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SOIL QUALITY INDEX IN THE UPSTREAM OF BENGAWAN SOLO RIVER BASIN ACCORDING TO THE SOIL FUNCTION IN NUTRIENT CYCLING BASED ON SOYBEAN PRODUCTION IN AGROFORESTRY

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ABSTRACT

Over the function of the upstream region watersheds causes the soil susceptible to degradation of soil fertility. Agroforestry systems that have been implemented should be reviewed to determine their effectiveness in improving soil fertility using a soil quality index. The varieties of soybean that cultivated in the study site were Grobogan, Kaba and Argomulyo. The variables of this study consists of organic-C, pH, cation exchange capacity (CEC), total-N, available-P, available-K, Na, Ca, Mg, base saturation and electrical conductivity (EC). Soil quality index calculation performed on selected outcome variables principal component analysis (PCA) which is then multiplied by the weights index on each PC. Selected variables from PCA consist of available-P, available-K, base saturation and pH. Soil quality index values for all types of agroforestry in the upstream of Bengawan Solo river basin (Wonogiri) is under secondary forest (<4.1) so that it can be concluded that the adoption of agroforestry in the upstream of Bengawan Solo river basin has not effect on soil quality based on soil functions in the recycling of nutrients. Mean of soybean grain yield in agroforestry system are higher than the mean of national soybean production, but there are an obstacle such as light conditions.

Keywords: agroforestry; land degradation; PCA; soil fertility

INTRODUCTION

Human living environment is basically a part of the river basin. The river basin has a very important significance for the survival of human beings, especially related to water availability and other aspects related to soil fertility. However, it turns out, the preservation of the river basin is often overlooked. Forests are converted to meet the increasing needs of life, the biggest one is for residential and agricultural areas, along with the increase of population. Over the function of land that does not pay attention to the health of the environment is ultimately propagate into the headwaters upstream so that the condition becomes progressively worse (Warsito, 2009). The deteriorating condition of the upstream cause much harm, such as high intensity of disasters (floods and landslides), the reduced wealth of diversity of flora and fauna, and most importantly is the reduction infertility due to soil erosion rates, erosion rates even at the upstream of Bengawan Solo river Wonogiri, the study site reached, 604,990 m^3 $year^{-1}$ (Rofiq, 2007). The high rate of erosion affects soil fertility, which then also affects the production of cultivated crop farmers. Low soil fertility levels will result in low production, and if it lasts for a long time, then it is possible there will be another disaster in the form of reduced production of forest and agricultural land in the upstream area and was followed by a decrease in the productivity of all sectors of the economy in the form of goods and services, including food, in the downstream region (Warsito, 2009).

One attempt to do is to implement agro-forestry cropping system. It serves not only as a water catchment area, the adoption of agroforestry systems with cover crop can play a role in improving soil fertility because of the cover crop supply the role of organic matter and protecting soil from erosion (Marzaioli *et al*., 2010). Traditionally, agroforestry has its origins in developing nations where high population densities coupled with scarce land resources have required that concurrent food and wood

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production often occur on the sameland base (Reynolds *et al.*, 2007). The resulting litter of permanent crops and cover crop variety, in addition to the resulting litter can also play a role in reducing the rate of erosion significantly (Pramono and Wahyuningrum, 2009) so that the rate of loss of topsoil, which contains a lot of nutrients, can be reduced. In agroforestry system farmer can combine many types of plant such as teak for perennial crop and soybean for annual crop. So, farmer can take multiple benefits from agroforestry. In the location of study there are 3 varieties of soybean: Grobogan, Kaba and Argomulyo varieties where cultivated to analyze crop growth in agroforestry system. The yield compo-nents of soybean are influenced by environmental conditions, management practices and cultivars planted (Mandal *et al.*, 2009).

Analysis of soil chemical properties in upland agroforestry Bengawan Solo river basin needs to be done as a reference in making decisions in an effort to improve soil quality in the upstream region. Soil quality can be measured by the index of soil quality through three stages, (1) determine the minimum data set, (2) give a score for each variable and (3) change the indicator to an index (Andrews *et al.*, 2002). The soil quality index is determined by summing the multiplication of scores on selected variables with weight index. Scores are at intervals of 1 to 3 to simplify the calculation. A variable is scored 1 if included in the classification of low, 2 moderate, and 3 high. Weight index derived from principal component analysis (PCA). This study was conducted to determine the soil fertility and the soil quality index in agroforestry land in the upstream of Bengawan Solo river basin.This study also to quantify the crop biomass, nodulationand grain yield of soybean, to analyze crop growth in agroforestry system.

