Soil quality assessment of Oxisols and Ultisols: The roles of site-specific factors

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Abstract
Soil quality (SQ) can change due to management practices and the inherent properties of soil. Designed for enabling sustainability of agriculture, the objectives of this study are to (i) examine the roles of site-specific factors of Oxisols and Ultisols, (ii) determine the soil quality index of Oxisols and Ultisols in order to see the change in SQ due to management practices. Three varieties of corn, Local Kima, Sukma Raga, and Bisi-2 were grown in a multilocation experiment on a Typic Hapludox (CLTH), Plinthic Kandiudults (CLPK), and Plinthic Hapludoxs (CLPH) in Panyipatan Tanah Laut South Kalimantan Indonesia. The 17 attributes of soil sampled from 0 – 15 cm soil surface were statistically analyzed using the multivariate analysis of variance (manova) followed by principal factor analysis (PFA) of SAS 6.12 (SAS Inst. 1996). Combined with an expert system of the Soil Management Assessment Framework (SMAF), step by step data reductions of manova and anova($\alpha \leq 0.05$), followed by factor analysis was used to determined the amount of variance explained by each factor (eigenvalue $\geq$ 1). The indicators included in the SQ equation are bulk density (BD), available water capacity (AWC), total organic carbon (TOC), soil pH, and soil P. The soils showed different relationships due to the difference of site-specific factors.Used the SMAF equation, it is found that the SQ index of CLTH, CLPK, and CLPH in Panyipatan are respectively 74.46, 69.47, and 54.00.

Key Words
Soil quality, oxisols, ultisols, site-specific factor.

Introduction
Soil quality (SQ) is the capacity of soil to function, within natural and managed ecosystem boundaries, to sustain plant and animal productivity, maintain and enhance water and air quality, and support human health and habitation (Karlen *et al.* 1997; Andrews *et al.* 2004). Understanding SQ means assessing and managing its quality so that it functions optimally now and for the future. SQ can not be measured directly; therefore it needed indicators to be evaluated. To determine the SQ index, indicators need to be scored. Scoring function depends also on site-specific factors. The indicator changes can be used to determine whether SQ is improving, stable, or declining. The objectives of this study are to (i) examine the roles of site-specific factors of Oxisols and Ultisols, (ii) determine the soil quality index of Oxisols and Ultisols in order to see the change of SQ due to management practices

Methods
The SMAF (Andrews *et al.* 2004) follows three basic steps: Indicators selection, indicator interpretation, and integration to SQ index value.

Table 1. Potential management goals and associated soil functions and SQ indicators for each function.

Management goals	Supporting soil function	Indicator	Criteria for selection of indicator
Productivity	Nutrient cycling	pH; P; TOC	Always suggested under this function; Organic amendment comparison or productivity goal
Waste recycling			
Environmental protection	Water retention	AWC, pH; BD; TOC	Always suggested under this function; Clay texture + practice comparison;
	Physical stability and support	BD; TOC	Clay texture + practice comparison
	Filtering and buffering	-	-
	Resistance and resilience	TOC	C change assessment or organic amendment comparison
	Biodiversity and habitat	-	-

Source: Modified and combining Table 1 and Table 2 of Andrews *et al.* 2004

1 – 6 August 2010, Brisbane, Australia. Published on DVD.

Indicator selection
To generate minimum data set (MDS), the SMAF uses a series of decision rules. The selection criteria of decision rules are the management goals associated soil functions, like maximizing productivity, waste recycling, or environmental protection; and site-specific factors, like region or crop sensitivity. These rules (Table 1) serve as an expert system to select appropriate SQ indicators (Bellocchi *et al.* 2002; Andrews *et al.* 2004). The user is asked to select four to eight indicators with at least one indicator from each function. In this study only five indicators are selected.

Indicator interpretation
Interpretation of indicators includes transformation of each MDS indicator to unit less value using nonlinear scoring curve (Andrews *et al.* 2004). The SMAF scoring curves consist of algorithms, which are quantitative relationships between empirical values of measured indicators and normalized scores, reflecting the performance of ecosystem service(s) or soil function(s). The algorithms (Andrews *et al.* 2004) were constructed using a curve fitting program, Curve Expert v. 1.3. It is assumed that the relationship between a given indicator and the soil function(s) it represents hold relatively constant among systems. This relationship determines the shape of curve or the algorithm equation of an indicator. An indicator score of 1 represents the highest potential function for that system. The SMAF assumed that the expected range for each indicator will vary according to site-specific controlling factors, such as climate or inherent soil properties.

Integration into an index
The SMAF integrates all indicator scores into the single, additive index value. This value is considered to be an overall assessment of SQ, reflecting management practice effects on soil functions. The SQI equation is:

$$SQI = \frac{\sum_{i=1}^{n} S_i}{100} \times \qquad (1)$$

Th ... e indicator value and n represents the number of indicators in the MDS.

