples (13) were taken based on previously defined points for study area of ± 13 ha. Variables being observed for peat soil morphology can be seen in Table 1.

Table 1. Parameters of peat soil morphology characteristics in field.

No	Soil morphology characteristics	Description
01	Rooting media (rc)	Effect of water percolation into soil
	Drainage	Peat layer thickness (cm)
	Peat depth	Fibre content (sapric, hemic, fibric)
	Maturity level	
02	Sulphidic hazard (xs)	Sulphidic depth
03	Toxicity (xc)	Salinity level
04	Flood hazard/water table depth (fh)	Water table depth and period

Source: [14,15]

Soil chemical properties was analyzed in laboratory. Several variables being observed included N-Total, available phosphor, potassium, pH and C-organic. According to FAO (Food and Agriculture Organization) land suitability can be classified into 4 classes: S1 (very suitable), S2 (fairly suitable), S3 (less suitable) and N (unsuitable at the moment). To determine land suitability for corn several peat characteristics (Table 2) will be matched with criteria to cultivate corn (Table 3).

Table 2. Assessment criteria of peatland suitability for food crops and vegetables.

Crop group	Peat characteristics	Land suitability class Suitable (S)	 Conditionally suitable CS	 Unsuitable N
Rice, second crops	Maturity	Sapric, Hemic	Hemic	Fibric
	Thickness (cm)	< 100	100-150	> 150
Vegetable crops	Maturity	Sapric, Hemic	Hemic	Fibric
	Thickness (cm)	< 100	100-200	> 200

Source: [7]

Table 3. Land suitability for corn crop (*Zea mays*).

Terms of use/ land characteristics	Land suitability classes			
	S1	S2	S3	N
Temperature (tc)				
Average temperature (°C)	20 - 26	26 - 30	16 - 20 30 - 32	< 16 > 32
Water availability (wa)				
Yearly rainfall (mm)	900 - 1.200	1.200 - 1.600 500 - 900	> 1.600 300 - 500	 < 300
Relative humidity (%)	> 42	36 - 42	30 - 36	< 30
Oxygen availability (oa)				
Drainage	good, fair	fairly fast, fairly resisted	resisted	very resisted, fast
Rooting media (rc)				
Texture	fine, fairly fine, moderate	fine, fairly fine, moderate	fairly rough	rough
Rough material (%)	< 15	15 - 35	35 - 55	> 55
Soil depth (cm)	> 60	40 - 60	25 - 40	< 25
Peat:				
Thickness (cm)	< 50	50 - 100	100 - 150	>150
Maturity	sapric	sapric, hemic	hemic	fibric
Nutrients retention (nr)				
Soil CEC (cmol)	> 16	5 - 16	< 5	-
Base saturation (%)	> 50	35 - 50	< 35	-
pH H_2O	5.8 – 7.8	5.5 – 5.8 7.8 – 8.2	< 5.5 > 8.2	-
C-organic (%)	> 1.2	0.8 – 1.2	< 0.8	-
Available nutrients (na)				
N total (%)	moderate	low	very low	-
P2O5 (mg/100 g)	high	moderate	low- very low	-
K2O (mg/100 g)	high	moderate	low-very low	-
Sulphidic hazards (xs)				
Sulphidic depth (cm)	> 100	75 - 100	40 - 75	< 40
Erosion hazard (eh)				
Slope (%)	< 3	3 - 8	8 - 15	> 15
Flooding/water table depth hazards at planting season (fh)				
- Height (cm)	-	-	25	> 25
- Period (days)	-	-	< 7	> 7

3. Result and discussion

3.1. General description of study area

Kebun Raya Sriwijaya area is classified as swamp characterized by flooding during wet season and drying during dry season. Kebun Raya Sriwijaya is mostly logged during wet season with water depth up to 40 cm. This is due to overflowing water of Musi River. This condition can be resolved with construction of canal and water gate. Kebun Raya Sriwijaya area had average rainfall of 2,225 mm per year (2017-2020) with average temperature of 27.6 °C annually.

Water regulation at crop areas of peatlands should suppress environmental degradation due to water table drawdown, but it allows plants to grow [16]. Crops generally require good soil drainage indicated by good aeration to ensure oxygen availability at the surrounding crops roots.

Figure 2. Secondary channel.

Figure 3. Tertiary channel.

