

Soil Quality under Agroforestry Trees Pattern in Upper Citarum Watershed, Indonesia

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ABSTRACT

This paper discusses the setting up of a multivariate statistical method in selecting the useful soil quality indicators for soil quality assessment under agroforestry pattern. The of soil quality has been recognized as a tool to determine the sustainability of land resources, especially in agroforestry development. The study was carried out at Upper Citarum Watershed of Bandung district, West Java province, Indonesia. The soil samples were taken with purposive sampling under agroforestry pattern. Principal component analysis (PCA) was used as the multivariate statistical method to identify the minimum data set (MDS); scoring of each indicator, and data integration in the index of soil quality. The MDS consisted of four soil chemical indicators and represented 83.6% of the variability of data, i.e., pH, and exchangeable Calcium (exch Ca), organic Carbon (org C), and exchangeable Natrium (exch Na) respectively. The soil quality index (SQI) was categorized under agroforestry pattern as moderate. The artificial agroforestry-based coffee with an intercropping system (timber woods, multi purpose trees and horticultures) provides better soil quality.

Keywords: soil quality, agroforestry, multivariate assessment, PCA, upper citarum watershed.

INTRODUCTION

The changes in land use has long been a problem around Upper Citarum watershed in Bandung district, Indonesia. Declining forest covers occurred due to the opening of forest lands for dry farming land and the proliferation of illegal logging (Chaidar et al., 2017). Land use conversions often negatively affect the functioning of soil (Emadi et al., 2009; Raiesi and Beheshti, 2014; Saviozzi et al., 2001; Spohn and Giani, 2011). The forests provide soil fertility, soil erosion protection and climate change mitigation (Aticho, 2013). Land conditions in the upper Citarum watershed, have been increasingly critical in recent times, causing various problems, especially the high erosion that is considered to be one of the factors causing river sedimentation and triggering flood disaster. A critical land area that occurred

in the Upper Citarum watershed in 2013 reached 46,543 ha or 20.2% of total upstream area DAS, while in 2015, it increased to 136,872.68 ha or 59.3% of the entire area of an upstream watershed (Ministry of Agriculture, 2015).

Appropriate land management practices needed to reduce soil degradation and maintain better soil quality, decrease the critical land and increase land productivity. Agroforestry is a combination of forestry and agronomy to create harmony between the intensification of agriculture and forest conservation (King, 1979, 1976). Agroforestry constitutes the land use systems in which trees or shrubs are grown together with crops, pastures or livestock, and provide an ecological and economic interaction (Young, 1989).

The agroforestry system has been evolving under the influence of various biophysical and socioeconomic factors. Multiple forms of agro-

forestry have long been known in the local land use systems (agroforestry) in the Upper Citarum watershed. The locally known *kebon tatangkalan* is one of the most typical ones and has long been playing a significant role in the entire production system of the agricultural landscape (De Foresta and Michon, 1996; Michon and de Foresta, 1999; Parikesit et al., 2005). The agroforestry was used to increase the land productivity with multi purpose tree species, relay-cropping, terracing and contour cultivation, strip and alley cropping (Acharya and Kafle, 2009). The agroforestry system has the potential to reduce runoff and erosion, maintain better soil organic matter, which improves the fertility status of the soil (Nair, 1998). Agroforestry has the potential to maintain the land productivity, and soil fertility, adding to the economic contribution of farmer, also providing a positive impact on the conservation aspect (Hainriah et al., 2006; León and Osorio, 2014). The soil fertility under agroforestry was high compared to cropland (Kassa et al., 2017) and enhanced the content of natural degradable components in the organic matter (Marinho et al., 2014).

Agroforestry in the Upper Citarum watershed is currently declining from the landscape due to population growth and rapid regional economic development. Serious effort to revitalize this tra-

ditional agroforestry is needed to prevent its disappearance (Parikesit et al., 2005). However, the dense and critical land in the Upper Citarum watershed has been converted to agroforestry in the last decades. In order to build the agroforestry system in Upper Citarum watershed, evaluating the current condition of soil quality comprehensively becomes a necessity to determine the next conservation action.

Soil quality index (SQI) has been recognized as a tool for determining the sustainability of land resources (Karlen et al., 2003). Some researchers have evaluated and proposed various soil quality indicators that readily measured the changes of soil condition (Doran and Parkin, 1994; Karlen et al., 1998; Larson and Pierce, 1994). There are two methods of calculating the soil quality index that is Expert Judgment and Principal Components Analysis (Laishram et al., 2012). The multivariate statistical technique has widely been used for selecting effective soil quality indicators. The principal components analysis (PCA) method is a tool in data reduction to select some of the potential indicators (Qi et al., 2009). The objectives of this study were to find the soil quality indicators with a multivariate statistical method for soil quality assessment and to evaluate the soil quality index (SQI) under the agroforestry pattern.

