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Soil Quality Index Analysis of Forest Secondary and Palm Oil Plantation

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Abstract: *Soil quality greatly determines the ability of the soil in carrying out its functions to support the life of organisms in a sustainable manner. Land use and land management have the role of increasing or decreasing the quality of a land. This research was conducted to determine the index of soil quality in secondary forest land use and oil palm plantations and evaluating the application of the concept of sustainable agriculture to oil palm plantations. This research was carried out from July to October 2019 in Bukit Biru and Loa Ipuh Darat village, Tenggarong and in the Mulawarman University Faculty of Agriculture. This study uses the concept of Minimum Data Set (MDS) with the assessment of several indicators and soil functions. The assessment function is adjusted to the environmental conditions in which the research is conducted. This study shows that secondary forest use has a soil quality index value of 0.638 with Good criteria, and oil palm plantation land use has a soil quality index of 0.592 with Moderate criteria. Oil palm plantations in this study have not yet reached the concept of sustainable agriculture.*
Keywords: *oil palm plantation; secondary forest; soil quality index (SQI); sustainable agriculture*

I. Introduction

Soil is a natural resource that is very important for the survival of most of the living things on earth. Humans use land as a place to live and as a place to make ends meet. Soil quality really determines its potential for various types of use, so the policy in the use and utilization of land must be carried out properly and in accordance with the proper rules so that the land is still able to provide what is expected to meet the needs of human life itself for a long time.

Soil quality is one of three components of environmental quality besides water and air quality (De Laurentiis et al., 2019; Shekofteh & Masoudi, 2019). According to Bünemann et al., 2018; Valani et al., (2020) Water and air quality is determined primarily by the level of pollution that has a direct impact on consumption and health of humans and animals, or on natural ecosystems. In contrast, soil quality according to (Yu et al., (2018) is not limited to the level of soil pollution, but is generally defined more broadly as the capacity of land to function in ecosystems and land use limits to maintain biological productivity, maintain environmental quality, and promote plant and animal health.

Soil like other natural resources is a non-renewable resource, besides that soil is also a very limited amount of resources. This is inversely proportional to the need for land use which from time to time is increasing. Population growth that is followed by development growth to achieve a degree of human well-being often causes problems in land use. These problems in addition to causing damage to the natural ecosystem structure also often have a direct impact on the quality of the soil itself. The tendency to increase the productivity value of a soil (land) often causes neglect of the aspect of soil conservation, so that the use value of a soil in meeting human needs decreases over time.

The limited availability of land amid the conditions of rapid population growth each year causes the extensification and intensification of agricultural land to continue to be pursued to meet basic human needs. The concept of extensification causes deforestation to expand the availability of agricultural land. However, inseparable from it is also intensification of land use which causes soil quality to decline. This is because agriculture with intensification of land use practices farming patterns with inputs that tend to be unsustainable.

Soil damage can occur by the loss of nutrients and organic matter, the accumulation of salts and toxic compounds in the rooting area, the filling of the soil by water, and erosion. Li et al., (2019) revealed that humans play a role in reducing the quality of land covering nearly 40% of the world's agricultural land through soil erosion, atmospheric pollution, intensive tillage, over grazing, land clearing, salination, and desertification.

Seeing the problem above, then currently developing a concept that is expected to improve the adverse impact on the concept of conventional agriculture, namely sustainable agriculture. In essence agriculture can be said to be sustainable if in its implementation it is able to conserve and maintain or even improve the quality of the land used physically, chemically, and biologically to the level that it should. The ability to maintain soil quality will certainly benefit humans because then the soil's ability to provide nutrients will be fulfilled, the soil will be protected from damage such as erosion and chemical residues, and most importantly, the health and biological activity of the soil are well maintained.

Secondary forest according to Juhos et al., (2019) is forest that grows and develops naturally after damage or change in the first forest. Secondary forest is a phase of forest growth from the condition of bald land, due to nature or anthropogen, until it becomes a climax again. Palm oil is one of the leading commodities in Kutai Kartanegara Regency so that a lot of land is used as oil palm plantations in this Regency. Including some of them can be found in Tenggarong which is managed by farmers or private / state companies. Palm oil has a high economic value because of the commodity produced various kinds of derivative products such as edible oil, cosmetics, household equipment, as well as a renewable energy source (biofuel). But besides that the development of oil palm has been hampered by environmental issues that hit the commodity.