Primary channels surrounds all areas of Kebun Raya Sriwijaya having width at about 12 meters and depth of 2 meters. The networks were well maintained, each secondary channels within Kebun Raya have been concreted having width of 2 meters while tertiary channels or micro channels having width at 1 meter. To facilitate crop cultivation, channel dimension (primary, secondary and tertiary) should be adjusted considering commodities [17]. For instances, annual plants (food and vegetable crops) require relatively shallow drainage between 20 and 30 cm, whereas perennial plants require deeper soil water level which vary between plants. It is expected that good condition of water network system results in good crop growth and capable to control soil water level depth which subsequently can suppress decomposition rate and control fire occurrence.

3.2. Peat thickness and maturity

Peat maturity is defined as weathering level of organic substances of peat soil. Peat maturity at the study area is dominated by sapric and hemic peats, whereas fibric maturity was found at two sampling points. Peat thickness varied from the shallowest at 150 cm (moderate) up to the deepest of 380 cm (Table 4). The recent depth was unsuitable for cultivating corn, since it was more than maximum depth threshold (>150 cm). Conditionally suitable (CS) for intensive management requires peat depth of 150-200 cm. Meanwhile, according to Djaenudin *et al*. [14], peat thickness of 150-200 cm is classified as marginally suitable while peat thickness >200 cm is classified as permanently unsuitable. Therefore, corn cultivation should be located on land with peat thickness less than 200cm. The yield of corn cultivated at peat land is approximately 4.5 ton/ha [18]. Current corn productivity at Palangka Raya peatland can reach 7.5 ton/ha [19].

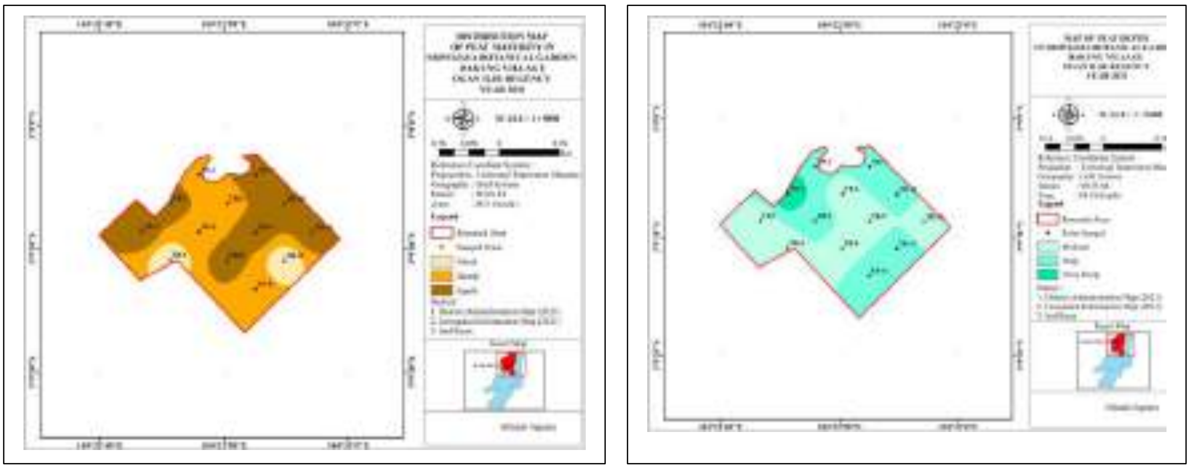

Figure 4. Distribution of peat maturity and depth.

Table 4. Peat maturity level and land suitability on the area study.

Maturity	Sample points	Depth (cm)	Land suitability
Fibric	T-4	180	S3rc
	T-12	380	Nrc
Hemic	T-3	285	Nrc
	T-5	250	Nrc
	T-6	150	S3rc
	T-11	220	Nrc
Sapric	T-1	190	S3rc
	T-2	380	Nrc
	T-7	240	Nrc
	T-8	187	S3rc
	T-9	180	S3rc
	T-10	295	Nrc
	T-13	195	S3rc

3.3. Assessing land characteristic

Peat thickness distribution of the study area is classified into moderate up to deep categories. We classified peat thickness into six categories as follows: (1) very shallow/very thin for thickness < 50 cm, (2) shallow/thin for thickness of 50-100 cm, (3) moderate for thickness of 101-200 cm (4) deep/thick for thickness of 201-400 cm, (5) very deep/very thick for thickness of 401-800 cm and (6) extremely deep/extremely thick for thickness of 801-1,200 cm [20]. Based on the government regulation peat depth more than 300 cm should be conserved and cannot be utilized for agricultural management. Non-rice crops should be cultivated on peat depth of 1-2 m [21].

