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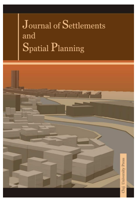

Mapping Soil Quality in Various Land Uses as a Basis for Soil Management in Wonogiri, Indonesia

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ABSTRACT

Soil quality is closely related to environment because soil is not only viewed as a growing media for plants but also encompasses various environmental and health functions. It is important to know the quality of soil in order to keep it healthy, productive, and optimally functioning. This research aims to evaluate soil quality status in various land uses and to learn the land factors that are related to soil quality. Soil quality index (SQI) represents the soil quality status. SQI will then be used as the basis for soil management. A descriptive explorative research study was carried out in the Giritontro Sub-district, Wonogiri District, Indonesia. SQI indicators were obtained from 12 existing Land Mapping Units (LMU). SQI was obtained by determining the Minimum Data Set (MDS) with a Principal Component Analysis (PCA) test. Then SQI was mapped and statistically analyzed to determine the influence of land use and the determinant factors of SQI. Results showed that SQI in all area is class 3 or moderate. SQI was significantly influenced by land use. SQI in paddy field is 9.09% higher than crop fields and 2.27% higher than of plantations. Indicators which are significantly related to SQI are bulk density, porosity, cation exchange capacity, available P, available K and microbial biomass carbon (MBC). The type of soil management that can be implemented to improve soil quality includes addition of organic or inorganic fertilizer and adoption of an agroforestry system.

1. INTRODUCTION

Soil is an important component in the ecosystem, especially in the agriculture sector, because of its function in supplying nutrition. It has the additional function of serving as a place where biological processes occur, including the cycling of soil nutrients, so in agricultural endeavours, soil is not only connected to its physical, chemical, and biological properties but also to the surrounding environment (Suntoro et al., 2020). Soil quality plays a significant role in defining cultivation systems in sustainable farming (Lal, 1994). Knowledge of soil quality status is needed to understand the conditions and processes taking place in the soil in order to ascertain that the soil is capable of carrying out its function properly (Marzaioli et al., 2010). The Soil Science Society of America defines soil quality as the capacity of soil function to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation (Karlen et al., 1997).

Soil quality index (SQI) represents the status of soil quality. It is an index calculated based on the value and weight of each soil quality indicator. The indicators of soil quality are chosen from the properties that show the capacity of soil function (Partoyo, 2005). Those used in the assessment of SQI include the physical, chemical, and biological properties of the soil. In addition, soil type, topography, and land use are other factors that should be taken into consideration in the SQI evaluation for the purpose of advancing the agriculture and plantation sectors (Rasyid, 2004).

However, in practice, farming endeavours often have a negative effect on ecosystems, leading to a decline in soil quality due to agricultural intensification (FAO, 1999). Incorrect land management and land use are the reason of land degradation (Winarno, 2009; Rahman et al., 2012). Land degradation may lead to drought or flooding, which are signs of a hydrological imbalance in watershed areas (Miardini and Susanti, 2016). Giritontro Sub-district is located in Wonogiri District, Indonesia, which is an area often affected by drought. A population of 10,663 local inhabitants was negatively impacted by droughts in 2018 and 2019 (Jawa Pos, 2019). Giritontro Sub-district also has one of the highest levels of erosion risk (Santoso et al., 2017), which is one of the indicators proving an increased level of land degradation.

Sustainable land management is needed to reduce land degradation and improve soil quality. Data about the soil quality in a region is required as the basis for compiling recommendations for land management. Evaluation and monitoring of soil quality is needed to formulate soil and land management recommendations in order to preserve the sustainability of agricultural production (Mujiyo et al., 2016; Mujiyo et al., 2017). SQI values is used to determine the distribution of SQI in a certain area, so that it can be employed for preparing land management recommendations, according to the weaknesses and strengths of each land. This research aims to evaluate of soil quality status in various land uses and to find out which land factors that are related to soil quality. In order to highlight the soil quality related factor it were formulated some recommendations for soil management in this region.

