JOURNAL OF DEGRADED AND MINING LANDS MANAGEMENT
ISSN: 2339-076X (p); 2502-2458 (e), Volume 5, Number 1 (October 2017): 1009-1018
DOI:10.15243/jdmlm.2017.051.1009

Research Article

The assessment of soil quality of various age of land reclamation after coal mining: a chronosequence study

A. Noviyanto, Purwanto, S. Minardi, Supriyadi*

Department of Soil Science, Faculty of Agriculture, Sebelas Maret University, Jl. Ir. H. Sutami, Surakarta, Indonesia

*corresponding author: supriyadi_uns@yahoo.com

Received 13 July 2017, Accepted 18 September 2017

Abstract : The assessment of soil quality index is one of the parameters to evaluate the goal of land reclamation. The research has been done in the various age of soil of PT Adaro Indonesia and natural forest. The research used descriptive explorative method and open field survey. Purposive sampling was used to take the sample in research location that represented the condition of every location. Principal component analysis used to know the main indicator. The main indicator was based on Eigen value >1 and chosen by indicator correlation having the highest weight index. The main indicator chosen was called minimum data set. The result of the research showed that minimum data set consisted of pH, base saturation, bulk density, electrical conductivity, cation exchange capacity, available P, total N, and soil organic carbon. The main indicators contributing to soil quality index value were total N and cation exchange capacity. Variable linear analysis showed that the longer age of land reclamation was followed by the development of soil quality index. Soil quality index in 18 years old soil reclamation (0.651) was higher than that in natural forest (0.575). Soil quality index of > 0.5 is defined as sustainable reclamation.

***Keywords**: land reclamation, principal component analysis (PCA), soil quality index (SQI)*

To cite this article: Noviyanto, A., Purwanto, Minardi, S, and Supriyadi. 2017. The assessment of soil quality of various age of land reclamation after coal mining: a chronosequence study. J. Degrade. Min. Land Manage. 5(1): 1009-1018, DOI: 10.15243/jdmlm.2017.051.1009

Introduction

Usually, coal mining in Indonesia uses open pit mining method. The process starts from taking the surface layer of top soil, moving the overburden layer and taking the coal out (Ghose and Majee, 2000). It causes the loss of vegetation, permanently soil topography alteration, the change of soil structure and geology, and disturbing the hydrological condition also destroying the surrounding environment (Keskin and Makineci, 2009). The problem of environment, economy, geology and human's health is related to soil quality (Brevik et al., 2015) as soil is a home for many organisms above and below it. Soil quality serves so many important ecosystems for not only human being but also the other organism in environment. According to Zornoza et al. (2015), soil quality has interaction with human healthy because soil supports the plant growth, fauna's habitually, and serves the human necessity (Masto et al., 2011). Shrestha and Lal (2006) state that the effect of coal mining, especially open pit mining method, can be reduced by reclamation and revegetation. The main purpose of revegetation is to make the continuity of plants community so it will recover the surrounding ecosystem (Courtney et al., 2009). After the revegetation, it will grow natural green plants (Powlson et al., 1998). The most important thing in ecosystem recovery is soil characteristic building (Wong, 2003). The development of soil quality becomes the key in soil reclamation process (Zhao et al., 2013). Based on that, it is necessary to identify the soil characteristics influencing soil quality alteration. Soil index quality can be used to measure the environmental conservation (Masto et al., 2007) and evaluate the result of land reclamation which has been done (Mukhopadhyay et al., 2014). Soil quality is the special ability of a soil to function naturally and makes the organism to continue living in the surrounding environment (Karlen et al., 2003). The value of soil quality uses soil quality index. Fixing the soil quality index depends on (1) choosing soil characteristic indicator that appropriate with set data minimum (2) changing the indicator to score (3) joining the score into soil quality index (Sinha et al., 2009). Soil quality index can be used to choose the tree which appropriates for land reclamation (Mukhopadhyay et al., 2013). Later, coal mining grows faster and faster so we cannot separate between coal mining and soil degradation. The soil characteristics are heterogeneous, dynamic, and complex so the assessment of soil quality is dependent on land use (Zornoza et al., 2015). Soil quality assessment can be done by the characterization of soil physical, soil chemical and soil biological properties (Islam and Weil, 2000). The purpose of this research was to know the minimum data set (MDS) and develop the soil quality index (SQI) to score the development of soil quality status based on soil reclamation age.

Materials and Methods

The research was done from July to October 2016. Open field research was done at reclamation area of PT. Adaro Indonesia that is located in Paringin (115°27'52.03"-115°28'56.86"BTand 2°17'17.34" - 2°18'54.95" LS) 1year old,15 years old and 18 years old. The area that is located in the natural rubber forest was chosen as the location. Laboratory analysis was done at Plant and Soil Laboratory of PT. Adaro Indonesia, and Chemical and Fertility Laboratory of Agriculture Faculty of Sebelas Maret University (Table 1). The research used descriptive explorative method and open field survey.

Purposive sampling was used to take the sample in research location which represented the condition of every location (Adepetu et al., 2000). The research area is located in Warukin geology formation in middle, up to last miocene age. The stone consists of clay, sandstone, and alluvial sedimentation. Ultisol is a soil type in the natural forest. Prasetyo and Suriadikarta (2006) stated that South Kalimantan Ultisols develop from the stone of clay and sandstone sedimentation. Based on Schmidt Ferguson's climate classification, the location has a wet condition of a month (Q =0.280) which has an average rainfall of 179.1mm. To know the data normality, we used normality test. Independent samples T-test was used to know the differentiation of age in soil reclamation. Pearson correlation was employed to know the relationship of variables each other and principal component analysis (PCA) was used to know the main indicator.

