Assessing characteristics and land suitability of an intercropping between soybeans and juvenile oil palm over peatlands in Riau, Indonesia

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Abstract. Soybean is one of essential food crops targeted for self-sufficiency. Indonesia’s largest oil palm plantation is located in Riau Province. Juvenile plants cover around 17.60 percent of the area. Soybeans can be intercropped with juvenile oil palm plantations. This study aims to determine the suitability of peatland in Muara Kelantan Village, Sungai Mandau District, Siak Regency. We collected data and information from primary observations, measurements, and from published articles recording secondary data including rainfall, annual temperature, and map of the research area. Soil type was classified as Typic Haplosaprist. Land suitability was determined by matching collected data with criteria for each class, resulting the class of marginal (S3), with base saturation and soil acidity (nr) as limiting factors. Lime and fertilization were required to increase base saturation and soil pH. After the improvement, the potential suitability becomes sufficiently suitable (S2) for intercropping between soybean and juvenile oil palm, with the air humidity (tc) and peat thickness (rc) as limiting factors.

1. Introduction
The government has achieved food self-sufficiency since 2014 through special program (Upaya khusus (UPSUS)) for rice, corn and soybean. Riau, as one of the food centers, took part in this success. Soybean is considered as main food crop, apart from rice and maize. Soybeans are used by food and feed industries. Riau’s soybean production in 2015 amounted to 2,145 tons of dry beans or decreased by 187 tons (down 8.02 percent) compared to the previous year [1]. This declining production was due to a decrease in the harvested area by 514 hectares or 25.32 percent. The government policies, including the intensification, extensification, mechanization, rehabilitation and diversification efforts are needed to increase national soybean production.

Food crops can be cultivated in rice fields or uplands. Food crop cultivation is strongly influenced by climatic factors, humidity, soil surface shape, and soil type. The yield of a cultivation depends on the management of those factors and implemented technologies.

Juvenile plantation may be intercropped with food crops, to increase land productivity. Soybean is suitable for intercropping in any plantation by utilizing spaces between juvenile plants. Riau Province has potential land for soybean development, including peatlands. This province has the largest oil palm plantation in Indonesia (39.57%) covering 1,348,076 ha in 2013. As much as 17.10% of the area is juvenile plants [2]. About 20% of the juvenile oil palm plantations was cultivated on peatland. Optimizing spaces between juvenile palm trees by any cash crops will increase on-farm income while reducing the cost for cover crops. Moreover, it may control weeds from growing.

Peatlands have distinctive characteristics from the accumulation of dead plants. The characteristics include high levels of organic matter and moisture content, small bulk density and low bearing
capacity. Peatlands can experience subsidence (surface subsidence) due to the shrinkage of the peat volume caused by the decomposition and drainage process: high soil acidity and uptake capacity, low exchange rates, and very low micro-elements. Activities to increase soybean production to support food security can be conducted by improving the condition of peatlands by amelioration, balanced and integrated fertilization, use of superior varieties and improving water management. Various amelioration and fertilization technologies are available, but the adaptation to local land conditions is needed, giving the variation in potential land suitability.

In applying peatland technologies, one must consider the characteristics of peatlands for agricultural cultivation. This study aims to identify the characteristics of peatlands in Muara Kelantan as an initial step to increase the productivity of peatlands for soybean development while optimizing available spaces on juvenile oil palm plantations for intercropping.

2. Methodology

2.1. Test site
The research was conducted in 2017 on smallholder oil palm plantations planted for two years, representing 16 hectares area in Sungai Mandau Village, Muara Kelantan District, Siak Regency, Riau, Indonesia. Data and methods were collected from observation, measurement, as well as information from various studies. Secondary data was collected from literatures, comprising of rainfall, annual temperature and a map of the research location (Figure 1).

