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THE ASSESSMENT OF SOIL QUALITY AT PADDY FIELDS IN MERAUKE, INDONESIA

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Abstract

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Indonesia's agricultural land has potentials to be expanded. To achieve a food security in Papua, Indonesia's government has been promoting a program namely Merauke Integrated Food and Energy Estate (MIFEE). The objective of this study is to determine soil quality on several paddy fields in Merauke District, Papua. Soil samples were gathered from 9 old paddy fields and 1 new paddy field (as the control). This study used the Principal Component Analysis (PCA) to determine the most appropriate indicator to form minimum data set (MDS). MDS was taken to calculate the Soil Quality Index (SQI). Some soil properties were used as indicators which were consist of soil pH, organic carbon (OC), bulk density (BD), particulate organic matter (POM), Available-N (Av-N) and it represented 89.3% of the variability of data. The results showed that all SQI in the study sites were lower than location 10/the control site (3.470), except for location 3 which has the same SQI level. In fact, land use changes from natural into paddy fields or other agriculture lands may degrade soil and land functions. Therefore, the action requires more efforts to maintain the soil function.

Key words: minimum data set; paddy field; principal component analysis; soil quality; soil quality index

Abbreviations: MIFEE – Merauke Integrated Food and Energy Estate; PCA – Principal Component Analysis; SQI – Soil Quality Index; MDS – Minimum Data Set; OC – Organic Carbon; BD – Bulk Density; POM – Particulate Organic Matter

Introduction

Rice is main food for most Indonesian citizen. Rice availability has big impact on food safety. In Indonesia, it depends on rice import. In 2015 (January-December), the total of rice imports has reached 1,222 million tons (Santoso, 2015) which is higher than in 2014 approximately 0.815 million tons (Statistics Indonesia, 2014). It was mostly caused by the conversion of agricultural land. Winoto (2005) stated that the annual rate of paddy field conversion has reached 187 720 ha, 56 000 ha in Java and 132 000 ha in other islands (Irawan, 2005), 58.68% of paddy fields are converted to non-agricultural activities and to non-rice production activities. Therefore, the government was forced to maintain the food security through the opening of new paddy fields.

Furthermore, the paddy soil has easily declined of soil fertility and soil quality (soil degradation), particularly which used continuously. Some researcher stated that the characteristics of rice cultivation are consist of (1) puddling during land preparation, (2) the provision of water-logging

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and drying during plant maintenance. The land preparation may lead to the destruction of soil aggregates, which leads to soil particles and its other physical properties destruction (Hardjowigeno, 2009) in (Sudaryanto, 2009).

According to Agus and Wahyunto (2003), Sutono et al. (2003) and Kundarto et al. (2003), paddy fields has the ability to control erosion and sedimentation; however, soil puddling may degrade soil particle and it affects to the soil physical properties, such as water retention, bulk density and soil permeability (Sharma and De Datta, 1985). Subagyono et al. (2001) stated that the puddling may increase the soil bulk density, increasing the run-off water and decreasing soil quality.

Practically, soil quality is not measureable; however, some indicators are possible to measure quantitatively. Various definitions of the indicators are indicated within the literature, it suggests an emphasis on measuring and monitoring soil properties that may affect soil's ability to perform its proper function. The United States Department of Agriculture has defined the indicators of soil quality in terms of its measurable physical, chemical, and biological properties to monitor soil changes. In general, the values of indicators are taken to determine the soil's ability to fulfill its functions (Anda, 2002).

In fact, the Soil Quality Index (SQI) has recognized as a tool to determine an adaptive soil resource management (Karlen et al., 2001). In particular, this study attempts to investigate any condition which has a correlation between the indicators and soil quality status of old and new paddy fields through the SQI. The results were expected as a reference for other regions with similar conditions, it includes land management recommendations which has potential soil quality maintenance.

