POLISH JOURNAL OF SOIL SCIENCE
VOL. LI/2 2018 PL ISSN 0079-2985

DOI: 10.17951/pjss/2018.51.2.173

SUPRIYADI SUPRIYADI*, RACHMAWATI SEPTIANA*,
HERAWATI AKTAVIA*, PURWANTO PURWANTO*

SOIL QUALITY ASSESSMENT OF THE RAINFED LOWLAND RICEFIELDS UNDER ORGANIC AND CONVENTIONAL FARMING SYSTEMS IN KALIWUNGU (CENTRAL JAVA)

Received: 05.01.2018
Accepted: 23.05.2018

Abstract. Rainfed lowland rice is grown in land where the irrigation systems depend on rainwater. The use of chemical fertilizers in large quantities in order to improve production of rice will result in soil quality degradation. In order to improve the condition of the soil, a system of organic farming was provided. The aim of this study was to quantify soil quality in rainfed lowland ricefields using soil quality indexes (SQI) and to compare SQIs of farming system under organic and conventional fertilization. The sample consists of seven sample points on soil fertilized organically and three sample points on soil which is managed in a conventional way, each taken from 5 subpoints at a depth of 0–30 cm and analyzed for 12 soil variables. The best representative soil quality variables forming a minimum data set (MDS) were selected using principal component analysis (PCA), and soil quality scores were obtained using both linear and non-linear scoring functions. The study results indicate that in case of organic farming system, the soil quality was better (SQI = 2.079) when compared to its quality in the conventional farming system (SQI = 1.397). The selected indicators used as the MDS are soil porosity, cation exchange capacity (CEC), soil organic carbon, C/N ratio, soil permeability, available-P (Av-P), and electrical conductivity (EC).

Keywords: soil quality index (SQI), rainfed lowland rice, principal component analysis (PCA), minimum data set (MDS)

* Department of Soil Science Faculty of Agriculture, Sebelas Maret University. Jl. Ir. Sutami 36A, Jebres, Surakarta, Central Java 57126, Indonesia; corresponding author: supriyadi_uns@yahoo.com

INTRODUCTION

Soil quality shows the ability of the soil to display its functions in land use or ecosystems, to support biological productivity, environmental quality and improve plant, human, and animal health (Plaster 2003). Indonesia has very large areas of rainfed lowland rice. Productivity of this land is generally lower than irrigated paddy fields, it only ranges from 3.0 to 3.5 tons/ha. Common production constraints on this land include: erratic rainfall, dense weeds, and low soil fertility (Widyantoro 2010). Soil fertility is one of the indicators of soil quality. Low soil fertility shows low soil quality, otherwise, good soil fertility indicates good soil quality. Good soil quality will support the functioning of soil as a medium for plant growth, regulate and divide the flow of water and support a good environment (Winarso 2005).To solve the productivity problems of rainfed lowland rice areas, farmers use a variety of chemicals such as inorganic fertilizers and pesticides. The use of inorganic fertilizers and pesticides in large quantities will affect the soil quality of the paddy fields (Lantoi *et al*. 2016). Degradation of environmental quality, especially agricultural land, due to the use of synthetic fertilizers and other chemicals encourages the development of organic farming systems. Organic farming is an agricultural system that uses only natural materials, whether provided by ground or cultivated by the plants. The main characteristic of organic farming system is the use of locally grown varieties followed by the use of organic and pesticides fertilizers. In terms of health, organic products are safe for human consumption because they are free from harmful residues. According to Astuti (2006), the average productivity of soil under organic farming system is higher than that of soil managed conventionally. Higher soil productivity also indicates higher soil quality. Some of the advantages that can be gained from the application of organic farming systems, especially those related to soil fertility, is their effects on the physical, chemical, and biological properties of the soil. This study aims to examine the differences in soil quality of rainfed lowland rice under organic and conventional farming systems.

