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Research Article
Minimum Soil Quality Determinant for Rice and 'Kayu Putih' Yield under Hilly Areas

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Abstract

Background and Objective: Soil quality indicator is an important instrument necessary to plan the sustainable forest management practices. This research aims to minimum soil quality determinant for rice and 'Kayu Putih' yield under hilly areas. **Materials and Methods:** The survey-based research was conducted during February-August, 2015 in Menggoran Forest Resort, Playen Forest Section, Yogyakarta Forest Management District, Indonesia. The Stratified Random Sampling method was used during the survey-based research by stratifying soil type. Soil type was chosen as the factor consisting Lithic Haplusterts, Ustic Endoaquerts and Vertic Haplustalf. Physical, chemical and biological characteristics of the soil, rice and kayu putih variable were observed during the research. The determination of soil quality minimum data set was done by using one-way analysis of variance (ANOVA), multivariate analysis of variance (MANOVA), structural equation modelling (SEM) and standardized stepwise regression. **Results:** The results showed that root, stem and leaf dry weight of rice is the highest at Ustic Endoaquerts followed by Vertic Haplustalf and Lithic Haplusterts. No significant difference was observed in branch dry weight of kayu putih in each soil type. Leaves dry weight of kayu putih on Lithic Haplusterts and Vertic Haplustalf shows significantly higher ($\alpha<0.05$) results than Ustic Endoaquerts. **Conclusion:** The study was concluded as the minimum soil quality determinant for rice and kayu putih yield under hilly areas are an amount of soil's microorganism (SM), available phosphorus (Ave-P), exchange potassium (Ex-K) and soil respiration (SR) factor. The application of organic materials should be done as a strategy for rice-kayu putih sustainable management.

Key words: Hilly areas, Lithic Haplusterts, Ustic Endoaquerts, Vertic Haplustalf, ustic soil moisture regime, kayu putih

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

INTRODUCTION

Intercropping is a practice in the agro-forestry system which is done by planting annual crops between trees[1]. The component crops of an intercropping system do not necessarily have to be sown and harvested at the same time, but they should be grown simultaneously for a great part of their growth periods[2]. Intercropping has become a focus for study by a range of agricultural, ecological and environmental scientists with broad research interests[3].

An ideal practice of seasonal crops cultivation can be found on kayu putih (*Melaleuca cajuputi*) plantations intercropping. In the kayu putih plantation, intercropping can be done for several crop rotations with rice, corn, soybeans, peanuts and other locally developed species. This is possible because the kayu putih trees are routinely being pruned for harvesting. Therefore, shade factor does not interfere the cropping system. Intercropping in kayu putih plantation can be done continuously up to 30 years[4].

Forests are natural supermarkets for one billion poorest people in the world. Forests provide nuts, berries, tubers, meat and fuel for cooking. It gives space for food crop agriculture while providing essential nutrients that may not be available in the absence of forests[5]. According to MoF[6], in 2008, more than 312,000 ha of forest area has contributed to the national food supply, with food production amount of more than 32,000 t. Forests are supplying food composed of rice, corn, beans, tubers and fruits, as well as meat from the forest animals[7]. Therefore, intercropping on the kayu putih forest is an important part of the movement for food security[8].

Improvements in land and water management, crop productivity and resource-use efficiency are required to fulfill the rapidly growing demand for food[9]. One factor determining the success of cropping system is soil quality. Soil quality is an assessment of how the soil functions and prepared for the future[10].

The assessment of soil quality could not be done directly, therefore, knowing indicators of soil quality are important. Indicators of soil quality can be measured from the physical, chemical and biological properties of the soil. Several soil quality indicators together produce a comprehensive soil quality measurement known as the minimum data set (MDS)[10].

Soil quality indicator is an important instrument necessary to plan the sustainable forest management practices[11]. Sustainable land management system will be possible if the soil quality is maintained to increase[12]. One way to measure soil quality is the determination of soil quality minimum data set[13]. The MDS is used to compare the effects of land management on soil quality in various locations[14]. A quantitative research of soil quality through MDS has the potential to determine best practices for sustainable land management, including cropping system.

Specialists have agreed to search for a MDS to reduce the cost of soil quality assessment[15,16]. Qi *et al*.[17] 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 maintaining soil quality and developing sustainable land management[18,19].

