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Research Article
Soil Quality Assessment for Yield Improvement of Clove, Cacao and Cardamom Agro-Forestry System in Menoreh Mountains Area, Indonesia

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Abstract

Background and Objective: Soil quality assessment is one way to formulate strategies to improve the quality and sustainability of land and productivity of the crop. This study aimed to determine parameters of soil quality that affect the yield of cloves, cocoa and cardamom in the agro-forestry system in Menoreh mountains area. **Methodology:** The stratified random sampling method was used during the research by stratifying the types of soil stratification in Menoreh mountains area, Samigaluh district, Kulonprogo regency, i.e. Yogyakarta, Indonesia that were Lithic Eutrudept, Vertic Haplustalf and Typic Hapludult. The observations were made on 24 physical, chemical and biological properties of soil and the yield of clove, cacao and cardamom. The determination of soil quality indicator was done by using one-way ANOVA at α 5%, factor analysis and standardized stepwise regression. **Results:** The result shows that the highest dry weight of clove flowers is produced in the soil type of Vertic Haplustalf, sequentially followed by soil types of Typic Hapludult and Lithic Eutrudept. The highest dry weight of cocoa beans and cardamom bulb is produced in the soil type of Vertic Haplustalf, sequentially followed by soil types of Lithic Eutrudept and Typic Hapludult. **Conclusion:** The dry weight of clove flowers is affected by the percentage of silt fraction of the soil. The dry weight of cocoa beans is influenced by the content of CEC, Ex-Ca and Ex-Na, while the dry weight of cardamom bulbs is influenced by the content of Ex-Ca.

Key words: Clove, cacao, cardamom, soil quality assessment, udic soil moisture regime

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Menoreh mountains area is a mountainous area that stretches in the West of Kulonprogo regency, East of Purworejo regency and a part of Magelang regency. People in Menoreh mountains area are mostly dry land farmers due to limited irrigation flow. Farmers try to meet various needs: Food, fuel, building timber, animal feed and non-timber forest products with agro-forestry[1].

Plant commodities that are the mainstay of the community in the mountains are clove, cocoa and cardamom in the agro-forestry system. In general, agro-forestry practices that are developed by the community are still considered not productive and innovative. This is reflected in the variation of clove, cocoa and cardamom. One of the most decisive factors of clove, cocoa and cardamom is soil quality[2].

An understanding of soil quality is important to identify problem areas, assess sustainable agricultural management and provide early warning signs of adverse trends[3-5]. Soil quality indices are tools for adaptive soil resource management that can help farmers and their advisors to determine soil health trends and thereby indicate whether one or more changes in practice are necessary[6]. Soil quality is the basis for improving sustainable land use management[7,8], evaluating the sustainability of soil management practices[9,10], providing early warning signs of adverse trends[11] and an estimation of the potential reduction in costs was carried out[12].

The assessment of soil quality could not be done directly; therefore knowing indicators of soil quality is important. Indicators of soil quality can be measured from the physical, chemical and biological properties of the soil. Physical, chemical and biological properties of the soil that can influence soil production and are sensitive to environmental changes are typically chosen as soil quality indicators[12,13]. Biological and microbial indicators, in particular, have recently attracted more attention, owing to their use in evaluating the short-term effects of environmental changes on soil function[14,15]. Several soil quality indicators together produce a comprehensive soil quality measurement known as the minimum data set (MDS)[16].

Specialists have agreed to search for a MDS to reduce the cost of soil quality assessment[17,18]. Qi *et al*.[8], evaluated soil quality at a county scale and showed that using an integrated quality index and MDS method can adequately represent the total data set and save time and money. Meanwhile, more attention should be focused on farmers' local knowledge, which is crucial to maintain soil quality and developing sustainable land management[19,20]. MDS is applied to compare the effect of land management systems on soil quality in various locations[21].

Various studies on soil quality assessment indicators using MDS have been conducted[22], each study producing MDS for different land valuation indicators. Differences in MDS combination are due to the diversity of location, scale and purpose of the study[23]. On the basis of this consideration, in the case of different land management, the combination of MDS used to assess the quality of the soil also varies.