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

Parameters	**Analytical method**	**Reference**
Moisture content	Gravimetric method	(Reeuwijk, 2002)
Bulk density	Stony soils method	(Anderson and Ingram, 1993)
Porosity	Determined from bulk density with a particle density	(Anderson and Ingram, 1993)
Texture	Pipette method	(Anderson and Ingram, 1993)
Soil organic carbon	Walkley and Black method	(Reeuwijk, 2002)
pH, EC, Eh	Soil: water suspension (1:5; w/v)	(Anderson and Ingram, 1993)
Total N	Kjeldahl method	(Reeuwijk, 2002)
Available P	Bray’s method for acidic soils and Olsen’s method for neutral and alkaline soils	(Reeuwijk, 2002)
Cation exchange capacity	1 N ammonium acetate extraction	(Reeuwijk, 2002)
Exchangeable Ca, Mg, Na, K	1 N ammonium acetate extraction	(Reeuwijk, 2002)
Base saturation	Calculated as the proportion of the CEC occupied by basic cations	(Reeuwijk, 2002)
Aluminum saturation	Determined from exchangeable aluminum with a cation exchange capacity	(Reeuwijk, 2002)
ESP	Determined from exchangeable sodium with a cation exchange capacity	(Reeuwijk, 2002)
Soil Fauna Diversity	Pit fall trap method	(Yi et al., 2012)

EC = Electrical conductivity, Eh = Redox potential, ESP = Exchangeable Sodium Percentage

Table 2. Research location description

Variable	Years after reclamation			Natural forest
	1-year	15-year	18-year	
Coordinate	115°29'5.34" BT 2°18'20.97" LS	115°29'18.53" BT 2°18'37.17" LS	115°29'16.93" BT 2°18'53.09" LS	115°29'44.28" BT 2°18'20.85" LS
Top soil (cm)	10	> 30	-	> 30
Overburden (cm)	> 20	-	> 30	-
Slope (%)	3	5	7	4
Elevation (m)	122	147	107	91
Cover crop	Bd, Cd, Cm, Cp, Cj, Pj, *Sorghum bicolor*, *Oryza sativa*, *Signal grass*	*Paspalum conjugatum* Berggr., *Mimosa pudica*	*Signal grass*, *Mimosa pudica*	-
Species of a tree	*Sesbania grandiflora*, *Paraserienthes falcataria*, *Leucaena leucocephala*	*Acacia mangium*, *Pinus merkusii*, *Leucaena leucocephala*, *Alstonia scholaris*, *Eucaliptus urophylla*	*Elaeis guineensis* Jacq., *Paraserienthes falcataria*, *Leucaena leucocephala*, *Vitex pinnata* L.	*Hevea brasiliensis* Muell. Arg

Bd = *Brachiaria decumbens*,Cd = *Cynodon dactylon*, Cm = *Calopogonium mucunoides*,
Cp = *Centrosema pubescens*,Cj = *Crotalaria junceae*, Pj = *Pueraria javanica*,

Table 3. The characteristic of physical, chemical, biological soil from various kind of land reclamation and natural forest (rate value, deviation standard, n=2 and T test with 95% value)

Soil quality parameters	Years after reclamation			Natural forest
	1-year	15-year	18-year	
Soil fraction				
Clay (%)	50.125 (±2.582)a	40.624 (±0.069)b	26.858 (±3.958)c	35.760 (±2.427)bc
Silt (%)	18.089 (±0.620)a	12.006 (±2.983)a	17.296 (±7.812)a	13.262 (±7.505)a
Sand (%)	31.787 (±3.202)a	47.371 (±3.052)b	55.846 (±3.854)b	50.978 (±5.077)b
Texture	Clay	Sandy clay	Sandy clay loam	Sandy clay
BD (g/cm^3)	2.078 (±0.020)a	1.471 (±0.056)b	1.886 (±0.104)ab	1.446 (±0.061)b
Porosity (%)	12.385 (±2.128)a	38.424 (±1.194)b	12.068 (±3.197)a	39.461 (±5.733)b
SOC (%)	1.107 (±0.183)a	0.988 (±0.137)a	4.829 (±0.990)b	2.939 (±0.272)b
pH	5.85 (±0.071)a	5.10 (±0.000)b	6.60 (±0.141)c	4.50 (±0.141)d
EC (dS/m)	0.217 (±0.023)a	0.047 (±0.002)b	0.155 (±0.004)a	0.037 (±0.008)b
Redox Potential (mV)	114.65 (±4.455)a	178.75 (±2.192)b	71.20 (±4.525)c	204.10 (±11.172)b
Total N (mg/kg)	4.440 (±0.032)a	4.520 (±0.054)a	8.730 (±0.071)b	7.340 (±0.020)b
Available P (mg/kg)	0.173 (±0.003)a	0.174 (±0.002)a	0.201 (±0.003)b	0.193 (±0.001)c
Exchangeable K (mg/kg)	4.29 (±0.000)a	4.29 (±0.000)ab	4.68 (±0.000)a	4.29 (±0.000)a
CEC (cmol(+)/kg)	19.88 (±0.962)a	22.20 (±0.509)a	28.20 (±1.301)b	25.76 (±0.226)b
Base Saturation (%)	8.640 (±0.268)a	5.268 (±0.535)b	22.228 (±1.210)c	4.619 (±0.826)b
Aluminum Saturation (%)	0.000 (±0.000)a	7.539 (±0.782)b	0.000 (±0.000)a	20.955 (±4.428)b
ESP (%)	4.469 (±0.638)a	2.935 (±0.445)a	3.993 (±1.300)a	2.782 (±0.026)a
SFD	0.781 (±0.045)a	0.684 (±0.051)a	0.966 (±0.010)a	1.328 (±0.122)a

BD = Bulk Density, SOC = Soil Organic Carbon, EC = Electrical Conductivity, CEC = Cation Exchange Capacity, ESP = Exchangeable Sodium Percentage, SFD = Soil Fauna Diversity

Soil quality index (SQI) is the addition of weighting factor and main indicator scoring, which pattern is:

SQI= $\sum_{i=1}^{n}$ Wi x Si (Wi: weighting factor and Si: the indicator score for variable i).