MATERIALS AND METHODS

Field survey

The study was conducted in the Kaliwungu village. The geographical coordinates of the village are 110°62’43”E and 7°46’41”S and the altitude is about 357 m a.s.l. The total study area is 6.12 km^2 with various land uses, such as settlement (34.8%), shrubs (15.5%), moor (14.5%), and paddy field (33%). The method used in this research is descritive-explorative. Information is collected from the field survey and supported by laboratory analysis. Soil sample was taken in order to analyze its physical, chemical and biological properties. The points of soil samples were determined by stratified random sampling using Land Map Unit (LMU) based on the overlay of slope maps, soil type maps, land use maps, and rock distribution maps. Based on the result of the overlay of some maps, there were obtained 7 sample points on soil with organic fertilization and 3 sample points in case of soil which is managed in a conventional way. The soil samples were collected from soil at a depth of 0–30 cm and were the composite of 5 sub samples.

Laboratory analysis

Observation variables include physical, chemical and biological properties of the soil. Soil analysis was compared to existing references (Table 1). The soil properties include soil porosity, soil permeability, soil texture, electrical conductivity (EC), hydrogen potential (pH), redox potential (Eh), available-P (Av-P), available-K (Av-K), cation exchange capacity (CEC), base saturation, total-N, soil organic matter and soil respiration (qCO_2).

Table 1. The procedure of physical, chemical and biological analysis of the soil

Parameters	**Method**	**References**
Soil Porosity	Using ratio bulk density and particle density methods	Indonesian Agency for Agricultural Research and Development, Ministry of Agriculture (2006)
Soil Permeability	Constant Head Permeameter method	Indonesian Agency for Agricultural Research and Development, Ministry of Agriculture (2006)
Hydrogen Potential	Electrometric method	Indonesian Soil Research Institute (2005)
Electrical Conductivity	Conductometry method	Indonesian Soil Research Institute (2005)
Total-N	Kjeldahl method	Indonesian Soil Research Institute (2005)
Available-P	Bray's method for acidic soils and Olsen's method for neutral and alkaline soils	Indonesian Soil Research Institute (2005)
Available-K	Measured by Flamefotometer	Indonesian Soil Research Institute (2005)
Base Saturation	Ammonium acetate extraction method	Indonesian Soil Research Institute (2005)
Cation Exchange Capacity	Ammonium acetate extraction method	Indonesian Soil Research Institute (2005)
Organic Carbon	Walkley–Black method	Indonesian Soil Research Institute (2005)
C/N Ratio	Using ratio carbon organic and total-N method	Indonesian Soil Research Institute (2005)
Redox Potential	Electrometric method	Indonesian Soil Research Institute (2005)
Soil Respiration	Titrimetric method	Anas (1989)

Data analysis

According to Andrews *et al.* (2004), the soil quality assessment framework is designed to follow three basic steps: indicator selection, idicator interpretation, and integration into a soil quality index (SQI) value. The result of the laboratory analysis were correlated with Pearson Correlation Analysis. The method used in determining the soil quality indicator is determined by the most influential characteristics in soil quality. SQI can be obtained by summing the score of each selected soil quality indicator to be the MDS, using the formula:

$$SQI = \sum_{i=1}^{n} Wi \times Si$$

Where, *W* is weighting index based on porportion in PC, *S* is the indicator score for each variable, and *n* is the sum of the SQI. MDS was obtained based on calculations from Principal Component Analysis (PCA) using software minitab 18.

RESULTS AND DISCUSSION

Soil properties

The results of the analysis of the quality of organic and conventional farming based on physical, chemical and biological indicators of soil (Table 2) were different. The soil physical properties used for laboratory analysis are soil porosity and soil permeability. Soil porosity where rainfed lowland rice is grown under organic farming system is 37.10%, whereas in case of conventional farming it is only 11.90%. Soil permeability in case of organic farming is 4.46 $cm \cdot hr^{-1}$ and in case of conventional farming it is only 0.424 $cm \cdot hr^{-1}$. Soil porosity and permeability in case of rainfed lowland rice under organic farming is higher than in case of conventional farming, because the high organic matter content in organic fertilizer is able to bind the soil aggreagate stability so as to increase soil porosity and permeability. It is supported by Santi (2008) that the aggregate can provide good physical condition for the development of plant roots through its effect on porosity, permeability, aeration and water retention.