This study tries to examine how differences in soil quality in different land uses and try to see the extent to which the concept of sustainable agriculture has been implemented. Using the concept of the Minimum Data Set (MDS) with the assessment of several indicators of soil properties is expected to produce better soil management direction.

II. Research Methods

2.1 Location and Time

This research was conducted in July to October 2019. Secondary forest soil samples were taken in Bukit Biru, Tenggarong with an area of eight hectares, while oil palm plantation soil samples were taken in the Plantation Departement of the Kutai Kartanegara in Loa Ipuh Darat, Tenggarong with an area of eight hectares. Analysis of soil physical and chemical properties was carried out at the Soil Laboratory of the Faculty of Agriculture, Mulawarman University, and Samarinda.

2.2 Tool and Materials

The tools used in this study are the Global Potitioning System (GPS), soil drill, ring sample, hoe, knife, camera, marker pen, clinometer, compass, measuring tape / meter, and hammer. The material used in this study is a map of the research location, soil samples, plastics, and chemicals for analysis of soil samples in the Soil Laboratory.

2.3 Procedure

This research uses descriptive analysis survey method through observation in the field and analysis in the laboratory. The data used in this study are in the form of primary data and secondary data. Survey activities were carried out in the field to obtain primary data in the form of regional physiographic conditions and data on physical, chemical and biological soil properties. Secondary data is retrieved by processing the basic map in the form of administrative maps, roads, rivers, and topography which are then overlaid with a land use map to get secondary data as a map of the research location. The series of research procedures carried out are the delivery.

Soil sampling in the field is carried out using the physiographic method, namely by taking soil samples based on the slope class on each land use. 21 soil samples were taken using a soil drill at the top soil with a thickness of 0-20 cm. Furthermore, using a sample ring for undisturb soil sampling, as well as observing the soil profil to determine the depth of the roots.

Soil samples taken from the study site are then analyzed in a soil laboratory to obtain the values of each of the determined physical and chemical characteristics. Physical and chemical indicators used in this study are among others.

The soil quality index is calculated based on the Jat et al., (2020) criteria modified by Shao et al., (2020). The calculation of the soil quality index is based on data from laboratory analysis of the soil quality indicators used. According to Shao et al., (2020) the steps to calculate the soil quality index are carried out as follows:

a. The weight index is calculated by multiplying the soil function weight (weight 1) with the root weight of the root (weight 2) with the root depth weight (weight 3). For example, the weight index for porosity is obtained by multiplying 0,40 (weight 1) by 0,33 (weight 2) by 0,60 (weight 3), and the result is equal to 0,080.
b. Indicator scores are calculated by comparing observational data from soil indicators and assessment functions. Scores range from 0 for bad conditions and 1 for good conditions. The assessment function represents three indicator scenarios, namely; (1) more is better, covering root depth, silt + clay, C-organic, and N total; (2) less is better, bulk density; and (3) optimum values include, porosity, pH, P and K available. Determination of the score can be through interpolation or linear equations in accordance with the range determined based on the value or based on the data obtained. According to Martunis et al., (2016) Linear Scoring Functions are:

$$Y = \frac{x - x2}{x - x2} \qquad (1)$$

$$Y = 1 - \frac{x - x2}{x1 - x2} \qquad (2)$$

Note: Y is linier score, x is soil properties result (from laboratory or profil observation, x1 is low limits (lowest score), and x2 is high limits (hingest score).

c. Soil quality index is calculated by multiplying the weight index with the score of the indicator.

$$SQI = Wi \times Si \qquad (3)$$

Note: SQI= soil quality index
Wi= weight index
Si= indicator score

III. Discussion

3.1 Analysis Result of Physical, Chemical, and Root Depth

This study uses nine indicators of physical, chemical, and root depth. This study also observed at the soil biological properties, but the data used came from physical and chemical properties of the soil that could describe the condition of the soil biological properties. Soil sampling uses three different methods according to the nature and purpose of the analysis of the soil properties. The three methods of soil sampling are, disturbed soil samples, undisturbed sampling, the last method of soil sampling, which is observing soil profiles in the field, aims to obtain root depth data. The results of physical, chemical and root depth analysis are presented in Table 1.