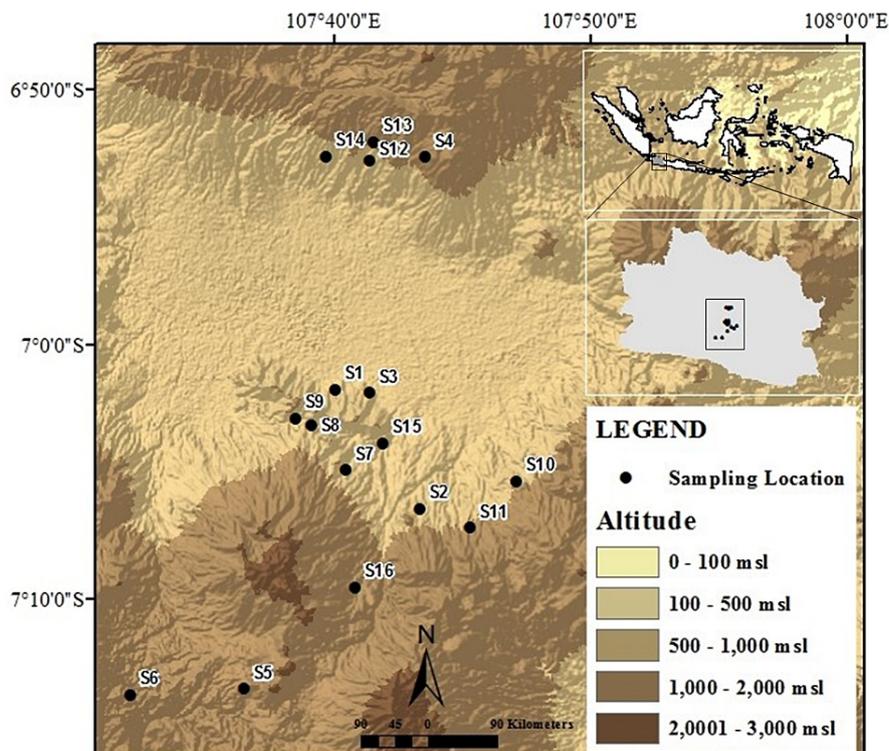


Figure 1. Index map showing the location of the collected sample

MATERIAL AND METHODS

Study area

The study was carried out at Upper Citarum Watershed of Bandung district, West Java province, Indonesia (Figure 1). The average of annual precipitation is approximately in the range of 1.500–3.000 mm.year⁻¹. The study site was located in a tropical region, geographically located at 107°27' to 107°49' east longitude and -7°16' to -6°48' south longitude. Figure 1 shows the index map of the study area in which the sample was collected.

The geological conditions of the study area, are composed of volcanic rocks, sedimentary rocks, intrusion rocks, lake sediments and alluvium deposits (Alzwar et al., 1992; Silitonga, 1973). The geomorphology of Bandung district is divided into flat and hills zones. The flat zone is located in the northern part of Bandung district with elevation ranging from 500 to 1000 mean sea level (msl) and composed of sedimentary volcanoes in Quarter age. The hilly zone is located in the southern part of the study area with the el-

evation ranging from 1000–2500 msl; it is composed of rocks with volcanic genesis. The major soil unit is separated into Inceptisol and Andisols (Soil and Agroclimate Research Center, 1993; Soil Survey Staff, 2014).

Method

This study was conducted from May to July 2017. Geo-referenced surface soil samples and tools were used in the field analysis consisting of soil auger, clinometer, pH stick, distilled water, and other chemicals for soil judgment. The soil samples collected with purposive sampling from 0–30cm depth were obtained from the agroforestry pattern (Table 1) based on Combe and Budowski (1979).

The samples were taken, and air-dried at room temperature for physical and chemical properties. The soil chemical analyses carried out involved determining: the soil pH in 1:2.5 soil-water suspension, measured using a pH-meter, cation exchange capacity (CEC) with the ammonium acetate method (Hesse and Hesse, 1971), organic carbon (Walky and Black, 1934), total

