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RESEARCH ARTICLE

UTILIZATION OF SOIL FUNCTION INFORMATION FOR ASSESSING SOIL QUALITY OF RICE FIELD IN THE QUATERNARY-TERTIARY VOLCANIC TRANSITIONAL ZONES IN CENTRAL JAVA

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ABSTRACT

Soil quality information of the rice field in the Quaternary-Tertiary volcanic transitional zone has not been specifically reported. Research on the assessment of soil quality widely reported only focuses on the discussion of quantitative-qualitative techniques and the use of minimum data sets without paying serious attention to the soil functions. This study aimed to assess soil quality through qualitative and quantitative methods based on the soil function information approach. The study was conducted in the quaternary-tertiary volcanic transitional zone with special cases of thick soil, high clay content, low nutrient content, high erosion, and vulnerability to landslide, which affects soil quality and farmer cultivation practice. The qualitative soil quality approach was based on the local knowledge of the farmers. The quantitative soil quality indexing was performed with the Soil Management Assessment Framework (SMAF) method to obtain sensitive indicators. The results found that the characteristics of paddy soil had high clay content and thick topsoil layers. The paddy soil is commonly called as ngrawa/mbel soil. The minimum qualitative data sets included color, plant condition, texture, ease of tillage, and drainage. Meanwhile, the minimum quantitative data sets included Na-dd, Mg-dd, texture, bulk density, porosity, and permeability. Information on soil functions obtained included the availability of nutrients, rooting media, root penetration, water storage capacity, and soil permeability. The soil function information approach can be used to assess soil quality in the quaternary-tertiary volcanic transitional zone.

Keywords: Rice field, Soil function, Soil quality, Volcanic transitional zone

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INTRODUCTION

Soil quality focuses on the capacity of the soil to meet the needs of human life because it is related to crop productivity. Soil quality is closely related to the environment because the soil is not only a transformation of minerals and organic matter but also a place to grow plants that affect the life on it. Biswas et al. (2017) explained that the assessment of soil quality by identifying key limiting indicators is important so that the function and balance of the soil and crop productivity are maintained. High soil quality values indicate a high level of soil fertility (Arifin, 2011). Information about

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soil quality is very important to evaluate soil productivity and identify suitable land management. Researchers have previously developed quantitative methods for assessing soil quality based on the physical, chemical, and biological properties of the soil (Karlen et al., 2003; Andrews et al., 2004; Obade & Lal, 2016). Rashidi et al. (2010) added that there are two important factors in the concept of soil quality. The first one that soil has inherent and dynamic properties and the second one is that the assessment of soil quality must reflect soil properties as well as the physical, chemical, and biological processes and interactions.

Soil quality assessment is carried out using a framework prioritizing management objectives, identifying soil functions, and selecting indicators that provide important information related to soil functions. The method of indexing soil quality commonly used is to synthesize soil indicators into a simpler format based on the soil function and its weighting, thus supporting multi-objective decision making (Askari & Holden, 2015). There are various choices of indicators and methods for integrating scoring of soil quality assessments so that each method has been developed for a specific purpose (Andrews et al., 2004; Lima et al., 2013; Masto et al., 2015; Noviyanto et al., 2017). Bunemann et al. (2018) added that in anthropogenic land, the sensitive soil attributes with intensive land management, such as paddy soil, are necessary. Inundation and puddling of paddy soil cause changes in the physical, chemical, and morphological characteristics of the soil.

Evaluation of soil quality is needed to be continuously developed in agriculture, especially in soil science. Results of qualitative soil quality evaluations have not been widely reported because they are considered not objective. Evaluation of soil quality is not limited to scientific steps, but it also requires an approach that is easily understood by farmers. Fierer et al. (2007) state that qualitative soil quality information can be assessed by (i) visual inspection (soil color) and depth of plant roots, (ii) soil compactness, (iii) soil fertility, and (iv) crop yields. Soil color is used by farmers to measure organic matter (Adeyolanu & Ogunkunle, 2016). Morphological visualization methods are used to assess plant growth (Murage et al., 2000). Farmers have practical knowledge from daily experience in the field. Farmers can adjust their farm management by evaluating the soil properties and characteristics of their farmland.