2. THEORY AND METHODOLOGY

2.1. Study area

This research was conducted in the Sub-district of Giritontro, in the Wonogiri District of Central Java Province, which is located between 8^{o}01’50,6”and 8°09’25,7” south latitude and between110°51’19,7”and 110°56’15,9” east longitude, with an mean altitude of 195 m AMSL, and covers an area of 6,163.1590 ha. Most of the land in the research location is used for agricultural cultivation, including paddy fields, plantations, and crop fields. Approximately 76.56% of land in the Giritontro Sub-district is farmland (BPS, 2017). The geographical conditions are dominated by limestone. The research location is covered by three soil types, namely mollisols, alfisols and inceptisols.

2.2. Methodology

The research followed 6 steps: (1) determination of Land Mapping Units (LMUs); (2) field survey; (3) laboratory analysis; (4) determination of Minimum Data Set (MDS); (5) determination of Soil Quality Index (SQI) - mapping of SQI distribution; and (6) statistical analysis. The LMUs were obtained from the results of an overlay of various maps, including soil type maps, slope gradient, rainfall, and land use. The region under study consists of 12 LMUs with 3 repetitions of each (Table 1 and Fig. 1).

Table 1. LMU and its elements in the research area.

LMU	Soil type	Slope (%)	Rainfall (mm/year)	Land use
1	Mollisols	0-8	1,750	Paddy Field
2	Mollisols	9-15	2,250	Paddy Field
3	Alfisols	0-8	1,750	Paddy Field
4	Inceptisols	0-8	1,750	Paddy Field
5	Mollisols	0-8	1,750	Plantation
6	Mollisols	0-8	2,250	Plantation
7	Mollisols	9-15	1,750	Plantation
8	Mollisols	26-40	1,750	Plantation
9	Mollisols	0-8	1,750	Crop Field
10	Mollisols	0-8	2,250	Crop Field
11	Mollisols	9-15	1,750	Crop Field
12	Mollisols	9-15	2,250	Crop Field

To determine the SQI, the physical, chemical, and biological properties of the soil were observed (Lal, 1994). Soil physical indicators were soil texture (pipette method), bulk density (BD) (clod method) (Blake and Hartge, 1986), cumulative porosity (bulk density comparison method) (Missimer and Lopez, 2018) and water content (gravimetric method). Soil chemical indicators were organic C (Walkey and Black method) (Walkey and Black, 1934), soil pH (pH meter with a soil and water ratio of 1:10), cation exchange capacity

(CEC)(extraction NH_4OAc 1N pH 7), base saturation (BS) (extraction NH_4OAc 1N pH 7), available K (extraction NH_4OAc 1N pH 7), available P (Olsen method)(Olsen et al., 1954), total N (Kjeldahl method) (Kjeldahl, 1883). Soil biological indicator was Microbial Biomass C (soil respiration method).