The study area has a flat topography with a 0-2% slope and an altitude of 0-2 m above sea level. Geographically, the research location is at coordinates 0° 50’ 54”- 0° 51’ 02” north latitude and 101° 40’ 12” - 0° 40’ 38” east longitude. The climate is tropical, with temperatures between 25° to 32 °C, high humidity, and rainfall. Based on the analysis of rainfall data obtained from BMKG Riau Province in the last five years, it is known that the wet months last from September to January, while the dry months last for three months, lasts from June to August. Based on the analysis of rainfall data in Sungai Mandau District, the results of annual rainfall intensity ranged from 2,148-2,741 mm / year or an annual average of 2,472.08 mm/year with a monthly average of 206 mm [3]. According to Oldeman and Frere [4], the research area belongs to the Agro-climate zone A, in which the rainfall is greater than 200 mm/year.

Figure 1. Sungai Mandau village map.
2.2. Datasets
Soil characteristics was observed and measured both from the field and the laboratory. A set of tools were used in soil surveys for analyzing soil samples in the laboratory, including a peat drill, Munsell Soil Color Chart, GPS, camera, peroxide solvent chemical (FeS$_2$). The land characteristics observed in the field included soil color, sulfidic depth, water table depth, peat maturity, peat thickness, soil pH, flood hazard, texture and structure of the mineral layers, and vegetation.

Soil samples were taken by using a peat drill for five points of diagonal arrangement to represent the location. Measurement of peat soil depth at each location was through drilling by using a peat drill from the top to the bottom layer of mineral soil. At each sample point, a soil sample was taken at a depth of 0-50 cm. The maturity level of peat was determined by the squeeze method, by looking at the yield of liquid and the remaining squeezed material on hand. The higher level of weathering of the peat, the more material escaping on the squeeze due to relatively finer structure. Raw peat is commonly dominated by coarse fiber. If less than a third of the peat is left on hand, then the peat is classified as sapric. Whereas, if more than two-thirds of the peat is left, it is classified as fibric. Peat is classified as hemic if around half of it is left. Meanwhile, the thickness of the peat was determined by measuring the depth from the top layer to the mineral soil.

Soil color was observed in the field by using the Munsell Soil Color Chart, expressed in 3 units, namely Hue, Value and Chroma. Soil drainage is related to the rate of infiltration and shows the depth and frequency of soil water saturation or stagnation. The groundwater depth is determined through drilling from the ground to the groundwater level. The mineral soil beneath the peat affects the fertility of the peatland.

The research also observed mineral content of soil such as sulfidic material, i.e. pyrite. Pyrite (FeS$_2$) was identified as mineral layer coming from marine deposits that are greenish-grey or dark grey.

Peatland samples at a 0-40 cm depth were put in a plastic bag and labeled. Soil samples were air-dried for a week and sieved at a 0.5 mm to obtain homogeneous yet clean samples and then proceed for chemical content analysis. Soil chemical analysis was carried out in the Soil Science Laboratory, Faculty of Agriculture, Riau University. The parameters of analyses included soil pH, % C-organic, % N total, potential P and K, CEC, and Base saturation.

2.3. Analysis
All data from survey, secondary sources and the result of laboratory analysis were then matched with criteria (Table 1) for soybeans to produce land suitability of the study area.

According to Ritung et al. as well as Hardjowigeno and Widiatmaka [5,6], the actual class of land suitability fall on the worst land characteristics. The actual land suitability has not considered any input to improve quality. The potential suitability classes are improved classes after applying appropriate technologies, amendment, or any inputs to the soil. Meanwhile, soil classification is determined based on the physical conditions of the area, morphology and the process of soil formation. The classification system used is the Soil Taxonomy system [7] to the subgroup level.
### Table 1. Land suitability criteria for soybean crops.