Table 1. Soil sampling description

Soil location	Agroforestry pattern		Slope (%)	Soil Type
	Composed	Cropping		
S1	<i>Mangifera indica</i> L, <i>Musa paradisiaca</i> L, <i>Bambuseae</i>	Random	3–8	Andisols
S2	<i>Albizia chinensis</i> , <i>Musa paradisiaca</i> L, <i>Manihot esculenta</i>	Random	8–15	Inceptisols
S3	<i>Persea americana</i> Mill, <i>Toona sureni</i> Merr, <i>Musa paradisiaca</i> L, <i>Manihot esculenta</i>	Random	15–30	Andisols
S4	<i>Coffea arabica</i> L, <i>Artocarpus heterophyllus</i> Lam, <i>Gmelina arborea</i>	Alley cropping	15–30	Andisols
S5	<i>Coffea arabica</i> L, <i>Artocarpus heterophyllus</i> Lam, <i>Mangifera indica</i> L, <i>Musa paradisiaca</i> L	Alley cropping	3–8	Andisols
S6	<i>Coffea arabica</i> L, <i>Brassica rapa</i> L, <i>Solanum lycopersicum</i>	Alley cropping	15–30	Andisols
S7	<i>Tectona grandis</i> , <i>Allium fistulosum</i>	Alley cropping	8–15	Andisols
S8	<i>Gmelina arborea</i> , <i>Manihot esculenta</i>	Alley cropping	8–15	Andisols
S9	<i>Gmelina arborea</i> , <i>Zingiber officinale</i> , <i>Carica papaya</i>	Random	30–45	Andisols
S10	<i>Albizia chinensis</i> , <i>Mangifera indica</i> L, <i>Manihot esculenta</i>	Random	3–8	Inceptisols
S11	<i>Tectona grandis</i> , <i>Albizia chinensis</i> , <i>Synedrella nudiflora</i>	Random	30–45	Inceptisols
S12	<i>Syzygium aromaticum</i> , <i>Manihot esculenta</i> , <i>Synedrella nudiflora</i>	Alley cropping	8–15	Inceptisols
S13	<i>Syzygium aromaticum</i> , <i>Manihot esculenta</i> , <i>Mangifera indica</i> L, <i>Gnetum gnemon</i> , <i>Durio sp</i>	Random	30–45	Inceptisols
S14	<i>Mangifera indica</i> L, <i>Musa paradisiaca</i> L, <i>Ageratum conyzoides</i>	Random	3–8	Inceptisols
S15	<i>Albizia chinensis</i> , <i>Manihot esculenta</i> , <i>Ageratum conyzoides</i>	Random	3–8	Inceptisols
S16	<i>Toona sureni</i> Merr, <i>Musa paradisiaca</i> L, <i>Synedrella nudiflora</i>	Random	30–45	Inceptisols

nitrogen using the Kjeldahl method (Bremner et al., 1996), available phosphorus (Olsen, 1954), available-K using a flamephotometer method, exchangeable potassium (K), sodium (Na), calcium (Ca), magnesium (Mg) by means of the ammonium acetate (1 M NH₄OAc at pH 7) extraction method. Soil chemical categorizing was based on the soil chemical standard (Indonesian Soil Research Institute, 2005).

All statistical analysis were performed by means of PAST v.3.18 software (Hammer et al., 2001). In order to synthesize all of the selected parameters, a soil quality index (SQI) was assessed by scoring of chosen variables. Determination of the weight of each determinant of soil quality, SQI was calculated using the formula (Andrews et al., 2004; Qi et al., 2009) with the following equation :

$$SQI = \sum_{i=1}^n (W_i + S_i) \quad (1)$$

where W_i = the assigned a weight of each indicator, which is gained from a selected principal component,

S_i = the score of the indicator,

n = the number of variables in the refined minimum data set (MDS).

SQI classification was used to determine soil quality status in the study site (Cantú et al., 2007). The high score of SQI indicates that the soil has high quality (Table 2).

RESULT AND DISCUSSION

Soil Attributes

The soil in the study area is composed by 3–31% of sand particles, 12–68% of silt particles and 27–83% of clay particles. The soil texture in the study area was 69% clay (S1, S2, S3, S5, S6, S7, S8, S9, S10, S15, and S16), 25% silty clay

loam (S11, S12, S13, S14), and 6% clay loam (S4). The categorized soil pH was acidic (<5.5) and slightly acidic (5.5–6.5) for all location. The location S7 had the lowest value of pH and the maximum pH showed in location S1. Total nitrogen considered as low to moderate, with the lowest concentration in the location S3 and the maximum showed in the location S4. Organic carbon (org C) was low (2–3%) in the locations S1, S3, S5, S7, S12, and S16, moderate (2–3%) in the locations S2, S6, S9, S14, and S15 and high (2–3%) in the locations S4, S8, and S13.

The available phosphorus (Av-P) was high (41–60 ppm) in the locations S2, S3, S8, and S12 and very high (>60 ppm) in the rest. The available potassium (av-K) was low (10–20 ppm) in the locations S2, S3, S7, S11, and S13, moderate (>20–40 ppm) in the locations S14, high (40–60 ppm) in the locations S4, S5, S6, and S13 and very high (>60 ppm) in the rest. The exchangeable magnesium (exch Mg) in all locations was high (>8 cmol.kg⁻¹). The exchangeable calcium (exch Ca) was moderate (6–10 cmol.kg⁻¹) in the locations S1, S2, S8, S9, S11, S15, and S16 and high (>10–20 cmol.kg⁻¹) in the rest.