MATERIALS AND METHODS

The study was conducted in the upstream of Bengawan Soloriver basin (Wonogiri). The total area is 19,412.81 ha (Indonesian Department of Watershed Management, 2009). The area located between 110° 53' 24"-111° 05'24" E and 07° 58' 48"-08° 04' 48" S. Laboratory analysis was conducted in Laboratory of Chemistry and Soil Fertility, Faculty of Agriculture, Sebelas Maret University, Surakarta. The study was conducted in June 2013 to March 2014. This study used descriptive and exploratory method. Stratified random sampling method was used to determine the study site with map of land unit (LU) based on overlay between map of land use, map of soil type and map of slope. Purposive sampling method was used to take soil samples. There are 14 sample points based on overlay, which is divided into 3 types of agroforestry and control.

The study site has tropical climate influenced by Munson wind. The annual precipitation about 1,800 mm year^{-1} to 2,900 mm year^{-1}. The average of annual temperature about 26º C with a humidity level ranging between 70-90%, while the average of evaporation rate about 4.5 mm day^{-1} (Rahman *et al.*, 2012). The study site describe in the Figure 1 and Table 1.

Soil chemical properties was analysed including soil acidity (pH) (electrometric method), electro conductivity (EC) (using a conductivity meter), cation exchange capacity (CEC) (ammo-nium acetate saturation method) (Rhoades, 1982), levels of organic carbon (Walkley and Black method) (Walkley and Black, 1934), total nitrogen (total N) (Kjeldal method) (International Institute of Tropical Agriculture, 1982), available phosphorus (available P) (Bray Imethod) (Murphy and Riley, 1962), available potassium (available K), and base saturation in the form of sodium (Na) and potassium (K) (using flamephotometer), magnesium (Mg) and calcium (Ca) (using AAS). The analysis results of secondary variables, such as soil moisture levels ctka 0.5 mm (gravimetric method), used to support the calculation of the results of laboratory analysis of organic carbon content, total N, available P and available K. Variable from crop production include crop biomass, nodulation and grain yield of soybean.