Materials and Methods

Study site and soil sample determination

This study was conducted in laboratory and field. Field study was conducted in Merauke District, Papua. The study site was located in tropical region (137°-141° E and 6°00'-9°00' S). It has monsoon climate zone with warm temperature (25°-29°C). It has also abundant sun light during the dry season and substantial rainfall during the wet season. The average of annual precipitation is approximately 1.513 mm. The slope ranges between 0-45%. The analysis of soil physical, soil chemical and soil biological properties were conducted on Laboratory of Soil Biology and Biotechnology (Faculty of Agriculture), Central Laboratory of Mathematics and Sciences in the Universitas Sebelas Maret, Surakarta and the Faculty of Agriculture in Musamus University, Merauke. This study was conducted on September to November 2015. The soil samples were taken purposively (purposive sampling) in different area and soil type.

Materials and tools

The materials and tools were used in the field analysis consist of soil auger, clinometer, pH stick, distilled water, and other chemicals for soil judgement. The materials consist of disturbed and undisturbed soil from 0~20 cm depth. Samples were taken from four different points and mixed. Vegetations and stones were removed from the sample.

Laboratory and data analysis

Soil bulk density (BD – clod method), soil aggregated stability (SAS – dry and wet sieving method), soil porosity (SP – ratio of BD and particle density method). Soil pH was determined in 1:2.5 soil-water suspension and measured using a pH-meter, Cation Exchange Capacity (CEC – the ammonium chloride-ammonium acetate method), organic carbon (OC – Walkey and Black method), available-N (Av-N – Kjeldahl method), Available-P (Av-P – Bray I method), Available-K (Av-K – Flamephotometer), electrical conductivity (EC – Conductometer), particulate organic matter (POM – the size fraction method) (Gregorich et al. 2006), and soil respiration (qCO_2 – titrimetric method).

The results of data were analyzed by Pearson Correlation and Principal Component Analysis (PCA). Soil quality was assessed by SQI (scoring of selected variables). The scores are between the interval of 0.1~1.0. The high score indicates that the soil has high quality. SQI formula was based on Andrews et al.(2004) and Qi at al. (2009) with modification as follows:

$$SQI = \frac{\sum_{1}^{n} wi \times si}{n},$$

where: *SQI* – soil quality index, W_i – the assigned weight of each indicator, which is gained from selected PC, Si – the score of the indicator, n – the number of variables in the refined minimum data set (MDS), SQI – classification was based on Cantu et al. (2007) to determine soil quality status in the study site.

Result and Discussion

Soil indicator analysis

Soil indicators consist of physical, chemical and biological properties of soil. It is used to assess and evaluate of soil quality (Rahmanipour et al., 2014). Table 1 sum-

Table 1
Result of soil properties analysis at different paddy field locations in Merauke district, Papua

SL[a)]	Av-N[b)] (ppm)	Av-P[c)] (ppm)	Av-K[d)] (pmm)	pH	BD[e)] (gr. cm^{-3})	POM[f)] (%)	OC[g)] (%)	SP[h)] (%)	SAS[i)] (%)	EC[j)] ($dS.m^{-1}$)	SR[k)] (mg. CO_2/cm/day)	CEC[l)] ($cmol.kg^{-1}$)
1	42.43	55.40	31.25	5.3	1.32	14.18	2.8	35	54	0.16	0.63	24.78
2	12.73	91.32	77.75	5.8	1.33	21.74	2.2	37	50	0.51	0.61	34.30
3	18.77	85.47	55.39	5.8	1.33	20.86	2.1	41	42	0.19	0.47	30.58
4	5.93	56.55	45.83	4.9	1.22	27.44	2.0	36	53	0.19	0.50	22.52
5	7.24	51.91	33.98	5.3	1.18	24.65	2.5	32	47	0.17	0.43	32.82
6	4.21	52.31	131.86	5.6	1.31	14.63	2.2	43	41	0.12	0.52	34.30
7	9.64	42.60	44.31	4.9	1.57	19.63	2.7	38	49	0.16	0.62	30.58
8	4.49	46.01	113.36	5.2	1.64	14.07	2.5	32	46	0.22	0.51	22.52
9	9.42	48.03	68.35	5.0	1.20	20.96	2.8	39	48	0.15	0.44	34.87
control	10.80	42.52	122.69	5.5	1.15	26.46	2.9	51	49	0.09	0.67	36.56