The exchangeable potassium (exch K) was low (0.1–0.3 cmol.kg⁻¹) in the locations S2, S3, S7, S8, S10, and S14, moderate (>0.3–0.5 cmol.kg⁻¹) in the locations S1, S9, and S15 and high (>0.6–1.0 cmol.kg⁻¹) in the locations S6, S11, S12, S13, and S16, very high (>1.0 cmol.kg⁻¹) in the rest. Base saturation (BS) in all locations was very high (>80%) and cation exchange capacity (CEC) was considered as very low (<5 cmol.kg⁻¹) in the locations S2 and S16, low (5–16 cmol.kg⁻¹) in the locations S1, moderate (>16–25 cmol.kg⁻¹) in the locations S2, S5, S6, S8, S9, S11, S13, and S15, high (>25–40 cmol.kg⁻¹) in the locations S3, S7, S10, and S14.

The statistical methods were applied regarding the correlation and classification among the selected soil. The basic statistical analysis was used to determine minimum, mean, maximum, standard deviation, a coefficient of variation (CV), and skewness (Table 3). The coefficient of variation (CV) is classified as weak variability if CV<10%, moderate variability if CV ranged 10–100% and strong variability if CV>100% (Jin et al., 2015). In this study, CV ranged from 10–100%, which is classified as weak to moderate variability. Table 3 shows the soil chemical statistical results. The pH was classified as weak variability with CV<10% and other variables

Table 2. Soil quality index (SQI) classification

No	SQI Classification	SQI Score
1	Very good	0.80 – 1.00
2	Good	0.60 – 0.79
3	Moderate	0.35 – 0.59
4	Low	0.20 – 0.34
5	Very low	0.00 – 0.19

Table 3. Soil chemical statistical analysis results.

Parameters	Min	Max	Mean	SD	Skewness	CV
pH	4.70	6.30	5.54	0.39	-0.64	7.13
org C	1.07	3.26	2.32	0.64	-0.25	27.49
total N	0.14	0.40	0.23	0.07	0.87	31.54
CN ratio	8.00	17.00	10.19	2.26	1.84	22.16
av P	41.65	324.20	141.53	82.17	0.61	58.06
av K	8.31	52.16	22.41	15.82	0.83	70.58
exch Ca	6.05	17.99	10.93	3.98	0.02	36.40
exch Mg	2.33	6.72	3.36	1.12	2.04	33.32
exch K	0.12	1.29	0.52	0.38	0.61	72.75
exch Na	0.05	0.79	0.38	0.22	0.33	59.31
CEC	15.98	36.29	23.35	5.73	0.69	24.55
BS	50.00	83.00	64.19	9.62	0.34	14.99

SD – standard deviation, CV – coefficient of variation, org C – organic carbon, av P – available phosphorus, av K – available potassium, exch Ca – exchangeable calcium, exch Mg – exchangeable magnesium, exch K – exchangeable potassium, exch Na – exchangeable sodium, CEC – cation exchange capacity, BS – base saturation.

were classified as moderate variability with CV ranging within 10–100%.

The pH and org C have smaller mean values instead of their median values, corresponding with their negative skewness. Furthermore, all indicators except pH and org C, have greater mean values instead of their median values, corresponding with their positive skewness. The av K and exch K exhibit larger variation than other indicators due to their higher CV values. The maximum values of av K and exch K were found in soil with agroforestry composed by *Artocarpus heterophyllus* Lam, *Coffea arabica* L, *Mangifera indica* L, *Musa paradisiaca* L with slope ranged 3–8% (S5). Furthermore, the minimum CV values represented by pH were observed in S7 by mixed food crops (*Allium fistulosum*) and wood crops (*Tectona grandis*).

The relationship between soil chemical variables

Pearson correlation analysis results of soil chemical data are performed with the confidence level 95% and 99%, to determine the relationship between variables (Li et al., 2013) as described in Table 4. Among the total concentration results, several variables have a positive correlation with others. On the other hand, several variables have negative correlation, which indicates that the indicators negatively affect each other. In Table 4, there were positive correlations at significant levels <0.01 among variables, i.e. total N–org C (0.785), Av-P–total N (0.626), Av K–Av-P (0.803), exch Mg–exch Ca (0.623), exch

K–av K (0.600), CEC–exch Ca (0.902), CEC–exch Mg (0.757), and BS–exch Ca (0.729). Furthermore, positive correlations at significant levels <0.05 among variables, i.e. total exch K–av P (0.600), exch Ca–total N (0.622), exch Na–exch Ca (0.568), and CEC–exch Na (0.537). The highest correlation was between CEC–av Ca (0.902 at significant levels <0.01) and the lowest correlation showed between CEC av Na (0.537) at significant levels <0.05.