Of the various soil chemical properties, all results indicate that the chemical soil properties of rainfed lowland ricefield under organic farming are higher than in case of conventional farming because soil organic matter is one of the soil amendments that can improve soil chemical properties. According to Souri (2001), using organic materials can improve soil chemical properties such as the CEC increase so the nutrient availability can be increasing and prevent the loss of nutrients from the soil due to leaching by rainwater or irrigation. As for base saturation, in the organic farming it is lower (11.49%) than in conventional farming (23.09%). Because base saturation is the ratio between the amount of basic cation (K, Na, Ca, Mg) and the amount of all cations contained in the soil exchange site. In the study area, the CEC for organic farming is higher (31.53 me/100 gr) than that for conventional farming (23.81 me/100 gr), so it makes the base saturation in organic soil lower than in inorganic soil.

Soil respiration shows the activity of microorganisms in the soil. Higher soil respiration indicates the higher number of microorganisms contained in the soil. High soil respiration rate indicates that biological activities occur at higher and faster pace than the decomposition of organic matters (Supriyadi *et al*. 2014). The result showed that soil respiration value is higher in case of organic farming (0.41 mg CO_2/cm/day) when compared to conventional farming (0.29 mg CO_2/cm/day), because areas where rainfed lowland rice is grown under organic farming contain more microorganisms when compared to conventional farming system. Soil that contains many organic materials will become an ideal habitat for microorganisms, because organic matter is the food source for microorganisms. As a result, *Eh* in case of organic farming is 201 mV, whereas in case of conventional farming it is 216 mV. Cyio (2008) explained that the submerged soil will lead to O_2 depletion and it will be followed by the decrease of *Eh*. Since soil *Eh* decreases in response to flooding it may even reach the value of -350 mV.

Table 2. Results of soil properties analysis in rainfed lowland ricefield of Kaliwungu

Soil Properties [a)]	Organic Farming	Conventional Farming
Soil Porosity (%)	37.10	11.90
Soil Permeability ($cm\cdot hr^{-1}$)	4.46	0.424
pH	6.43	6.36
CEC ($cmol\cdot g^{-1}$)	31.53	23.81
OC (%)	1.52	0.74
Total-N ($mg\cdot g^{-1}$)	0.33	0.27
C/N Ratio ($mg\cdot g^{-1}$)	4.86	2.92
Av-P ($mg\cdot g^{-1}$)	20.87	20.10
Av-K ($mg\cdot g^{-1}$)	0.72	0.52
Base Saturation (%)	11.49	23.09
EC (dS)	0.62	0.49
qCO_2 (mg CO_2 cm^{-1} day^{-1})	0.41	0.29
Eh (mV)	201	216

[a)] SP – Soil Permeability; pH – Hydrogen Potential; CEC – Cation Exchange Capacity; OC – Organic Carbon; Av-P – Available P; Av-K – Available K; BS – Base Saturation; EC – Electro Conductivity; qCO_2 – Soil Respiration; Eh – Redox Potential

Indicator correlation

Correlation is used to find out indicators that affect other indicators. Indicators have a strong correlation if the Pearson correlation value is close to 1 or -1 and the *P*-value is less than α (5%). A positive correlation (close to 1) indicates that both indicators are mutually beneficial, an increase in one indicator will raise another indicator, whereas a negative correlation (close to -1) means that an increase of one indicator will decrease the value of another one. As mentioned by Sarwono (2006), the correlation coefficient shows the strength of the linear correlation and relation of two random variables. If the correlation coefficient is positive, that means that both variables have significant relation. But if the correlation coefficient is negative, the two variables have an inverse relation.