Local information related to land conditions and agricultural management is needed to evaluate soil quality. An ethnopedological approach through semi-structured interviews is used to interpret the results of the soil quality qualitatively to make it more accurate according to the site conditions. Ethnopedological approach is used to explain the understanding of farmers (local knowledge) related to the perception of the properties and characteristics of the soil. Farmers' perceptions are integrated by researchers (scientific knowledge) to formulate qualitative soil quality values. According to Obade (2019), an ethnopedological approach using illustrative interviews was carried out to integrate land management information by farmers with the dynamics of soil quality in monitoring agricultural productivity. Farmers' viewpoints are based on soil management experience, rice productivity, and land use, therefore gender, age, education, knowledge, occupation, length of stay, and period of farming can influence the subjectivity of the farmers.

The volcanic transition zone is a transitional zone between quarternary and tertiary age material. Soil formed in volcanic transition zones has unique properties with different developments. Parent material, relief, climate, and geomorphological processes occur intensively. Specific characteristics of areas with volcanic transition landscapes are thick soils, high levels of cliffs, low nutrient content, high erosion, and vulnerability to a landslide (Pulungan & Sartohadi, 2018a). Intensive material transportation occurs in volcanic transitional zones so that colluvial material is found in the depositional zone. Depositional zones tend to have flat reliefs so that farmers use them for agricultural cultivation activities. The adaptation of soil management is carried out by farmers to maximize agricultural cultivation activities in volcanic transition zones. From the farmers' perspective, there are typical local soils in quarternary-tertiary-age volcanic transition zones, namely 'cabuk hitam', 'cabuk putih', 'cabuk grogol', 'lendut', 'lincat', 'lempung', 'baturan', and 'gresik'. Paddy soil is included in a typical local soil, which is called 'lendut', 'ngrawa', or 'mbel'. 'Ngrawa' or 'mbel' soils have thick topsoil, high clay content, and high soil plasticity index. High clay content and high soil plasticity index cause more micropore space than macropore space. Poor soil aeration conditions cause low microorganism activity in the soil.

Although there are a lot of methods and indicators to characterize soil quality, almost no standard soil quality method is used universally. An accurate evaluation of soil quality can be found on a detailed and local scale, however, it has limited site specifications. Based on the characteristic of paddy soil at the study site, soil function indicator was added to determine soil quality index. This study aimed to assess soil quality through qualitative and quantitative methods based on the soil function information approach. The novelty of this research is to add soil function indicators to the weighting factor system and formula soil quality.

MATERIALS AND METHODS

Study Area

The research location is in Bompon sub-watershed upstream, Magelang, Central Java (7°32'36.57"-7° 33'01.86"S and 110°03'44.43"-110°03'55.13"E at an elevation of 450 m asl) with the land use of rainfed rice field. The climate at the study site tends to be rather wet, with an average rainfall of 2,806 mm yr^{-1}. The bedrock in Bompon sub-watershed upstream is formed from volcanic parent materials in the form of sandy tuffs and andesite breccias. The soil unit from volcanic parent material, with a slightly wet climate. The texture was dominated by clay, has thick soil solum. Land management is classified as heavy due to the depth of more than 1 meter. Soil that is not easy to plow causes poor soil drainage, making the paddy soil easily flooded. The research location is presented in Figure 1.

Soil Sampling and laboratory analysis

Sampling was done by purposive sampling at a depth of 0-20 cm and 20-40 cm with a distance between sample points of 40 m. Soil samples were taken from a composite sample of two replications, consisting of 12 qualitative sample points (12 soil samples) and 10 quantitative sample points (20 soil samples). According to Jobbagy & Jackson (2004), soil quality varies greatly with soil depth, nutrient cycle dynamics, and leaching factors. Visual observation of rice morphology and farmers' interviews were conducted in a semi-structured manner. The practical knowledge and experience of farmers in the field were measured to formulate qualitative soil quality. Soil physicochemical parameters are used to formulate quantitative soil quality. Biological parameters are not used because of low microorganism activity. Characteristics of thick soils, high clay content and high plasticity index caused poor soil aeration conditions and disturbed organisms in the soil. Soil quality assessment based on soil physico-chemical parameters was also carried out by Govaerts et al. (2006), Rezaei et al. (2006), and Li et al. (2013). Analysis of soil parameters was performed using the instructions of Carter & Gregorich (2009), including moisture content with gravimetric method, bulk density with ring method, porosity by calculating bulk density and particle density, hydraulic conductivity with permeameter method, texture with hydrometer method, pH H_2O with soil: water suspension (1:2.5), organic soil carbon with Walkley and black method, total N with Kjeldahl method, available P with Bray method (acid soil) and Olsen method (alkaline soil), and exchangeable Ca, Mg, Na, K and cation exchange capacity with 1 N ammonium acetate and 10% sodium chloride extraction.