[a)] sample location, [b)] Available-N, [c)] Available-P, [d)] Available-K, [e)] bulk density, [f)] particulate organic matter, [g)] organic carbon, [h)] soil porosity, [i)] soil aggregate stability, [j)] electrical conductivity, [k)] soil respiration, [l)] cation exchange capacity

marizes the current condition of all soil indicators which were measured. The result indicated that BD in Location (5), (9) and Control were lower than 1.2 [$g.cm^{-3}$], it is categorized as an optimal value (Wander et al., 2002). Low BD indicates as good condition, it means that soil has good soil pore, root penetration, water and air circulation and soil aggregates (Macci et al., 2012; Mondal et al., 2015). According to Wander et al. (2002), the optimum of SP ranges between 40-60%, it was in Location (3), (5) and Control.

Based on the Indonesian Agency for Agricultural Research and Development (2006), SAS in Location (1) was slightly solid (54%) and Location (6) was inadequately solid. On the other hand, based on the Indonesian Soil Research Institute (2005), soil pH was acid (<5.5); OC was moderate (2-3%); Av-N was high in Location (1), moderate in Location (2), (3), (7), (9) and Control, and low in the rests; CEC was 30.18 in all locations and considered as high (25-40 $cmol.kg^{-1}$); EC was very low in all locations (<0.1 $dS.m^{-1}$); and Av-K was moderate in Location (1) and (5) (20-40 ppm), high in Location (3), (4) and (7) (40-60 ppm), and very high in the rests (>60 ppm). According to Wander et al. (2002), Av-P in all locations were high (>15 ppm), while soil respirations were also high (>0.132 mg $CO_2.gr^{-1}$). High soil respiration rate indicates that biological activities occur at higher and faster pace than the decomposition of organic matters (Supriyadi et al., 2012), and it is able to supply of plant nutrients (Lu et al., 2015). It can be maintained by organic and mineral fertilizer with 10 t/ha of manure or with equivalent amount of mineral fertilizers for long time period (Kosolapova et al., 2016). The soil properties in cultivated soils are generally lower than in the native grassland (Kilic et al., 2011).

The correlation of soil quality indicators

Soil quality indicators were analyzed by Pearson Correlation Analysis to determine the relationship among variables (Li et al., 2013) and it presents on Table 2. The result shows that there were correlations among variables *i.e.* pH–Av-P (0.694), OC–Av-P (-0.637), EC–Av-P (0.742) and Av-Mg– CEC (0.764). Negative correlation indicates that the indicators negatively affect each other, if an indicator increases then the other will decrease. On the other hand, positive correlation indicates that the indicators are correlating in a line. soil pH in the study site was is between 4.9-5.8 lower than the minimum range of optimum pH for the availability of P, it leads to a positive correlation between pH and Av-P(Rastija et al., 2010).

Furthermore, liming and other activity to increase soil pH has positive influence on soil Av-P (Rahman et al., 2002). CEC and Av-Mg has positive correlation, Mg is one of the main bases to determine CEC, high Mg will increase CEC and vice versa (Rayment and Higginson, 1992; CUCE, 2007). Positive correlations between Av-P and EC are generally present in sodic soils due to the presence of sodium carbonate that is form soluble sodium phosphates and improves the status of dissolved P (FAO, 1988).

Minimum data set and soil quality index calculation

PCA method is a data reduction tool to select some of potential indicators in the study site (Qi et al., 2009)a wide variety of methods are used to evaluate soil quality using vastly different indicators. A universally accepted method of soil quality evaluation would assist agriculture managers, scientists, and policy makers to better understand the soil quality conditions of various agricultural systems. This study analyzes the soil quality of Zhangjiagang County, a