Based on the correlation analysis (Table 3) there were found some indicators that have a strong correlation, either positive or negative. Organic matter has positively correlated with soil permeability (r = 0.728). According to Tan (1998), organic materials can improve the physical, chemical and biological soil properties. One of the physical soil properties that is affected by organic matter is the soil permeability. This view is supported by Islami and Utomo's (1995) statement that the increase in soil organic matter content, as a binding agent in the formation of soil aggregates, can lead to inter-aggregate space (macro pore) and pore space in aggregates (micro pores) become more precise so that the aeration pores and water available pores make the amount of organic matter higher so that the permeability is better.

Table 3. Correlation analysis results

Var[a)]	Por	SP	pH	CEC	OC	Tot-N	C/N	Av-P	Av-K	BS	CEC	qCO_2
SP	0.54											
pH	0.26	-0.31										
CEC	**0.74***	0.53	0.19									
OC	0.55	**0.73***	-0.15	0.13								
Tot-N	0.31	-0.03	0.12	0.10	-0.11							
C/N	**0.87***	0.40	0.28	0.64	0.31	0.32						
Av-P	0.19	0.44	0.10	0.25	0.46	-0.08	0.01					
Av-K	0.37	0.36	0.19	0.68	-0.23	0.25	0.52	-0.11				
BS	-0.85	-0.46	-0.12	-0.80	-0.32	-0.13	-0.79	-0.31	-0.40			
EC	0.14	-0.01	-0.16	0.25	-0.24	0.01	0.52	-0.15	0.48	-0.38		
qCO_2	**0.66***	0.43	-0.21	0.22	**0.67***	0.33	0.39	-0.08	-0.17	-0.34	-0.27	
Eh	-0.10	-0.57	0.62	-0.08	-0.46	0.27	-0.15	-0.16	-0.19	0.14	-0.49	-0.12

[a)] Var – Variables; Por – Porosity; SP – Soil Permeability; pH – Hydrogen Potential; CEC – Cation Exchange Capacity; OC – Organic Carbon; Tot-N – Total N; C/N – C/N ratio; Av-P – Available P; Av-K – Available K; BS – Base Saturation; EC – Electro Conductivity; qCO_2 – Soil Respiration; Eh – Redox Potential.

The asterisk means a positive correlation. The underlined values mean a negative correlation.

According to Hairiah (1996), organic material serves as a binder of aggregate stability, so that the infiltration rate increases and the soil porosity is higher too. Hardjowigeno (2007) revealed that the soil porosity is influenced by the organic matters content, structure, and soil texture. Soil porosity is better when the organic matter content is high. C/N ratio is the ratio between carbon mass and nitrogen. Higher C/N ratio entails higher organic matter content. Therefore, the C/N ratio also has a positive correlation with porosity (r = 0.868). Similar to organic matter and C/N ratio – CEC also has positively correlated with porosity (r = 0.735). This is the case because, according to Nugroho and Istianto (2009), the value of CEC is related to organic matter. Half of the CEC value is formed of organic matter, because the decomposition process of microbes that always attach to organic matter can improve the ability of soil absorption. The organic matter is strongly correlated with porosity, hence, higher CEC indicates higher porosity.

Base saturation has a negative correlation with porosity (r = -0.861) and C/N ratio. That means that if base saturation increases, the porosity and C/N ratio will decrease, and *vice versa*. One of the factors that increase C/N ratio is the high activity of microorganism. Most microorganisms can grow well at neutral pH (4–6), some microorganisms can survive even under low pH conditions. According to Soewandita (2008), the base saturation is related to pH, where soils with high pH have high base saturation, so that on soils with high pH or alkaline conditions, the C/N Ratio becomes low due to the absence of activity from the predominant miroorganism that helps decomposition of organic matter. The low activity of microorganisms will also decrease soil porosity because microorganisms can improve soil porosity through the improvement of soil structure. The above-mentioned statement is in line with Lavelle *et al.*'s (1994) opinion that macrofauna activity can affect soil structure, i.e. it improves soil porosity.