Soil Quality

Qualitative method

The approach used to formulate a qualitative soil quality index was an illustrative case study. According to Hollweck (2016), illustrative case studies allow the understanding at the local and detailed level for farmers. Individual interview methods with a semi-structured questionnaire were used to collect data in the form of information on conditions and management of the soil as well as on rice production. The weighting process was used based on soil functions and minimum qualitative data sets, including soil color, plant conditions, texture (sand content), ease of tillage, wet-dry periods, and drainage. A qualitative soil quality indexing system is presented in Equation [I] (Adeyolanu & Ogunkunle, 2016) with modification:

$$\text{SQ-QL}= \left(\sum_{i=1}^{n} Wi \times Si\right)\times W(SF) \qquad [1]$$

Where SQ-QL: qualitative soil quality; Wi: variable weight i; Si: variable score i; W(SF): soil function weight.

Quantitative method

The SMAF method has been developed to assess soil quality with three basic steps, namely: the selection of indicators, interpretation of indicators, and integration into soil quality index values. Andrews et al. (2004) explained that the selection of indicators must be following the objectives of land management, soil function, and site-specific factors (area or plant sensitivity). Indicator interpretation involves the transformation of each minimum data set using a non-linear scoring curve (Andrews et al., 2002). The assessment uses an algorithm that links the empirical value of the indicator measured by the performance of the soil function. Each indicator size is transformed through an assessment algorithm into a score without units (0 to 1), which represents the level of soil function in the system. Equation [2] has been developed by Masto et al. (2007) and Mukhopadhyay et al. (2016) to formulate non-linear scoring.

$$Si = {}^{a}\Big/\left[1+\left(\frac{x}{x0}\right)^{b}\right] \qquad [2]$$

Where a: maximum score (1.00); x: soil properties values; x0: average value of each soil property; b: gradient value of the equation (-2.5 for ‘more is better’, 2.5 for ‘less is better’).

The weighting in the quantitative soil quality index was determined based on varian percentage. The variance percentage was generated from selected Principal Component (PC). The formulation of a quantitative soil quality index is presented in Equation [3]:

$$\text{SQ-QN}= \left(\sum_{i=1}^{n} Wi \times Si\right)\times W(SF) \qquad [3]$$

Where SQ-QN: quantitative soil quality; Wi: variable weight i; Si: variable score i; W(SF): soil function weight

The result at minimum data set was grouped into five soil functions in the agricultural perspective, i.e.: (1) availability of nutrients; (2) rooting media; (3) root penetration; (4) water storage capacity; and (5) soil permeability.

Statistical analysis

Principal Component Analysis (PCA) is performed to determine the minimum data set of sensitive soil properties. The PC value is determined based on eigenvalue >1. Correlation analysis is performed to determine the minimum data set on the selected PC. Statistical Analysis Data were analyzed using Minitab software version 16.0 and maps using ArcGIS 10.5 software.

RESULTS

The study area is located in the disposition zone with colluvium sediment type material. Colluvium deposits allow a mixture of sand and fresh rock fractions to be found. Based on local information, the disposition zone was formed due to a landslide process on the surrounding cliffs. Budianto (2016) added the study area was formed by colluvial plain with material derived from Sumbing Muda volcanic ash mixed with landslide sediment. A total of 12 qualitative sample points were observed according to the minimum data set that had been formulated. Based on Table 1, the condition of plants at the study site was moderate, and the color of the soil showed a red-yellow matrix with a different hue and chroma value.

Texture at the study site was dominated by clay with a consortium of dust fractions and sand minorities. The sand fraction was found at site 1 due to the parent material in the form of sandstone interbreeding. Soil tillage was categorized as moderate to severe caused deep solum and high clay content. The wet-dry periods and drainage have affected from characteristics of soils and climate at the study site.