Weighting factor gets from the result of principal component analysis (PCA) which has a correlation in every PC (Andrews et al., 2002; Mukhopadhyay et al., 2014). Linear scoring was made based on value classifying of each parameter. It consists of score 1 for low class, score 2 for a middle class, and score 3 for highest class (Andrews et al., 2002).

Results and Discussion

Soil physical characteristics

In the post coal mining soil reclamation area, the physical characteristics of the reclaiming materials were the limiting factors in the revegetation process. The materials cause high soil compaction so the plant root was difficult to penetrate into the soil. Bulk density had negative correlation with soil porosity (p-value = 0.000). The result showed that the high bulk density in the whole research location was followed by the soil porosity descent. In 1 year old soil reclamation area showed that the soil had the highest bulk density value (2078 g/cm^3). The bulk density decreased with the increasing age of land reclamation (Mukhopadhyay et al., 2014). The bulk density descent was influenced by the growth of root (Macci et al., 2012). Thomas et al. (2000) state that the growth of root system and the addition of biomass in the 15 to 20 years old post coal mining land reclamation can rebuild soil structure, decrease bulk density and improve soil porosity. Akala and Lal (2001) state that the growth and development of root are equal to soil organic carbon (SOC) which can lose soil compaction from time to time. Repairing process of physical soil is the cause of growing vegetation in soil reclamation. Wander et al. (2002) state that the good bulk density value is <1.2 g/cm^3 and the good porosity is between 40% and 60%. The value of bulk density is based on aggregate distribution value, soil organic material (SOM) and coarse fraction (Amacher et al., 2007). The low bulk density indicates that the soil has good structure and has balanced pores (Tematio et al., 2011). Rodrigue and Burger (2004) pointed out that soil porosity is the parameter influencing soil quality. Soil texture is the comparison of sand (2-0.05mm), silt (0.05-0.002mm), and clay (<0.002mm) (Sheoran et al., 2010). Triangle texture that was used in measuring soil texture indicated that soil in the 1 year old land reclamation area was clay texture with 50% clay content. Soils in the 15 years old reclamation and natural forest areas showed similar texture of sandy clay. In sandy clay texture often occurred nutrients reduction because of the greater sand fraction than clay fraction so that soil colloid particle cannot hold nutrients in the soil. Soil texture of the 18 years old land reclamation was sandy clay loam. Texture is one of many soil characteristic that affected soil quality and forest productivity in coal mining in USA (Rodrigue and Burger, 2004). Mukhopadhyay et al. (2013) reported that coarse fraction can influence the retention capacity of soil moisture content, bulk density, and porosity.

Soil chemical characteristics

Plant biomass is the main nutrient source for plant growth. Selection of the pioneer plants, therefore, becomes the alternative method in facing the reduction of nutrient in land reclamation area. Soil pH in the studied areas varied based on the sources of overburden and topsoil (Table 3). Mukhopadhyay and Maiti (2011) stated that heaping of overburden acid material can affect soil pH in land reclamation. Heaping of top soil material before the mining was done determines the acid pH of the soil in the area that is called as Ultisol (Prasetyo and Suriadikarta, 2006). The highest SOC (4.829%) was on 18 years old land reclamation area and the lowest (0.988%) was on the 15 years old land reclamation area. The Natural forest had SOC of about 2.939%, because of the accumulation of organic litter and the result of organic matter decomposition. SOC value had positive correlations with total N (p-value =0.000), available P (p-value =0.001) and cation exchange capacity (p-value =0.001). These values were supported by the result of soil reclamation study conducted by Mukhopadhyay et al. (2014) that the high total N and available P followed the value of SOC. Nitrogen accumulation can be counted by organic material input and nitrogen fixation, while phosphate can be determined by organic material, pH, and soil weathering process. Cation exchange capacity (CEC) can be used to measure the soil fertilization (Wang et al., 2005). CEC is a soil ability to supply and save the nutrient influenced by soil processing practice (Yao et al., 2013). CEC value of the 1 year old land reclamation was 19.88 cmol(+)/kg while that of the15 years old land reclamation was 22.20 cmol(+)/kg. Results of T-test on independent samples from both locations showed that those values were similar. The 1 year old soil reclamation area has various kind of closed plant such as *Brachiaria decumbent, Cynodon dactylon*, *Calopogonium mucunoides*, *Centrosema pubescens*, *Crotalaria junceae*, *Pueraria javanica*, *Sorghum bicolor*, *Oryza sativa*, *Signal grass* that produce many litter biomass that can increase the CEC value. The 1 year old reclamation area has clay texture that makes litter as a nutrient source cannot lose. Tomašić et al. (2013) stated that soil texture is a parameter which has a big influence on CEC. Wang et al. (2005) pointed out that there is positive correlation between CEC with the content of SOC and clay content, the negative correlation appears in CEC with the coarse fraction content. The 15 years old land reclamation has some closed plant such as *Paspalum conjugatum* Berggr., *Mimosa pudica* and species of a tree on *Acacia mangium*, *Pinus merkusii*, *Leucaena leucocephala*, *Alstonia scholaris*, *Eucaliptus urophylla*. Various kinds of plants above have low biomass because of sandy clay texture. CEC in 18 years old was 28.20 cmol(+)/kg and that in the natural process was 25.76 cmol(+)/kg. Results of T-test of independent samples from both conditions indicated that the values were similar. This was because of the presence of cover plants like *Signal grass*, *Mimosa pudica* and kind of trees like *Elaeis guineensis* Jacq., *Paraserienthes falcataria*, *Leucaena leucocephala*, *Vitex pinnata* L. in the 18 years old soil reclamation area. Cover plants such as *Signal grass* and wide canopy of *Elaeis guineensis* Jacq. can reduce kinetic energy of the rain and reduce runoff, erosion and leaching. The soil electrical conductivity (EC) in the research location was very low. The EC in a natural forest was significantly low (0.037 dS/m). In a coal mining area in USA indicated that dissolved salt is a soil parameter influencing living and growth of tree seeds; if the dissolved salt is high the soil productivity becomes low (Rodrigue and Burger, 2004). EC had positive correlation with the exchangeable sodium percentage (ESP) (p-value=0.024). This was probably caused by the dissolved salt structure component. As sodium ion can be exchanged, so the increase of ESP causes the increase of EC. There was a low value of reduction potential (Table 3). If the soil is in oxidation, the soil drainage is in good condition, meanwhile, if the soil is in reduction, it is saturated by water. It affects toward some nutrients which can be lost by evaporation and leaching. According to Soewandita (2008), base saturation shows the comparison of a number of base cations with the amount of all cations (acid cation and base cation) in a soil component. Base saturation in the whole research area was in low and very low levels. Base saturation had positive correlation with the soil pH (p-value = 0.003). In acid to very acid soils base saturation is normally very low. In neutral pH, the base saturation is low (Table 3). According to Mukhopadhyay et al. (2014), there is very high base saturation about 82.6 % in the revegetation overburden. With the increase in age of land reclamation, the base cation will be naturally weathered and leached. Aluminum saturation had negative correlation toward soil pH (p-value=0.005). The decline of soil pH was followed by the enhancement of aluminum saturation. The result of aluminum saturation analysis showed that the whole land reclamation area was in low and lowest levels of aluminum saturation (Table 3). The high aluminum saturation in the other conditions because of the inherent characteristic of Ultisols. Prasetyo et al. (2001) said that South Kalimantan Ultisols develop from sediment stone, sandy stone, and clay stone having base saturation of 3-9 %, aluminum saturation of 33-95 % and pH of 3.70-5.