The assessment of soil quality determinants is a promising tool for monitoring and evaluating the effects of different soil types on the crop performances in terms of both biological and economic yields. This study aimed, therefore, to determine the soil parameters that could be used to relate and furthermore to predict the productivity of clove, cocoa and cardamom, especially in the agro-forestry system on Menoreh mountains area, Indonesia.

MATERIALS AND METHODS

Study area: This study was conducted in Menoreh mountains area, Samigaluh district, Kulonprogo regency, special Province of Yogyakarta, Indonesia. The study period starts from September, 2013 until August, 2014. Menoreh mountains area is located ±40 km to the West from downtown Yogyakarta, Indonesia. The height of the Menoreh mountains area varies from 250-1000 m above sea level. The average air temperature ranges between 25-28°C and the average rainfall ranges from 2000-2400 mm/year. The soil moisture regime belongs to the udic group[2].

Soil sampling and analysis: Soil sampling is conducted on 3 dominant soils in Menoreh mountains area at a depth of 0-60 cm. Each type of soil consists of 6 strata. Soil sampling is done randomly as many as 6 samples in each stratum before being composited. The observations were made 4 times a year from September, 2013-August, 2014. The observation variables include the physical, chemical and biological properties of the soil. The observations were conducted directly in the field and at the General Soil Laboratory, Faculty of Agriculture, Universitas Gadjah Mada, Yogyakarta, Indonesia. Detailed components of each variable and its protocol indicated in Table 1.

Observations at clove, cacao and cardamom harvest: Clove observation was conducted on the dry weight of clove flowers, dry weight of cocoa beans without pulp and on dry

Table 1: Protocol of measurements for each indicator

Variables	Symbols	Protocols
Physics		
Texture[24]	Silt, loam, clay	Robinson pipette method
Bulk density[25]	BD	Ring sample
Available soil moisture[2,26]	ASM	Gravimetric
Permeability[25]	Perm	Permeameter
Chemical		
pH H_2O[27]	pH	pH meter
Soil organic matter[28]	SOM	Walkey and black
Cation exchange capacity[27,29,30]	CEC	Ammonium acetate
Electrical conductivity[31]	EC	Saturated soil paste extract
Total nitrogen, NO_3^-, NH_4^+[32]	Tot-N, NO_3, NH_4	Devarda's alloy method
Total phosphorus, available phosphorus[33,34]	Tot-P, Ave-P	HCl 25% extraction and olsen
Total potassium, exchange potassium, exchange sodium[30,35]	Tot-K, Ex-K, Ex-Na	Flame photometer
Exchange calcium, exchange magnesium[30,35]	Ex-Ca, Ex-Mg	AAS
Exchange aluminum, exchange iron[27]	Ex-Al, Ex-Fe	AAS
Biology		
Amount of soil's microorganism[36]	SM	Plate count
Soil respiration[37,38]	SR	Trapping of CO_2

weight of cardamom bulb. The observation of dry weight of clove flower and dry weight of cardamom bulbs was done at harvest time in July-August. The observation of dry weight of cocoa beans without pulp was done during June-August, which is the peak of cacao harvest. The observations were made on 10 samples of clove, cocoa and cardamom plants and repeated 6 times.

Statistical approach: The stratified random sampling method was used during the research by stratifying the types of soil stratification in Menoreh mountains area, Samigaluh district, Kulonprogo regency, Yogyakarta, Indonesia, which were Lithic Eutrudept, Vertic Haplustalf and Typic Hapludult. Comparative analysis of clove, cocoa and cardamom yields on each soil type was performed with one-way ANOVA at 5% and followed by HSD-Tukey at α 5%[39]. The production of clove, cacao and cardamom was done visually by Prism 5 software. The approach used to determine the relationship between soil parameters and the common factor (soil quality) was with the analysis factor on soil parameters which showed a real difference and has a coefficient of diversity <40% based on the result of one-way ANOVA at α 5%. The number of components were determined by the eigen value-one criterion[40]. Moreover, a Scree test was performed to corroborate primer results[41]. A varimax rotation was performed to enhance the interpretability of the uncorrelated components[42]. Furthermore, standardized stepwise regression on soil parameters of screening results of factor analysis was also performed[16].