Table 2
Result of soil quality correlation analysis at paddy fields in Merauke

Var[a]	Av-N[b]	Av-P[c]	Av-K[d]	pH	BD[e]	POM[f]	OC[g]	SP[h]	SAS[i]	EC[j]	SR[k]	CEC[l]	Av-Na[m]	Av-Ca[n]
AP	0.221													
AK	-0.462	-0.179												
pH	0.133	0.694*	0.355											
BD	-0.059	-0.081	0.095	-0.186										
POM	-0.323	0.077	-0.223	-0.064	-0.630									
OC	0.312	-0.637*	-0.013	-0.387	-0.002	-0.124								
SP	-0.071	-0.106	0.526	0.328	-0.405	0.281	0.219							
SAS	0.390	-0.151	-0.492	-0.515	-0.151	0.297	0.314	-0.220						
EC	0.007	0.742*	0.083	0.372	0.182	0.030	-0.422	-0.355	0.184					
SR	0.405	-0.052	0.161	0.138	0.159	-0.065	0.391	0.432	0.413	0.134				
CEC	-0.225	0.093	0.315	0.432	-0.473	0.265	0.221	0.617	-0.373	-0.003	0.069			
Av-Na	-0.033	0.456	-0.231	0.425	-0.022	-0.109	-0.272	-0.156	-0.437	0.316	-0.207	0.496		
Av-Ca	-0.277	0.197	0.177	0.482	-0.060	0.279	0.070	0.123	-0.212	0.376	0.205	0.592	0.495	
Av-Mg[o]	0.371	-0.065	0.065	0.309	-0.546	0.107	0.603	0.586	-0.001	-0.211	0.356	0.764*	0.240	0.361

[a] sample location, [b] Available-N, [c] Available-P, [d] Available-K, [e] bulk density, [f] particulate organic matter, [g] organic carbon, [h] soil porosity, [i] soil aggregate stability, [j] electrical conductivity, [k] soil respiration, [l] cation exchange capacity, [m] Available-Na, [n] Available-Ca, [o] Available-Mg, *significant at 0.05

rapidly developing region of China (n=431. PCA can generate data in PC (principal component) or a major component. PC is linear combination of different variables that represents the maximum variance of data set. It indicates that data set represents soil quality in the entire study site. PC which has eigenvalues equal or higher than 1 was taken as MDS, in every selected PC was chosen one indicator with the highest value. The value was taken as weighting index (Wi). PCs which eligible as data set were PC1 to PC5 (eigen values ≥1), and it represented 89.3% of the data variability. Some selected indicators consist of pH (r = 0.469), OC (r = 0.429), BD (r = 0.408), POM (r = 0.496) and Av-N (r = 0.505), and it presents on Table 3. The results of PCA analysis were used to calculate SQI, and it presents on Table 4.

SQI in the control location (new paddy field) was used to determine the long term effect of paddy field on soil quality. The results exhibited in Table 4 indicate that soil on the control location has higher SQI (0.33) than the other, except for Location (3). It was caused by soil type and tillage methods. The soil type in Location (3) is Histosols which is composed mainly of organic materials and contains more than 20% organic matter (FAO). It has also very good scores in particulate organic matter (POM) and bulk density (BD), and has moderate score in organic matter (OC) content. Farmer in Location (3) has added manure as crop nutrient source besides the inorganic fertilizers, and has returned some of crop residues to the land.

On the other hand, the results indicate that long term paddy field utilization may decrease soil quality. Subagyono et al. (2001) stated that the puddling has potential to increase soil bulk density and run-off, and decrease soil quality. It requires an effort to prevent soil quality degradation e.g. changing of cultivation method, improving the status of se-