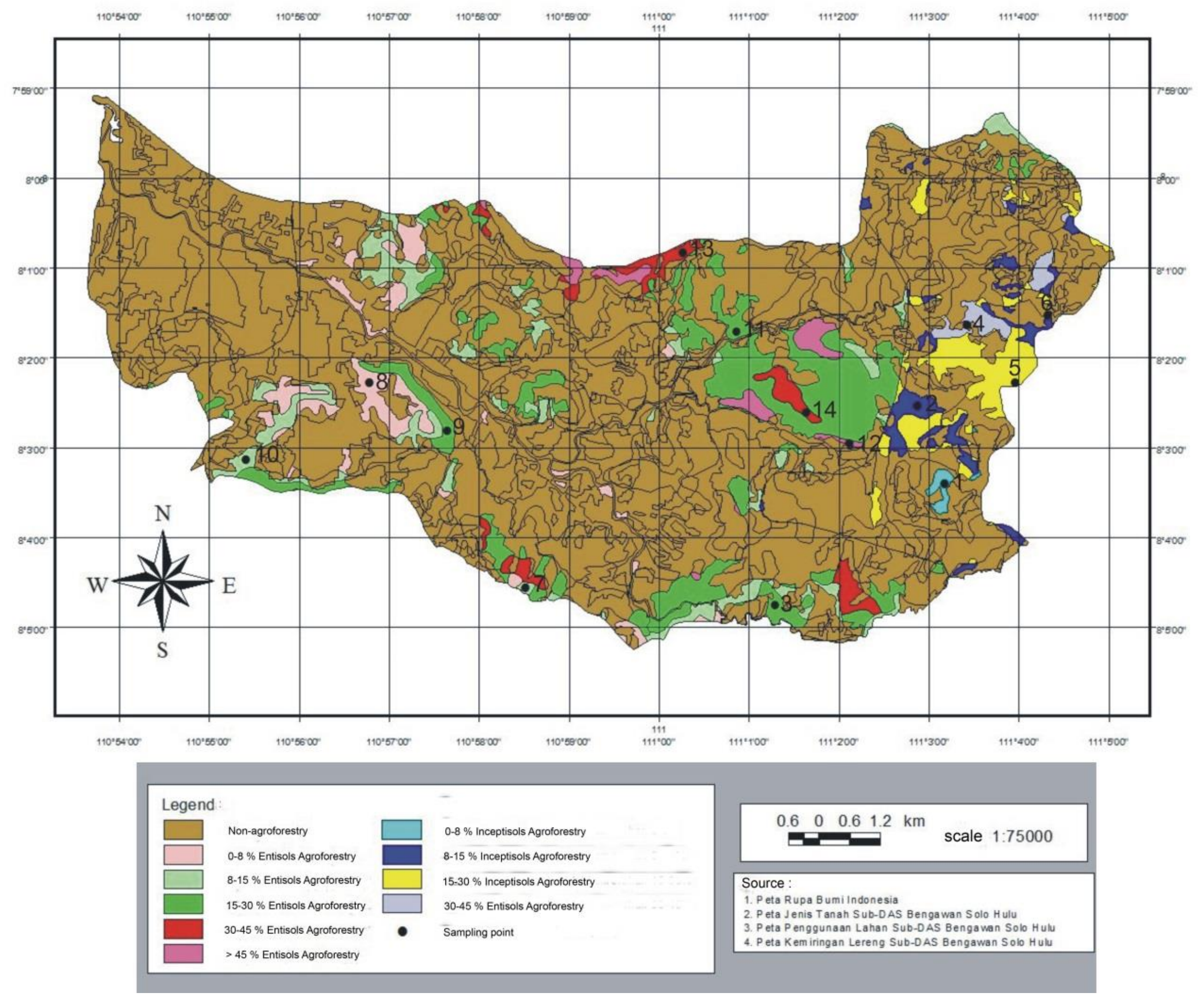

Figure 1. Map of Land Unit (LU) of the upstream of Bengawan Soloriver basin (Wonogiri)

Table 1. Study site description

LU	Sampling Location	Elevation (m)	Soil types USDA 1975	Slope (%)
1	111° 02' 22.7" E and 07° 59' 04.1" S	503	Inceptisols	15-30
2	110° 03' 32.2" E and 08° 02' 01.2" S	592	Inceptisols	30-45
3	110° 05' 44.8" E and 07° 59' 27.9" S	830	Inceptisols	>45
4	110° 02' 40.9" E and 08° 01' 42.6" S	522	Inceptisols	15-30
5	110° 03' 31.9" E and 08° 02' 31.9" S	591	Inceptisols	>45
6	111° 42' 00.0" E and 08° 12' 00.0" S	682	Entisols	30-45
7	110° 58' 22.1" E and 08° 04' 33.0" S	440	Entisols	15-30
8	110° 55' 56.2" E and 08° 03' 26.0" S	351	Entisols	15-30
9	110° 00' 31.1" E and 08° 01' 41.1" S	203	Entisols	>45
10	111° 00' 38.3" E and 08° 02' 52.8" S	296	Entisols	30-45
11	111° 00' 15.4" E and 08° 00' 42.5" S	409	Entisols	15-30
12	110° 00' 14.8" E and 08° 03' 50.8" S	261	Entisols	15-30
13	110° 56' 30.2" E and 08° 01' 40.0" S	177	Entisols	15-30
14	110° 57' 33.5" E and 08° 02' 18.2" S	196	Entisols	30-45

Remarks: LU = land unit

Results of laboratory analysis were analysed by ANOVA, correlation analysis and principal component analysis (PCA). Assessment of quantitative soil quality used Soil Quality Index (SQI) by scoring on some variable data selected from the PCA. Value scores were at intervals of 1 to 3. The higher score of a variable, the higher the quality of the soil. The calculation was done by summing soil quality scores were multiplied by the variable weights index. Assessment of soil quality using SQI (Liu *et al*., 2014) described as follows:

$$SQI = \sum_{I=1}^{n\ Soil} Wi \times Si$$

SQI = soil quality index
Si = score on the indicator chosen
Wi = weight index
n = number of indicators of soil quality