Various studies on indicators for soil quality assessment using MDS has been done[20,21], each study resulted in different MDS. The MDS combination difference between each of the study is the influence of the diversity of location, scale and purpose of research[22]. Therefore, the combination of MDS varies based on the land management practice in a specific site.

This research aims to determine minimum soil quality for yield improvement of rice and 'Kayu Putih' yield under hilly areas.

MATERIALS AND METHODS

Characteristics of location: The survey-based research was conducted during February-August, 2015 in Menggoran Forest Resort, Playen Forest Section, Yogyakarta Forest Management District, Indonesia. The study site has ustic soil moisture regime. Ustic moisture is a soil regime containing limited moisture but is suitable for plant growth when the environmental conditions favor[23]. The interpretation of soil horizons in each soil profile at the site identified the soil type of Lithic Haplusterts, Ustic Endoaquerts and Vertic Haplustalf. Lithic Haplusterts is a Vertisol soil type which has shallow solum and a lithic contact within 50 cm of the soil surface. Ustic Endoaquerts a Vertisol soil which has $\geq$5 mm fracture with $\geq$25 cm thickness for 90 days in each year in normal years when it is not irrigated[23]. Moreover, Vertic Haplusterts is the type of Alfisol soil with vertic nature because it has a 5 mm width fracture from the surface of the soil to a depth of >60 cm[23].

Soil sampling and analysis: The measurement of soil involves physical, chemical and biological characteristics. Observations were made on the site and in the General Soil Laboratory, Faculty of Agriculture, Universitas Gadjah Mada, Yogyakarta, Indonesia. Details of each parameters and protocol components are shown in Table 1.

Table 1: Protocol of measurements for each indicator

Parameters	Symbols	Protocol
Physics		
Bulk density[24]	BD	Ring sample
Available soil moisture[25,26]	ASM	Gravimetry method
Permeability[24]	Perm	Permeameter
Chemical		
pH H_2O[27]	pH	pH meter
Soil organic matter[28]	SOM	Walkey and black
CEC[27,29,30]	CEC	Ammonium acetate
Total nitrogen, NO_3^- and NH_4^+ [28,30,31]	Tot-N, NO_3^- and NH_4^+	Kjeldahl and devorda aloy
Total phosphorus and available phosphorus[32,33]	Tot-P and Ave-P	HCl 25% extraction and olsen
Total potassium, exchange potassium and exchange sodium[34,35]	Tot-K, Ex-K and Ex-Na	Flame photometer
Exchange calcium and exchange magnesium[30,34]	Ex-Ca and Ex-Mg	AAS
Exchange aluminium and exchange iron[27]	Ex-Al and Ex-Fe	AAS
Biology		
Amount of soil's microorganism[36]	SM	Plate count
Soil Respiration[37,38]	SR	Trapping of CO_2

Rice and kayu putih variable: Observations of variable growth and rice yield, consisting of the dry weight (roots, stems, leaves and seeds)/rice clump was done during the harvesting season (±115-120 days). Meanwhile, the observation of kayu putih growth and yield, which includes the dry weight of kayu putih branches and leaves were done 4 months after harvesting. Furthermore, rice roots, stems and leaves of rice were put in the oven at 105°C to constant weight. The same procedure was done to the kayu putih branches and leaves. Rice seeds was sun dried until it reaches 12% moisture content.

Statistical analysis: The stratified random sampling method was used during the research by stratifying the types of soil stratification. Soil type stratification was chosen as the factor consisting Lithic Haplusterts, Ustic Endoaquerts and Vertic Haplustalf. Variables were grouped into the growth of rice and kayu putih, the chemical sample of plants from 0-60 cm and physical, chemical and biological characteristic of soils.

The homogeneity of covariance was confirmed using SAS GLM[39]. Multivariate analysis of variance analysis (MANOVA) was used to determine whether there was a significant effect of a class factor on at least one of the physical, chemical and biological variables assessed. Pillai's Trace and derived F-statistics were used to test the null hypothesis that no overall treatment has the effect.

Comparative analysis of rice yield and kayu putih was performed with one-way analysis of variance (ANOVA) $\alpha<0.05$ and continued with LSD Test $\alpha<0.05$[40]. The approach to the relationship between the variables of physical, chemical and biological soil properties, rice and kayu putih was done using structural equation modeling (SEM) with partial least square (PLS). The SEM-PLS calculation was performed with SmartPLS 3[41,42]. The PLS is a method most commonly used in the social sciences, although it has increasingly been used in ecological studies[43-45].

