JOURNAL OF DEGRADED AND MINING LANDS MANAGEMENT
ISSN: 2339-076X, Volume 1, Number 3 (April 2014): 105-110
DOI:10.15243/jdmlm.2014.013.105

Research Article

The quantitative soil quality assessment for tobacco plant in Sindoro mountainous zone

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Abstract. The long-term cultivation of tobacco (*Nicotiana tabacum*) plant in the Sindoro mountainous zone of Central Java has resulted in soil quality degradation that could affect economic development in the region if sustainable production practices are not identified. The objective of the study was to identify appropriate indicators for assessing soil quality on tobacco plant. The quantitative soil quality indicators were total organic-C, pH, available P and available K (chemical), soil depth, bulk density, AWC (available water capacity) and soil aggregate stability (physical), and qCO_2 (soil respiration), MBC (microbial biomass carbon) (biological). The decreases in the soil aggregate stability, available water capacity, cation exchange capacity, soil respiration, microbial biomass carbon and total organic-C; or increases in bulk density (compaction), available P, available K and total nitrogen indicated the decrease in soil quality due to long-term tobacco production. The result of this research showed that the change of soil quality had occurred in Sindoro Mountain**.** The Soil Quality Index (SQI) for three land use systems in Sindoro mountain (forest, mixed farm, and tobacco) were 0.60, 0.47, and 0.57, respectively. The comparison of these rates with soil quality classes showed that the soil quality presented moderate to good level of quality; class SQI.

***Keywords** : indicator, soil quality, Sindoro Mountain, tobacco*

Introduction

Tobacco is a major annual cash crop in the humid areas of the Sindoro mountainous zone of Central Java. The tobacco production system is undergoing major changes in response to population pressure and improved market access. Consequently, there has been an increase in both land-use intensity and soil degradation. as Although the tobacco plantations remain productive for long periods, yields tend to decline in the latter years. This is traditionally attributed to natural aging of the plants (Allen et al., 2011), although there is some speculation that this may also reflect a loss of soil quality. Degradation in soil quality is often associated with the type of intensive land use involved in tobacco production. Moreover, because crop growth and productivity are a reflection of soil quality, any degradation of the soil can be expected to affect the stability of system. Therefore, an evaluation of soil quality changes during long-term tobacco production is necessary to enhance the sustainability of tobacco cultivation in Central Java. Agricultural methods that degrade the soil are only profitable in the short term under our current systems. This is because the losses of natural capital due to soil erosion or degradation are invisible in conventional economic accounts, and not included directly in the costs of food production (Doran and Zeiss, 2000).

Recent efforts in the USA have prioritized the development of soil quality (SQ) assessment strategies that would be used by individual farmers (Wander et al., 2002). Quantitative (based on soil analysis) and qualitative (based on farmer interviews) indicators were defined based on their sensitivity to change. The quantitative indicator keys were organic-C, pH, N, P, K and S concentration (chemical), mechanical resistance, bulk density, total porosity, PAWC (plant available water capacity) and MWD (mean weight diameter) of aggregates (physical), and earthworm populations (biological). Decreases in the organic-

C, N, K and S content, pH, total porosity, PAWC, MWD and earthworm populations, or increases in bulk density and mechanical resistance (compaction) indicated a decrease in soil quality due to long-term tea production (Dang, 2007).

Soil quality indicators must provide a sensitive and timely measure of the soil's ability to function and be able to identify whether the change in soil quality is induced by natural processes or it occurs because of management (Doran and Parkin, 1994). Quantitative assessments involve analytical data (Harris and Bezdicek, 1994). Several techniques or methods that have been developed by many workers to quantify soil quality indicators were the comparative approach (Pierce and Larson, 1994), dynamic approach using statistical quality control procedures (Pierce and Larson, 1994; Pierce and Gilliand, 1997), computer models (Larson and Pierce, 1994; Burger and Kelting, 1998), multi-scale approach (Karlen et al., 1997) and performance-based scale index (Doran and Parkin, 1994). Among these methods, monitoring of dynamic of soil properties is a very important method because these properties are always in state of flux as they respond to environmental and management forces (Pierce and Larson, 1994).

The objective of this study was to identify appropriate indicators for assessing the impact of long-term tobacco cultivation on soil quality in the Sindoro mountainous zone of Central Java.