Table 1. Analysis Result of Physical Chemical and Root Depth

No	Indicator	Unit	Land Use	
			Secondary Forest	**Oil Palm Plant**
1	Root depth	cm	110	95
2	Bulk density	g cm^{-3}	1.27	1.26
3	Porosity	%	45.26	51.32
4	Texture (silt + clay)	%	67.89	56.03
5	pH		4.22	4.07
6	C-organic	%	1.83	1.72
7	N Total	%	0.17	0.21
8	P avl	ppm	20.20	102.86
9	K avl	cmol kg^{-1}	0.40	0.08

Remarks: Analysis Laboratory and Field Observation

3.2 Scoring Result of the Soil Quality Index on the Function of Sustaining Biological Activity

The function of the soil in sustaining biological activity is one of the functions which is an assessment of the soil quality index. The function of the soil in sustaining biological activities in this study focuses on biological activities related to plant growth needs.

3.3 Scoring Result of the Soil Quality Index on the Function Regulation and Partitioning Water

Results of the calculation of the soil quality index on the function of regulation and partitioning water show that land use of secondary forest has a better score compared to the SQI score owned by the land use of oil palm plantations. The secondary forest SQI score is 0,188 and the SQI score on oil palm plantations is 0,172 with this value indicating that the quality land use of secondary forest is better in managing and distributing water.

3.4 Scoring Result of the Soil Quality Index on Filtering and Buffering

The results of the calculation of the soil quality index in the filtering and buffering functions show that the scores owned by secondary forest land use and oil palm plantation land use do not differ greatly, the filter and buffering score secondary forest are 0,197 and oil palm plantation 0,193.

3.5 Scoring and Criteria Soil Quality Index

The SQI score of three functions is then ranked and given criteria (status) so that it can be seen the results of the quality of each land use studied easily and clearly. The rank and criteria (status) of soil quality are compiled based on the criteria made by by Partoyo, (2005) which are presented in Table 3. Ranking and Criteria of index of soil quality on secondary forest land use and land use of oil palm plantations are presented in Table 2.

The calculation of the soil quality index using the minimum data set method by Jat et al., (2020) on the land use of secondary forest and oil palm plantations in Bukit Biru and Loa Ipuh Darat, Tenggarong shows a secondary forest SQI score of 0,6398 with criteria good (G) and SQI scores on oil palm plantations are lower at 0,592 with moderate criteria (M).

Table 2. Rangking and Criteria SQI Based on Land Use

No	Land Use	SQI Score	Criteria
1	Secondary Forest	0.638	Good (G)
2	Oil Palm Plantation	0.592	Moderate (M)

Remarks: Calculation result of weight and score

3.6 Sustaining Biological Activity

The results of the research presented in Table 4 show that secondary forest land use has a very deep root reaching 110 cm which in this assessment can be categorized very well. The depth of the roots owned by secondary forest land use in this study is in accordance with the results of research conducted by Sitanggang et al., (2016) states that some forest plants have a root depth that can reach 100 to 140 cm. The depth of the roots found in the use of oil palm plantations is also considered quite deep, with an average of 95 cm. The results of observing the depth of rooting in the land use of oil palm plantations are consistent with the results of research by Pradiko et al., (2016) that the depth of oil palm roots can reach 80 to 100 cm from the ground surface.

The roots depth in plants is influenced by plant height, stem diameter and crown width. Morphological conditions of these plants cause the roots that are owned can penetrate deep soil layers in order to obtain nutrients and minerals needed for the development of these plants. In addition to plant morphology, soil properties also have a role in influencing the depth of the root, one of the soil properties is bulk density. Bulk density can affect root penetration (Utomo et al., 2016), but in this study bulk density in both land uses has a low score index so that in this study bulk density has no significant effect on root depth. Shahzad et al., (2018) state that bulk density values correlate with thicker and shorter roots. Another study conducted by Chen et al., (2013) stated that the difference in bulk density had little effect on the root systems of sunflower and corn plants.