Standardized stepwise regression analysis was also performed to determine soil parameters which influence rice and kayu putih yields[46]. The MANOVA, one-way ANOVA and standardized stepwise regression analysis were performed using statistical analysis software (SAS) software (version 9.1.3 for Windows; SAS Institute Inc., Cary, NC, USA).

RESULTS

Yields of rice and kayu putih: The results showed significant differences ($\alpha<0.05$) in dry weight of roots, stems, leaves and grains. Results were highest in Ustic Endoaquerts followed Vertic Haplustalf and Lithic Haplusterts. The dry weight of kayu putih branches showed no significant differences in the three soils, while the dry weight of kayu putih leaves on Lithic Haplusterts and Vertic Haplustalf show higher tangible results than Ustic Endoaquerts (Table 2).

Alfisol soil types showed significantly higher ($\alpha<0.05$) leaf greenish values than Vertisol. This is caused by the higher moisture and nutrient Alfisol soil contains compared to Vertisol soil type. In the dry season, nutrients in the Vertisol soil is more difficult to be absorbed by plants due to the strong bound by clay mineral types of 2:1[4].

Selection of key soil quality indicators: Ustic Endoaquerts soil type has higher moisture content than Lithic Haplusterts and Vertic Haplustalf. This is due to the characteristics of Ustic Endoaquerts which is mainly located in the basin, causing the soil to be consistently inundated for 90-120 days. Such conditions result in physical, chemical and biological characteristics difference.

Table 2: A t-test (LSD) grouping based on mean yields of rice and kayu putih with different soils types

	Yield of rice			Yield of kayu putih		
Soil types	Roots dry weight (g/clump)	Stem dry weight (g/clump)	Leaf dry weight (g/clump)	Seeds dry weight (kg/tree)	Branch dry weight (kg/tree)	Leaf dry weight (kg/tree)
Lithic haplusterts	7.040[c]	35.583[c]	4.740[c]	38.604[c]	1.692[a]	3.122[a]
Ustic endoaquerts	8.285[a]	40.755[a]	5.042[a]	47.026[a]	1.382[a]	1.663[b]
Vertic haplustalf	7.501[b]	37.668[b]	4.896[b]	42.223[b]	1.282[a]	3.073[a]
Mean	7.609	38.002	4.893	42.618	1.593	2.619

Number followed by the same letter in the same column are not significantly different by LSD α = 5%

Table 3: Effect of different types of soil on the physical, chemical and biological soil

		Mean squares treatment ANOVA	
Groups	Parameters	Error	Treatment
Physics	Bulk density (g cm^3)	0.00108	0.169**
	Available soil moisture (mm cm^{-1})	0.07233	38.796**
	Permeability (cm h^{-1})	0.00008	0.006**
Chemical	pH H_2O	0.00049	1.581**
	Soil organic matter (%)	0.00327	0.945**
	CEC [cmol (+) kg^{-1}]	0.40993	448.816**
	Total nitrogen (%)	0.00043	0.005**
	NO_3^- (%)	0.00028	0.003**
	NH_4^+ (%)	0.00058	0.003**
	Total phosporus (mg/100 g)	0.90486	155.194**
	Available phosporus (ppm)	0.60941	35.361**
	Total potassium (mg/100 g)	1.71858	807.247**
	Exchange potassium [cmol (+) kg^{-1}]	0.00162	0.308**
	Exchange magnesium [cmol (+) kg^{-1}]	0.00667	1.033**
	Exchange sodium [cmol (+) kg^{-1}]	0.00006	0.026**
	Exchange aluminium (ppm)	0.00013	0.054**
	Exchange iron (ppm)	0.00015	0.176**
Biology	Amount of soil's microorganism (colony)	0.37222	444.389**
	Soil respiration (m^{-2} h^{-1})	0.86515	53.609**

**Significantly different by LSD Test with α = 1%

Table 4: Influence of soil characteristics variables on rice and kayu putih yield