Negative correlation also occurs in base saturation with CEC (r = -815). According to Hardjowigeno (2003), on the soil with low pH, the cations that will accumulate are cations with acidic properties of H^+, as well as metal cation such as Al and Fe, whereas the level of base cations (Ca, Mg, K and Na) is low. In case of dry soil with alkaline properties, the value of base saturation is high but the quantity of other cations is low so they make the CEC value lower even if the base saturation is of high value. If the CEC value is high and base saturation value is low it means that the soil is in poor condition (high H^+, Al, and Fe).

Soil respiration is positively correlated with soil porosity (r = 0.659) and organic carbon (r = 0.672). Soil respiration is the process which refers to the production of CO_2 when soil organisms respire. The activity of microorganisms can increase the soil porosity, because the movement of microorganisms can improve soil structure. This is supported by the opinion of Pairunan (1985), who stated that the value of porosity is directly proportional to the size of the soil structure. Granular soil structure makes the porosity level higher, and in case when the soil structure is low, the porosity value will also decrease. A large number of microorganisms also support the process of decomposition of organic matter, so it will be simple compounds that serve as the base ion exchangers that keep and release nutrients within the plant.

Soil Quality Index

Soil quality is measured by observing the dynamic conditions of soil quality indicators. Measurements of soil quality indicators resulted in determining a soil quality index. The soil quality index is an index calculated based on the value and weight of each soil quality indicator (Mausbach and Seybold 1998). Determination of SQI will lead to the establishment of PC value. The selected PC must have eigenvalue ≥1. Approriate indicators are chosen as the MDS. The PCA result (Table 4) showed that PC1–PC4 represent 82.7% of the total data. The selected indicators which constitute the MDS of each PC are porosity, cation exchange capacity, C/N ratio, permeability, organic carbon, electrical conductivity, and available-P. The results of the indicator scores were classified according to Wander *et al.* (2002), whereas the results of SQI calculations (Table 5) were classified on the basis of Cantú *et al*. (2007) with modification. The SQI values were normalized to a 0–10 scale by dividing each weighting factors by the total weighting factor (Mukhopadhyay *et al*. 2014).

Soil quality shows the ability of the soil to display its functions in the ecosystem, to sustain biological productivity, to maintain environmental quality, and to improve the health of plants, animals and humans. High soil quality shows high soil fertility (Winarso 2005). The results of this study, according to Cantú *et al.* (2007), showed that the quality of soil where rainfed lowland riceis grown under organic farming is moderate (2.079) and in case of conventional farming it is low (1.397). Soil under organic farming is of higher quality when compared to conventional farming because it has a high level of sustainability. Organic farming is considered as an agricultural system in which soil fertility is perceived as the production basis, and as such it can optimize the quality of all the factors involved, especially the quality of soil. In accordance with the statement of Nugroho *et al.* (2011), the high content of organic matter in the soil will improve the chemical, physical and biological properties of the soil and, in consequence, the soil quality will also increase.

The soil quality index for each sample point is presented in Figure 1. In case of some selected soil quality indicators for MDS there was indicated that porosity, organic carbon, cation exchange capacity and permability in the rainfed lowland ricefield under organic farming was higher than under conventional farming, whereas for EC, available-P and C/N ratio in organic farming was at the same level as in conventional farming. Organic farming has a significant influence on the SQI in terms of soil porosity, organic carbon, cation exchange capacity and soil permeability. Application of an organic fertilizer with high

Table 4. Results of principal component analysis (PCA) of soil indicators

Eigenvalue	**4.8023**	**2.5345**	**2.0206**	**1.3976**
Proportion	0.369	0.195	0.155	0.108
Cumulative	0.369	0.564	0.720	0.827
Variable [a)]	PC1	PC2	PC3	PC4
Porosity	**0.425***	-0.048	-0.212	-0.067
Permeability	0.336	**0.306***	0.105	0.109
pH	0.025	-0.371	-0.376	0.351
CEC	**0.369***	-0.189	0.021	0.204
OC	0.255	**0.468***	-0.156	0.044
Total-N	0.105	-0.210	-0.259	-0.415
C/N ratio	**0.392***	-0.206	-0.014	-0.136
Av-P	0.135	0.219	-0.076	**0.620***
Av-K	0.239	-0.357	0.263	0.035
BS	-0.398	0.115	0.010	-0.107
EC	0.144	-0.249	**0.521***	-0.130
qCO_2	0.242	0.271	-0.320	-0.454
Eh	-0.162	-0.318	-0.510	0.076