RESULTS AND DISCUSSION

Selection of key soil quality indicators: Determination of key indicators of soil quality that affect the yield of clove, cacao and cardamom is started with screening using analysis of variance at α 5% then continued with factor analysis and standardized stepwise regression. The results of analysis of variance on physical, chemical and biological variables of the soil showing significant differences and having a coefficient of variation <40% is maintained for continued factor analysis.

Based on the results of analysis of variance on soil properties of land tax variables that show significant differences ($p<0.05$) are the percentage of silt and clay, bulk density (BD), available soil moisture (ASM) and soil permeability (Perm). The soil chemical properties variables that show significant differences $p<0.05$ are pH H_2O, cation exchange capacity (CEC), electrical conductivity (EC), exchange calcium (Ex-Ca), exchange magnesium (Ex-Mg), exchange sodium (Ex-Na), exchange aluminium (Ex-Al) and exchange iron (Ex-Fe) (Table 2).

Multivariate statistical techniques are often appropriate and useful to choose the most representative properties that account for the highest variability in the total data set from large existing data, to obtain much more information from soil data[9,43,44]. In this study, the multivariate analysis used factor analysis and standardized stepwise regression. Determination of relationships between parameters and factors which become common factor in pattern of correlation between variables can be known by factor analysis. Factor analysis is the commonly used because of its ability to group related soil properties into a small set of independent factors and to reduce the original data set[45].

The result of factor analysis shows 2 set of the quality factor of soil formed (Table 3). Factor 1 consists of Ex-Ca, pH H_2O, Ex-Al, CEC, BD, Ex-Fe, ASM and Ex-Na. Factor 2 consists of Ex-Na, silt, clay, perm and EC. The first and second factors show the Ex-Ca and silt having the highest positive value of 0.990 and -0.983, respectively (Table 3). Andrews *et al.*[45] and

Table 2: Analysis of variance (ANOVA) of physical, chemical and biological properties of soil

Group/Parameter	Lithic Eutrudept	Vertic Haplustalf	Typic Hapludult	CV (%)
Physics				
Silt (%)	59.81±1.31^a	21.42±3.94^b	28.02±2.97^b	17.08
Loam (%)	23.43±1.45^a	30.20±2.17^a	31.87±4.63^a	16.48
Clay (%)	16.76±0.17^b	48.44±6.17^a	40.12±2.38^b	17.84
Bulk density (g cm^{-3})	1.47±0.08^b	1.81±0.05^a	1.31±0.03^b	5.04
Available soil moisture (mm)	354.90±20.08^b	360.88±14.57^b	454.08±5.94^a	5.00
Permeability (cm h^{-1})	14.53±1.74^a	0.00±0.00^b	0.61±0.09^b	33.64
Chemical				
pH H_2O	6.07±0.04^a	6.19±0.12^a	4.94±0.05^b	1.84
Soil organic matter (%)	0.43±0.07^a	0.42±0.18^a	0.28±0.06^a	34.89
Cation exchange capacity (cmol(+) kg^{-1})	18.43±0.35^b	28.07±0.64^a	14.77±0.27^c	3.24
Electrical conductivity (dS cm^{-1})	6.33±0.33^a	5.00±0.33^b	4.67±0.00^b	7.65
Total nitrogen (%)	0.07±0.01^a	0.09±0.01^a	0.08±0.01^a	19.09
NO_3^- (%)	0.04±0.01^a	0.08±0.02^a	0.07±0.01^a	32.59
NH_4^+ (%)	0.04±0.00^a	0.09±0.03^a	0.07±0.01^a	35.97
Total phosphorus (mg 100/g)	16.97±2.22^a	14.19±3.95^a	15.25±0.79^a	23.03
Available phosphorus (mg L^{-1})	7.81±1.12^a	7.74±1.96^a	7.00±0.40^a	22.19
Total potassium (mg 100/g)	28.41±5.12^a	49.43±3.07^a	40.55±5.55^a	25.08
Exchange potassium (mg 100/g)	0.48±0.07^a	0.79±0.09^a	0.78±0.12^a	26.60
Exchange calcium (mg 100/g)	10.27±0.91^b	14.48±1.03^a	0.68±0.09^c	15.09
Exchange magnesium (mg 100/g)	1.32±0.03^b	2.38±0.14^a	1.37±0.29^b	19.77
Exchange sodium (mg 100/g)	0.49±0.04^b	0.91±0.01^a	0.42±0.02^b	6.93
Exchange aluminium (mg L^{-1})	0.06±0.01^b	0.18±0.06^b	1.27±0.04^a	12.05
Exchange iron (mg L^{-1})	0.07±0.01^c	0.40±0.05^b	1.46±0.04^a	7.80
Biology				
Amount of soil's microorganism (colony)	27.73±1.90^a	26.33±3.33^a	20.33±0.67^a	11.89
Soil respiration (CO_2 m^{-2} h^{-1})	10.03±0.23^a	9.90±0.08^a	9.70±0.14^a	3.45