Total effects	Standard error (STERR)	T-stat	p-value
Biology → Yield of rice	0.100	8.856**	0.000
Physics → Yield of rice	0.571	1.038ns	0.300
Chemical → Yield of rice	0.359	0.495ns	0.621
Biology → Yield of kayu putih	0.254	3.210**	0.001
Physics → Yield of kayu putih	0.448	0.334ns	0.738
Chemical → Yield of kayu putih	1.494	0.552ns	0.581
Physics → Biology	0.560	0.843ns	0.399
Biology → Chemical	0.282	1.868ns	0.062
Physics → Chemical	0.698	1.238ns	0.216

ns: Not significantly different, **Significantly different at α = 1%

The MANOVA results on the characteristics of soil which include physical, chemical and biological properties showed a highly significant difference (p<0.0001). These indices represent the cumulative effects of different soil properties (physical, chemical and ecological) as an index from the role of each indicator in soil quality[47].

The initial approach to looking at the soil parameters that affecting rice and kayu putih yield is screening with α = 5% ANOVA to the parameters that will be used as indicators of soil quality. Soil parameters which indicate a real difference and has a diversity coefficient of <40% was maintained to be analyzed with SEM-PLS. The ANOVA results showed all soil parameters have significant differences (α<0.05) and diversity coefficient of <40% (Table 3). Therefore, SEM-PLS analysis was performed after ANOVA.

The results of SEM-PLS analysis indicate that in general, the biological properties of the soil significantly affect (α<0.05) rice and kayu putih yield. On the other hand, the soil physical and chemical properties do not affect rice and kayu putih yield significantly (Fig. 1, Table 4). Moreover, the analysis generally indicates no tangible relationship between physical, chemical and biological soil properties.