Soil biological characteristics

Soil is a habitat for soil fauna that has a special function in ecosystem complexity (Gardi and Jeffery, 2009). In the soil, the amount of nutrients served for plant growth is based on the root interaction, microorganism and soil fauna (Bonkowski et al., 2000). Soil arthropods in a habitat are influenced by the condition of the habitat. Soil arthropods will go to the environment which supports their life likes food, optimal climate and the existing of natural enemies (Syaufina et al., 2007). The soil fauna diversity in the whole land reclamation was low, while that in the natural forest was medium (Table 3). According to Baker (1998), the amount and diversity soil arthropods in an ecosystem tightly related to the condition and age of the ecosystem itself. The amount of soil arthropods has a positive correlation with the high of plant biomass (Hooper et al., 2000) and the nutrient in the soil (Nahmani and Lavelle, 2002). Wardle et al. (1999) stated that the amount of soil arthropods is based on the extent of land cover. The result of T-test on independent samples showed that the soil fauna diversity in the whole soil reclamation area and in the natural forest was in the same condition. This was because the research location is near the coal mining operation. The bad condition may occur in this location.

Soil quality index (SQI)

The assessment of soil quality needs identification of the condition of natural resources several times (Karlen et al., 2008). The assessment of soil quality index (SQI) uses minimum data set (MDS) (Andrews et al., 2002). MDS is potentially selected by the chosen indicators from the kind of soil quality indicators such as soil physical, soil chemical and soil biological properties. The chosen indicators represent the whole data (Lima et al., 2013). The determination of MDS uses statistical analysis like Principal Component Analysis (PCA) (Andrews et al., 2002), that can classify soil characteristic in the right independent group and lose the original data (Yao et al., 2013). Some previous studies (Bastida et al., 2006; Masto et al., 2007, 2008, 2011, 2015; Mukhopadhyay et al., 2013, 2014, 2016; Sinha et al., 2009) used the same method to get the SQI. The different of the research is a linear scoring method based on the highest score in soil function (Andrews et al., 2002). Liebig et al. (2001) noted that pH indicator could be high up to limit level (pH 6.5), after that, the score can be low up to limit level. The results of main component analysis from various kind of soil quality are presented in Table 4.

Table 4. Principal component analysis

Eigen value	74.810	49.195
Proportion	0.534	0.351
Cumulative	0.534	0.886
Variable	PC1	PC2
Bulk density	**0.298**	-0.205
Porosity	-0.338	0.119
Soil organic carbon	0.211	**0.362**
pH	**0.347**	-0.057
Electrical Conductivity (EC)	**0.290**	-0.224
Redox potential (Eh)	-0.358	0.051
Total N	0.158	**0.403**
Available P	0.135	**0.406**
Exchangeable K	0.300	0.173
Cation exchange capacity	0.117	**0.420**
Base saturation	**0.337**	0.141
Aluminum saturation	-0.289	0.237
Exchangeable Sodium Percentage	0.265	-0.176
Soil Fauna Diversity	-0.074	0.340

Values printed in bold are main indicators

Based on the PCA, chosen indicator must have Eigen value ≥ 1 (Lima et al., 2013). The main indicator on PC1 consisted of pH, base saturation, bulk density (BD), and electrical conductivity (EC). The main indicator on PC2 consisted of cation exchange capacity (CEC), available P, total N, and soil organic carbon (SOC). Eight variables above had high sensitivity toward soil quality in research location. The choosing of indicator was based on the correlation of weighting factor index (Andrews et al., 2002). According to Andrews et al. (2002), some main indicator consists of SOC, EC, pH and available P as a MDS for various kind of soil system. Soil quality indicator is a process and sensitive soil character toward the changes of soil function (Qi et al., 2009). There are several ways to measure the soil quality indicator (Yao et al., 2013), consisting of several soil physical, chemical and biological properties which are used to evaluate and score the soil quality (Rahmanipour et al., 2014). SQI is the result of weighting factor with MDS.