Experimental design, sampling, and statistical analysis
In multilocation experiment in randomized completely block design with 3 blocks at each site, 3 varieties of corn, Local Kima, Sukmaraga, and Bisi-2 were planted in 3 nearly level upland locations stratified based on the differences of soil subgroups of Oxisols and Ultisols: Tipyc Hapludoxs (CLTH), Plinthic Kandiudults (CLPK), and Plinthic Hapludoxs (CLPH) in Panyipatan Tanah Laut South Kalimantan Indonesia. One month prior to planting, soil was plowed and harrowed; chicken manure was applied to each site on the rate of 2 ton/ha. During the planting season, urea, SP36 and KCl were applied twice on the 15 days and 37 – 40 days after planting. Soils were sampled 3 times from 0 – 15 cm, before planting, at the time of silking period, and on harvesting, and were analyzed using standard methods of soil analysis. Soil texture was measured using the Bouyoucos hydrometer method. BD is the ratio of oven dried soil (mass) to its bulk volume measured from an undisturbed soil sample. AWC, the amount of water held between field capacity and wilting point is calculated between 1/3 bar – 15 bars. Other soil analysis carried out are the organic-carbon (TOC), nitrogen (N), potential P_2O_5 and K_2O_5 (25 % HCl extraction), available soil P (Bray extraction), exchangeable cations, and cation exchange capacity (1 N NH_4OAC, pH 7.0). Corn leaves were also sampled at the silking period and analyzed for N, P, and K.

Statistical analysis was performed using UNIVARIATE, GLM, and PFA of SAS 6.12 (SAS inst. Inc 1996). These variables were checked for homogeneity and normality. Assessment of SQ was achieved by examining soil attributes simultaneously (Brejda *et al.* 2000). Multivariate analysis of variance (MANOVA) was first used to determine whether there were significant management effects on the 17 soil variables. Wilk's lambda and F statistic were examined to test the hypothesis of no overall treatment effect. The soil variables with p value ≤ 0.05 and CV ≤ 40 were retained then examined using PFA to test the (null) hypothesis of no common factors. Factors with eigenvalue > 1 were retained for interpretation using rotation. Combined with the expert system table of SMAF, SQ indicators MDS were determined. To examine the roles of site-specific factors, treatment means for observed and scored indicators were compared using anova with regions (soil subgroups) and varieties as independent variables.

Results
The minimum data set, MDS
The result of the first step manova performed to observe the effects of regions (soil subgroups) and varieties

on 17 soil variables sampled on 27 experimental points were (1) there was no interaction between regions and varieties, and TOC was significantly affected by regions and corn varieties, whilst the other soil variables are significantly affected only by the regions; (2) six variables NO3, NH4, exch. Al, Fe, exch. K, and variable Na had p values > 0.05 and CV >40 %; therefore, they were not considered for further analysis; (3) eleven variables: BD, AWC, TOC, N, pH, P, K, Pbray1, Ca, Mg, and Cations will be subjected to factor analysis.

Factor analysis
There are four eigenvalues 3.3220, 2.6268, 1.5131, and 1.1332, which together account for 78.14 % of the standardized variance. Four factor retained on the basis of the eigenvalue-greater-than-one-rule is rotated (equamax). Brejda *et al.* (2000a), named each factor based on their loadings. In this study, based on their loadings, the first factor was termed the soil P, the second factor named soil Pbray, the third factor named soil K , and the fourth factor named soil N. The four factors and soil attributes from which they are comprised based on their correlations can be seen in Table 3.

Table 2. SQ factors and the soil attributes that comprises these factors.

Factor 1	Factor 2	Factor 3	Factor 4
P (soil)	*Pbray (Fertility)*	*K (Fertility)*	*N (Organic matter)*
P	Pbray1	K	N
AWC	Soil pH	Exch. Mg	
TOC	Exch. Ca		
BD			

Expert opinion, SMAF
The second method to determine MDS is based on expert opinion, SMAF. Table 1 act as an expert system. Combining these two methods, the MDS indicator includes BD, AWC, TOC, soil pH, and soil Pbray1.

Indicator interpretation and the site-specific factor roles
The expected range for each indicator and site-specific factor values were decided based on SMAF (Andrews *et al.* 2004), and research (Djaenuddin *et al.* 1994; Grossman *et al.* 2001; Diaz-Zorrito *et al.* 1999: 91; USDA 1966; Walf and Baker 1985; and Bappedal PPLH UGM, PSSL UGM 2000).

Table 3. MDS indicators observed and scored of three soil subgroups CLTH, CLPH, and CLPK in Panyipatan District South Kalimantan Indonesia.