Materials and Methods

Study site and soil sampling procedures

The study was conducted during 2007-2008 in the Parakan and Ngadirejo Districts of Temanggung Regency, the largest tobacco area in the Sindoro mountainous zone of Central Java covering an area of 1698.529 ha.. Geographically, the area is located at 110 ° 01'00 "-110 ° 3'10" east longitude and 7 ° 16'00 "-7 ° 19'50" south latitude. Slope of the site is gentle and approximate 10-15 %. The soils are moderately deep with little mixing of stones in the surface horizons. Soil parent material consists of Alluvium (on the landform plains material in the form of deposition of sand and clay deposits), sedimentary rocks (composed of marl, volcanic breccias, and volcanic ash), and volcanic (volcanic ash, andesite, basalt, andesite-liparit, and dacite).

The study was based on land use approach that represents an ecological time series of soil where the differences in land use are selected but not differences in environmental conditions (Dyck and Cole, 1994). Based on such approach, field sites were selected based on native forest (control), tobacco cultivation, and mixed farm. Each land use class was replicated three times. Soil samples were collected from each land use system. Each soil sample was a composite of 5 sub-samples (0-30 cm soil dept) collected from an area of 200 m^2 (20 m x 10 m) of agricultural land (tobacco and mixed farm) and 100 m^2 (10 m x 10 m) of forest land. Finally, 30 composite samples were collected from three land use system, of which 12, 12, and 6 represented the mixed farm, tobacco, and forest soils, respectively. The soil samples were air-dried at room temperature for physical, chemical and biological properties. The analyses carried out were bulk density (Kim, 2005), soil aggregate stability (Kim, 2005), available water capacity (Coyne and Thompson, 2006), pH (Coyne and Thomson, 2006), cation exchange capacity (Blackmore et al., 1987), soil organic carbon (Anderson and Ingram, 1993), total nitrogen (Anderson and Ingram, 1993), available P (Blakemore et al., 1987), available K (Blakemore, 1987), soil respiration (Coyne and Thompson, 2006), and microbial biomass carbon (Coyne and Thompson, 2006).

Data Analysis

In order to synthesize all of information provided by selected parameters, a soil quality index was calculated. According to Karlen et al. (2003), there are three steps in the elaboration of a quality index, i.e. definition of minimum data set (MDS); scoring of each indicator by mathematical functions; and data integration in index. The parameters obtained for each variable or indicator was analyzed in Principal Component Analyses (PCA) in order to identify the MDS. Principal components (PCs) with eigen value >1 were selected for interpretation, and PCs receiving high eigen value and variable with a high weight or factor loading were considered to best represent the soil indicators (Andrews et al., 2004). After determining the weight of each determinant of soil quality, soil quality index (SQI) was calculated using the following equation :

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

Where, SQI is the soil quality index, n = number of indicators included in the MDS, Wi is the PC weighting factor and Si is the indicator score for variable i. In the model, higher index scores indicate better soil quality or greater performance of soil function. Finally, the SQI was compared with different classes of soil quality specified in Table 6. Data were subjected to statistical analysis using SPSS16.0

Results and Discussion

Evaluation of soil quality indicators

The variation of land use for soil quality indicators presented in Table 1 shows that there was no significant bulk density (BD) differences between the land uses (forest, mixed farms and tobacco). Soil aggregate stability (SAS) of the forest and tobacco soils were significantly higher than that of mixed farm soils (57.22%), but no significant differences was observed between the mixed farm and tobacco soils. Potential available water capacity of the forest (61.44%) and tobacco soil (59.55%) were significantly higher than that of mixed farm soils (51.92%), but no significant differences were observed between the mixed farm and tobacco soils.

Total nitrogen, available phosphorus, available potassium, and cation exchange capacity were affected by the land use management. Total nitrogen content that ranged from 0.25 to 0.27 g/kg were significantly different ($p \leq 0.05$) between land use management. Available phosphorus that ranged from 5.01 to 23.90 g/kg were significantly different ($p \leq 0.05$) between land use management. Available potassium and CEC also showed significant differences ($p \leq 0.05$) between land use management. The pH value in mixed farm, tobacco, and forest soils, however, showed no significant differences. The total organic carbon (TOC) contents in mixed farm and tobacco soils were not significantly different, but they were significantly lowers than that of forest soils.