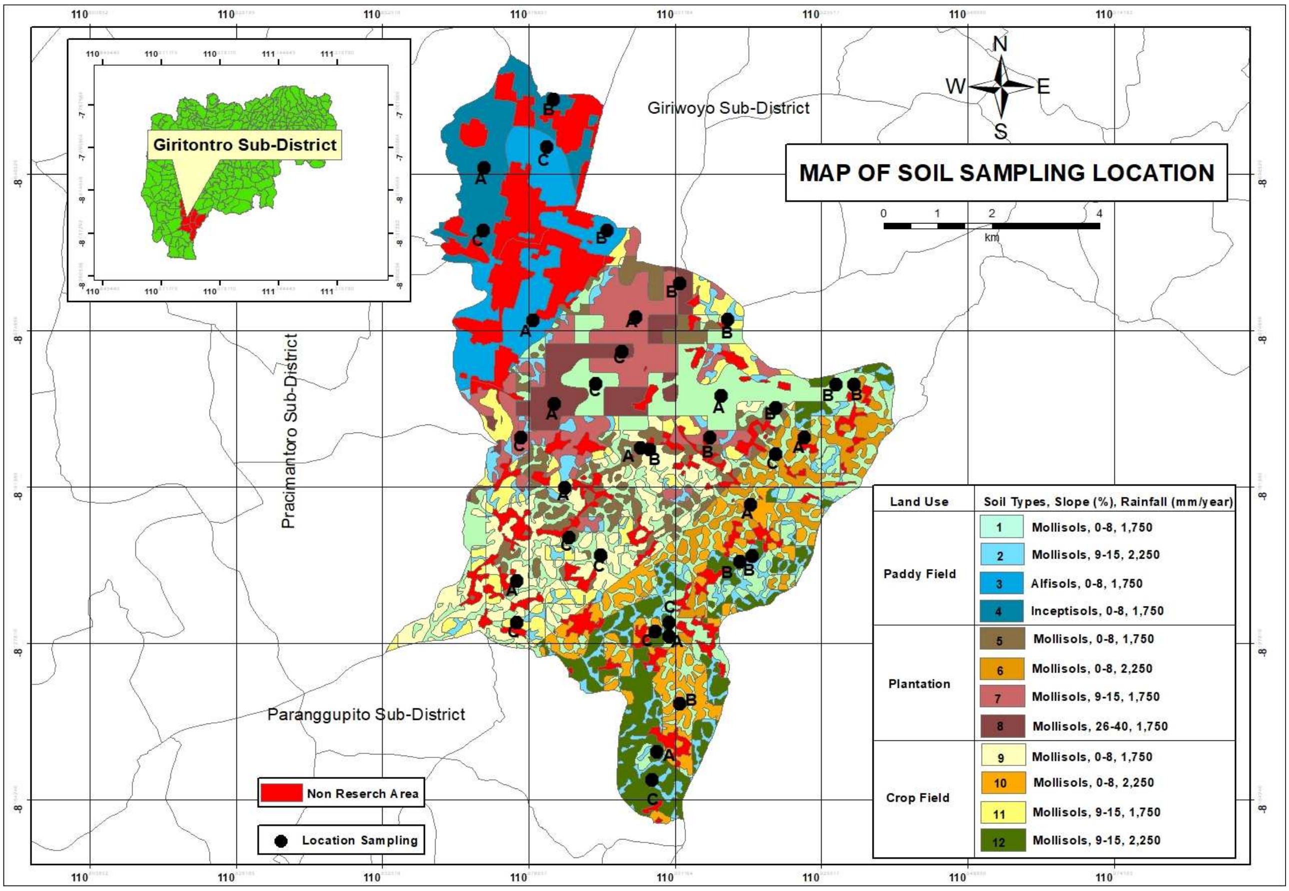

Fig. 1. Soil sampling location.

Soil quality indicator data were analyzed using Principal Components Analysis (PCA) test for MDS determination (Chenet al., 2013) using a statistical application Minitab 19 (Minitab Company, 2019). PCA will produce PC data (principal component) or the main component. The selected PC must have an eigenvalue ≥1 (Chandel et al., 2018). PC data is used to determine the MDS of soil quality.

Soil quality is determined by calculating the value of the SQI, which can be obtained by multiplying the indicator score index (S_i) and the weight index (W_i) (Mukhopadhyay et al., 2014) using the equation:

$$SQI = \sum_{i=1}^{n} W_i \times S_i^n$$

where :

SQI - soil quality index;

W_i - weight index (obtained from the result of the PCA test);

S_i - scoring index of chosen indicator (value of scoring index based on Lal (1994), Andrews (2002), Wander (2002), Balai Penelitian Tanah (2005);

n -number of soil quality indicators.

SQI classification values were based on Cantu et al. (2007) (Table 2).

Table 2. Classification of soil quality (Cantu et al., 2007).

SQI	Class	Soil quality
0.80-1	1	Very good
0.60-0.79	2	Well
0.35-0.59	3	Moderate
0.20-0.34	4	Low
0-0.19	5	Very low

To map the spatial distribution of the SQI the ArcGIS 10.3 (ESRI, 2014) was employed. Statistical analysis was performed including One Way ANOVA with the Duncan's Multiple Range test to determine the influence of LMU's elements (soil type, slope gradient, rainfall, land use) to the SQI.

The correlation test was used to determine the relationship between indicators and SQI (Steel and Torrie, 1980). SQI value was used as the basis for formulating soil management recommendations in order to improve soil quality in the Giritontro Sub-district.