PCA, MDS, and SQI clustering

The relationship between the eigenvalue and principal components (PCs) is shown in Figure 2, with an increase in PC, there is a corresponding decrease in the eigenvalue. In Figure 2, the increase in PCs up to 4, there was a steep decline in eigenvalue. However, after the increase in PC from 4 to 12, there was a gradual decline in the eigenvalue.

The PCs with the eigenvalue >1 were selected for interpretation, and the PCs receiving high eigenvalue and variable with a high weight or factor loading were considered to best represent the soil indicators (Andrews et al., 2004; Brejda et al., 2000). The PCs which were eligible as data set included PC1 to PC4 (eigenvalue ≥ 1), and represented 83.6% of the data variability (Table 5). PC1 with an eigenvalue of 4.365, explained about 36.4% of the variance (Table 5). The pH with positive factor loading (0.256), org C (0.300), total N (0.622), av P (0.766), av K (0.748), exch Ca (0.825), exch Mg (0.159), exch K (0.531), exch Na (0.714),

Table 4. Pearson correlation analysis results.

Parameters	pH	org C	total N	CN ratio	av P	av K	exch Ca	exch Mg	exch K	exch Na	CEC	BS
pH	1											
org C	0.03	1										
total N	0.063	.785**	1									
CN ratio	-0.09	0.281	-0.345	1								
av P	0.063	0.487	.626**	-0.182	1							
av K	0.222	0.287	0.373	-0.188	.803**	1						
exch Ca	0.13	-0.09	0.221	-0.481	0.425	0.461	1					
exch Mg	0.139	-0.475	-0.347	-0.238	-0.34	-0.162	.623**	1				
exch K	0.178	0.175	0.302	-0.241	.600*	.673**	0.212	-0.391	1			
exch Na	0.139	0.434	.622*	-0.335	0.431	0.328	.568*	0.154	0.001	1		
CEC	0.003	-0.042	0.193	-0.396	0.256	0.286	.902**	.757**	-0.052	.537*	1	
BS	0.348	-0.222	0.061	-0.425	0.347	0.427	.729**	0.29	0.485	0.37	0.383	1

SCP – soil chemical properties, org C – organic carbon, av P – available phosphorus, av K – available potassium, exch Ca – exchangeable calcium, exch Mg – exchangeable magnesium, exch K – exchangeable potassium, exch Na – exchangeable natrium, CEC – cation exchange capacity, BS – base saturation, **correlation is significant at the 0.01 level (2-tailed), * correlation is significant at the 0.05 level (2-tailed)

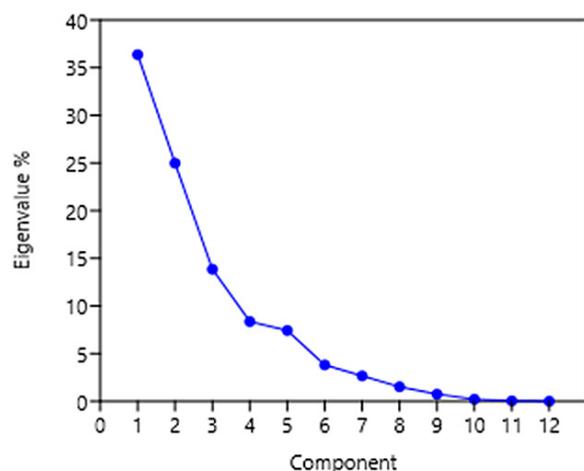


Figure 2. The relationship between eigen value and principal component

CEC (0.656), and BS (0.681). PC2 included org C with positive factor loading (0.741), total N (0.538), CN ratio (0.314), av P (0.478), av K (0.302), and exch K (0.410)

PC2 explained about 25% of variance and eigenvalue of 2.997. Organic C with positive factor loading (0.495), total N (0.425), CN ratio (0.097), exch Ca (0.050), exch Mg (0.180), exch Na (0.512), and CEC (0.345), was included in PC3 and explained 13.9% of the variance with eigenvalue of 1.662. PC4 included the pH with positive factor loading (0.880), org C (0.205), total N (0.020), CN ratio (0.247), exch Na (0.176), and BS (0.106), with negative factor loading in av P, av K, exch Ca, exch K, and CEC, respectively. PC4 explained about 8.4% of the variance and eigenvalue of 1.003.