Significant lower level of microbial biomass carbon was found in mixed farm and tobacco soils compared with forest soils. The soil respiration (qCO_2) presented a variation range from 0.47 to 0.67 mg/g/day were significant differences ($p \leq 0.05$) between land use management. No significant different was observed between forest, mixed farm and tobacco soils, although the forest soils showed higher in qCO_2 and TOC content.

The relationship between soil indicators

Base on correlation analysis of the 12 soil indicators, is a soil physical, chemical, and biological indicators, resulted in a significant correlation in 14 of the soil attribute pairs (Table 2). Among the significant correlation indicator, we found negative but significant linier relationships between these indicators. In this study, total organic C, pH and available water capacity is showing high correlation with soil respiration (q CO_2). Andrews et al. (2004) reported that total organic C and aggregate stability are ascending logistic or more is better functions on their role in soil fertility and structure stability. Available water holding capacity (AWC) more is better functions on water availability for crop productivity and biological activity.

The high total organic C is important for sustainability since is influences the soil quality. Total organic C showed a significant correlation with all the physical soil properties, the role of organic C in infiltration, water retention and water available. Sinha et al. (2014) reported that, the soil physical environment might affect for microbial activity in soil. Highly correlation with soil microbial biomass and the availability of labile nutrients such nitrogen, phosphorus and cation exchange capacity. Microbial biomass reflects the functional capability of soil to provide and habitat, cycle nutrients, and decomposes organic matter (Franzlubbers and Haney, 2006). The soil pH is negative correlation with available P and available K, it indicated that at higher or lower pH, these nutrients are less available to crop. Wright et al. (2012) have critically reviewed the availability of plant nutrients under varying pH and suggested that nutrients in soils are strongly affected of soil pH.

The soil quality index (SQI)

The soil physical, chemical and biological parameters obtained for each land use were determined, and the mean values for each land use were subjected analysis (Tables 3). The variable showing significant differences were analysis with principal component analyses (PCA). The communalities of soil properties showed that the extracted four components were explained by 70 to 90% of the variance of soil properties, which indicated that the components represented by the soil parameters. As a result the PCA identified 5 indicator with highly weighted variables (Eigen value >1; Table 4).

The first principle component (PC1) that included SAS and TOC, are all highly correlated. TOC and SAS were chosen for the MDS. Only one indicator was highly weighted for PC2, PC3 and PC4, are CEC, AWC and AP respectively.

Table 1. The mean soil physical properties measurement for difference of land use

Land Use	Soil Physical Indicators				Soil Chemical indicators					Soil Biological Indicators		
	SD (cm)	**SAS (%)**	**BD (Mg/m^3)**	**AWC (% Vol.)**	**pH**	**TN (g/kg)**	**AP (mg/kg)**	**AK (mg/kg)**	**CEC (cmol/kg)**	**qCO_2 (mg/g/day)**	**MBC (g/kg)**	**TOC (g/kg)**
Forest	82.11	71.11	1.07	61.44	5.94	0.25	5.01	0.27	30.13	0.56	0.53	8.37
mixed farms	82.11	57.22	1.32	51.92	5.94	0.24	16.57	0.25	29.69	0.67	0.45	5.44
Tobacco	82.11	62.22	1.19	59.55	5.94	0.27	23.90	0.37	29.87	0.47	0.45	6.90
Significant- level	ns	*	ns	*	ns	*	**	*	*	*	*	*

SD = Soil depth, SAS = Soil aggregate stability, BD = Bulk density, AWC = Available water capacity, TN = total nitrogen, AP = Available phosphorus, AK = Available potassium, CEC = Cation exchange capacity, qCO_2 = Soil respiration, MBC = microbial biomass carbon, TOC = total organic carbon. Significant at 0.05 (*), and 0.01 (**) level of probability; ns = not significant.