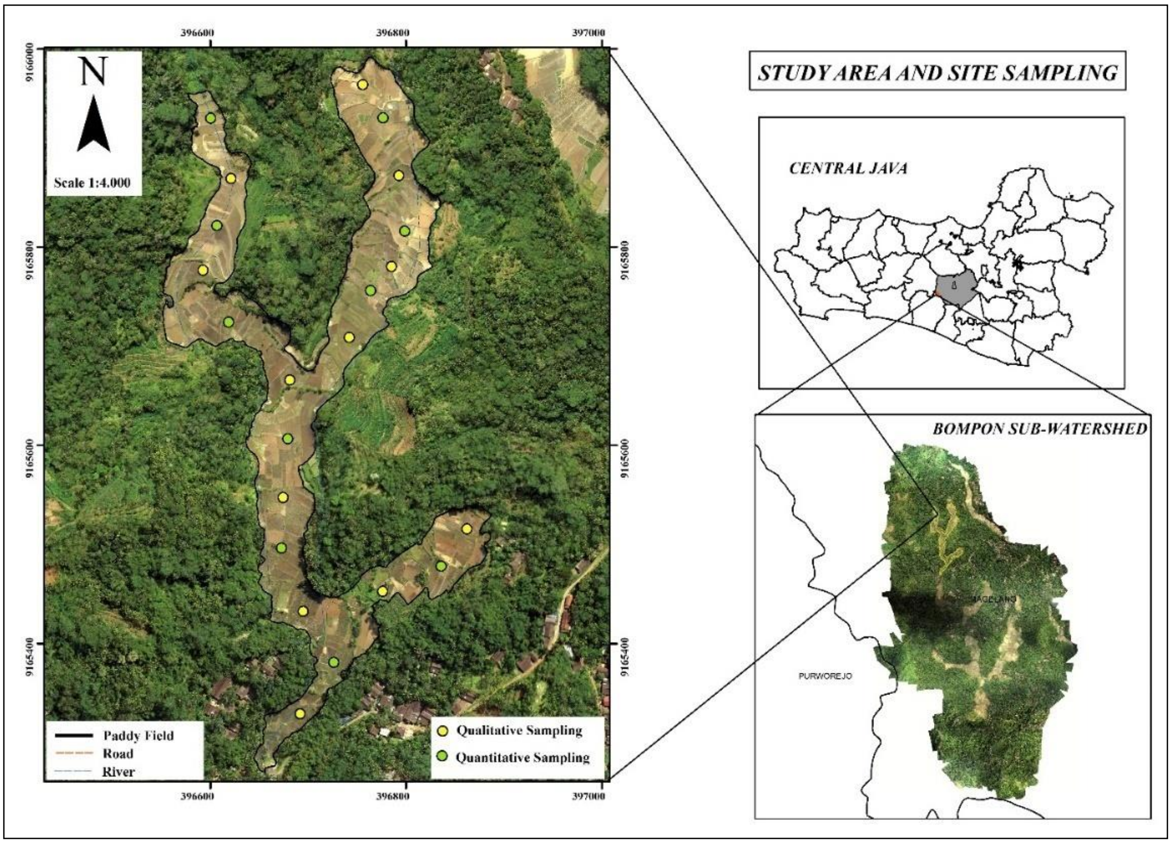

Figure 1. Research location

Table 1. Qualitative observations in the research location

Parameters	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Site 11	Site 12
Soil Color	5YR 5/4	5YR 4/6	7.5YR 4/4	7.5YR 4/4	5YR 5/4	10YR 4/6	7.5YR 4/4	7.5YR 4/6	5YR 4/6	5YR 4/6	5YR 4/6	5YR 4/6
Plant condition	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
Field texture	Sandy Clay	Clay	Silty Clay	Clay	Clay	Silty Clay	Silty Clay	Silty Clay	Silty Clay	Silty Clay	Silty Clay	Silty Clay
Ease of tillage	Medium	Hard	Hard	Hard	Medium	Medium	Hard	Hard	Medium	Medium	Medium	Medium
Dry/wet period	Low	Medium	Medium	Medium	Low	Medium	Medium	Medium	Medium	Medium	Low	Medium
Drainage	Low	Medium	Low	Medium	Medium	Medium	Low	Low	Low	Medium	Low	Medium