| Land characteristics | S1 | S2 | S3 | N |
|----------------------|----|----|----|----|
| **Temperature (tc)** |    |    |    |    |
| Average temperature (°C) | 23-25 | 20-23 | 18-20 | < 18 |
|                      | 25-28 | 28-32 | > 32 |
| **Water availability (wa)** |    |    |    |    |
| Rainfall at growth period (mm/3 months) | 350-1.100 | 250-350 | 180-250 | < 180 |
|                      | 1,100-1,600 | 1,600-1,900 | > 1,900 |
| **Humidity (%)** |    |    |    |    |
|                      | 24-80 | 20-24 | < 20 | - |
|                      | 80-85 | > 85 | - |
| **Oxygen availability (oa)** |    |    |    |    |
| Drainage | Well-drained, medium | Moderately poorly drained | Poorly drained, moderately excessive drained | Very poorly drained, excessively drained |
| **Root condition (rc)** |    |    |    |    |
| Texture | Fine – moderately fine | Fine – moderately fine | Moderately coarse | Coarse |
| Coarse material (%) | < 15 | 15-35 | 35-55 | > 55 |
| Soil depth (cm) | > 50 | 30-50 | 20-30 | < 20 |
| Peat: Depth (cm) | < 50 | 50-100 | 100-150 | > 150 |
| Maturity | Sapric | sapric, hemic | Hemic | Fibric |
| Nutrient retention (nr) |    |    |    |    |
| Soil CEC (emol) | > 16 | 5-16 | < 5 | - |
| Base saturation (%) | > 35 | 20-35 | < 20 | - |
| pH H2O | 5.5-7.5 | 5.0-5.5 | < 5.0 | - |
|                      | 7.5-7.8 | > 7.8 | - |
| C-organic (%) | > 1.2 | 0.8-1.2 | < 0.8 | - |
| Nutrient availability (na) |    |    |    |    |
| N total (%) | Medium | Low | Very low | - |
| P2O5 (mg/100 g) | High | Medium | Low – very low | - |
| K2O (mg/100 g) | High | Medium | Low – very low | - |
| Toxicity (xc) |    |    |    |    |
| Salinity (DS/m) | < 4 | 4-6 | 6-8 | > 8 |
| Sodicity (xm) |    |    |    |    |
| Alkalinity/ESP (%) | < 15 | 15-20 | 20-25 | > 25 |
| Sulphidic hazards (xs) |    |    |    |    |
| Sulphidic depth (cm) | > 100 | 75-100 | 40-75 | < 40 |
| Erosion hazard (eh) |    |    |    |    |
| Slope (%) | < 3 | 3-8 | 8-15 | > 15 |
| Erosion hazard | Very light | Light - medium | Heavy – very heavy | - |
| Flood hazard (fh) |    |    |    |    |
| - Height (cm) | - | - | 25 | > 25 |
| - Length (days) | - | - | < 7 | > 7 |
| Land preparation (lp) |    |    |    |    |
| Rock on the surface (%) | < 5 | 5-15 | 15-40 | > 40 |
| Rock outcrop (%) | < 5 | 5-15 | 15-25 | > 25 |

Source: [1]

3. Results and discussion

Peatlands of the research site have organic horizon ranging from 60 - 90 cm with a hemic-sapric maturity level and a clay substrate. The field observation indicated the area is in non-flooded conditions with groundwater level ranging from 20-35 cm, well-drained and somewhat obstructed. The area is considered as shallow peat and is suitable for the development of food and seasonal crops. According to Suriadi Karta, Masganti et al., and Noor et al. [8–10], peat thickness affect the level of fertility. The thicker the peat, the more fertility decreases, hindering plants to reach the mineral layers.
below. Thus, peat thickness has a significant effect to land productivity. The peat thickness is primary factors for selecting land management for agricultural development. Characteristics of peatlands samples from the field are presented in Table 2.