Soil pH is kind of acid measurement of active soil and becoming the area of soil quality indicator generally used (Sheoran et al., 2010). Soil pH relates to the existing nutrients, if there is a low soil pH so that the nutrients inside (Amacher et al., 2007). Soil pH is easy to change based on the edaphic environment. Soil pH has a positive correlation with base saturation, bulk density, and electrical conductivity. The indicators are part of a minimum data set. Base saturation determines the base cations which can be exchangeable like Ca^{2+}, Mg^{2+}, Na^{2+}, and K^{+} (Tomašić et al., 2013). Soil pH determination will follow the determination of base saturation. Bulk density is a parameter commonly used to measure the soil compaction. It can limit the plant growth because many species cannot effectively grow the root (Sheoran et al., 2010). The value of high and low bulk density can influence the plant growth (Liu et al., 2014). Electrical conductivity can be the main indicator of soil quality, because of its influence toward the plant growth. If the electrical conductivity increases, the soil productivity will decrease. This increases the failure of soil reclamation area. Shen et al. (2001) noted that root exudates can grow up the salinity in rhizosphere soil. The repairing process of soil organic matter and nutrient cycling is very important for the land reclamation after the ecosystem is disturbed (Banning et al., 2008). There are several elements in the organic material, but the most elements are carbon (C) and nitrogen (N) (Amacher et al., 2007). Soil organic carbon (SOC) is the right parameter to evaluate the soil quality in reclamation area after the mining process (Bodlák et al., 2012). SOC is the soil quality indicator that easy to check every time (Mukhopadhyay et al., 2013). SOC is a discriminative soil quality indicator which can be used to check the soil degradation caused by soil erosion (Rajan et al., 2010). SOC can be used as a dominant indicator in the soil depth of 0-10 cm, and scoring of the soil quality in various kinds of area and cultivation. Besides that, soil organic C is classified as an important indicator to check the soil quality in agro-ecosystem (Shukla et al., 2006). SOC has a positive correlation with cation exchange capacity (CEC), total N and available P.

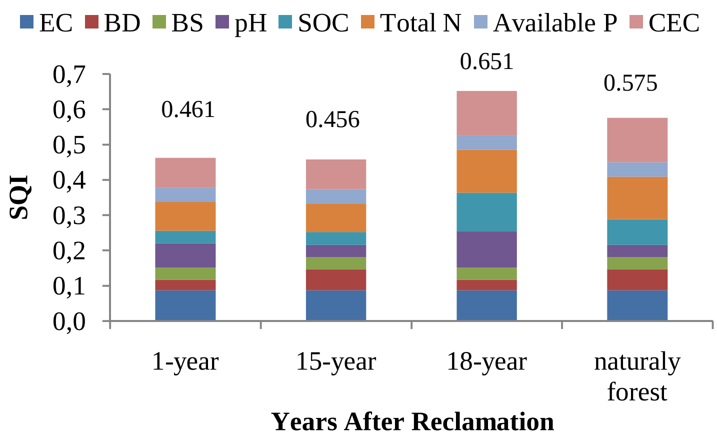

Figure 1. Contribution of each soil indicator parameter on calculated SQI with age of reclamation

The addition of organic material will increase CEC value (Agus et al., 2014). Organic material has a function as plant nutrients source, especially nitrogen and phosphorus (Sheoran et al., 2010). The determination and conservation of SOC will determine the CEC, repairing the microorganism activity and repairing the nutrient's source (Lal, 2006). The main indicator contributed as a way to measure the value of soil quality (Figure 1). CEC and total N had higher soil quality index value than another. This was caused by the highest weighting factor and indicator scoring. CEC indicated that soil can serve nutrients in the form of cation (such as H^+, K^+, Ca^{2+}, Mg^{2+}, Fe^{2+}, Mn^{2+}, Mo^{2+}, Cu^{2+}, Zn^{2+}, Na^{2+}). CEC has a positive correlation with soil pH, soil texture and SOM (Tomašić et al., 2013). The high organic matter and clay can determine the CEC because of negative charge inside both of colloid surface, so it can pull and hold back the cations. Soil having high CEC can absorb and serve the nutrients in the colloid surface so the nutrients are hard to lose by water (Soewandita, 2008). The negative charge on the colloid surface is the subtraction of isomorfic substitution on a phyllosilicate structure or functional organic dissociation (Tomašić et al., 2013). Nitrogen that is used by plant comes from fixation N and mineralization, subtraction with organic nitrogen (Sheoran et al., 2010). In the soil, nitrogen element in organic form and litter decomposition can increase the total N. Organic nitrogen will change to ammonium (NH_4^+) by a microorganism. Sheoran et al.(2010) noted that the microorganism uses ammonium for processing nitrite (NO_2^-) to nitrate (NO_3^-) in nitrification.