[a)] SP – Soil Permeability; pH – Hydrogen Potential; CEC – Cation Exchange Capacity; OC – Organic Carbon; Av-P – Available P; Av-K – Available K; BS – Base Saturation; EC – Electro Conductivity; qCO_2 – Soil Respiration; Eh – Redox Potential.

The asterisk means minimum data set.

Table 5. Soil quality value in rainfed lowland ricefield under organic and conventional farming systems

MDS [a)]	Wi	Si	
		Organic Farming	Conventional Farming
Porosity	0.369	3	1
CEC	0.369	3	2
C/N ratio	0.369	1	1
Permeability	0.195	2	1
OC	0.195	3	2
EC	0.155	1	1
Av-P	0.108	2	2
SQI		2.079	1.397
Scale		L	VL
Class		4	5

[a)] MDS – Minimum Data Set; SQI – Soil Quality Index; CEC – Cation Exchange Capacity; OC – Organic Carbon; Av-P – Available P; EC – Electro Conductivity; L – Low; VL – Very Low.

organic material content increases soil fertility and improves soil physical properties especially soil porosity. What is more, it also can improve the value of cation exchange capacity. This view is shared by Goenadi (2006) who claims that the effect of organic matter on soil physical properties can improve soil aggregate stability, thereby creating a stable soil structure ideal for plant growth resulting in good porosity levels and reduced soil density. The enhancement of organic matter with regard to its influence on soil chemical properties aims at increasing the cation exchange capacity which is the location and the nutrient center before it is utilized by the plant. Undoubtedly, organic matter can increase the permeability of the soil, because of increased soil pores. According to Arthur *et al.* (2013), the OC content increased with increased fertilisation and resulted in decreased initial bulk density, higher air-filled and total porosities, and increased organisation of the pore space. Pores are crucial in the permeability of the soil, the larger the pore in the soil, the faster the permeability of the soil.

For EC, soil available-P, and C/N ratio between organic farming and conventional farming belong to the same class. According to Ponnamperuma (1972), as the oxygen concentration in the soil solution becomes saturated, the electrons generated by the bacterial metabolism reduce N, Fe, Mn, and S, and in the process consume H^+ and cause the soil pH to increase. It will cause the dominant reduction process and, in consequence, the soil pH will increase after flooding. High pH conditions will increase soil EC levels. The increase in EC levels, will make the rice plants unable to grow properly. Additionally, too high soil pH will lead to the fixation or P-sedimentation by Mg and Ca, and, finally, to the decrease in P-availability. In dryland paddy field, under both organic and inorganic management systems, the pH conditions are not too diverse because these were not flooding conditions, so the soil pH tends to be neutral and so the level of EC and P-availability is high.

Generally, the profitability of rainfed lowland rice cultivation is not very high mainly due to low fertility and erratic rainfall patterns. Implementation of organic farming methods can improve the physical and chemical soil properties.