RESULTS AND DISCUSSION

RESULTS

Table 2 showed that soil chemical analysis of some types of agroforestry. The organic carbon content of the soil in the secondary forest, agrosilvopastoral, and agrosilviculture upstream of Bengawan Solo river basin was low (<1%), whereas in silvopastoral classified as moderate (1% to 5%). Soil acidity of agrisilviculture was relatively acidic (4.5 to 5.5), while the secondary forest, agrosilvopastoral, and silvopastoral were slightly acidic (5.5 to 6.5). Cation exchange capacity in secondary forests was low, whereas in agrisilviculture, agrosilvopastoral, and silvopastoral classified as moderate. The content of nitrogen (N) total in secondary forest, agrosilvopastoral, and silvopastoral were moderate (0.1% to 0.5%), while agrisilviculture classified as low (<0.1%). The content of available phosphorus (P) on all types of agroforestry and secondary forest is high (11 to 15 ppm). The content of potassium (K) available in agrosilvo-pastoral soil was low, while the secondary forest, agrisilviculture, and silvopastoral classified as moderate. The low macro nutrients in agroforestry land in the upstream of Bengawan Solo river could be impacted by the low organic content.

The content of sodium (Na) in secondary forest soil in upstream of Bengawan Solo river basin was high, agrisilviculture and agrosilvopastoral classified as moderate, while silvopastoral classified as very high. The content of calcium (Ca) in the secondary forest and all types of agroforestry was low. The content of magnesium (Mg) in silvopastoral was low, the agrisilviculture and agrosilvopastoral classified as moderate, whereas the secondary forest relatively high. Base saturation in the secondary forest was moderate, whereas in all types of Agroforestry was low. Electrical conductivity (EC) or salinity relatively very low (<1 dS m^{-1}) so that the effect of salinity was negligible (Table 2).

Two variables were strongly correlated if the Pearson correlation value has come closer to

1 or | -1 | and P-value less than α (0.05 or 5%) (Iriawan and Septin, 2006). It is known that the variables that are correlated: the organic carbon with available P (98.5%), pH with total N (97.4%), pH with Na (95.3%), capacity cation exchange with Ca (98.0%), cation exchange capacity with base saturation (97.1%) were negatively correlated, and Mg with base saturation (95.0%).

Variables used in the determination of soil quality index were determined by principal component analysis (PCA) showed in Table 3. Selected variables were variables with the highest scores on each PC. The number of PCs was determined by the Eigen values (≥1) and cumulative percentage (>60% or up to 85%). It was known that the selected variables were available P, available K, and base saturation, because the pH was an important variable related to other soil chemical properties, pH was included.

Classes were based on the soil quality index (SQI) by Cantu *et al*. (2007) and modified soil quality secondary forest and agroforestry in the upstream of Bengawan Solo river basin by the availability of nutrients including moderate (3.5 to 5.9). The SQI for three types of Agroforestry was lower than secondary forests (<4.1). The closest SQI as secondary forest was silvopastoral.

Table 2. Value (average ± standard deviation) of soil chemical analysis of some types of agroforestry in the upstream of Bengawan Solo river basin and ANOVA

Variables	Secondary forest		Agrosilvopastoral		Agrisilviculture		Silvopastoral	
Organic C (%)	0.37	(± 0.00)	0.63	(±0.00)	0.17	(±0.00)	1.16	(±0.00)
pH	5.6	(± 0.17)[b]	5.5	(±0.06)[b]	5.2	(±0.15)[c]	6.2	(±0.10)[a]
CEC (cmol kg^{-1})	12.27	(±18.48)[a]	24.63	(±0.66)[a]	23.20	(±1.60)[a]	24.27	(±2.81)[a]
Total N(%)	0.12	(± 0.00)	0.12	(±0.00)	0.06	(±0.00)	0.18	(±0.00)
Available P (ppm)	11.6	(± 0.00)	12.6	(±0.00)	11.5	(±0.00)	13.7	(±0.00)
Available K (cmol kg^{-1})	0.43	(± 0.01)[b]	0.37	(±0.01)[c]	0.45	(±0.02)[b]	0.51	(±0.03)[a]
Na (cmol kg^{-1})	0.80	(± 0.07)[a]	0.65	(±0.10)[a]	0.63	(±0.42)[a]	1.60	(±1.56)[a]
Ca (cmol kg^{-1})	2.50	(± 0.00)	4.98	(±0.00)	4.26	(±0.00)	4.48	(±0.00)
Mg (cmol kg^{-1})	3.07	(± 0.35)[a]	1.70	(±0.18)[b]	1.40	(±0.41)[bc]	0.94	(±0.34)[c]
Base saturation (%)	52	(± 2.65)[a]	31	(±1.00)[b]	27	(±2.52)[b]	29	(±7.21)[b]
EC (dS m^{-1})	0.052	(± 0.01)[b]	0.130	(±0.01)[a]	0.046	(±0.01)[b]	0.142	(±0.03)[a]