Number followed by the same letter in the same column were not significantly different by HSD-Tukey α 5%. The bars was indicated Standard Error of Mean (SEM)

Table 3: Factor analysis after varimax rotation method

Parameter	Factor 1	Factor 2	Communality
Ex-Ca	0.990*	0.001	0.980
pH H_2O	0.969*	-0.188	0.975
Ex-Al	-0.922*	0.370	0.986
CEC	0.876*	0.430	0.952
BD	0.869*	0.414	0.926
Ex-Fe	-0.861*	0.488	0.981
ASM	-0.835*	0.382	0.842
Ex-Na	0.808*	0.558*	0.964
Silt	0.053	-0.983*	0.969
Clay	0.048	0.968*	0.940
Perm	0.177	-0.956*	0.945
EC	0.026	-0.923*	0.853
Eigen-values	6.466	4.847	

*Significant soil's parameters in each soil set factor

Imaz *et al.*[46] obtained a minimum data set of indicators from a total data set using factor analysis and reported a high consistency in soil quality evaluation between the two data sets. The final result of the factor analysis informs that all parameters are eligible to proceed to the stepwise regression analysis since it has a communality value of higher than 0.5[42].

The end point of this study is to determine the soil quality by separating the effect of soil properties that have clove, cocoa and cardamom. Soil quality is the result of physical, chemical and biological properties. The result of the factor analysis is used to determine the parameters used for the stepwise regression analysis. The result of standardized stepwise regression shows that clove yield is influenced by the percentage of silt fraction. Cocoa yield is influenced by CEC, Ex-Ca and Ex-Na contents in the soil, whereas cardamom yield is influenced by Ex-Ca content in soil (Table 4).

Yield of clove, cocoa and cardamom: The results show that there were significant differences in the yields of cloves, cocoa and cardamom. The dry weights of clove flowers in Vertic Haplustalf were significantly higher ($p<0.05$) than Lithic Eutrudept and Typic Hapludult (Fig. 1). The dry weights of cocoa beans in Vertic Haplustalf were significantly higher ($p<0.01$) than Lithic Eutrudept and Typic Hapludult (Fig. 2). The dry weights of cardamom bulb in Vertic Haplustalf were significantly higher ($p<0.05$) than Lithic Eutrudept and Typic Hapludult (Fig. 3).

The difference is due to different types of soil in the study sites. Based on the results of the soil horizon interpretation on each soil profile, it indicates that the soil at the study site is included into the type of Lithic Eutrudept, Vertic Haplustalf and Typic Hapludult. Lithic Eutrudept have a cambic horizon. These soils are the base saturation of >60% in the upper 75 cm or free carbonates throughout the soil, that has a lithic contact within 50 cm of the mineral soil surface[47].