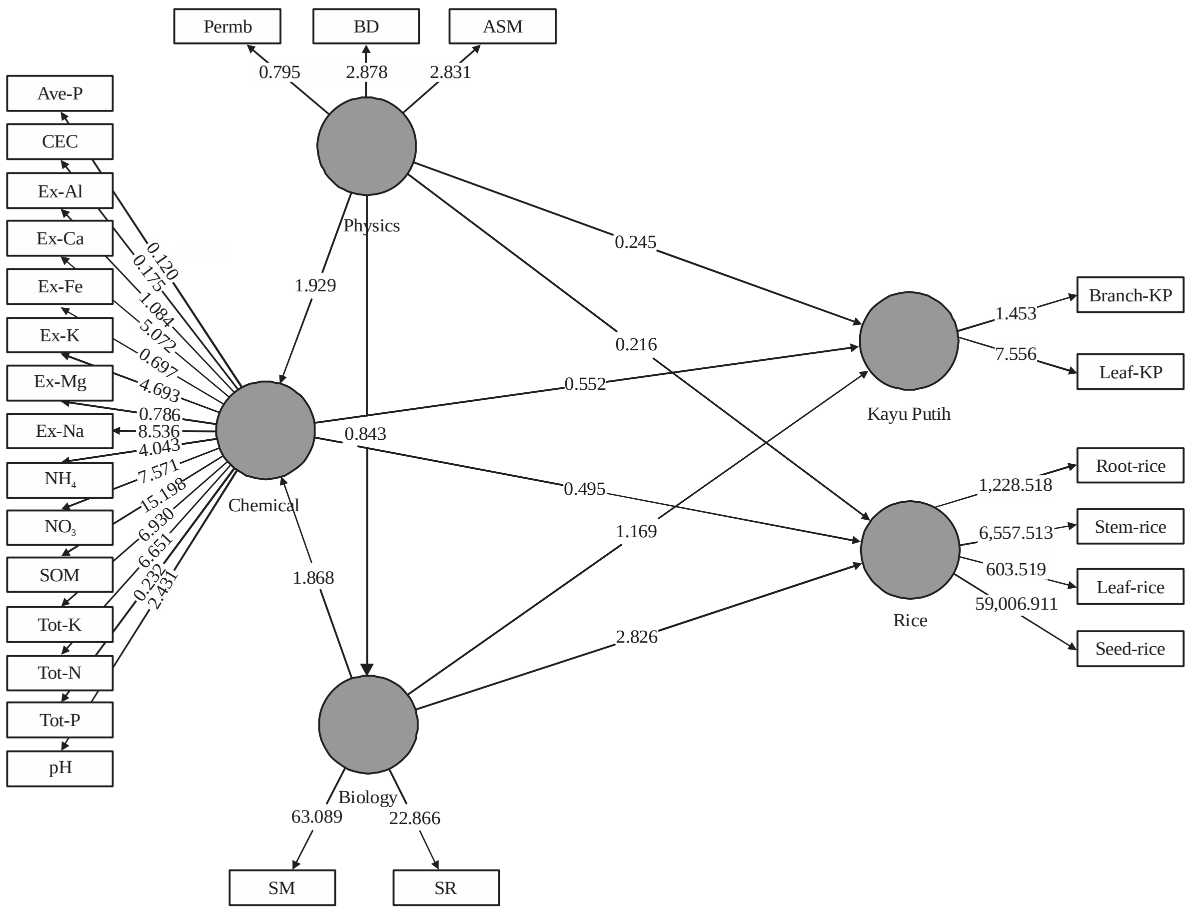

Fig. 1: Structural equation modeling (SEM) of the relationship between physical, chemical and biological soil properties on the dry weight of rice and kayu putih

Table 5: Standardized stepwise regression analysis

Parameters	Regression equations	R^2
Root dry weight of rice (g/clump)	Y = 3.752**+0.962 SM**+0.091 Ave-P**	0.994**
Stem dry weight of rice (g/clump)	Y = 22.427**+0.977 SM**+0.056 Ave-P*	0.995**
Leaf dry weight of rice (g/clump)	Y = 4.082**+0.881 SM**+0.150 Ex-K**	0.996**
Seeds dry weight of rice (g/clump)	Y = 18.310**+0.996 SM**	0.992**
Branch of kayu putih (kg/tree)	-	-
Leaf weight of kayu putih (kg/tree)	Y = 6.374** - 0.597 SR**	0.357**

*Significantly different at α = 5%, **Significantly different at α = 1%

The endpoint of this study is to determine minimum data sets (MDS) of soil quality indicators by identifying properties affecting the dry weight of rice (roots, stems, leaves) and kayu putih (leaves and branches). Standardized Stepwise Regression results showed that the quality factors of land which effective sustainability is the amount of soil's microorganism (SM), available phosphorus (Ave-P) and the exchange of potassium (Ex-K). Meanwhile, the quality factor of land that affect the sustainability of kayu putih is soil respiration (SR) (Table 5).

DISCUSSION

The results of this study are expected to enrich the scientific references concerning soil quality assessment indicators, especially on rice cropping system in kayu putih forests. This study also provides information about the effect of soil quality on the kayu putih and rice production.

Soil quality factors that influence rice sustainability is the amount of soil's microorganism (SM), available phosphorus (Ave-P) and the exchange of potassium (Ex-K), while the factor affecting kayu putih sustainability is soil respiration (SR). The typology of Ustic Endoaquerts which is mainly located in the basin causes the soil to be constantly inundated for 90-120 days[23].

Such conditions impact the physical, chemical and biological soil properties. Waterlogged soil conditions significantly affect the behavior of essential nutrients and plant growth. The chemical changes caused by soil inundation strongly influence nutrient dynamics and availability. Chemical transformations that occur are closely associated with soil microbes'activities using oxygen as a source of energy in the process of respiration. The state of the reduction due to inundation would alter soil microbial activity in which aerobic microbial being replaced by anaerobic microbial. The energy for the anaerobic material is sourced from an easily reduced oxidized compound, which acts as electron acceptors such as ion NO_3, SO_4, Fe^{3+} and Mn^{4+} [47].

In a waterlogged ground, the oxygen supply decreases and reaches zero in less than a day[48]. The rate of oxygen diffusion through a layer of water is 10 thousand times slower compared to air-filled pores. Aerobic microbes will quickly spend the remaining air and become inactive or dead. Anaerobic facultative microbial and obligate aerobic then take over soil organic matter decomposition using oxidized soil components (such as nitrate, Manganese, Fe-oxides and sulfates) or the decomposition of organic material (fermentation) as an electron acceptor in the respiratory[49,50].

Respiration of soil microorganisms reflects the level of activity in it. Microorganisms play an important role in soil nutrients acquisition and transfer. For phosphorus (P), soil microorganisms are involved in a range of processes affecting P transformation and thus influence the subsequent availability of P (as phosphate) to plant roots. In particular, microorganisms can make soluble and mineralize P from inorganic and organic pools of total soil P. Moreover, microorganisms may effectively increase the surface area of roots[46]. The extent of the diversity of microorganisms in soil is seen to be critical to the maintenance of soil health and quality, as a wide range of microorganisms is involved in important soil functions[51].