Remarks: 5YR 5/4 (reddish brown); 5YR 4/6 (yellowish red); 7.5YR 4/4 (dark brown); 10YR 4/6 (dark yellowish brown); 7.5YR 4/6 (strong brown); 5YR 4/6 (yellowish red)

Table 2. Physical-chemical properties of the soil

Parameters	Site 1		Site 2		Site 3		Site 4		Site 5		Site 6		Site 7		Site 8		Site 9		Site 10	
(cm)	0-20	20-40	0-20	20-40	0-20	20-40	0-20	20-40	0-20	20-40	0-20	20-40	0-20	20-40	0-20	20-40	0-20	20-40	0-20	20-40
BD	1.11	1.09	1.12	1.10	0.99	0.97	1.22	1.21	1.17	1.18	1.06	1.07	1.07	1.07	1.08	1.12	1.16	1.14	1.05	1.04
PD	2.37	2.30	2.40	2.41	2.37	2.28	2.29	2.26	2.27	2.35	2.41	2.29	2.24	2.29	2.32	2.59	2.20	2.24	2.21	2.27
POR	53.09	52.61	53.24	54.22	58.17	57.39	46.57	46.45	48.47	49.86	56.02	53.06	52.44	53.27	53.41	56.86	47.47	49.35	52.59	54.18
HC	0.34	0.32	0.43	0.39	0.51	0.72	1.43	1.33	0.47	0.38	0.32	0.24	0.22	0.20	0.27	0.29	0.45	0.53	0.67	0.69
Texture	clay	clay	clay	clay	clay	clay	clay	clay	clay	clay	clay	clay	clay	clay	clay	clay	clay	clay	clay	clay
Sand	12	11	12	12	6	7	24	17	12	13	14	12	12	9	11	15	13	18	9	11
Silt	25	20	25	25	28	26	26	24	28	18	19	16	16	16	25	20	19	17	22	20
Clay	63	69	63	63	66	67	50	59	60	69	67	72	72	75	64	65	68	65	69	69
pH	5.8	5.8	5.9	6.2	6.7	6.2	5.6	6.1	5.8	5.8	5.9	5.9	5.7	5.7	5.7	6.3	5.6	5.7	5.5	6.0
SOC	1.6	0.99	1.6	1.5	2.9	2.3	1.5	0.91	1.4	1.2	1.9	1.2	1.8	1.2	1.8	1.1	1.2	1.2	1.9	1.9
T-N	0.15	0.10	0.15	0.11	0.21	0.12	0.08	0.06	0.09	0.10	0.14	0.09	0.12	0.09	0.11	0.12	0.05	0.09	0.25	0.13
C/N	11	10	11	14	14	19	19	16	15	12	14	14	15	14	16	10	24	14	8	13
Av. P	41	24	31	34	13	16	17	21	40	22	37	25	14	13	26	24	30	37	32	20
Ex. K	0.22	0.50	0.35	0.58	0.31	0.41	0.17	0.44	0.04	0.26	0.50	0.55	0.51	0.69	0.50	0.59	0.39	0.52	0.26	0.14
Ex. Na	0.60	0.54	0.60	0.71	0.75	0.91	0.09	0.25	0.28	0.39	0.68	0.61	0.42	0.57	0.56	0.62	0.35	0.26	0.48	0.79
Ex. Ca	6.14	4.36	6.32	5.71	10.98	9.24	4.32	6.04	6.93	6.24	8.01	6.70	4.97	5.35	7.02	5.34	4.10	4.75	5.18	6.07
Ex. Mg	1.77	1.73	1.49	1.55	2.14	2.32	1.46	2.04	2.03	2.26	1.82	2.01	1.60	1.89	1.85	2.30	1.33	1.61	1.15	1.71
CEC	12.9	10.0	13.5	12.4	15.6	13.7	8.4	9.2	12.2	10.5	11.7	10.0	10.5	9.5	11.8	9.4	8.8	12.3	14.9	12.5
BS	68	72	65	69	91	94	72	96	76	87	94	99	71	89	84	94	70	58	47	70