Peat decomposition produces organic acids which affect soil acidity [22]. Peat found on surface is relatively more mature due to faster decomposition rate. However, mature peat is sometimes found on deeper layer. In this case, peat layers was formed sequentially, in which peat of deep layer was from continuous submersion from the surface [23]. Nutrients availability at more mature peatland is relatively higher than that of immature peat land. .

3.4. Chemical soil characteristics

The pH of peatland of the research site was considered very acid. The lowest and the highest pH were 3.0 and 3.5 respectively. Low pH is closely related to organic matter [24]. Decomposed organic matter has reactive groups of carboxyl and phenol signifying weak acid which acidify peat soil. Peat acidity tends to be higher by peat depths [25].

Nitrogen content of the study area varied over sample points from moderate to very high. The high N-total content does not guarantee sufficient availability for crops due to blockage of mineralization and humification. N availability of peat soil is also affected by C/N, in which N immobilization by soil microbia will proceed to meet C/N greater than 30. N immobilization or N release into peat soil may occur at C/N between 20 and 30. When C/N is higher than 30, N-total of peat is high but available N for crops could be insufficient due to N-organic form and N immobilization by soil microbial [26]. Peat reclamation may cause high C/N providing N nutrient as source of energy for microorganisms to decompose organic materials. The result will decrease N nutrient availability for crops [27] which is required by crop for development during vegetative stages [28].

Available P at the study area is categorized as moderate. According to Cheesman *et al.* [29], phosphor is important to accelerate seedling, strengthen the growth of young crop, accelerate flowering and seed ripening, and has a role in lipid and protein composing. Problems related to P in peat soil is low storability [30] and low availability [31]. The strategy to increase P availability may be by adding P-absorbing compound such as natural phosphate and time setting of P amelioration and fertilization [32].

The availability of K (potassium) on peat soil varies depending on peat decomposition level. Kalium content of the study area was considered low. Reclaiming sapric peat, implies to a decrease in availability of K content by 50% at flooded condition, whereas natural peat (fibric) contains 34 % of K content [33]. It may be due to higher ash content of sapric peat than that of fibric peat.

Cation Exchange Capacity (CEC) of peat at the research site was considered as high to very high. The CEC of peat is dominated by H^+ which is also a source of acidity. High CEC of peat soil does not represent high availability of alkali elements [15]. The study results by Riyandani [22] at peat land of Saponjen Village, Kumpeh Subdistrict showed very high CEC (56.64-98.08 cmol+kg-1). This is similar to the study results by Suarjana *et al*. [34] in Rundeng Subdistrict, Subulussalam City which observed CEC of about 60.48 cmol/kg and the highest CEC of 88.72 cmol/kg. High CEC is commonly due to very acid soil of peat land [35]. The CEC of peat soils ranges from <50 to more than 100 cmol(+)/kg. The pH-dependent negative charge composed of carboxyl and hydroxyl groups of phenol. A high CEC in peatland does not indicate sufficiently high cations since peatland is dominated by hydrogen ions (H+) [36].

3.5. Soil physical characteristics

Physical properties including aeration, drainage, load bearing capacity and level or potential of peat land degradation are important factors to determine crop productivity. Essential peat physical properties determining utilization of peat land for agriculture are peat maturity, water content, bulk density, load bearing capacity, soil surface subsidence and irreversible drying [37]. In addition, Dariah *et al.* [38] stated that increasing organic matter decomposition results in decreasing soil pore size, which in turn affects water flow and soil nutrients losses. For instance, nitrogen element is more immobile at degraded peat land than that of undegraded one.

Peat land has much higher capacity to absorb and store water than mineral soil. Water content in the study area was 87-89%. The low water content was due to drainage system construction. Organic matter predominating composition of peat enable high water absorption. Peat soil can absorb water up to 300-3,000% of its dry weight which is much higher than mineral soil at 20-35% of its dry weight [39]. Meanwhile, peat maturity determines peat water content in its natural condition (flooded). Fibric organic matter (very immature peat) is porous allowing water to fill inter spaces. However, since most water is within macro pores, it is quickly losses by draining. More mature peat stores water in micro and meso pores resulting much higher water retention. Gravitational force is not sufficient to drain water stored within micro or meso pores [38].