Table 4: Standardized stepwise regression analysis

Commodity	Regression equation	R^2
Clove	Y = 25.217**+0.033 Silt**	0.651**
Cocoa	Y = -385.865**+6.323 CEC*+2.421 Ex-Ca**+137.163 Ex-Na*	0.997**
Cardamom	Y = 219.051**+0.515 Ex-Ca**	0.820**

**Significant at α 5%. *Significant at α 1%

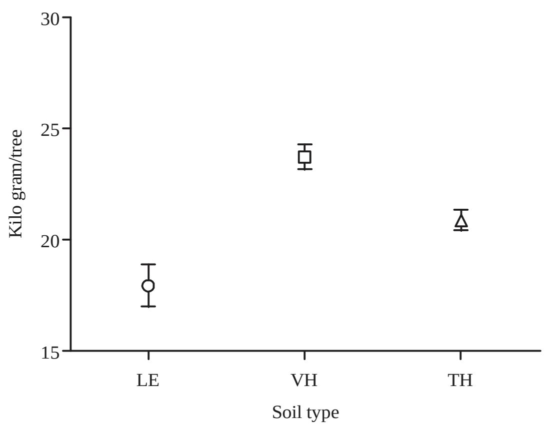

Fig. 1: Dry weight of clove flowers. LE: Lithic Eutrudept, VH: Vertic Haplustalf, TH: Typic Hapludult
The bars was indicated Standard Error of Mean (SEM)

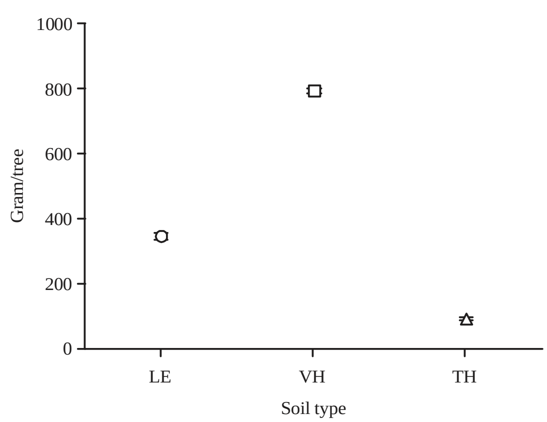

Fig. 2: Dry weight of cocoa beans. LE: Lithic Eutrudept, VH: Vertic Haplustalf, TH: Typic Hapludult
The bars was indicated Standard Error of Mean (SEM)

Vertic Haplustalf have an argillic (clay accumulation) horizon with a significant decrease ($p<0.05$) in clay content within a depth of 150 cm. These soils are the more or less freely drained Alfisol that has seasonally well-distributed precipitation (udic moisture regime) and cold to warm temperature regimes. Vertic Haplustalf have cracks within 125 cm of the mineral soil surface that are 5 mm or more wide through a thickness of 30 cm or more for some time in normal years and slickensides or wedge-shaped peds in a layer of 15 cm or more thick that has its upper boundary within 125 cm of the mineral soil surface[47].

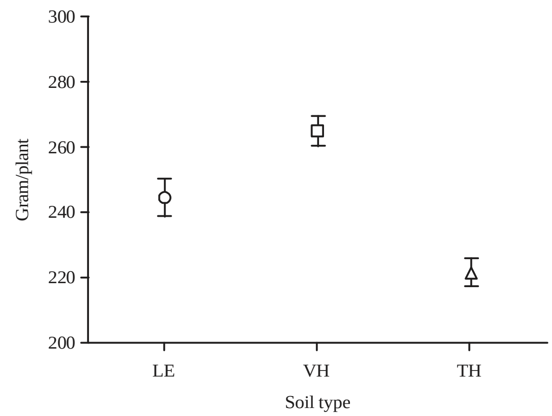

Fig. 3: Dry weight of cardamom bulbs. LE: Lithic Eutrudept, VH: Vertic Haplustalf, TH: Typic Hapludult
The bars was indicated Standard Error of Mean (SEM)

Typic Hapludult has an argillic (clay accumulation) horizon and a significant decrease in clay content within a depth of 150 cm. These soil are the more or less freely drained, humus-poor Ultisol in humid areas with seasonally well-distributed precipitation (udic moisture regime). Most have light-coloured upper horizons and commonly a greyish horizon that rests on a yellowish brown to reddish argillic (clay accumulation) subsoil horizon[47].

Lithic Eutrudept has the main rock consisting of a conglomerate, marl and lime stone with lignite inserts. These rocks are formed in the lower Miocene tertiary period that is about 11-25 million years ago. Vertic Haplustalf and Typic Hapludult have a parent rock with Alluvium type. These rocks formed during the upper Oligocene period up to the lower Miocene i.e. about 25-40 million years ago[48].