Remarks: BD= Bulk Density (g/cm^3); PD= Particle Density (g/cm^3); POR= Porosity (%); HC= Hydraulic Conductivity (cm/h); SOC= Soil Organic Carbon (%); T-N= Total Nitrogen (%); C/N= Ratio C/N; Av. P= Available P (mg/kg); Ex. K= Exchangeable K (cmol(+)/kg); Ex. Na= Exchangeable Na (cmol(+)/kg); Ex. Ca= Exchangeable Ca (cmol(+)/kg); Ex. Mg= Exchangeable Mg (cmol(+)/kg); CEC= Cation Exchange Capacity (cmol(+)/kg); BS= Base Saturation (%)

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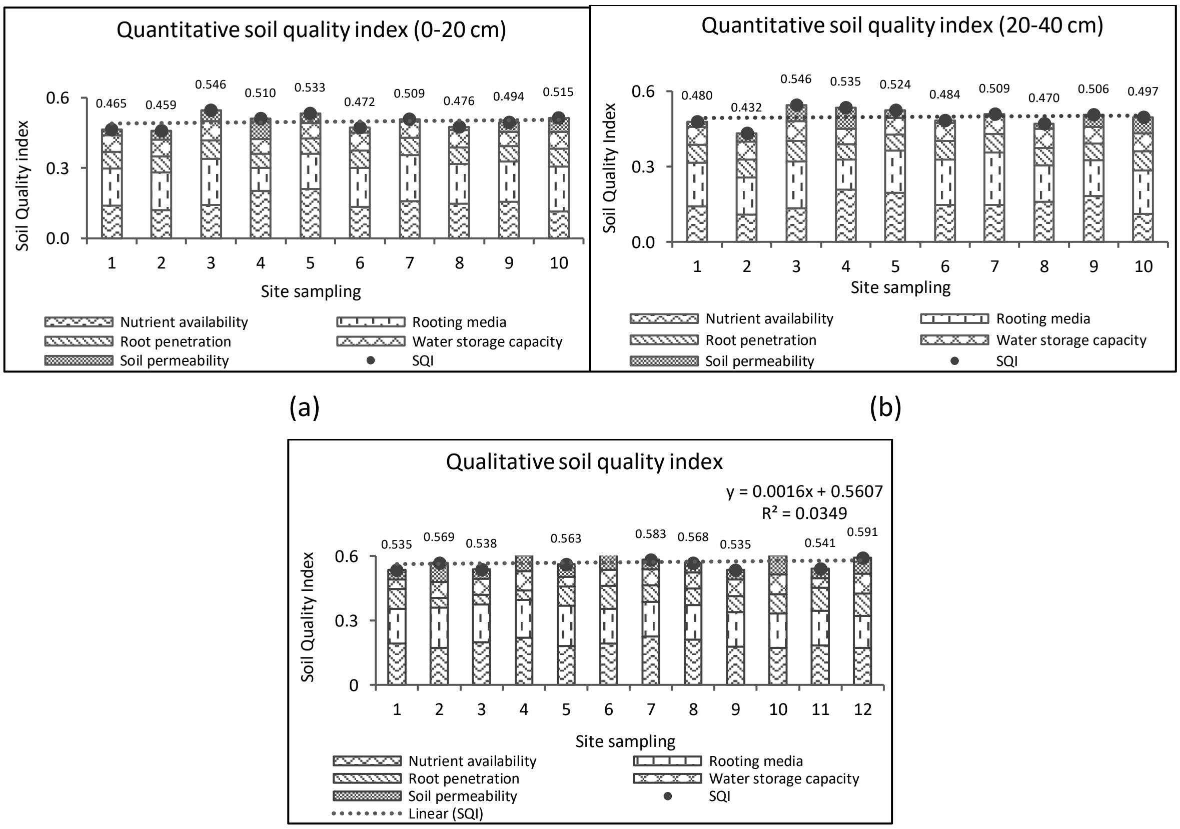
The physical-chemical properties of the soil are used as a determinant indicator for quantitative soil quality (Table 2). A sampling at depths of 0-20 cm and 20-40 cm is assumed to represent the ability of the soil to support plant growth. Based on the analysis of the soil physical properties, the soil has a low bulk density (<1.2 g cm^{-3}) and high porosity (40-60%) with clay texture, indicating that the soil is easily cultivated to a depth of 40 cm with high ability to retain water and good rooting media. Mechanized tillage is constrained because of the depth and high plasticity of the soil. Soil permeability is slow to slow, indicating the low ability to pass water and poor drainage. The porosity and permeability parameters of the soil strengthen that the soil is easily flooded.