Bulk density is soil physical property indicating the weight of solid mass per unit volume. Bulk density of the study area was between 0.11 and 0.12 g/cm^3. Low bulk density soil generally has high porosity that potentially allows water to be absorbed or drained easily. Very low bulk density implicates to low bearing capacity. Very low bulk density for peat soil with magnitude of <0.1 g cm^{-3} was found at fibric peat (immature) which was located at lower layer, whereas coastal peat and peat located at river flow path had relatively high bulk density with magnitude of >0.2 g cm-^{3} [40] due to mineral effect, but it was much lower than bulk density of mineral soil (0.7 to 1.4 g/cm^{-3}). Selmitri *et al*. [41] studied the effect of peat maturity on peat bulk density and showed that more mature peat produced higher bulk density. Bulk density of peat describes dry weight of peat solids per unit volume. The higher the bulk density, the more mature the peat soil [3]. Fibric, hemic and sapric peats have bulk density of <0.10 g cm-^{3}, 0.10-0.20 g cm^{-3} and >0.20 g cm^{-3}, respectively.

High water retention of peat is closely related to soil porosity. Peat porosity is in the range of 83.62 to 95.13% [42]. The higher soil porosity, the higher water retention of peat could be. Total pore space in the study area was between 95% and 96%. Peat porosity is determined by its decomposition level [43]. Fibric peat has higher porosity than hemic and sapric peats. Heating on peat causes decreasing porosity [6].

3.6. Land suitability assessment and improvement effort

There are three main objectives of land suitability assessment consisting of crop, management and conservation purposes. These objectives are reflected in land characteristics and land quality criteria.

There are two criteria of improvement effort consideration consisting of S3rc and Nrc,nr in which their distribution can be seen in Figure 5. Actual land suitability class of S3rcn (less suitable) with limiting factors of nutrients retention, high management level and root can be upgraded into S3rc (less suitable) through nutrients enrichment. The improvement can overcome acidity and base saturation by adding dolomite and biochar.

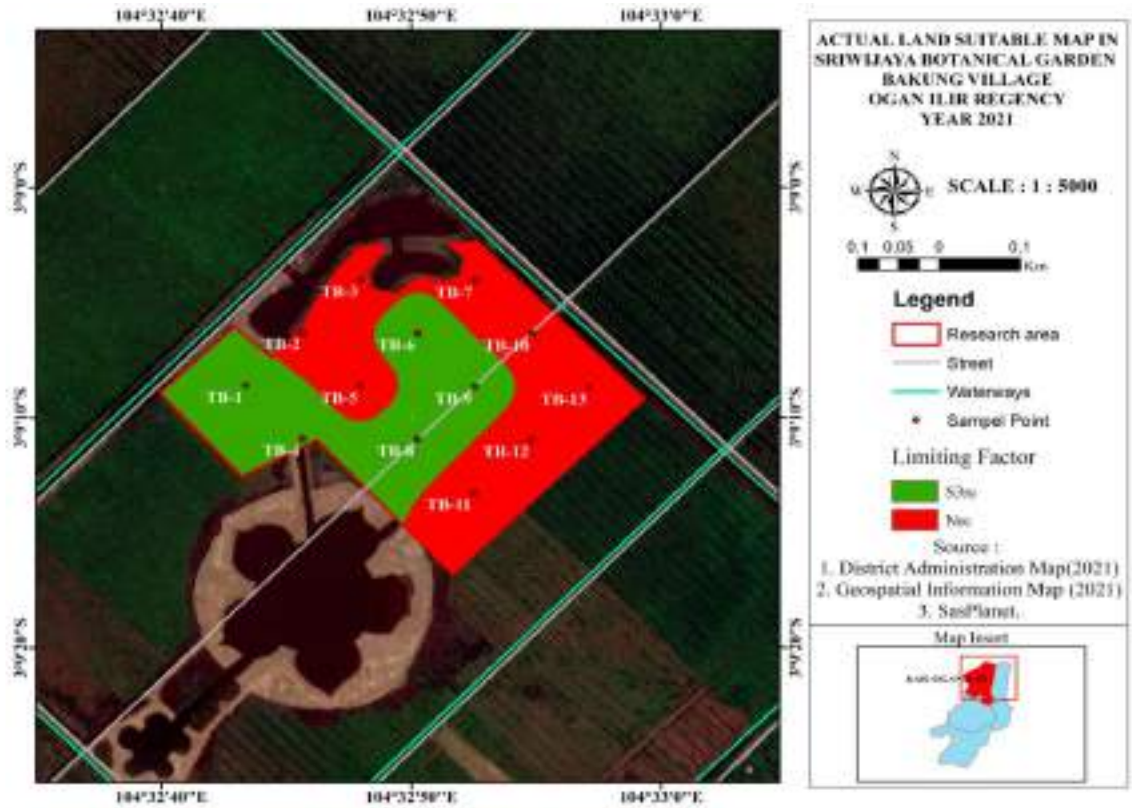

Figure 5. Land suitability for corn.