Tabel 2 . Matrix correlation of soil indicators

Indicators	qCO_2	MBC	TOC	TN	AK	CEC	pH	AP	SD	BV	AWC	SAS
qCO_2	1											
MBC	-.295	1										
TOC	-.481**	.226	1									
TN	-.243	.401*	.248	1								
AK	.074	.261	-.063	.121	1							
CEC	-.111	-.342*	-.052	.012	-.371*	1						
pH	.362*	-.300	-.172	.117	-.078	.158	1					
AP	.067	-.117	-.568**	.117	.258	.053	.070	1				
SD	.090	.077	-.063	.434*	-.068	.089	.721**	.033	1			
BV	.268	-.219	-.380*	-.098	-.058	.109	-.171	.229	.050	1		
AWC	-.347*	-.079	.503**	-.012	-.184	.098	-.200	-.208	-.197	-.120	1	
SAS	-.189	-.138	.461**	-.051	.042	.180	.147	-.503**	.053	-.405*	.218	1

**. Correlation is significant at the 0.01 level, *. Correlation is significant at the 0.05 level

Therefore, the final variable chosen for MDS included the following indicators; SAS, TOC, CEC, AP and AWC. The soil quality index was calculated only from the indicators was chosen for MDS (SAS, TOC, CEC, PAWC and AP); this variable identified as indicators of soil quality. Each indicator was assigned scores, based on the weighting coefficient factors for MDS variable was determined with the PCA result. Therefore the weighting factor for the variable in PC1 (SAS, and TOC), PC2 (CEC), PC3 (PAWC) and PC4 (AP), are 0.945, 0.490, 0.991, 0.945, and 0.983 respectively. The scores of SQI were calculated with Equation (1), and there were significant differences between the forest, mixed farming, and tobacco land uses.

Table 3. Results of the PCA of statistically significant soil indicators

Statistical parameter	PC1	PC2	PC3	PC4	Communalities
Eigen value	1.527	1.398	1.340	1.315	
% of Variance	26.182	28.454	19.766	21.439	
Cumulative variance	26.182	54.636	74.402	95.841	
Eigen value soil indicator					
qCO2	-.185	-.154	-.295	.003	.15
MBC	-.086	-.357	.000	-.131	.15
TOC	.490	-.003	.391	-.438	.52
TN	-.021	.020	-.019	.115	.01
AK	.206	-.356	-.120	.365	.32
CEC	-.071	.991	-.104	-.048	1.00
pH	.133	.152	-.303	.099	.14
AP	-.334	.069	-.057	.938	1.00
SD	.046	.080	-.284	.036	.09
BV	-.432	.080	-.038	.084	.20
AWC	.226	.210	.945	-.099	.99

The SQI for three land use system in Sindoro mountain (forest, mixed farm, and tobacco) were 0.60, 0.47, and 0.57 respectively. The comparison of these rates with soil quality classes showed that the soil quality were established presented moderate to good level of quality class of SQI (Table 4).

Table 4. Soil quality classes

Soil quality	Scale	Classes
Very good	0.80 – 1	1
Good	0.60 – 0.79	2
Moderate	0.35 – 0.59	3
Low	0.20 – 0.34	4
Very low	0 – 0.19	5

(Modified from Cantu et al., 2007)

The low value of index implied that soil quality under land use system is bad, the result indicated that land use system in Sindoro mountain generally deteriorate the physical, chemical and biological soils properties. Sinha et al. (2014) reported that soil quality under continuous cropping system in the arid ecosystem of India generally deteriorate the physical, chemical, and biological soil quality indicators. Although the physical, chemical, and biological indicators of soil quality generally declined in this land use; available P, available K, and bulk density increased. The increase in available P and K is because of the long term fertilizer applications (organic and inorganic fertilizer). According to Dang (2007), the physical, chemical, and biological indicators of soil quality generally declined in response to long term cultivation in the tea fields, but total P and bulk density tended to increase with same time. The soil physical indicator strongly influence soil function and determine potential land use. The high bulk density may affect plant root growth, soil aggregate stability is considered one the most important indicators of soil degradation, also closely related for many intrinsic soil properties, e.g., soil organic matter and nutrient cycle (Tesfahunegn et al., 2011).

Conclusion

The soil quality in Sindoro Mountain has considerable changed. The soil quality levels for three land use system in Sindoro mountain (forest, mixed farm, and tobacco) ranged from moderate to good.

Acknowledgements

This study was supported by DIPA Project of Sebelas Maret University.

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