3. RESULTS AND DISCUSSION

3.1. SQI mapping

The results of the PCA analysis showed that there were 3 PCs with an eigen value greater than 1 selected as main components and 5 indicators chosen as the MDS for determining the soil quality value (Table 3 and Fig. 2).

Table 3. Results of the PCA.

Eigenvalue	3.0848	2.1000	1.4343
Proportion	0.308	0.210	0.143
Cumulative	0.308	0.518	0.662
Variable	PC1	PC2	PC3
BD	0.276	**0.531***	0.100
Porosity	-0.214	-0.533	-0.266
Organic C	0.063	0.294	-0.649
CEC	**0.487***	-0.215	-0.084
BS	-0.429	**0.357***	0.152
Available P	0.325	0.154	**0.378***
Total N	-0.255	0.260	-0.057
Available K	-0.433	0.103	0.142
pH	0.234	-0.057	**0.324***
MBC	0.200	0.261	-0.444

Note: *= MDS.

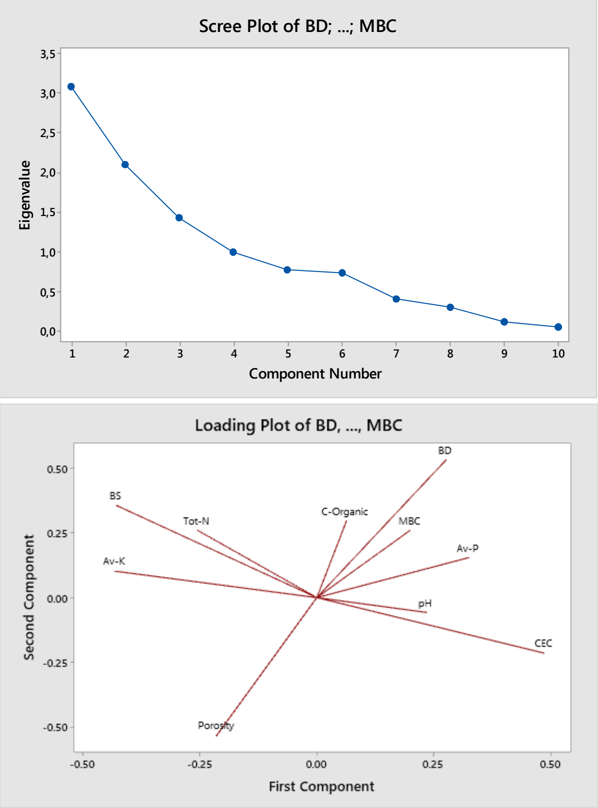

Fig. 2. Results of the PCA.

The chosen indicators had a high level of sensitivity (i.e. representative) in displaying the properties of soil that would be assessed to determine the SQI (Supriyadi, 2018). PC 1 represented 30.8% of soil quality data and CEC was selected as MDS. Bulk density and base saturation were selected as MDS in PC 2, where both have a high value, but no correlation. Indicators selected as MDS on PC 3 available P and pH, where both have high values, and no correlation between pH - available P, but both were maintained as part of the MDS because of its high value.

Table 4. Weight Index of MDS.

MDS	Proportion	Cumulative	Wi
CEC	0.308	0.662	0.465
BS	0.210	0.662	0.317
Available P	0.143	0.662	0.216
pH	0.143	0.662	0.216
BD	0.210	0.662	0.317

The SQI values were calculated for the indicators that constituted the MDS by multiplying the W_i value (Table 4) with the S_i value (Table 5) (Fig. 3).

Table 5. Scoring Index (Si) Values for each LMU.