There are three steps in the elaboration of a quality index (Karlen et al., 2003), i.e., a definition of minimum data set (MDS), scoring of each indicator by mathematical functions, and data integration in the index. The parameters obtained for each variable or indicator were analyzed in the principal component analysis (PCA) to identify the MDS. The principal component (PCs) which has an eigenvalue equal or higher than 1 was taken as MDS. One indicator with the highest value and taken as weighting index (W_i) was chosen in every selected PC.

The first principle component (PC1), a highly weighted attribute included (total N, av P, av K, exch Ca, exch Na, CEC, and BS) were significantly ($p < 0.01$) correlated with each other. The highest factor loading in PC1 are exch Ca was chosen for the MDS (Table 5). In PC2, org C showed higher factor loading, while in PC3, and PC4 – exch Na and pH. Therefore, the final variable chosen for MDS included the following indicators; pH, org C, exch Ca and exch Na. Hence, the weighting factors (W_i) for the variable in PC1 (exch Ca), PC2 (org C), PC3 (exch Na) and PC4 (pH), are 0.825, 0.741, 0.512, and 0.825.

The soil quality index calculated from the indicators was chosen for MDS (pH, org C, exch Ca and exch Na). This variables were identified as indicators of soil quality. Each indicator was assigned scores, based on the weighting coefficient factors for MDS variable determined with the PCA result. Quantifying the soil quality requires a minimum data set (Schloter et al., 2006), and combining minimum data set variables in a meaningful way into a single index may enhance the assess-

Table 5. PCA for MDS determination

Statistical parameters	PC1	PC2	PC3	PC4
Eigen value	4.365	2.997	1.662	1.003
% variance	36.371	24.976	13.851	8.362
Cumulative variance (%)	36.371	61.347	75.198	83.560
Soil chemical properties				
pH	0.259	-0.058	-0.315	0.880
org C	0.300	0.741	0.495	0.205
total N	0.622	0.538	0.425	0.020
CN ratio	-0.531	0.314	0.097	0.247
av P	0.766	0.478	-0.080	-0.162
av K	0.748	0.302	-0.318	-0.055
exch Ca	0.825	-0.514	0.050	-0.081
exch Mg	0.159	-0.926	0.180	0.115
exch K	0.531	0.410	-0.636	-0.147
exch Na	0.714	-0.010	0.512	0.176
CEC	0.656	-0.581	0.345	-0.116
BS	0.681	-0.331	-0.448	0.106

PC – Principal component, org C – organic carbon, av P – available phosphorus, av K – available potassium, exch Ca – exchangeable calcium, exch Mg – exchangeable magnesium, exch K – exchangeable potassium, exch Na – exchangeable sodium, CEC – cation exchange capacity, BS – base saturation

ment (Andrews et al., 2004). The minimum data set (MDS) for selecting and representing the total dataset (Doran and Parkin, 1994; Karlen et al., 1998) can save time and money (Govaerts, et al., 2006). Principal component analysis (PCA) for selecting minimum data set (MDS) was used to evaluate agricultural soil quality in Zhangjiagang, China (Qi et al., 2009) and was applied in soil quality assessment of wheat and maize cropping in the highlands of Mexico (Govaerts, et al., 2006).

In this study, four indicators were selected from twelve as soil quality indicators i.e., pH and exch Ca, org C, and exch Na (Table 5). The properties in soil quality rating (Doran and Parkin, 1994) resulted from soil organic carbon, soil pH, nitrogen (N), exchangeable phosphorus and exchangeable potassium as soil chemical indicators. Ten soil properties, as MDS (pH, electric conductivity, NO₃-N, available phosphorus, soil organic carbon, microbial biomass carbon, Cd, Hg, HCHs and DDTs) were used to evaluate soil quality index under different planting patterns and soil types (Bi et al., 2013). Soil organic carbon was selected as the most dominant soil attribute in soil quality assessment (Shukla et al., 2006). Organic-C, pH, available P and available K constituted the minimum data set in soil quality assessment on tobacco plant in Sindoro mountainous zone (Supriyadi et al., 2017).

The scores of SQI in all locations were indicated in Table 6. The comparison of these rates with soil

quality classes (Cantú et al., 2007) showed that the soil quality in agroforestry pattern was established as low (0.20–0.34) and moderate (0.35–0.59).

The SQI obtained through soil location in the agroforestry pattern varied within 0.3–0.58 (Table 6). The lowest SQI (0.3) at location S16 in slope condition ranged between 30–45% –this is the location of agroforestry with vegetation arranged by *Toona Sureni Merr*, *Musa paradisiaca L*, *Synedrella nudiflora* with random cropping pattern. The location of S13 is a natural agroforestry site consisting of mixed fruit and food crops (*Syzygium aromaticum*, *Manihot esculenta*, *Mangifera indica L*, *Gnetum gnemon*, *Durio sp*) which has the highest SQI (0.58).

