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Soil quality measurement for sustainable soybean yield agroforestry system under different crop rotation models

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Abstract. *Alam T, Suryanto P, Handayani S, Supriyanta, Wulandari RA, Anshari A, Aisya AW, Purba AE, Widowati R, Taryono. 2022. Soil quality measurement for sustainable soybean yield agroforestry system under different crop rotation models. Biodiversitas 23: 6155-6163.* Soil quality is essential for sustaining the soybean yield in an agroforestry system. This study determined the soil quality variables that affect soybean yield under different crop rotation models in the agroforestry system with *kayu putih* (*Melaleuca cajuputi*). A 2-year experiment was conducted during the dry season (March-June 2021) and the wet season (November 2021-February 2022) at Menggoran Forest Resort, Playen District, Gunungkidul Regency, Special Province of Yogyakarta, Indonesia. All of the trials during each season were laid out in a randomized complete block design with three blocks as replication. The treatment crop rotation model consisted of soybean planting after fallow (FS), soybean planting after maize (MS), soybean planting after rice (RS), and continuous soybean planting (SS). The observations were soybean yield and 21 soil quality variables. The data were analyzed using analysis of variance, multiple factor analysis, heatmap cluster, generalized pair plot, and standardized stepwise regression. The increase in soybean yield during the dry season was affected by TB, Fe, and N in the soil, while it was affected by TF, Fe, and silt during the wet season. Soil quality and soybean yield can be improved by applying organic matter and soil amendment.

Keywords: Agroforestry, crop rotation models, soil quality, soybean

INTRODUCTION

Soybean is one of the top three most important commodities in Indonesia besides rice and maize. Soybean production in 2020 decreased by 632.3 thousand tons or 3.01% compared to 2021 (Ministry of Agriculture, 2021). Increasing soybean production in agricultural areas faces problems, one of which is converting agricultural areas. Mulyani et al. (2017) predict that in 2045 the agricultural areas from 8.1 million hectares will decrease to 5.1 million hectares. An agroforestry system is a land use system and technology in which woody plants are integrated with annual and perennial crops and animals in the same land management unit (FAO 2015). Agroforestry systems in Indonesia are primarily applied in community forests (De Royer et al. 2018). The area between *kayu putih* (*Melaleuca cajuputi*) stand is an alternative solution for soybean development (Alam et al. 2022; Suryanto et al. 2022). The total area of *M. cajuputi* forests in Indonesia is 248,756 hectares (Sunanto 2003). The advantage of soybeans planted among *M. cajuputi* stands is no competition for sunlight, nutrients, water, and root development (Alam et al. 2022; Suryanto et al. 2022).

The main problem with soybean planting in agroforestry systems with *M. cajuputi* is low soil quality (Alam et al. 2020a; Suryanto et al. 2020c). This is due to the high clay content, shallow solum (rock contact 50 cm from the soil surface), and low infiltration rate (Boettinger 2015). Soil quality is an assessment to determine the capability of the soil in the future as well as predict crop yields. In addition, soil quality assessment can be used to evaluate fertilizer recommendations (Arslan 2017; Cheng et al. 2016; Firdous et al. 2016; Jiang et al. 2020; Lin et al. 2017). Soil quality in *M. cajuputi* forest is very low until low (Alam et al. 2020b; Alam et al. 2021). Soil quality is essential to increase plant growth and yield (Qi et al. 2009). Soil quality assessment depends on site diversity, scale, land management, and research objectives (Rousseau et al. 2012). Determining soil quality can be a reference for sustainable land management and soybean yield. Chemical, physical, and biological properties are the soil quality factors that are vulnerable to soil management practices (Bilgili et al. 2017).

Several studies on how soil quality affects annual crops in agroforestry systems with *M. cajuputi* have been carried out. Alam et al. (2020a) revealed that the soil quality variables affecting soybean yield, include phosphorus, magnesium, nitrate, manganese, and calcium availability in the soil, while the % clay, soil moisture content, pH H_2O, soil organic carbon, total nitrogen, magnesium availability, iron exchange, total fungi, and total bacteria in the soil affect upland rice yield (Suryanto et al. 2020c). Suryanto et al. (2017) assessed soil quality on perennial crops, namely cloves, cocoa, and cardamom, in Mountain Menoreh Areas in the Special Province of Yogyakarta, Indonesia. The results showed a positive correlation between clove yield and % silt in the soil. The cocoa yield was affected by the increase in CEC, Ca, and Na availability in the soil, while the cardamom yield was influenced by Ca availability in the soil.