Microbial activity is affected by changes in the availability of soil moisture. The relationship between water potential and microbial activity is not limited by the availability of substrate. This relationship appeared to hold for the range of water potentials from -0.01 to -8.5 MPa. Even at -0.01 MPa (wet soil) a decrease in water potential from -0.01 to -0.02 MPa caused a 10% decrease in microbial activity[52].

The relative importance of various environmental variables in governing the composition of microbial communities could be ranked in the order: Soil type>time> specific farming operation (e.g., cover crop incorporation or side dressing with mineral fertilizer)>management system>spatial variation in the field[53].

The greater availability of P in waterlogged conditions is caused by redox changes in the soil and the resultant of Fe status change in the soil. At the beginning of inundation, P concentration in soil solution increases and then decreases in all types of soil, but the highest value and time of occurrence varies depending on the nature of the soil[54]. Increased availability of P due to flooding is caused by the release of P produced during the reduction process[55].

The effects of phosphorus deficiency on the photosynthetic characteristics were studied in rice seedlings (*Oryza sativa* L.) every 8 days after treatment. P deficiency caused a significant reduction in the net photosynthesis rate (*P*N) in rice plants. The excitation energy capture efficiency of PS II reaction centers (F v/F m) was significantly declined in the P-deficient rice leaves[55]. Meanwhile, in the stressed leaves, we also found a significant increase in nonphotochemical quenching (NPQ) as well as in the activities of superoxide dismutase (SOD) and ascorbate peroxidase (APX)[55].

The majority of the soils of the region ware Alfisol and Vertisol, all soil types had a similar available nutrient status and a similar pattern in relative grain yields. K response was noticeable in Alfisol with respect to grain and straw yields. The grain P concentration in Vertisol and straw K in Alfisol indicated the contribution of K towards the productivity of two soil groups[56].

Soil microbial biomass is the living component of soil organic matter (SOM)[57] and has already been used successfully to assess soil conditions under kayu putih stands in tropical soils, i.e., evaluating the effect of the land-use change from grassland to *E. grandis* plantations[58].

The values for soil respiration showed that soil microorganisms from kayu putih plantations may be more active than in the native forest. It is likely that higher soil respiration indicates an ecological stress and lower C use efficiency. To test this, we evaluated the metabolic quotient (qCO_2), which is a useful indicator of soil microbial C use efficiency and stress[59,60].

The total value of respiration obtained can be used as an indicator of the activity soil microorganisms, either bacteria or fungi. The higher the value of total respiration indicates more soil microorganisms. Soil respiration is the primary path by which CO_2 fixed by land plants returns to the atmosphere. Estimated at Approximately 75×10^{15} g C/year, this large natural flux is likely to increase due changes in the earth's condition[61].

Increases in soil respiration by fertilization are attributed to the increases in plant growth, litter input, decomposition rate and microbial biomass[62,63], while decreases are generally explained by decreases in fine root biomass, fungal activity and rhizosphere respiration[64-66]. Over the past few decades, fertilizer addition has been widely used as an intensive management practice in tropical and subtropical commercial kayu putih plantations and fertilization application is expected to continue to increase[35].

CONCLUSION

Biological and grain yield of upland rice at the Ustic Endoaquerts is significantly higher than those at other two soil types (Lithic Haplusterts and Vertic Haplustalf). On the other hand, leaves dry weight of kayu putih at the Lithic Haplusterts and Vertic Haplustalf is comparatively equal but those are higher than at the Ustic Endoaquerts. No significant difference was observed in branch dry weight of kayu putih in each soil type. The minimum soil quality determinant for rice yield under hilly areas of 'kayu putih' are an amount of soil's microorganism (SM), available phosphorus (Ave-P), exchange potassium (Ex-K) and soil respiration (SR) factor.

SIGNIFICANCE STATEMENTS

The results of this study are expected to enrich the scientific references concerning minimum soil quality determinant, especially on rice cropping system with kayu putih. This study also provides information about the effect of soil quality on the rice intercropping with kayu putih production.

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