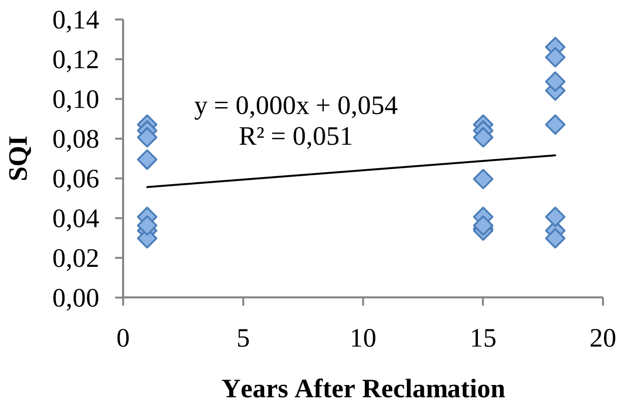

Figure 2. Relation between soil quality index (SQI) and age reclamation

The results of research by Mukhopadhyay et al.(2014) showed that main indicators of soil quality in land reclamation area are SOC, soil CO2 flux, texture, dehydrogenase activity, moisture content and base saturation. Meanwhile, the result of research by Masto et al.(2015) showed that soil quality indicators consist of soil respiration, bulk density, lead, nickel, chromium, cobalt, beryllium, losing organic material, polycyclic aromatic hydrocarbon total. The latest research by Mukhopadhyay et al. (2016) in land reclamation area showed that soil quality indicators consist of texture, pH, SOC, dehydrogenase activity, calcium, EC, available P, and sulfur. Based on the variable linear, the land reclamation area in 1, 15 and 18 years old has been increased (Figure 2). SQI in the 18 years old land reclamation area was higher than that in the natural forest. It occurred in the same research of Mukhopadhyay et al.(2014) that 17 years old land reclamation area was little higher (0.670) than natural forest (0.633). If the soil quality index value >0.5, the soil reclamation area is successful and it has ecological sustainability (Mukhopadhyay et al., 2014). In the 18 years old land reclamation area, SQI was 0.651 and that in the natural forest was 0.575. The high index indicated that the soil quality is good (Supriyadi et al., 2014). Soil quality indicator which consists of pH, base saturation, bulk density, electrical conductivity (EC), cation exchange capacity (CEC), available P, total N, and soil organic carbon (SOC) can be used as an indicator to evaluate the success of reclamation, the appropriate tree for revegetation, and biochemical cycling occurring in land reclamation area ecosystem. Soil holistic study that had been done by Brevik et al. (2015) showed that soil can support kind of biological, biochemical cycling, hydrologic cycling, and human sociology and health.

Conclusion

Characteristics of physical, chemical and biological of soils from various kinds of land reclamation areas were used to value the soil quality improvement from the degraded soil caused by coal mining. PCA used to count the MDS consisted of pH, base saturation, bulk density, electrical conductivity, cation exchange capacity, available P, total N and soil organic carbon. Soil quality index (SQI) in the 18 years old soil reclamation (0.651) was higher than that in the natural forest (0.575). Soil quality index that has > 0.5 defines as sustainable reclamation. The high index value shows the good soil quality and well soil function. Based on variable linear, SQI showed the enhancement along the addition of soil reclamation age.

Acknowledgements

The first author would like to thank PT. Adaro Indonesia, for providing necessary facilities during the field study at land reclamation area and natural forest.

References

Adepetu, J.A., Nabhan, H. and Osinubi, A. 2000. Simple soil, water and plant testing techniques for soil resource *management*. FAO Proceedings of a Training Course, 166p.

Agus, C., Pradipa, E., Wulandari, D., Supriyo, H. and Herika, D. 2014. Role of revegetation on the soil restoration in rehabilitation areas of tropical coal mining. *Jurnal Manusia dan Lingkungan* 21:60–66.

Akala, V. and Lal, R. 2001. Soil organic carbon pools and sequestration rates in reclaimed minesoils in Ohio. *Journal Environtal Quality* 30: 2098–2104.

Amacher, M.C., Neill, K.P.O., Perry, C.H. and Service, F. 2007. Soil Vital Signs : A New Soil Quality Index (SQI) for Assessing Forest Soil Health. Research Paper RMRS-RP-65WWW. U.S Department of Agriculture, Forest Service, Rocky Mountain Reasearch Station, 12p.

Anderson, J.M. and Ingram, J.S.I. 1993. Tropical Soil Biology and Fertility: A Handbook of Methods, 2nd *edition*.C.A.B International. Wallingford. Oxon. UK. 221p

Andrews, S.S., Karlen, D.L. and Mitchell, J.P. 2002. A comparison of soil quality indexing methods for vegetable production systems in Northern California. *Journal of Agriculture, Ecosystems and Environment*90:25–45.

Baker, G.H. 1998. Recognising and responding to the influences of agriculture and other land-use practices on soil fauna in Australia. *Journal of Applied Soil Ecology* 9:303–310.

Banning, N.C., Grant, C.D., Jones, D.L. and Murphy, D.V. 2008. Recovery of soil organic matter, organic matter turnover and nitrogen cycling in a post-mining forest rehabilitation chronosequence. *Journal of Soil Biology and Biochemistry* 40:2021–2031.

Bastida, F., Moreno, J.L., Hernández, T. and García, C. 2006. Microbiological degradation index of soils in a semiarid climate. *Journal of Soil Biology and Biochemistry* 38:3463–3473.

Bodlák, L., Křováková, K., Kobesová, M., Brom, J., Šťastný, J. and Pecharová, E. 2012. SOC content-An appropriate tool for evaluating the soil quality in a reclaimed post-mining landscape. *Journal of Ecological Engineering* 43:53–59.

Bonkowski, M., Griffiths, B. and Scrimgeour, C. 2000. Substrate heterogeneity and microfauna in soil organic "hotspots" as determinants of nitrogen capture and growth of ryegrass. *Journal of Applied Soil Ecology*14:37–53.

Brevik, E.C., Cerdà, A., Mataix-Solera, J., Pereg, L., Quinton, J.N., Six, J., and Oost, K.V. 2015. The interdisciplinary nature of soil. *Journal of Soil*1:117–129.

Courtney, R., Mullen, G. and Harrington, T. 2009. An evaluation of revegetation success on bauxite residue. *Journal of Restoration Ecology* 17:350–358.