Remarks: CEC = cation exchange capacity EC = electro conductivity

Table 3. Determination of soil quality index of some agroforestry type in the upstream of Bengawan Solo river basin Wonogiri

No.	Variables	Wi	Si			
			Secondary forest	Agrosilvopastoral	Agrisilviculture	Silvopastoral
1.	Available P	0.381	3	3	3	3
2.	Available K	0.720	2	1	2	2
3.	Base saturation	0.443	2	1	1	1
4.	pH	0.323	2	2	2	3
SQI			4.1	3.0	3.7	4.0

Remarks: Wi = weight index from PC; Si = score of chosen indicator; SQI = Soil Quality Index

DISCUSSION

In the beginning of this study, three soybean varieties were cultivated in the location of the study; they were Grobogan, Kaba and Argomulyo varieties showed in Table 4. The study was observed vegetative and generative phase. At the vegetative phase at the end of growth, the plants reached maximum habitus then enter the generative phase (forming flowers and seeds) and died. The growth of plants in the form of the body (habitus) when it was dry reflected the accumulation of photosynthesis was expressed in weight of the biomass. As an indicator of growth, the increased weight of biomass was also increasing the age of the plant. The maximum growth of soybean in agroforestry system reached before the age of 50 days after transplanting (DAT). Differences between varieties of soybean growth reflected in the time of harvest. Grobogan, Kaba and Agromulyo varieties harvested at the age 70, 78 and 84 DAT respectively, so at the age of 30 DAT each of them had a different growth rate. At the age of 30 DAT the rate of growth Grobogan varieties had fallen, Kaba varieties began to fall, while Argomulyo varieties were still growing.

Table 4. Mean of crop biomass, nodulation and grain yield of soybean

Variables	Varieties		
	Grobogan	**Kaba**	**Argo-mulyo**
Crop biomass (g day^{-1})			
15 DAT	0.11	0.09	0.08
30 DAT	0.70	0.50	0.48
45 DAT	0.84	0.83	0.91
Harvest	0.84	1.11	1.45
Nodulation	4.87	15.05	7.69
Grain yield (t ha^{-1})	2.77	2.13	1.5-2

Remarks: DAT = day after transplanting

Generative growth started from the formation of flowers and then the formation of pods and seed filling (Purnomo *et al.*, 2011). The number of empty pods of Argomulyo varietis and Grobogan varieties were relatively low (<2). Pod formation followed by grain filling process reflected the seed weight per plant or per hectare. In the Kaba varieties the number of empty pods were higher than other varieties (around 7). The consequences of increasing empty pods of Kaba varieties resulted in grain yield per hectare were low which was almost equal to the Grobogan varieties (0.6 t ha^{-1}). For Argomulyo varieties reduction of empty pods resulted in increasing seed production (1.0 t ha^{-1}). All three varieties showed grain yield was still below the description of each (2.77 t ha^{-1} for Grobogan, 2.13 t ha^{-1} for Kaba, and 1.5-2 t ha^{-1} for Argomulyo) (mean nationally soybean crop production is 1.1 t ha^{-1}). Purnomo and Sitompul (2005) said that light condition is still an obstacle in soybean cultivation in agroforestry systems.

There are three types of Agroforestry in the upstream of Bengawan Solo river basin, agrosilvopastoral, agrisilviculture, and silvo-pastoral. Agrosilvopastoral is a combination of components or activities with forestry and livestock farming. Agrisilviculture is a combination of agriculture with forestry components. Silvopastoral is a combination of components of the farm forestry (World Agroforestry Centre (ICRAF), 2004; Razak, 2008). To determine the effectiveness of the agroforestry systems on nutrient availability or soil fertility, the use of secondary forest, a pine forest (*Pinus merkusii*), as a comparison. Secondary forest contains very low soil organic carbon. This is due to the dominance of vegetation such as pine. Pine litter regarded as litter of high quality, so it is difficult to decompose. In addition, because of the lack of cover crop that can serve as a supplier of soil organic matter and protect of erosion (Marzaioli *et al.*, 2010). Factors that affect carbon returns to the soil such as soil type, environmental factors, and management, such as tillage and crop rotation (Lawrence and Gupta, 2009). The type of soil in the study site is Litosol and reddish brown Latosol which generally contain little organic matter. Land at the study site has also undergone tillage due to the formation of secondary forest and agroforestry, there is human intervention. Moscatelli *et al.* (2007) describes that the content of organic carbon conventional farms lower compared to natural forest.