In general, the chemical properties of soil at a depth of 0-20 cm are relatively higher compared to at a depth of 20-40 cm. Soil pH values are slightly acidic (5.5-6.5), base saturation is relatively high (more than 60%), and cation exchange capacity is low (less than 16 cmol(+) kg^{-1}). Pulungan & Sartohadi (2018b) explained that the material from andesitic breccia parent material undergoing geothermal alteration showed high base saturation, low CEC, and high clay content. Organic C content <2% and total N <0.2% are categorized as low criteria. The use of organic fertilizer that is low and not continuous causes low organic C and total N content. The availability of P indicates low to moderate values that correlate with pH values. pH values tend to be slightly acidic, causing P to be fixed by Al and Fe in the soil. In general, the physical-chemical properties of quantitative soils can support plant growth.



(c)

Figure 2. Quantitative soil quality index at 0-20 cm (a), at 20-40 cm (b) and qualitative soil quality index(c)

DISCUSSION

Knowledge of agricultural soil is very important to maintain or improve soil quality. Reliable, objective and consistent assessment of soil quality requires systematic methods to measure and interpret soil properties. Qualitative soil quality index was performed using the concept of ethnopedology. According to Barrera-Bassols & Zinck (2003), ethnopedology aims to understand local approaches in the perception of indigenous land, local classification, assessment of soil quality, land use, and land management. Farmers' knowledge about soil/land and its management is a local and site-specific wisdom system.

The PC value was obtained by involving eigenvalue >1. At each selected PC, the loading factor with the highest value was determined. Other loading factors were determined based on correlation with a significance of 0.01 and not less than 90% of the highest loading factor value. Table 3 shows the results of the PCA, which explained more than 76.8% of the variation of soil attributes. The minimum data set selected for quantitative soil quality analysis includes porosity, bulk density, Na-dd, sand, silt, clay, permeability, and Mg-dd. Soil texture is the most basic physical properties of soil (Schoenholtz, Miegroet & Burger, 2000) and is considered the most effective indicator of soil quality (Li et al., 2013). The selected soil texture becomes the minimum data set and correlates with bulk density, porosity, and permeability. Plant root systems, air, and water circulation can be negatively affected by increasing bulk density (Doran, 2002). Base cations such as Na-dd and Mg-dd become the minimum data set related to the response and availability of nutrients for plants.

Table 3. Principal Component Analysis (PCA)

Eigenvalue	6.2728	3.3306	1.9155
Proportion	0.418	0.222	0.128
Cumulative	0.418	0.640	0.768
Variable	**PC1**	**PC2**	**PC3**
pH	0.247	– 0.082	0.448
Soil organic carbon	0.311	– 0.213	– 0.084
Total N	0.290	– 0.128	– 0.325
Available P	– 0.086	– 0.128	– 0.367
Exchangeable K	0.040	0.417	0.144
Exchangeable Na	**0.352**	0.098	0.013
Exchangeable Ca	0.319	– 0.177	0.227
Exchangeable Mg	0.144	0.046	**0.564**
Cation Exchange Capacity	0.291	– 0.244	– 0.295
Sand	**– 0.331**	– 0.110	0.107
Silt	0.092	**– 0.468**	0.111
Clay	0.164	**0.441**	– 0.161
Bulk density	**– 0.362**	– 0.111	0.124
Porosity	**0.366**	0.104	0.015
Hydraulic conductivity	0.088	**0.435**	– 0.098

Remark: Bold= minimum data set

Table 4. Weighting on the soil function, qualitative soil quality, and quantitative soil quality