But in general, the dominant soil type in both land uses, ultisol, and several other soil types such as oxisol and alfisol do not have significant mechanical barriers for root development (Sitanggang et al., 2016).

Soil moisture is the water that fills most or all of the soil pores or adsorbed on the surface of clay and organic matter (Shao et al., 2020). Soil moisture in this study was assessed using three indicators, namely porosity, C-organic, and texture (clay + silt). The results of the analysis in Table 5 show that the porosity of secondary land use and oil palm plantations is very good. The highest assessment function in this study on the porosity indicator score is set at the optimum point which is close to the porosity value of 50% by volume. This is due to porosity with a value close to 50% reflecting a balance between aeration pore space and available pore space. This statement as stated by Thoumazeau et al., (2019) that there are two important types of pores, namely (a) to provide water, and (b) for the supply of air. The content of C organic in secondary forest and oil palm plantations has good criteria. The high C organic content indicates that the organic matter content is found in the soil. Soil organic matter has a role in increasing the capacity of the soil to retain water and increase the strength of water bound in the soil.

Based on the results of the calculation of the soil quality index on the function of sustaining biological activities as presented in Table 6 shows that this subfunction of the security is a subfunction with the lowest indicator value among other function indicators. This condition occurs because high rainfall causes intensive leaching. These conditions ultimately cause soil pH in both land uses to have a very low indicator score with a very acidic pH. This is also the case that Potassium (K) is available in low secondary forest land uses and in very low oil palm plantations. Phosphate (P) available on secondary forest land use has moderate indicators, whereas P available on oil palm plantation land use is very high. Although the use of oil palm plantations has a very high available P, it has a bad indicator score. This is because the P value available on oil palm plantation exceeds the set optimum value. The determined value is based on the optimum dose according to the Palm Oil Research Center (PPKS) for plants producing 9 - 12 year mineral soil is 46 ppm, while the P content available on oil palm land use is 102,86 ppm. P is available on very high oil palm plantations because of inorganic fertilization that is out of balance and not based on optimum dosages.

Organic carbon (C-organic) and Nitrogen total (N) reflect the composition of soil organic matter. The content of organic matter is important in the cycle so that it cannot run well and maintain health in order to stay healthy. C organic on both land uses has a very good indicator. Based on the C organic content in the second land use, only 1,83% in secondary forest and 1,72% in oil palm plantation but still very good according to Hardjowigeno (2003) in ultisols at present, less than 1%. N total in secondary forest land use has a low indicator, whereas in oil palm plantations it has a good indicator value. Low total N in secondary forest use because it only gets input from a closed nutrient cycle, while oil palm plantations get additional input involving fertilizing the soil of oil palm plantations.

Table 3. SQI Scoring Result on the Function of Sustaining Biological Activity

Scoring Indicator	Weight index	Soil Indicator Score				Soil Quality Index	
		Secondary forest		Oil palm			
		Data	Score	Data	Score	Secondary forest	Oil palm
Rooting medium							
Rooting depth	0.08	110	0.9	95	0.75	0.072	0.060
Bulk density	0.053	1.27	0.217	1.26	0.233	0.011	0.012
Water relation							
Porosity	0.027	45.26	0.882	51.31	0.958	0.024	0.026
C-organic	0.053	1.83	0.879	1.72	0.800	0.047	0.042
Silt + Clay	0.053	67.89	0.679	56.03	0.560	0.036	0.030
Nutrient relation							
pH	0.013	4.22	0.073	4.07	0.023	0.001	0.000
P avl	0.027	20.20	0.556	102.86	0.271	0.015	0.007
K avl	0.027	0.403	0.262	0.082	0.024	0.008	0.002
C-organic	0.04	1.83	0.879	1.72	0.800	0.035	0.032
N-tot	0.027	0.17	0.2	0.21	0.6	0.005	0.016
Total	**0.4**					**0.253**	**0.227**

Remarks: Calculation of weight and score

3.7 Regulation and Partitioning Water

Water is a very important requirement for living organisms, including plants and soils according Utomo et al., (2016) is a natural resource that serves as the main water storage for life. Some of the physical properties of the soil plays an important role in soil functions as a regulator and distribute of water to be utilized by plants in supply their needs is such, texture (silt + clay), porosity, and bulk density.