Low levels of organic carbon may affect other soil properties, such as cation exchange capacity, nutrient availability (Sinha *et al.*, 2014), and pH. Cation exchange capacity of the soil in secondary forests is low, even among the lowest in the entire sample. Cation exchange capacity of the soil is affected by the clay type, but can be improved, even up to 3 times the mineral soil, with the addition of organic matter (Tan, 1998).

The content of macro nutrients, such as N and K, in the secondary forest is classified low, but the P content is high. Likewise, micro nutrients, Ca content is low, while Mg is high. The high content of P and Mg were allegedly influenced by fertilization that is done at the beginning of cultivation. The addition of organic material can neutralize the pH of the soil and increase the supply of nutrients in the soil so that the availability of nutrients, macro and micro, for the plant to be optimum.

Levels of organic carbon in agrisiviculture and agrosilvopastoral are relatively very low due to the lack of input in the form of organic matter and high levels of erosion due to the unequal distribution of cover crop cover on the soil surface. Marzaioli *et al*. (2010) revealed that the land of the permanent crop yield was generally low for nutrient and organic components. Agrosilvopastoral, agrisilviculture, and silvopastoral dominated by teak (*Tectonia grandis*), but the levels of organic carbon in silvopastoral was higher because the cover crop covers more evenly. Cation exchange capacity of the three types of agroforestry were infected by soil types, Litosol and Latosol reddish brown, which cation exchange capacity ranges is 30 cmol kg^{-1} (Tan, 1998). P available three types of agroforestry is high presumably because the effect of fertilizer. The content of Ca, Mg and base saturation in the three types of agroforestry classified as low, medium and low.

Total N content in agrosilvopastoral and silvopastoral classified as moderate, while the relatively low in agrisilviculture. Total N content in agrosilvopastoral is higher than agrisilviculture because agrosilvopastoral more varied vegetation that litter produced vary between high quality to low, such as teak and *Leucaena glauca*. High quality litter decomposes difficultly so it take a long time to be able to provide nutrients for the plants, while the low-quality litter can be decomposed so that it can be utilized by plants.

Cover crop also affects nutrient cycling in the soil because of the cover crop can supply organic material and create the appropriate conditions for soil microbes, including microbial fastening N. According to Krener (2013), the ground under the cover crop increased nitrogen mineralisation so that the nutrients for plants be fulfilled. Cover crop found in a silvopastoral and agrosilvopastoral, grass and legume, but cover the silvopastoral more evenly than agrosilvopastoral. The prevalence of the cover crop cover of silvopastoral make conditions more suitable for soil microbes. So that the soil total N in silvopastoral is higher than other types of agroforestry and secondary forest.

The conditions of soil fertility can be summarized with the soil quality index. Soil quality index values of agrosilvopastoral, agrisilviculture, and silvopastoral according to soil function in nutrient cycling is under secondary forest. That is, the application of agroforestry systems in the upstream of Bengawan Solo river basin has insufficient in improving soil fertility. If all three types of agroforestry are compared, soil quality index of silvopastural is closest to secondary forest. Soil quality on all three types of agroforestry can be improved by the addition of organic matter inputs in the form of cover crop and by minimizing tillage. According to Fernandez-Ugalde *et al*. (2009), no-tillage can increase soil organic matter in the semiarid Mediterranean Ebro Valley of Spain.

CONCLUSION

The quality of the soil on the application of Agroforestry systems in the upstream of Bengawan Solo river basin Wonogiri is under secondary forest. Among the three types of existing Agroforestry, the quality index value of silvopastoral is closest to the secondary forest. The importance of cover crop in soil nutrient cycling need to be considered and implemented. Mean of soybean grain yield that cultivated in agroforestry system higher than the mean of national soybean production, but there are an obstacle in soybean cultivation in agroforestry systems such as light conditions.

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