On the other hand, land at suitability class of Nrc limited by peat depth cannot be improved by nutrients enrichment. This area is better be conserved or reforested with local forest plants. Farmers traditionally enrich soil nutrients by burning technique at initial period of tillage. This activity is cheaper and efficient to amend nutrients from ash of burning residue [44]. However, if it is left unchecked, it may ignite extensive fires in peat land.

Land assessment should be taken carefully preceding plant cultivation. Water drainage was not managed effectively at the research site. An excessive drainage can result in peat soil subsidence, release CO_2 and methane emission since peat soil stores huge carbon stocks. If peat subsidence continuously takes place, it will contribute to global warming. In addition, excessive soil water drawdown at peat soil induce dry condition of surface and lead to fire occurrence [17]. Therefore, conservation is needed to maintain environmental sustainability and take care of nature. Replanting should be done at burned peat land to recover the wetland ecosystem. Corn (or any other food crop) may provide environmental conditions that are safe from fire hazards. The study by Egene *et al.* [45] showed that maintaining water level below 30cm from embankment could create ideal water level for corn growth at about 40 cm. Meanwhile, water drawdown could be tolerated up to 60 cm. The study of Wang *et al.* [46] showed that optimal yield of oil palm can be obtained at 40 to 60 cm of water depth. This condition is suitable to maintain surface moisture for preventing land fire. In line with the study of Poole *et al.* [47], soil water tends to be at a constant level when rainfall is above 100 mm/month at more than 40 cm. On the other hand, during dry season where evaporation is higher than rainfall, the water level drops below 70 cm and the surface soil is dry. Therefore, to conserve the peatland soil, the water level of the channel should be maintained less than 40 cm from April annually. The effort would likely prevent water drawdown at 30 - 40 cm.

As fertilization is required, the fertilizers should contain N, P, K, Ca and Mg as well as micro elements. Although CEC value of peat is high, the holding capacity to exchangeable cations is low so that fertilization should be applied several times at low dose to prevent nutrients washed away. The use of slow-release fertilizers is better than NPK fertilizers to increase soil pH.

Amelioration in forms of organic fertilizer, mineral soil, zeolite, dolomite, natural phosphate, manure, agricultural lime, husk ash and purun tikus (*Eleocharis dulcis*) can increase soil pH and soil alkaline. Ameliorant containing more polyvalent cations can also reduce the negative effect of toxic organic acids. Meanwhile, biochar application at 2-5% of soil weight can increase soil pH and significantly immobilize Cd and Zn elements over a 3-year period [48]. The addition of 5% biochar is effective for remediation of salts content within soil. Moreover, the use of biochar can increase water use efficiency as well as nutrients uptake of P and N by crop roots. Applying 20 tons ameliorant (80% chicken manure + 20% dolomite) per hectare gave the highest dry weight and NPK nutrients uptake. Adding rice husk biochar at 10 ton/ha and NPK fertilizer at 200 kg/ha may produce better uptake of N,P, K nutrients and better yield of corn on peat media [49].

Post improvement and nutrient enrichment, the water level should be controlled to minimize nutrients loss rate, particularly nitrogen. The study showed drainage control may increase 10-15 % corn yield [50]. Another study in Netherland showed that controlling water level in peat land by implementing subsurface drainage system was effective to supply water during dry season.

4. Conclusion

The main limiting factors of peatland of research site for corn were nutrients retention, peat depth and peat maturity. To improve soil properties, nutrients enrichment and refining water network system are required. The effort may increase the suitability class into S3 (less suitable). Land clearing is not recommended for peat depth more than 2 m. It is better to grow local plants in this area or with adaptive forests on wetlands.

Intercropping food crop with industrial forest plants such as sengon (*Falcataria moluccana*) is potential to increase farmer income. It will keep soil water depth suitable for food crops and prevent it from the critical fire prone limit. Canal blocking technology is an effective strategy in keeping the water level of the canal.

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