Gardi, C. and Jeffery, S. 2009. Soil Biodiversity. JCR Scientific and Technical Reports. 1–27p

Ghose, M.K. and Majee, S.R. 2000. Assessment of dust generation due to opencast coal mining – an indian case study.*Journal of Environmental Monitoring and Assessment* 61:255–263.

Hooper, D.U., Bignell, D.E., Brown, V.K., Brussard, L., Dangerfield, J.M., Wall, D.H., Wardle, D.A., Coleman, D.C., Giller, K.E. Lavelle, P., Putten, W.H.V.D, Ruiter, P.C.D, Rusek, J., Silver, W.L., Tiedje, J.M. and Wolters, W. 2000. Interactions between aboveground and belowground biodiversity in terrestrial ecosystems: patterns, mechanisms, and feedbacks. *JSTOR* 50:1049-1061.

Islam, K.R. and Weil, R.R. 2000. Soil quality indicator properties in mid-Atlantic soils as influenced by conservation management. *Journal of Soil and Water Conservation* 55:69–78.

Karlen, D.L., Andrews, S.S., Weinhold, B.J. and Doran, J.W. 2003. Soil quality: Humankind's foundation for survival a research editorial by conservation professionals. *Journal of Soil and Water Conservation* 58:171–179.

Karlen, D.L., Andrews, S.S., Wienhold, B.J. and Zobeck, T.M. 2008. Soil quality assessment : past, present and future. *Journal of Integrative Biosciences* 6:3–14.

Keskin, T. and Makineci, E. 2009. Some soil properties on coal mine spoils reclaimed with black locust (Robinia pceudoacacia L.) and umbrella pine (*Pinus pinea* L.) in Agacli-Istanbul. *Journal of Environmental Monitoring and Assessment* 159:407–414.

Reeuwijk, L.P.V. 2002. Procedures for soil analysis 6nd edition. International Soil Reference and Information Centre. 101p.

Lal, R. 2006. Enhancing crop yields in the developing countries through restoration of the soil organic carbon pool in agricultural lands. *Journal of Land Degradation and Development* 17:197–209.

Liebig, M.A., Varvel, G. and Doran, J. 2001. A simple performance-based index for assessing multiple agroecosystem functions. *Agronomy Journal* 93:313–318.

Lima, A.C.R., Brussaard, L., Totola, M.R., Hoogmoed, W.B. and de Goede, R.G.M. 2013. A functional evaluation of three indicator sets for assessing soil quality. *Journal of Applied Soil Ecology* 64:194–200.

Liu, Z., Zhou, W., Shen, J., Li, S., Liang, G., Wang, X., Sun, J. and Ai, C. 2014. Soil quality assessment of acid sulfate paddy soils with different productivities in Guangdong Province, China. *Journal of Integrative Agriculture* 13:177–186.

Macci, C., Doni, S., Peruzzi, E., Masciandaro, G., Mennone, C. and Ceccanti, B. 2012. Almond tree and organic fertilization for soil quality improvement in southern Italy. *Journal of Environmental Management* 95:215–222.

Masto, R.E., Chhonkar, P.K., Singh, D. and Patra, A.K. 2007. Soil quality response to long-term nutrient and crop management on a semi-arid Inceptisol. *Journal of Agriculture, Ecosystems and Environment* 118:130–142.

Masto, R.E., Chhonkar, P.K., Singh, D. and Patra, A.K. 2008. Alternative soil quality indices for evaluating the effect of intensive cropping, fertilisation and manuring for 31 years in the semi-arid soils of India. *Journal of Environmental Monitoring and Assessment* 136:419–435.

Masto, R.E., Ram, L.C., George, J., Selvi, V.A., Sinha, A.K., Verma, S.K., Rout, T.K., Priyadarshini and Prabal, P. 2011. Impacts of opencast coal mine and mine fire on the trace elements' content of the surrounding soil vis-à-vis human health risk. *Journal of Toxicological & Environmental Chemistry* 93(2), 223–237.

Masto, R.E., Sheik, S., Nehru, G., Selvi, V.A., George, J. and Ram, L.C. 2015. Assessment of environmental soil quality around Sonepur Bazari mine of Raniganj coalfield, India. *Journal of Solid Earth* 6:811–821.

Mukhopadhyay, S. and Maiti, S.K. 2011. Trace metal accumulation and natural mycorrhizal colonisation in an afforested coalmine overburden dump: a case study from India. *International Journal of Mining Reclamation and Environment* 25:187–207.

Mukhopadhyay, S., Maiti, S.K. and Masto, R.E. 2013. Use of Reclaimed Mine Soil Index (RMSI) for screening of tree species for reclamation of coal mine degraded land. *Journal of Ecological Engineering* 57:133–142.

Mukhopadhyay, S., Maiti, S.K. and Masto, R.E. 2014. Development of mine soil quality index (MSQI) for evaluation of reclamation success: A chronosequence study. *Journal of Ecological Engineering* 71:10-20.

Mukhopadhyay, S., Masto, R.E., Yadav, A., George, J., Ram, L.C. and Shukla, S.P. 2016. Soil quality index for evaluation of reclaimed coal mine spoil. *Journal of Science of the Total Environment* 542:540–550.

Nahmani, J., and Lavelle, P. 2002. Effects of heavy metal pollution on soil macrofauna in a grassland of Northern France. *European Journal of Soil Biology*38:297–300.

Powlson, D.S., Smith, P., Coleman, K., Smith, J.U., Glendining, M. J., Korschens, M. and Franko, U. 1998. A European network of long-term sites for studies on soil organic matter. *Journal of Soil and Tillage Research* 47:263–274.

Prasetyo, B.H., Suharta, N. and Subagyo, H. 2001. Chemical and mineralogical properties of ultisol Sasamba Area, East Kalimantan. *Indonesian Journal of Agricultural Science* 2:37-47.