Indicator	CLTH		CLPK		CLPH	
	Observed	Scored	Observed	Scored	Observed	Scored
BD	1.08	0.98	1.20	0.79	1.23	0.72
AWC	15.00	0.66	9.78	0.49	12.71	0.59
TOC	2.55	0.70	2.21	1.00	1.88	0.41
pH	4.46	0.77	4.19	0.57	4.33	0.62
Pbray1	6.39	0.61	6.45	0.62	4.52	0.37

To examine the roles of site-specific factors, treatment means for observed and scored indicators were compared using anova with regions (soil subgroups) and varieties as independent variables.
BD is assigned a less-is-better function because of the inhibitory effect on root growth and porosity; the site-specific factors are texture and mineralogy (Grossman *et al.* 2001). AWC is a more-is-better function based on its roles of water availability for crop requirement, nutrient solubility, and biological activity; the site-specific factors are texture and inherent organic matter (Gregory *et al.* 2000). TOC is a more-is-better function based on its roles in soil fertility, water partitioning, and structural stability; the site-specific factors are inherent organic matter, texture, and climate (Herrick and Wander 1998). Variation of mid-point optimum or Gaussian function was used for soil pH based on crop sensitivity and effects on nutrient availability; the site specific factors are crop (Smitt and Doran 1996) and land suitability level. The curve of soil P , according to Maynard and Pierzynski (Andrews *et al.* 2004) is mid-point optimum based on crop response and environmental risk; the site-specific factors are crop, TOC, texture, and the test procedure.

Determining soil quality index, SQI
Using Equation (1) the SQI of CLTH was 74.46 > CLPK is 69.47 > CLPH 54.00.

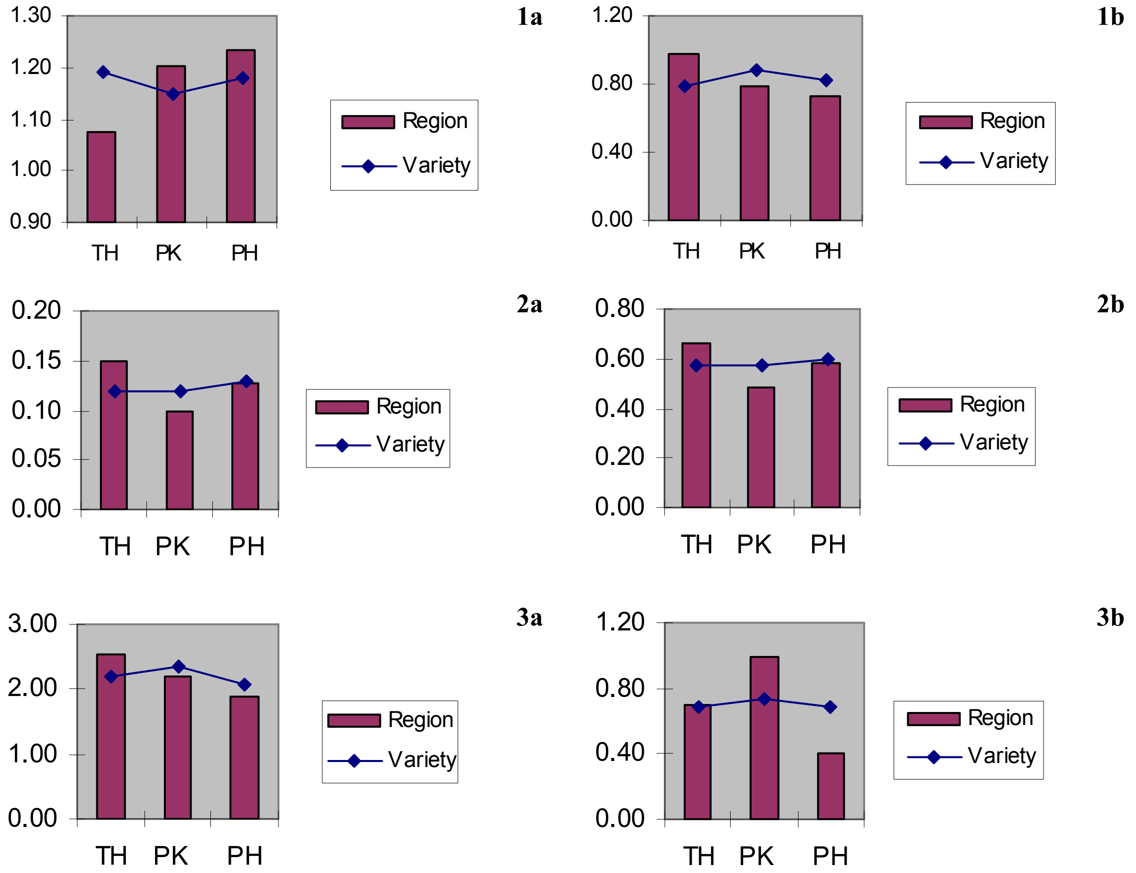

Figure 1. Shape of treatment mean variables for BD observed (1a), BD scored (1b), AWC observed (2a) AWC scored (2b), TOC observed (3a) and TOC scored (3b).

Conclusions

SMAF is considered an appropriate tool for assessing management effects on SQ because the framework encompasses productivity and environmental goals. It is also flexible and especially sensitive to the differences of site-specific factors, such as inherent soil and climate. Although analysis factor (PFA) can statistically support the SMAF expert system, further research is needed to avoid the redundancy of SQ indicators in MDS due to the correlations among soil attributes. The study found that in general, the most sensitive indicator in MDS is soil organic matter due to its roles and functions as dynamic and inherent SQ.

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