Soil function	Qualitative			Quantitative		
	W_{SF}	Parameter	W_{MDS}	W_{SF}	Parameter	W_{MDS}
Nutrient availability	0.300	Soil color Plant condition	0.600 0.400	0.302	Ex. Na Ex. Mg	0.449 0.551
Rooting media	0.250	Field texture (coarse fraction)	1.000	0.323	Sand Silt Clay	0.395 0.311 0.293
Root penetration	0.150	Ease of tillage	1.000	0.140	Bulk density	1.000
Water storage capacity	0.150	Dry/wet period	1.000	0.141	Porosity	1.000
Soil permeability	0.150	Drainage	1.000	0.094	Hydraulic conductivity	1.000

Remarks: W_{SF}= Weighting factor of soil function; W_{MDS}= Weighting factor of minimum data set

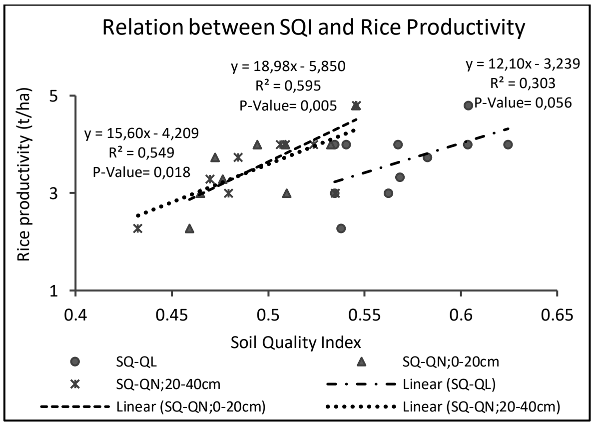


Figure 3. Relationship between soil quality index and rice productivity

Weighting was divided into two, namely weighting for each minimum data set and weighting on soil functions (Table 4). The linear scoring method requires little prior knowledge of the soil work system, while the non-linear scoring requires in-depth knowledge of the behavior and work of the soil indicator (Yu et al., 2018). The non-linear scoring method is considered as an appropriate method for indexing soil quality indicators as has been done by previous researchers (Andrews et al., 2002; Askari & Holden, 2015; Mukhopadhyay et al., 2016; Zhao et al., 2017; and Yu et al., 2018). The results of the study show that non-linear scoring is considered more objective.

Figure 2 presents qualitative and quantitative soil quality indexes with the property of soil function indicator. The qualitative soil quality index presents the highest proportion of nutrient availability. Local understanding of farmers assumes that soil color and plant conditions interpret nutrient availability. The quantitative soil quality index presents rooting media as the highest proportion. Penetration and root development are influenced by soil texture as a function of rooting media. Both qualitative and quantitative soil functions positively affect plant responses. The effect of soil quality on the plant response can be seen in plant productivity. This research presents rice productivity data based on the results of farmer interviews and observations in the field when harvesting. The relationship between qualitative and quantitative soil quality on rice productivity is presented in Figure 3.

Quantitative soil quality had P-value <0.05 which is 0.005 (0-20 cm) and 0.018 (20-40 cm), while qualitative soil quality has a P-value >0.05 (0.056). Quantitative soil quality shows a higher correlation (R^2 value) than qualitative soil quality, indicating that quantitative soil quality is more objective and accurate. The quantitative soil quality shows a higher R^2 than qualitative soil quality. The quantitative and qualitative soil quality indexes show positive linear equations, which means that improvement in soil quality (x) will be followed by plant response or rice productivity (y). The results of the study are in line with Masto et al. (2007), proving that the response of soil quality increased with long-term nutrition supply, which was followed by increased plant growth. The best linear relationship is shown in quantitative soil quality at 0-20 cm depth (R^2= 0.595) and continued at 20-40 cm depth (R^2= 0.549). The linearity results are in accordance with the predictions and expectations of researchers, which prove that the indexing of soil quality multiplied by soil functions is more objective and accurate.

CONCLUSION

Soil quality assessment using the soil function approach is more objective and accurate. The soil function information obtained has weighting criteria based on the farmers' perspective and the proportion of each PC. Soil function information includes nutrient availability, rooting media, root penetration, water storage capacity, and water permeability. Positive linearity is shown between the index of soil quality and the productivity of lowland rice. Quantitative soil quality can be recommended to researchers, stakeholders, and farmers. However, the qualitative soil quality method was useful, especially for farmers with limited time and cost.

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