| Horizon | Depth | Maturity level | Soil colour | The depth of groundwater | Soil pH | The depth of sulphidic |
|---------|-------|----------------|-------------|--------------------------|--------|------------------------|
| Oe      | 0-25  | Hemic          | 5R 2.5/1    | Reddish black            | 23 cm  | -                      |
| Oa      | 25-80 | Sapric         | 5R 2.5/1    | Reddish black            | 3.74   | -                      |
| Ap      | 80-100| Clay           | 5 YR 4/3    | Reddish brown            | 3.58   | -                      |
| Oe      | 0-16  | Hemic          | 7.5 R       | Very dark red            | 20 cm  | -                      |
| Oa1     | 16-35 | Sapric         | 2.5/2       | Reddish black            | 3.81   | -                      |
| Oa2     | 35-90 | Sapric         | 5R 2.5/1    | Very dark red            | 4.22   | -                      |
| Ap      | 90-100| Clay           | 10R 2.5/2   | Brownish grey            | 4.29   | -                      |
| Oe      | 0-14  | Hemic          | 5R 3/2      | Dark red                 | 20 cm  | -                      |
| Oa      | 14-60 | Sapric         | 5R 2.5/1    | Reddish black            | 3.91   | -                      |
| Ap      | 60-100| Clay           | 2.5Y 6/2    | Brownish grey            | 4.19   | -                      |
| Oa      | 0-82  | Sapric         | 5 R 3/1     | Dark red grey            | 30 cm  | -                      |
| Ap      | 82-100| Clay           | 7.5YR       | Dark brown               | 4.39   | -                      |
| Ap      | 0-64  | Sapric         | 5 R 2.5/1   | Reddish black            | 35 cm  | -                      |
| Ap      | 64-100| Clay           | 2.5Y 5/2    | Grey brown               | 4.38   | -                      |

It can be seen from the table that maturity level of the organic horizon is at hemic-sapric. Sapric is peat with an advanced level of weathering (ripe). Hemic is peat with a moderate level of weathering (half-ripe), some of the material has been weathered and partly in the form of fibers. Mature peat tends to be more refined and fertile. Conversely, the immature ones contain lots of fibers and less fertile. The maturity of peat determines peatland productivity and substantially affects the level of peatland fertility and nutrient availability. The maturity level of peat varies depending on materials, environmental conditions, and time [11]. Raw peat that has not been decomposed contains higher levels of organic acids, while mature peat generally contains more ash as a source of chats [12].

Peat on the surface (top layer) is relatively more mature due to faster decomposition rate. However, ripe peat is often found in deeper layers. This indicates that peat is formed several stages [13].

Based on observations from drilling data, the research area is in a non-flooded condition with a shallow groundwater level (15-35 cm). The indicator of the peatland depth is groundwater depth because it may inhibit rooting media.

Soil drainage is related to the rate at which water enters the soil (infiltration) and shows the length and frequency of soil water saturation or stagnation. The state of soil drainage will determine the types of plants to grow in that land. Soybean require good drainage, good soil aeration to provide sufficient oxygen in the soil. Thus, plant roots can develop properly and absorb nutrients optimally. Soybean does not suit waterlogged areas since it will affect the growth of plant roots.
The mineral soil beneath the peat soil affects the fertility level of peatland. The mineral soil of the research location does not have sulfidic material, pyrite (FeS2).

Details of soil classification are presented in Table 3.

| Classification | Profile | Profile | Profile | Profile |
|----------------|---------|---------|---------|---------|
| Ordo           | Histosol| Histosol| Histosol| Histosol|
| Sub Ordo       | Saprist | Saprist | Saprist | Saprist |
| Great Grup     | Haplosaprist | Haplosaprist | Haplosaprist | Haplosaprist |
| Sub Grup       | Typic   | Typic   | Typic   | Typic   |

Samples 1-5 are included in the Histosols order. This is indicated by the presence of a histic epipedon with a thickness of > 40 cm. This soil has undergone an advanced decomposition (sapric) indicated by remaining material at about 1/3 after squeezing and has sapric organic matter, so it is included in the Saprists suborder. The absence of other features made the class fell into Haplosaprists, likewise at the level of the soil subgroup classified into the Typic Haplosaprists.