MDS	Scoring Index (Si) for each LMU					
	1	2	3	4	5	6
CEC	3	3	3	2	3	2
BS	3	2	2	3	3	3
Available P	1	1	1	1	1	1
pH	4	4	4	4	4	4
BD	4	4	4	4	4	4
MDS	Scoring Index (Si) for each LMU					
	7	8	9	10	11	12
CEC	2	2	3	2	2	2
BS	3	3	2	3	3	3
Available P	1	1	1	1	1	1
pH	4	4	4	4	4	4
BD	4	4	4	4	1	2

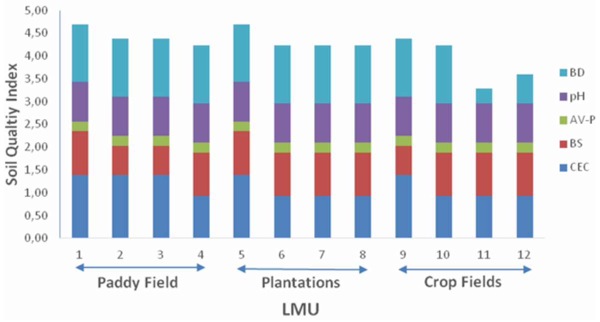

Fig. 3. Indicator scoring values of SQI in Giritontro Sub-district.

Results of the analysis showed that the SQI values for all LMUs except LMU 11 correspond to class 3 (moderate). SQI values for LMU 11 is included in low class (0.33). SQI values of LMUs with paddy field use (0.44) were higher than LMUs with plantation use (0.43) and crop field use (0.39) (Table 6 and Fig. 4).

The combination of LMU elements consisting of Mollisols, a slope gradient of 0-8%, rainfall of 1,750 mm/year, paddy field land use (LMU 1) and plantation land use (LMU 5) had the highest soil quality value, while a slope gradient of 9-15% and crop field land use (LMU 11) had the lowest soil quality value.

Table 6. SQI for each LMU.

MDS	LMU											
	1	2	3	4	5	6	7	8	9	10	11	12
∑(Wi*Si)	4.70	4.38	4.38	4.23	4.70	4.23	4.23	4.23	4.38	4.23	3.28	3.60
∑(Wi*Si)/n	0.470	0.438	0.438	0.423	0.470	0.423	0.423	0.423	0.438	0.423	0.328	0.360
SQI each land use	0.44 (Paddy field)				0.43 (Plantation)				0.39 (Crop field)			
SQI	0.42											
SQI Class	Moderate											

Note: n= number of soil quality indicators.