The silt + clay content in secondary forest land use is considered to have a good indicator value in carrying out the water regulation and partitioning function. Texture class on secondary forest land has loamy which is assessed both in the regulation and partitioning of water in accordance with Easton et al., (2016) statement that soil with loamy has a proportional portion in the regulation and partitioning of water. This is because loamy has available water content, gravity water, and unavailable water which is almost the same level. Available plant water is water that can be directly absorbed by plants at a pressure of 1/3 to 15 atm (2,5 – 4,2 pF), while gravity water is water that is lost into the soil layer until it is lost to water table (lakes, rivers , or sea) through pore drainage and aeration in macro pores, and unavailable water plant is water that is bound very strongly by soil aggregation so that it cannot be absorbed by plants (Utomo et al., 2016). Where as the land use of oil palm plantations has a higher water loss due to lower silt + clay content so that the sand content that forms macro pores will be large.

Porosity in the use of secondary forest land and oil palm plantations is considered good in carrying out its functions as a regulation and partitioning of water. The second porosity of land use approaches the optimum porosity value of 50% due to the balance between the soil matrix and the pore space of the soil. So that the ideal percentage for soil porosity is a value of 50% because there is a balance between the aeration pore and the pore holding water.

Bulk density of the two land uses has almost the same value, which is the indicator value with very low criteria. Bulk density, in addition to being influenced by the level of soil management is also influenced by the distribution of particles in the soil. According to Wang et al., (2019) in general sand soils have volume between 1,4 – 1,7 gr cm-3, whereas in clay soils heavy soil volumes range from 0,5 – 1,2 gr cm-3. In both land uses, the distribution of particles owned is almost the same proportion. Bulk density can disturb the regulation and partitioning of water owned by a land use. Although the bulk density in both land uses has a low indicator value criteria, this value is commonly found in mineral soils so that the effect on the soil function as a regulation and partitioning of water does not have a main effect because in this function the distribution of particles (texture) and porosity more dominant effect.

Table 4. SQI Scoring Result on Regulation and Partitioning Water

Scoring indicator	**Weight index**	**Soil indicator score**				**Soil Quality Index**	
		Secondary forest		**Oil palm**			
		Data	Score	Data	score	**Secondary forest**	**Oil palm**
Silt + Clay	0.18	67.89	0.679	56.03	0.560	0.122	0.101
Porosity	0.06	45.26	0.882	51.31	0.958	0.053	0.057
Bulk density	0.06	1.27	0.217	1.26	0.233	0.013	0.014
Total	**0.3**					**0.188**	**0.172**

Remarks: Calculation of weight and score

3.8 Soil Filtering and Buffering

Soil health is one of the goals that must be achieved in the concept of sustainable agriculture so that the soil continues to be able to provide output for the life of organisms on this earth. The ability of the soil to carry out the filter and buffering functions of pollutants is related to the nature of resistance and resilience that is owned by a land. The composition of silt + clay and porosity in the soil determine the ability of the filter and buffer the soil against pollutants. According to Easton et al., (2016), micro pores in soils measuring ≤ 0,08 mm have the ability to withstand contaminants so they do not penetrate deeper layers of soil.

Silt + clay content in secondary forest land use is considered to have a good indicator score, whereas in oil palm plantations it has moderate indicator score as a filter and buffering the soil. The porosity owned by oil palm plantation land use is better than that owned by secondary forest land use because it is closer to the optimum value, but the contents of silt +

clay particles is lower than that of secondary forest land use. Land on oil palm plantations has a large sand content so that it reduces the ability of the soil to filter pollutants.

C organic and N total in this case are used as indicators showing the microbiological processes and activities of the soil. C organic owned by both land uses based on the calculation of soil quality indicators has good criteria. This shows that soil biological activities in both land uses can work well in supporting soil microbiological activities so that soil filtering and buffering can be carried out. The N total contained in the two land uses has different indicator score. N total on oil palm plantation land use is higher and has an indicator score with good criteria while N total indicator score on secondary forest use has a low criterion.