Cluster analysis is used to assemble objects based on the soil chemicals characteristics. In this process, hierarchical clustering joins the most similar observations in the dendrogram. The dendrogram of the 16 soil samples is shown in Figure 3.

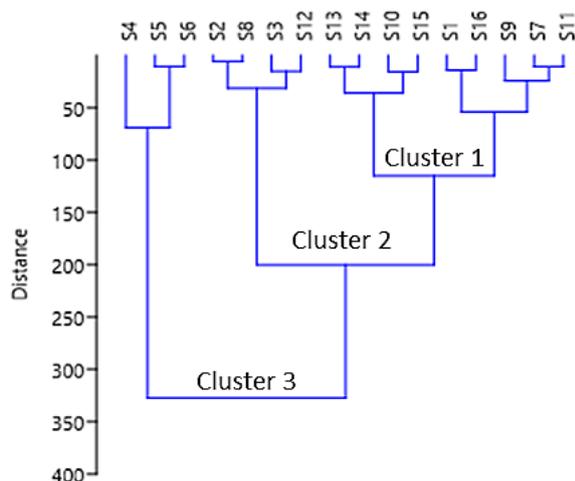
There are three cluster groups in the dendrogram, in which cluster 1 group possess 56% of total samples, cluster 2 has 25% samples, and cluster 3 has 19% soil samples. Table 7 shows the cluster group, sample location concerning cluster group, percentage of sample belongs to each cluster group and soil quality index group.

The similarity of grouped soil samples, their grouped min., max., and mean value of chemical parameters showed in Table 8. Cluster 1 group has

Table 6. SQI classification of each study location

Soil location	MDS				SQI	
	pH	org C	exch Ca	exch Na	Score	Classification
	PCA (Wi)					
	0.880	0.741	0.825	0.512		
	Si					
S1	0.909	0.552	0.318	0.334	0.41	Moderate
S2	0.808	0.577	0.312	0.058	0.36	Moderate
S3	0.837	0.298	0.909	0.265	0.46	Moderate
S4	0.808	0.890	0.761	0.587	0.57	Moderate
S5	0.837	0.502	0.701	0.334	0.46	Moderate
S6	0.823	0.714	0.638	0.403	0.50	Moderate
S7	0.678	0.538	0.625	0.449	0.44	Moderate
S8	0.779	0.848	0.316	0.334	0.44	Moderate
S9	0.778	0.756	0.405	0.230	0.42	Moderate
S10	0.749	0.759	0.638	0.806	0.54	Moderate
S11	0.802	0.678	0.319	0.150	0.39	Moderate
S12	0.810	0.496	0.649	0.575	0.48	Moderate
S13	0.798	0.909	0.724	0.702	0.58	Moderate
S14	0.846	0.625	0.756	0.909	0.57	Moderate
S15	0.837	0.811	0.463	0.690	0.52	Moderate
S16	0.693	0.404	0.306	0.092	0.30	Low

MDS – minimum data set, PCA (Wi) – principal component analyses (weighting index), Si – scoring index, SQI – soil quality index, org C – organic carbon, exch Ca – exchangeable calcium, exch Na – exchangeable sodium

**Figure 3.** The dendrogram of the cluster analysis

low pH value (acid) based on soil chemical standard (Indonesian Soil Research Institute, 2005), whereas cluster 2 and cluster 3 have higher pH value than cluster 1. The presence of lower pH value can be related to the decrease of base saturation in the soil. Table 8 shows that cluster 1 has a low base saturation rate compared to other clusters.

In SQI clustering, group of cluster 1 has higher value than cluster 2 and lower than cluster 3 (Table 7). In Table 8, cluster 1 has a high value of CN ratio and exchangeable Na while in cluster 2, only exchangeable Mg had the high value.

The locations of group cluster 1 was mainly a natural agroforestry system with random cropping pattern (S1, S9, S10, S11, S13, S14, S15, S16), except for S7 with an alley cropping pattern with mixed food crops (*Allium fistulosum*) and timber (*Tectona grandis*). Most of the locations in cluster 1 consist of a mixture of timbers (*Tectona grandis*, *Gmelina arborea*, *Albizia chinensis*, *Toona sureni Merr*), horticultures (*Manihot esculenta*, *Allium fistulosum*), multi purpose trees (*Mangifera indica L*, *Musa paradisiaca L*, *Syzygium aromaticum*, *Mangifera indica L*, *Gnetum gnemon*, *Durio sp*, *Carica papaya*) and grasses (*Ageratum conyzoides*, *Synedrella nudiflora*) that result in high CN ratio content. A higher diversity of tree species result in faster decomposition of organic content (Wang et al., 2014) and enhanced carbon-nitrogen (CN) ratio.