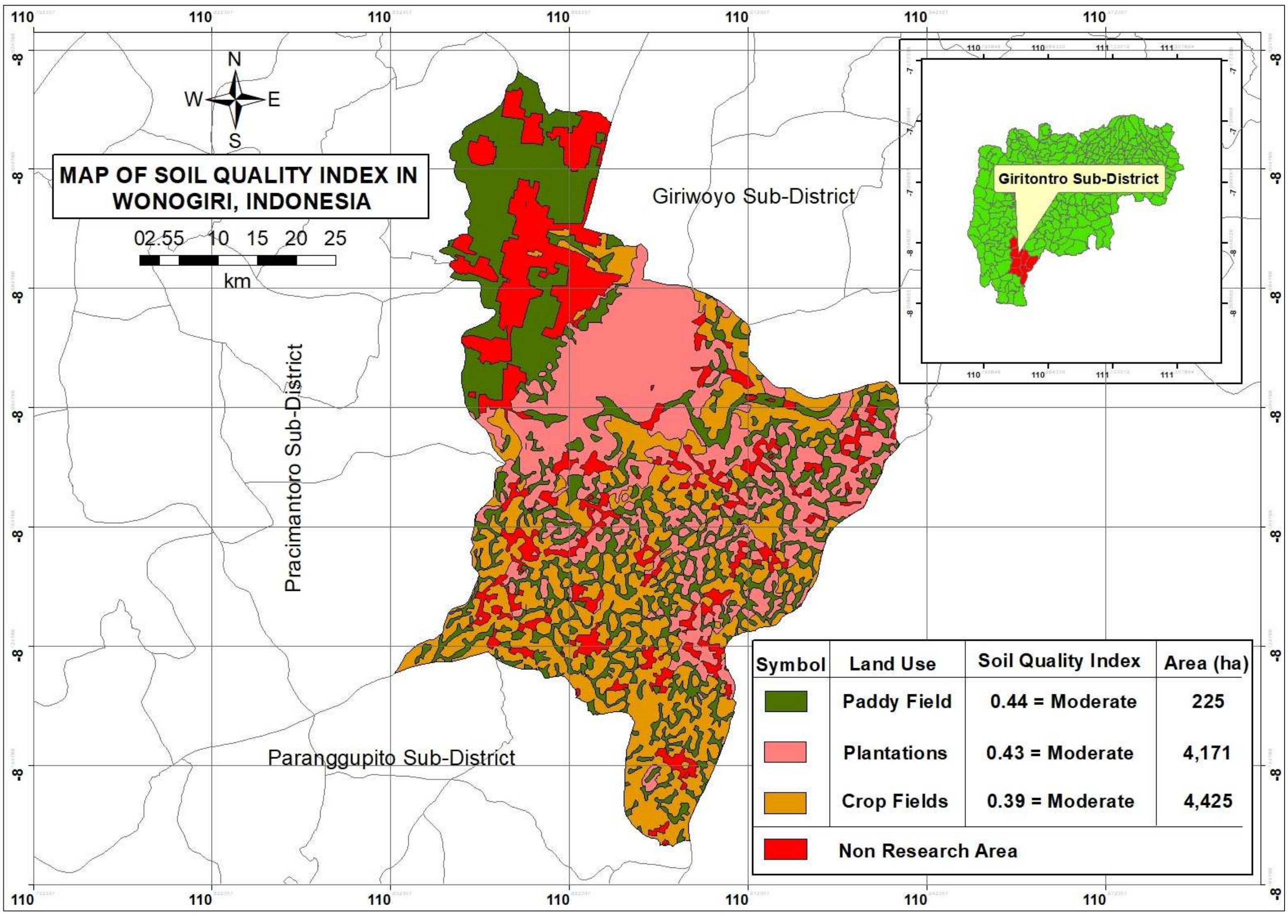

Fig. 4. SQI in several land uses in Giritontro Sub-district.

3.2. Correlation between SQI and soil indicators

The results of the One Way ANOVA test show that land use has a significant effect on SQI (F = 7.83; P-value = 0.002; n = 36) (Table 7). Land use types affect variations in soil indicators due to differences in land management (Pham et al., 2018; Moges et al., 2013; Girmay et al., 2008; Moges and Holden, 2008). Land use can influence soil quality by altering the physical and chemical properties of the soil (Tematio et al., 2011). Changes to the system of land use can cause long-term and large-scale changes to soil structure and alter microbial activity in the biological process which in turn influences soil quality (Xiao et al., 2017).

In addition to land use, slope gradient (F = 9.79; P-value = 0.000; n = 36) also has a significant effect on the SQI. Slope gradient is related to erosion risk and landslides, especially in open land that is not covered by vegetation, resulting in a top soil loss (Herawati et al., 2018; Priyono et al., 2018). Slope gradient influences soil washing and transportation, and the slope gradient factor will influence organic material content because of the top soil erosion. The factors of soil type (F = 1.61; P-value = 0.214; n = 36) and rainfall (F = 3.83; P-value = 0.075; n = 36) do not have a significant influence on SQI.

The indicators significantly related to SQI are cation exchange capacity, available K and MBC, while those very significantly related are bulk density, porosity and available P (Table 8). Soil bulk density shows how the condition of soil structure is influenced by soil management. Intensity of soil management and clay content in the soil influence soil bulk density (Marlina and Satriawaniqbal, 2014). Soil with a high bulk density can interfere with the movement of plant roots and groundwater (Mujiyo et al., 2020).

Table 7. Result of One-Way ANOVA for SQI in relation with LMU's elements.

Source of variation	df	SS	MS	SQI	
				F-value	P-value
Soil type	2	0.004	0.002	1.61	0.214
Error	33	0.042	0.001		
Total	35	0.046			
Slope gradient	2	0.017	0.009	9.79*	0.000
Error	33	0.029	0.001		
Total	35	0.046			
Rainfall	1	0.004	0.004	3.83	0.075
Error	34	0.042	0.001		
Total	35	0.046			
Land use	2	0.015	0.007	7.83*	0.002
Error	33	0.032	0.001		
Total	35	0.046			

Table 8. Correlation between SQI and indicators.