The analysis of peat soil at a depth of 0-40 cm is presented in Table 4. The soil acidity (pH) at the study site was 3.97, considered as very acid. Soil pH determines the ability of plants to absorb nutrients. High acidity is not suitable for soybean growth since ideally, soybean requires a pH range of 5.5 – 7.5 to grow optimally. High acidity of peat soil is caused by the hydrolysis of organic acids, which is dominated by fulvic and humic acids [8,10,14]. The decomposed organic material has reactive groups, including carboxylic (-COOH) and phenolics (C6H4OH) which dominate the exchange complex and act as weak acids to dissociate and produce large amounts of H ions.

| No  | Parameter | Observed values | Units | Methods | Classes |
|-----|-----------|-----------------|-------|---------|---------|
| 1   | pH H2O    | 3.97            | -     | Electrode | Very Acid |
| 2   | pH KCl    | 3.69            | -     | Electrode | Very High |
| 3   | C-Organic | 26.19           | (%)   | Walkey n Black | Very High |
| 4   | N-Total   | 0.39            | (%)   | Kjedhal | Medium |
| 5   | C/N       | 67.15           | -     | -       | Very High |
| 6   | P-Total   | 52.88           | (mg/100g) | HCl 25% | High |
| 7   | K Total   | 35.09           | (mg/100g) | HCl 25% | Medium |
| 8   | CEC       | 30.27           | cmol/kg | NH4OAc pH 7 | High |
| 9   | Ca        | 2,800           | cmol/kg | NH4OAc pH 7 | Low |
| 10  | K         | 0.2657          | cmol/kg | NH4OAc pH 7 | Low |
| 11  | Mg        | 0.5933          | cmol/kg | NH4OAc pH 7 | Low |
| 12  | Na        | 0.2957          | cmol/kg | NH4OAc pH 7 | Low |
| 13  | H_exch    | 4.95            | me/100g | KCl 1 N | Very Low |
| 14  | A_exch    | 0.44            | me/100g | KCl 1 N |     |
High soil acidity affects the availability of nutrients such as P, K, Ca, and microelements [15,16]. In general, nutrients are easily absorbed by plant roots at a neutral pH since most of the nutrients are easily dissolved in water at that condition. The C-organic content was very high (26.19%) indicating the imperfect level of peat maturity, and characterized by low soil nitrogen, at about 0.39%. The total P and K contents were high-medium, the cation exchange capacity (CEC) on peat soils was high, around 30.27 me / 100g measured on the absolute dry weight. Even though the peatlands had a high cation exchange capacity (CEC), base saturation (KB) was very low, at 13.06%. The high CEC was due to negative charge from carboxylate and phenolic groups. The high CEC causes soil response to acid-base reactions to reach equilibrium requiring more reactants (ameliorants).

Very low base saturation results in low nutrient availability, especially K, Ca, and Mg. The availability of Ca, K, Na, and Mg in peatland is generally low; according to Hakim et al., Andriesse, Marwanto et al. [15,17,18], most of the total N, P, K in peat is in organic form.

Indonesia’s peatlands are formed on nutrient-poor soils and/or get nutrients from rainwater (ombrogen). According to Noor et al. and Suryanto [10,19], a good base saturation to allow absorption is around 30%. In addition, the available phosphorus and potassium are low, so fertilization are needed to provide good crop yields.

It can be seen from Table 5 that the actual land suitability for soybean is marginally suitable (S3) with the limiting factor of base saturation and soil acidity (nr). Adding lime and fertilization may improve the suitability into sufficiently suitable (S2), with limiting factors of air humidity (tc) and peat thickness (rc).

4. Conclusion
The actual suitability of the study area for soybean cultivation is marginally suitable (S3) with the limiting factor of base saturation and soil acidity (nr). It requires the addition of lime and fertilization for increasing base saturation and soil pH to improve the suitability. Following the application of lime or fertilization, the potential suitability becomes sufficiently suitable (S2) for soybean with limiting factors air humidity (tc) and peat thickness (rc).