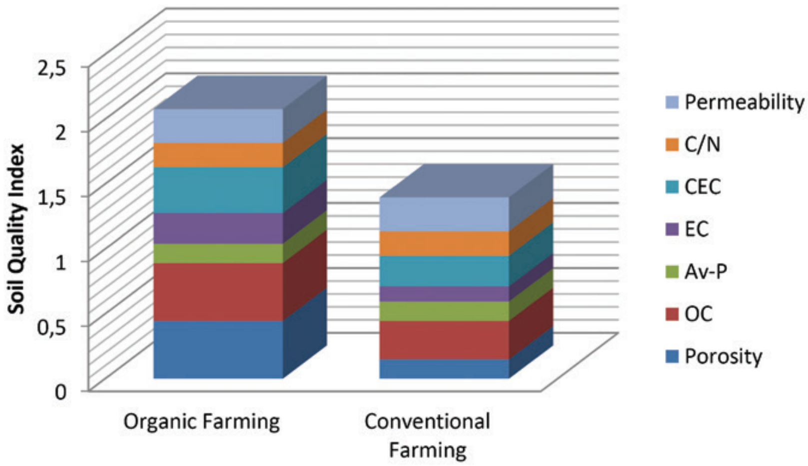

Fig. 1. Soil quality index in organic and conventional farming systems; C/N – C/N ratio; CEC – Cation Exchange Capacity; EC – Electrical Conductivity; Av-P – Available P; OC – Organic Carbon

CONCLUSIONS

1. In this study, the soil quality has been determined by using the minimum data set (MDS) from various indicators of soil quality.

2. The principal component (PC) in this study has represented 82.7% of the total data.

3. The selected indicators used as the MDS are porosity, CEC, C/N ratio, soil permeability, OC, EC, and available P.

4. The soil quality where rainfed lowland rice is grown under organic farming system is better than in case of conventional farming system since organic farming relies heavily on the natural breakdown of organic matter.

5. The application of organic farming systems in rainfed lowland ricefields can also increase the productivity of those areas which had been considered infertile.

ACKNOWLEDGEMENTS

This study was supported by the Ministry of Research, Technology, and Higher Education of the Republic of Indonesia and Sebelas Maret University, Surakarta.

REFERENCES

[1] Anas, I., 1989. *Soil Biology in Practice* (in Indonesian). Departemen Pendidikan dan Kebudayaan Direktorat Jenderal Pendidikan Tinggi. Pusat Antar Universitas Bioteknologi. Institut Pertanian Bogor.

[2] Andrews, S.S., Karlen, D.L., Cambardella, C.A., 2004. *The soil management assessment framework: A quantitative soil quality evaluation method*. Soil Science Society of America Journal, 68: 1945–1962.

[3] Arthur, E., Schonning, P., Moldrup, P., Tuller, M., Jonge, L.W.D., 2013. *Density and permeability of aloess soil: Long-term organic matter effect and the response to compressive stress*. Geoderma, 193–194: 236–245, DOI: 10.1016/j.geoderma.2012.09.001.

[4] Astuti, D.A.L., 2006. *Analysis of Organic Rice Farming in Purworejo* (in Indonesian), Skripsi, Fakultas Pertanian Universitas Negeri Sebelas Maret.

[5] Cantú, M., Becker, A., Bedano, J.,Schiavo, H.F., 2007. *Soil quality evaluation using indicators and indices* (in Spanish). Ciencia delsuelo, 25(2): 173–178.

[6] Cyio, M.B., 2008. *The effectiveness of organic matter and high of inundation to change of Eh, pH and Fe, P, Al dissolved in ultisols* (in Indonesian). Jurnal Agroland, 15(4): 257–263.

[7] Goenadi, D.H., 2006. *Fertilizer and Biological Based Fertilization Technology from Petri Dishes to Farmers Land* (in Indonesian), Yayasan John Hi-Tech. Idetama, Jakarta.

[8] Hairiah, K., 1996. *Roots as a Source of Organic Matter* (in Indonesian), Biologi Tanah, Fakultas Pertanian, Universitas Brawijaya, Malang.

[9] Hardjowigeno, S., 2007. *Soil Sciece* (in Indonesian), Penerbit Pusaka Utama, Jakarta.

[10] Hardjowigeno, S., 2003. *Ultisols* (in Indonesian), Edisi Baru. Akademika Pressindo, Jakarta.