	BD	Por	C-Org	CEC	BS	Av-P	Tot-N	Av-K	pH	MBC
SQI	0.743**	-0.691**	0.108	0.362*	-0.133	0.533**	0.003	-0.346*	0.084	0.378*
	0.000	0.000	0.531	0.030	0.439	0.001	0.987	0.038	0.626	0.023

Note: Cell contents = Pearson correlation and P-Value.
*= correlation is significant (at P < 0.05 level).
**= correlation is very significant (at P < 0.01 level).

The capacity of cation exchange correlates with the ability of soil to make nutrients available to the plants. Soil with a high cation exchange capacity has a potentially high quality because it has the ability to make sufficient nutrients available for the plants. Available K are essential nutrients needed by plants in large quantities. Phosphorus and potassium are essential macro elements that affect soil fertility and plant growth, so their availability must be considered (Cozzolino et al., 2013; Qiu et al., 2014; Srinivasarao et al., 2014; Sanyal et al. 2015). Wibowo (2013) explains that the increase in microorganism biomass carbon (MBC) indicates an increase in the activity of soil microorganisms. The increased activity of soil microorganisms indicates that the soil has ideal quality. Soil organisms play an important role in the cycle process of nutrients and organic matter (Syamsiyah et al., 2018).

3.3. Soil management

Soil management is based on indicators that are significantly related to the SQI and indicators that have a low score. Indicators significantly related to SQI are bulk density, porosity, cation exchange capacity, available P, available K and MBC. Available P is one indicator with a low score andvery significantly related to SQI . The soil types in Giritontro Sub-district have a range of very low - low available P content. Soil with a very low available P content will interfere with plant growth without the application of additional P fertilizer (Kusumastuti, 2014).

The application of organic material can increase the P availability because organic material in the soil serves to replace the anion $H_2PO_4^-$in the adsorption site and increases the amount of organic P that is mineralized to become inorganic P (Noor, 2003). The P content can be added by using rice straw biochar (RSB) and rice husk ash (RHA), both of which can increase the available P and available K content (Gupta et al., 2019). Singh et al. (2013) state that the addition of RHA and inorganic or organic fertilizer can increase P availability. The addition of superphosphate inorganic fertilizer (SP-36) can also offer an alternative solution for increasing P availability (Julianto et al., 2019) but the fertilization must follow the recommended dose.

Another alternative recommendation for land management is to choose land use that is appropriate to the land capacity. The analysis revealed that land use has a significant influence on the SQI as well as on most of its indicators. Land use has a significant effect on bulk density, cation exchange capacity, base saturation, available P, available K, and microbial biomass C. The adoption of an agroforestry system is another strategy for restoring soil quality. An agroforestry system can improve the physical qualities of the soil, especially in relation to soil aggregate and biological activity (roots and macrofauna). The most suitable system is a multiple cropping agroforestry pattern between annual and seasonal crops (Maroeto, 2017). The presence of trees produces litter which is a source of organic material (Soelaeman and Haryati, 2012). Organic material can help break up the soil, creating space for tiny pores so that the bulk density declines. It also has the ability to increase cation exchange capacity, available P, and available K (Angelova et al., 2013; Suntoro et al., 2018). Wibowo (2013) and Mujiyo et al. (2018) explains that the existence of microbial biomass carbon (MBC) in soil is influenced by the presence of organic material. Supriyadi et al. (2020) also explain that the increasing amount of organic material leads to an increase in the soil microorganism activity.

4. CONCLUSIONS

The SQI in Giritontro corresponds to the moderate class (0.42). SQI was significantly influenced by land use. Paddy field has a higher SQI (0.44) than plantation (0.43) and crop field (0.39). The indicators that are significantly related to SQI are cation exchange, available K and MBC, and indicators that are very significantly related to SQI are available P, bulk density, and porosity. The soil types in Giritontro Sub-District have a range very low - low available P content. Available P is very significant related to SQI and has low score. Agricultural endeavours still need to be implemented to increase soil quality and improve soil structure and soil nutrients, especially the available P. The use of organic materials alongside inorganic fertilizer can increase the available P content. The adoption of an agroforestry system could also offer an alternative solution for land management.

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