C organic and N total that are well available in the soil will support soil decomposition activities that play a role in the process of buffering the soil. Pollutants that are filtered by soil pores will be absorbed and transformed, and in this process microorganisms need C organic and N total as sources of energy and nutrients for microorganisms in soil biological processes.

According to Ramos et al., (2020) microbiological functions are likely to be more easily interpreted as bioindicators of soil health because the measured processes directly affect soil productivity. The microbiological function has an important role as buffering the soil from pollutants through biological activities that occur on the soil. Ghosh et al., (2020) adds that measurement of soil microbial biomass has been used to assess the effect of pesticide and heavy metal contamination. Several types of soil microorganisms in the form of microfauna and soil microflora have the ability to support the soil from pollutants. Research Krüger et al., (2018) say that bacteria from the genus mettalogenium are able to accumulate Fe, Al, and Mn into insoluble forms and can grow in environments where the dissolved metals are in high quantities. The development of these bacteria is positively correlated to the concentration of heavy metals. In addition, several types of aerobic bacteria are able to produce chemical compounds that can prevent the development of pathogenic microorganisms.

In general, the function of soil as a filter and buffering on both land uses has an index that is not much different, but based on the calculation of SQI on this function with four indicators of the soil properties used, secondary forest land use has a higher SQI score than the use of oil palm plantations.

Table 5. SQI Scoring Result on Filtering and Buffering

Scoring indicator	Weight index	Soil indicator score				Soil Quality Index	
		Secondary forest		Oil palm			
		Data	Score	Data	Score	Secondary forest	Oil palm
Silt + Clay	0.18	67.89	0.679	56.03	0.560	0.122	0.101
Porosity	0.03	45.26	0.882	51.31	0.958	0.026	0.029
Microbial processes							
C-organic	0.045	1.83	0.879	1.72	0.800	0.040	0.036
N-tot	0.045	0.17	0.2	0.21	0.6	0.009	0.027
Total	**0.3**					**0.197**	**0.193**

Remarks: Calculation result of weight and score

3.9 Soil Quality Index and Recommendations for Sustainable Land Management

The assessment of the soil quality index must be based on a holistic approach between soil properties and processes that occur in the ecosystem, this is in accordance with the opinion of Cornelis et al., 2019; Ojekanmi et al., 2020; Thoumazeau et al., 2019; Yu et al., (2018) that soil quality indicators must show the processes that occur in the ecosystem, and integrate physical, chemical, and biological biological processes. The statement aims to ensure that properties soils can truly reflect the condition of the actual soil quality in accordance with the behavior and changes that occur in the ecosystem

The ability of the soil to sustaining biological activities for plant growth in secondary forest land use and oil palm plantations is considered good but has sufficient limitations on the nutrient sub-function. Whereas the function of water regulating and partitioning as well as the function of filter and buffering of the land are considered to be good in both land uses.

Soil quality on forest land is generally only influenced by the environment, without the influence of land management carried out by humans. However, in non-forest land uses such as oil palm plantations, the quality of the land is influenced by human activities as managers of the land. This means that in this condition soil quality can degraded, survive, or even increase according to the nature and manner of land management carried out on the land. Some land management actions that can be recommendations for good land management directives and can achieve the goals of sustainable agriculture include adding organic material to the soil, sustaining fertilizing at the optimum dosage, using land according to its capacity, and using environmentally friendly agricultural materials and techniques.

Table 6. Soil Quality Index Based On the Soil Functions

Soil Function	**Soil Quality Index**	
	Land Use	
	Secondary Forest	**Oil Palm Plantation**
Sustaining biological activity	0.253	0.227
Regulation and partitioning water	0.188	0.172
Filtering and buffering	0.197	0.193
Total	**0.638**	**0.592**

Remarks: Calculation result of weight and score

IV. Conclusion

Based on the results of the analysis of the soil quality index, it can be concluded that The Soil Quality Index (SQI) on secondary forest soils has a score of 0.639 (good criteria), and the SQI of oil palm plantations with a score of 0.593 (medium criteria). The results of the SQI analysis show that oil palm plantations have not yet achieved sustainable agriculture. In order to achieve sustainable agriculture, should adding organic material to the soil, using land according to its capacity, and using environmentally friendly agricultural materials and techniques and further research is needed to obtain more accurate and complete information.

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