Table 3
Determination of MDS using PCA

Eigenvalue	29 612	26 993	20 951	18 921	10 642
Proportion	0.247	0.225	0.175	0.158	0.089
Cumulative	0.247	0.472	0.646	0.804	0.893
Variabel	PC112	PC2	PC3	PC4	PC5
Av-N[a]	-0.210	-0.082	-0.369	-0.383	0.505
Av-P[b]	0.278	-0.469	-0.248	-0.070	0.082
Av-K[c]	0.330	0.215	0.312	-0.232	-0.317
pH	0.469	-0.180	-0.118	-0.263	0.185
BD[d]	-0.201	-0.187	0.408	-0.355	-0.273
POM[e]	0.119	0.106	-0.371	0.498	-0.290
org-C[f]	-0.238	0.429	-0.107	-0.225	0.089
SP[g]	0.332	0.409	-0.164	-0.138	-0.056
SAS[h]	-0.387	0.009	-0.435	0.038	-0.322
EC[i]	0.114	-0.452	-0.193	-0.114	-0.425
SR[j]	-0.045	0.159	-0.313	-0.517	-0.381
CEC[k]	0.405	0.259	-0.152	0.012	0.068

[a] Available-N, [b] Available-P, [c] Available-K, [d] bulk density, [e] particulate organic matter, [f] organic carbon, [g] soil porosity, [h] soil aggregate stability, [i] electrical conductivity, [j] soil respiration, [k] cation exchange capacity, [l] principal component

Table 4
Soil quality class of each study location in Merauke district, Papua Indonesia

		PCA (Wi)[a]	Location									
			1	2	3	4	5	6	7	8	9	control
			Si[c]									
MDS (n)[(b)]	pH	0.469	0.75	0.75	0.75	0.50	0.75	0.75	0.50	0.75	0.50	0.75
	org-C[d]	0.429	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	BD[e]	0.408	0.75	0.75	0.75	0.75	0.75	0.75	0.50	0.10	0.75	0.75
	POM[f]	0.498	0.50	1.00	1.00	1.00	1.00	0.50	0.75	0.50	1.00	1.00
	Av-N[g]	0.505	1.00	0.50	0.75	0.50	0.50	0.10	0.50	0.10	0.50	0.75
SQI[h]			0.33	0.32	0.35	0.30	0.32	0.33	0.26	0.18	0.30	0.35
Scale*			Li)	L	M	L	L	L	L	V	L	M
Class*			4	4	3	4	4	4	4	5	4	3

[a] the assigned weight of each indicator, [b] number of selected MDS, [c] the indicator score, [d] organic carbon, [e] bulk density, [f] particulate organic matter, [g] Available-N, [h] soil quality, [i] low, [j] moderate, [k] very low

lected MDS through adding of organic matters (crop residues or organic fertilizer).

Soil organic matter (SOM) has reported as the most critical indicator of soil quality and agronomic sustainability due to its impact on other physical, chemical and biological indicators of soil quality (Reeves, 1997). Gopalakrishnan et al. (2013) stated that applying organic fertilizers in various SRI-organic and SRI-organic + inorganic treatments has potential to enhance the population of indigenous bacteria (Lal et al., 2000). Organic farming can generate better soil fertility status (N, P, K, and OC %), compared to chemical fertilizers. It is able to enhance microbial activity, increasing the rates of carbon and nitrogen mineralization and soluble carbon content (Sharma and Singh, 2004; Singh, 2004). Moreover, other soil quality indicators linked to SOM e.g. the available of water capacity for plants (Hudson, 1994) in (Reeves, 1997), infiltration (Pikul and Zuzel,1994) in (Reeves, 1997), aggregated formation and stability (Boyle et al., 1989), bulk density (Thomas et al., 1995) in (Reeves, 1997), soil strength (Ekwue and Stone, 1995) in (Reeves, 1997), CEC (Chen et al., 1992; Riffaldi et al., 1994) in (Reeves, 1997), soil enzymes (Dick, 1984) in (Reeves, 1997) and invertebrate bioindicators (earthworm) (Hendrix et al., 1992) in (Reeves, 1997).

Conclusion

The result showed that MDS was consist of 5 indicators and represented 89.3% of the variability of data, i.e. pH, organic matter, bulk density, particulate organic matter and Available-N. SQI in old paddy fields was classified as Class 4 (low). Meanwhile, SQI in control location and Location 3 has high value (0.35). Thus, long term utilization of paddy field was able to decrease soil quality. To maintain and sustain the productivity of paddy fields, conservation farming is required e.g. adding of organic matter to improve the physical, chemical and biological properties of soil.

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