The higher levels of exchangeable magnesium (Table 8) in cluster 2 were possibly caused by the clay content in the each soil location. There is a correlation between the magnesium content and the clay content in the soil (Mikkelsen, 2010). Cluster 2 mainly consisted of a mixture of timbers (*Gmelina arborea*, *Albizia chinensis*, *Toona sureni Merr*), multi purpose trees (*Persea americana Mill*) and food crop (*Manihot esculenta*) as dominant.

Table 7. Cluster analysis of the soil location

Cluster	Soil Location	Sample (%)	SQI
Cluster 1	S1, S7, S9, S10, S11, S13, S14, S15, S16	56%	0.46
Cluster 2	S2, S3, S8, S12	25%	0.43
Cluster 3	S4, S5, S6	19%	0.51

Table 8. Cluster analysis of chemical parameters of different clustered groups

Cluster	pH	org C	total N	CN ratio	av P	av K	exch Ca	exch Mg	exch K	exch Na	CEC	BS
Cluster 1												
Min	4.70	1.45	0.16	8.00	84.30	9.58	6.05	2.33	0.12	0.08	15.98	50.00
Max	6.30	3.26	0.33	17.00	192.10	40.80	14.97	4.49	0.81	0.79	31.08	70.00
Mean	5.46	2.40	0.23	10.78	141.67	20.04	10.01	3.22	0.42	0.42	23.05	60.22
Cluster 2												
Min	5.40	1.07	0.14	8.00	41.65	8.31	6.17	3.01	0.12	0.05	16.43	51.00
Max	5.80	3.04	0.26	12.00	50.33	10.70	17.99	6.72	0.86	0.50	36.29	83.00
Mean	5.60	1.99	0.20	9.75	45.80	9.39	10.82	4.09	0.33	0.27	23.34	65.25
Cluster 3												
Min	5.60	1.80	0.19	8.00	236.70	40.30	12.63	2.52	0.94	0.29	22.58	71.00
Max	5.80	3.19	0.40	10.00	324.20	52.16	15.05	2.94	1.29	0.51	26.90	78.00
Mean	5.70	2.52	0.28	9.00	268.78	46.92	13.85	2.78	1.09	0.38	24.30	74.67

org C – organic carbon, av P – available phosphorus, av K – available potassium, exch Ca – exchangeable calcium, exch Mg – exchangeable magnesium, exch K – exchangeable potassium, exch Na – exchangeable sodium, CEC – cation exchange capacity, BS – base saturation

Cluster 3 had the highest SQI (Table 7) compared to other clusters. This cluster has a high value of pH, organic C, total N, available P, available K, exchangeable Ca, cation exchange capacity and base saturation (Table 8). The location of S4, S5, S6 in cluster 3 group was artificial agroforestry system with an alley cropping pattern with coffee as the main product. Cluster 3 consists of a mixture of timbers (*Gmelina arborea*), multi purpose tree (*Coffea arabica* L, *Mangifera indica* L, *Artocarpus heterophyllus* Lam) and horticultures (*Brassica rapa* L, *Solanum lycopersicum*). Agroforestry-based coffee with an intercropping system (timber, multi purpose tree and horticulture) provides better soil quality compared to other clusters. This corresponds with the findings high soil carbon stocks in agroforestry-based coffee compared to the arable land (Lal, 2004; Mohammed and Bekele, 2014). The available phosphorus showed the highest value in the cluster with agroforestry-based coffee and corresponds with the research which found that the phosphorus content was higher in the coffee under organic rather than conventional management (Tully et al., 2013). Agroforestry-based coffee is most commonly cultivated to cope with the physiological stress, decreased soil erosion and to generate additional income for the farmer (Pimentel et al., 2011; Tschamtkke et al., 2011).

In order to improve the soil quality, soil and vegetation management by conservation farming need to be considered. The selection of crop types considers the suitability of the growing place, types of protection forest trees. The multipurpose tree species that have strong and deep roots, as well as the grasses that are suitable for livestock are preferred. The arrangement of plant pattern, layout and planting spacing should be taken into consideration.

CONCLUSION

The results showed that MDS consisted of four soil chemical indicators and represented 83.6% of the variability of data, i.e., pH, and exchangeable Calcium (exch Ca), organic Carbon (org C), and exchangeable Sodium (exch Na) respectively. The soil quality index (SQI) under agroforestry pattern was categorized as moderate. The artificial agroforestry-based coffee with an intercropping system (timber, multi purpose tree and horticulture) provides better soil quality.

Conclusively, appropriate land, soil, and vegetation management by conservation farming, adding of organic matter and fertilizers well-organized are required to improve and maintain better soil quality and productivity. Furthermore,

there is need to investigate the technologies for mapping of soil quality and to monitor the health/quality of the soil from time to time.

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