The dry weight of clove flowers is influenced by soil texture, especially the percentage of silt fraction. Lithic Eutrudept shows the highest percentage of silt and significantly different from Vertic Haplustalf and Typic Hapludult (Table 2). The low dry weight of clove flowers on Lithic Eutrudept was due to the high percentage of silt (59.81%). This result causes low available soil moisture and many nutrients are lost due to leaching.

Soil texture is the relative proportions of sand, silt and clay and also includes particles larger than sand in soil. These proportions describe the classes of soil texture with a textural triangle. It has a large influence on water holding capacity[49,50], water conducting ability, soil structure[51], chemical soil properties and the relative stabilization of soil organic matter[52-54]. Moreover, the proportions of sand, silt and clay can significantly correlate diversely with crop yield[55,56].

The dry weight of cocoa beans is influenced by the soil chemical properties of CEC, Ex-Ca and Ex-Na, whereas the dry weight of cardamom bulb is influenced by Ex-Ca. CEC and Ex-Ca on Vertic Haplustalf showed the highest value, followed by Lithic Eutrudept and Typic Hapludult. Ex-Na highest in Vertic Haplustalf compared to Lithic Eutrudept and Typic Hapludult.

CEC is used as a measure of soil nutrient retention capacity and the capacity to protect groundwater from cat-ion contamination[57]. It buffers fluctuations in nutrient availability and soil pH[58]. Plants obtain many of their nutrients from the soil by an electrochemical process called cat-ion exchange. This process is the key to understanding soil fertility[59]. Nutrients that are held by charges on a soil are termed 'exchangeable' as they become readily available to plants[59].The higher the CEC of soil, the more nutrients it is likely to hold and the higher will be its fertility level[60].

Cui *et al.*[61] reported that the higher the smectite content in bentonite, the higher the cation exchange capacity (CEC) of the soil. The results of X-Ray Diffraction (XRD) show that Lithic Eutrudept is dominated by clay type smectite minerals. Vertic Haplustalf and Typic Hapludult is predominantly by kaolinite clay minerals[2].

The role and function of Ca in the development and growth of plants especially in the participation of many processes, such as formation of the cell wall and plasma membrane cell growth and secretion[62]. If the CEC of the soil is too high, the Ca in the pore solution of the stabilized soil does not reach the saturation level and further cat-ion exchange would then consume the Ca^{2+} ions which should be originally used to generate calcium silicate hydrate, thus resulting in the poor strength of the stabilized soil[63].

Sodium cycling through plants and the overall environment can be a critical factor influencing the productivity of biological systems[64]. Sodium appears to play a critical role in the regeneration of phosphoenolpyruvate (PEP) in mesophyll chloroplasts of *Amaranthus tricolor*[65]. Also, for many C4 plants, Na has been reported to take part in chlorophyll synthesis[66]. Sodium deficiency has been reported to impair this conversion of pyruvate to PEP, which takes place in the mesophyll chloroplasts[67].

Over the past few decades, fertilizer addition has been widely used as an intensive management practice in clove, cacao and cardamom in Menoreh mountains area and fertilization application is expected to continue to increase[68].

CONCLUSION

The dry weight of clove flowers in Vertic Haplustalf was significantly higher than Lithic Eutrudept and Typic Hapludult. The dry weight of cocoa beans in Vertic Haplustalf was significantly higher than Lithic Eutrudept and Typic Hapludult. The dry weight of cardamom bulb in Vertic Haplustalf was significantly higher than Lithic Eutrudept and Typic Hapludult. The dry weight of clove flowers is influenced by soil texture especially the percentage of silt fraction of the soil. The dry weight of cocoa beans is influenced by soil chemical properties especially CEC, Ex-Ca and Ex-Na while the dry weight of cardamom bulb is influenced by Ex-Ca. The application of organic materials should be done as a strategy for yield improvement of clove, cacao and cardamom agro-forestry system in Menoreh Mountains Area, Indonesia.

SIGNIFICANCE STATEMENT

The results of this study can be used as information to determine appropriate, practical and efficient land management practices to improve the productivity of cloves, cocoa and cardamom in Menoreh Mountains Area.

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