Prasetyo, B.and Suriadikarta, D. 2006. Characteristics, potential, and management technology of Ultisol for the development of dryland agriculture in Indonesia. *Jurnal Litbang Pertanian* 25:39–47 (*in Indonesian*).

Qi, Y., Darilek, J.L., Huang, B., Zhao, Y., Sun, W. and Gu, Z. 2009. Evaluating soil quality indices in an agricultural region of Jiangsu Province, China. *Journal of Geoderma* 149:325–334.

Rahmanipour, F., Marzaioli, R., Bahrami, H.A., Fereidouni, Z. and Bandarabadi, S.R. 2014. Assessment of soil quality indices in agricultural lands of Qazvin Province, Iran. *Journal of Ecological Indicators* 40:19–26.

Rajan, K., Natarajan, A., Kumar, K.S.A., Badrinath, M.S. and Gowda, R.C. 2010. Soil organic carbon - the most reliable indicator for monitoring land degradation by soil erosion. *Journal of Current*

Science 99:823–827.

Rodrigue, J.A. and Burger J.A. 2004. Forest soil productivity of mined land in the Midwestern and Eastern Coalfield Regions. *Soil Science Society of America Journal* 68:833–844.

Shen, H., Wang, X., Shi, W., Cao, Z. andYan, X. 2001. Isolation and identification of specific root exudates in elephantgrass in response to mobilization of iron- and aluminum-phosphates. *Journal of Plant Nutrition* 24:1117–1130.

Sheoran, V., Sheoran, A.S., and Poonia, P. 2010. Soil reclamation of abandoned mine land by revegetation : a review. *International Journal of Soil, Sediment and Water* 3:1–21.

Shrestha, R.K. and Lal, R. 2006. Ecosystem carbon budgeting and soil carbon sequestration in reclaimed mine soil. *Journal of Environment International* 32:781–796.

Shukla, M.K., Lal, R. and Ebinger, M. 2006. Determining soil quality indicators by factor analysis. *Journal of Soil and Tillage Research* 87:194–204.

Singh, A.N. and Singh, J.S. 2006. Experiments on ecological restoration of coal mine spoil using native trees in a dry tropical environment, India: A synthesis. *Journal of New Forests* 31:25–39.

Sinha, S., Masto, R.E., Ram, L.C., Selvi, V.A., Srivastava, N.K., Tripathi, R.C. and George, J. 2009. Rhizosphere soil microbial index of tree species in a coal mining ecosystem. *Journal of Soil Biology and Biochemistry* 41:1824–1832.

Soewandita, H. 2008. Soil fertility study and la nd suitability analysis for estate crop comodities in Bengkalis Regency. *Jurnal Sains dan Teknologi Indonesia*10:128–133 (*in Indonesian*).

Supriyadi, Sudaryanto, R., Winarno, J., Hartati, S. and Jamil, I.S. 2014. The quantitative soil quality assessment tobacco plant in Sindoro mountainous zone. *Journal of Degraded and Mining Lands Management* 1(3):105–110.

Syaufina, L., Haneda, N. F. and Buliyansih, A. 2007. Diversity of soil arthropods in gunung walat education forest. *Media Konservasi* 12:57–66.

Tematio, P., Tsafack, E.I. and Kengni, L. 2011. Effects of tillage , fallow and burning on selected properties and fertility status of Andosols in the Mounts. *Journal Agricultural Sciences* 2:334–340.

Thomas, K.A., Sencindiver, J.C., Skousen, J.G. and Gorman, J.M. 2000. Soil horizon development on a mountaintop surface mine in Southern West Virginia. *Journal of Green Lands* 30:41–52.

Tomašić, M., Zgorelec, Ž., Jurišić, A. and Kisić, I. 2013. Cation exchange capacity of dominant soil types in the Republic of Croatia. *Journal of Central European Agriculture* 14:84–98.

Wander, M.M., Walter, G.L., Nissen, T.M., Bollero, G.A, Andrews, S.S. and Cavanaugh-Grant, D.A. 2002. Soil quality: science and process. *Agronomy Journal* 94:23–32.

Wang, Q., Li, Y. and Klassen, W. 2005. Determination of cation exchange capacity on low to highly calcareous soils. *Journal of Communications in Soil Science and Plant Analysis* 36:1479–1498.

Wardle, D.A, Bonner, K.I., Barker, G.M., Yeates, G.W., Nicholson, K.S., Bardgett, R.D., Watson, R.N. and Ghani, A. 1999. Plant removals in perennial grassland : vegetation dynamics , decomposers , soil biodiversity , and ecosystem properties. *Jorunal of Ecological Monograph* 69:535–568.

Wong, M. 2003. Ecological restoration of mine degraded soils, with emphasis on metal contaminated soils. *Journal of Chemosphere*, 50:775–780.

Yao, R., Yang, J., Gao, P., Zhang, J. and Jin, W. 2013. Determining minimum data set for soil quality assessment of typical salt-affected farmland in the coastal reclamation area. *Journal of Soil and Tillage Research* 128:137–148.

Yi, Z., Jinchao, F., Dayuan, X., Weiguo, S., and Axmacher, J.C. 2012. A Comparison of terrestrial arthropod sampling methods. *Journal of Resources and Ecology* 3:174–182.

Zhao, Z., Shahrour, I., Bai, Z., Fan, W., Feng, L. and Li, H. 2013. Soils development in opencast coal mine spoils reclaimed for 1-13 years in the West-Northern Loess Plateau of China. *European Journal of Soil Biology* 55:40–46.

Zornoza, R., Acosta, J.A., Bastida, F., Domínguez, S.G., Toledo, D.M. and Faz, A. 2015. Identification of sensitive indicators to assess the interrelationship between soil quality, management practices and human health. *Journal of Soil* 1:173–185.