[11] Indonesian Agency for Agricultural Research and Development, Ministry of Agriculture, 2006. *The Physical Properties of the Soil and Its Method of Analysis* (in Indonesian), Department of Agriculture, Bogor.
[12] Indonesian Soil Research Institute, 2005. *Analysis of Soil Chemistry, Plant, Water and Fertilizer* (in Indonesian), Department of Agriculture, Bogor.
[13] Islami, T., Utomo, W.H., 1995. *Soil, Water and Plant Relationships* (in Indonesian). IKIP Semarang Press. Semarang.
[14] Lantoi, R.R., Darman, S., Patadungan, Y.S., 2016. *Assessment of wetland rice soil quality at several locations in Palu Valley using lowery scoring method* (in Indonesian). Jurnal Agroland, 23(3): 243–250.
[15] Lavelle, P., Decaëns, T., Jimenez, J.J., Escobar, G., Rippstein, G., 1994. *Impact of land management on soil macrofauna in the Oriental Llanos of Colombia*. European Journal of Soil Biology, 571(30): 157–168.
[16] Mausbach, M.J., Seybold, C.A., 1998. Assessment of soil quality. In: R. Lal, (eds.), *Soil Quality and Agricultural Sustainability*, Ann Arbor Press, Chelsea, Michigan, pp. 33–43.
[17] Mukhopadhyay, S., Maiti, S.K., Masto, R.E., 2014. *Development of mine soil quality index (MSQI) for evaluation of reclamtion success: A chronosequence study*. Ecological Engineering, 71: 10–20, DOI: 10.1016/j.ecoleng.2014.07.001.
[18] Nugroho, W.A., Utomo, S., Dewi, W.S., 2011. *Preparation of soil quality management in Jatipuro Karanganyar regency* (in Indonesian). Jurnal Ilmu Tanah dan Agroklimatologi, 8(1).
[19] Nugroho, P.A., Istianto., 2009. *Characteristic and potential of ultisols for the development of rubber plants in some areas of Pulau Laut, South Kalimantan* (in Indonesian). Jurnal Penelitian Karet, 27(2): 51–64.
[20] Pairunan, A.K., 1985. *Fundamental of Soil Science* (in Indonesian), BKPT INTIM, Ujung Pandang.
[21] Plaster, E.J., 2003. *Soil Science and Management*, 4th ed., Thomson Learning, New York.
[22] Ponnamperuma, F.N., 1972. *The chemistry of submerged soils*. Advances in Agronomy, 24: 29–96.
[23] Santi, L.P., Dariah, A., Goenadi, D.H., 2008. *Stability improvement of mineral land aggregates by exopolysaccharide-producing bacteria* (in Indonesian). Menara Perkebunan, 76(2): 93–103.
[24] Sarwono, J., 2006. *Quantitative and Qualitative Research Methods* (in Indonesian), Graha Ilmu, Yogyakarta.
[25] Soewandita, H., 2008. *Soil fertility study and analysis of land suitability for plantation crop commodities in Bengkalis District* (in Indonesian). Jurnal Sains dan Teknologi Indonesia, 10(2): 128–133.
[26] Souri, S., 2001. *Using of Manure to Increase Rice Production* (in Indonesian). Instalasi Penelitian dan Pangkajian Teknologi Pertanian Mataram.
[27] Supriyadi, S., Sudaryanto, R., Winarno, J., Hartati, S., Jamil, I.S., 2014. *The quantitative soil quality assessment for tobacco plant in Sindoro mountainous zone*. Journal of Degraded and Mining Lands Management, 1(3): 105–110, DOI: 10.15243/jdmlm.2014.013.105.
[28] Tan, K.H., 1998. *Fundamental of Soil Chemistry* (in Indonesian), Gadjah Mada University Press, Yogyakarta.
[29] Wander, M.M., Gerald, L.W., Nissen, T.M., Bollero, G.A., Andrews, S.S., Deborah, A.C., 2002. *Soil quality: Science and process*. Agronomy Journal, 94: 23–32.
[30] Widyantoro dan Husin, M.T, 2010. *Optimization of Rainfed Paddy Management Through Integrated Crop Management Approach* (in Indonesian), Prosiding Pekan Serealia Nasional. Balai Penelitian Tanaman Padi.
[31] Winarso, S., 2005. *Soil Fertility: Basic of Soil Health and Quality*, Gava Media, Yogyakarta.