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Table 5. Land suitability for soybean.

| Land use requirements/characteristics                      | Score                                      | Input | Actual suitability | Input | Potential suitability |
|-----------------------------------------------------------|--------------------------------------------|-------|--------------------|-------|------------------------|
| Temperature (tc)                                           |                                            |       |                    |       |                        |
| Average temperature (°C)                                  |                                            | 25-32 | S1                 | -     | S1                     |
| Water availability (wa)                                   |                                            |       |                    |       |                        |
| Rainfall at growth period (mm/3 months)                   |                                            | 618   | S1                 | -     | S1                     |
| Humidity (%)                                              |                                            | 85    | S2                 | -     | S2                     |
| Oxygen availability (oa)                                  |                                            |       |                    |       |                        |
| Drainage                                                  |                                            | Moderately poorly drained                 | S2    | Drainage channel construction (+) |
| Root condition (rc)                                        |                                            | nd    | -                  |       |                        |
| Texture                                                   |                                            |       |                    |       |                        |
| Coarse material (%)                                       |                                            | nd    | -                  |       |                        |
| Soil depth (cm)                                           |                                            |       |                    |       |                        |
| Peat:                                                     |                                            |       |                    |       |                        |
| Depth (cm)                                                |                                            | 60-90 | S2                 | -     | S2                     |
| Maturity                                                  |                                            | Sapric| S1                 | -     | S1                     |
| Nutrient retention (nr)                                   |                                            | 30.27 | S1                 | -     | S1                     |
| Soil CEC (cmol)                                           |                                            |       |                    |       |                        |
| Alkaline saturation (%)                                   |                                            | 13.06 | S3                 | Liming and fertilizing (+++) | S1 |
| pH H₂O                                                    |                                            | 3.97  | S3                 | Liming (++)   | S1 |
| C-organic (%)                                             |                                            | 26.19 | S1                 | -     | S1                     |
| Nutrient availability (na)                                |                                            |       |                    |       |                        |
| N total (%)                                               |                                            | Medium| S1                 | -     | S1                     |
| P₂O₅ (mg/100 g)                                           |                                            | High  | S1                 | -     | S1                     |
| K₂O (mg/100 g)                                            |                                            | Medium| S2                 | Fertilizing | S1 |
| Toxicity (xc)                                             |                                            |       |                    |       |                        |
| Salinity (dS/m)                                           |                                            | Td    | -                  |       |                        |
| Sodicity (xn)                                             |                                            | nd    | -                  |       |                        |
| Alkalinity/ESP (%)                                        |                                            |       |                    |       |                        |
| Sulphidic hazard (xs)                                     |                                            |       |                    |       |                        |
| Sulphidic depth (cm)                                      |                                            | >100  | S1                 | -     | S1                     |
| Erosion hazard (eh)                                       |                                            |       |                    |       |                        |
| Slope (%)                                                 |                                            | < 3   | S1                 | -     | S1                     |
| Erosion hazard                                            |                                            | Sr    | S1                 | -     | S1                     |
| Flood hazard (fh)                                         |                                            |       |                    |       |                        |
| - Height (cm)                                             |                                            | -     | S1                 | -     | S1                     |
| - Length (days)                                           |                                            | -     | S1                 | -     | S1                     |
| Land preparation (lp)                                     |                                            |       |                    |       |                        |
| Rock on the surface (%)                                   |                                            | < 5   | S1                 | -     | S1                     |
| Rock outcrop (%)                                          |                                            | < 5   | S1                 | -     | S1                     |
| Note:                                                     |                                            |       |                    |       |                        |
| (+): moderate level of management                          |                                            |       |                    |       |                        |
| (++): High level of management                            |                                            |       |                    |       |                        |
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