Crop rotation is widely used by farmers in *M. cajuputi* forest because it significantly increases crop yield. Crop rotation is one of the effective management strategies to increase farmers' yields and income (Bowles et al. 2020). Farmers in the *M. cajuputi* forest have a habit of planting soybeans in the wet season after rice or maize. The yield of soybean planted after maize is higher than continuously planted soybeans (Neupane et al. 2021). Taryono et al. (2022) revealed differences in soybean yield using various crop rotation models in the agroforestry system with *M. cajuputi*. In the wet season, soybeans planted after the rice had the highest yield, while in the dry season, after the maize. However, the effects of the crop rotation model on soil quality were not determined.

This study examined the soil quality variables that affect soybean yield under different crop rotation models in *M. cajuputi* agroforestry system. The results of this study will form a reference for improving soil quality and soybean yield in agroforestry systems with *M. cajuputi*.

MATERIALS AND METHODS

Study area

A 2-year experiment was conducted during the dry season (March-June 2021) and the wet season (November 2021-February 2022) at the Menggoran Forest Resort, Playen Sub-district, Gunungkidul District, Special Province of Yogyakarta, Indonesia. The research location was ± 43 km to the southeast of Yogyakarta City. The altitude and slope of the study site were 150 m above sea level and 0%–8%, respectively. The total rainfall, mean temperature, and relative humidity during the dry season part of the study was 586 mm, 24.80°C, and 85.00%, respectively, while they were 117 mm, 24.58°C, and 87.25%, respectively during the wet season (Taryono et al. 2022). The soil type was a Lithic Haplustert with a ustic moisture regime (Alam et al. 2019).

Experimental setup and their management

All trials were laid out in a randomized complete block design with three blocks as replication. The treatment crop rotation models consisted of soybean planting after fallow (FS), soybean planting after maize (MS), soybean planting after rice (RS), and continuous soybean planting (SS). Soil tillage was carried out with minimum tillage. Planting was completed by direct seeding in the area. The experimental plots were placed between *M. cajuputi* stands with a plot size of 12 m^2 (4 m × 3 m), with a distance between plots and blocks of 0.5 and 1 m, respectively. The soybean harvest area was 7 m^2 and does not include border crops. The standard spacing was used 40 cm × 20 cm with two seeds per planting hole with a seed planting depth of 5 cm. The fertilizer used was 50 kg ha^{-1} Urea, 100 kg ha^{-1} SP-36, and 150 kg ha^{-1} KCl. Fertilizer application was made once a week after planting (wap). Irrigation was not carried out during the study, as the experimental plots were situated in rainfed areas.

Soil and crop observation

The observations consisted of soybean yield and 21 soil quality variables. The soybean yield variable was seed dry weight per hectare with a moisture content of 12%. The soil quality variables were soil texture (% clay, % sand, % silt), bulk density, soil moisture content, permeability, pH of the H_2O, soil organic carbon, cation exchange capacity, total nitrogen, nutrient availability (phosphorus, potassium, sodium, calcium, and manganese), nutrient exchange (iron and aluminum), total bacteria, and total fungi (Bandyopadhyay et al. 2012; David and Davidson 2014; Peters 2013). Soil sampling was carried out twice at the beginning of the dry and wet seasons randomly for each treatment in each replication (Alam et al. 2020a; Suryanto et al. 2020a). The observations were carried out at the study site and at the Laboratory of General Soil and Microbiology, Faculty of Agriculture, Universitas Gadjah Mada, Yogyakarta, Indonesia.

Statistic approach

Soybean yield and soil quality data must meet the assumptions of a linear model (normally distributed and a homogeneous variance). Normal distribution and homogeneity variance were evaluated by a Q-Q plot and values vs. residuals graph (Welham et al. 2015). Comparisons of soybean yield among crop rotation models during the dry and were season was conducted using analysis of variance (ANOVA) ($p < 0.05$) and was followed by the least square means (LS-Means) test and the Tukey-Kramer test ($p < 0.05$) (Welham et al. 2015). The soil quality variables were initially screened using ANOVA ($p < 0.05$). The soil quality variables that were significantly different and had a coefficient of variation (CV) of <40% underwent multiple factor analysis (MFA) using the varimax rotation method (Alam et al. 2020a; Andrews et al. 2002).

The relationships between the soil quality variables and soybean yield were analyzed using generalized pairs plots and heatmap clusters (Ambarwati et al. 2022; Widyawan et al. 2020). The final screening of the soil quality variables that affected soybean yield was made using standardized stepwise regression (Alam et al. 2020a; Putra et al. 2021; Ruslanjari et al. 2020; Suryanto et al. 2020a; Suryanto et al. 2020c). Assumptions of the linear model (Q-Q plot and residuals vs. values graph), ANOVA, and standardized stepwise regression were performed using SAS 9.4 with the PROC GLIMMIX, PROC GLM, and PROC REG procedures (SAS Institute, 2013). MFA, generalized pair plot, and heatmap clusters were visualized using Rstudio with corrplot, FactoMineR, factoextra, ggplot2, GGally, magrittr, pheatmap, and scatterplot3d packages (R Core Team, 2017).

RESULTS AND DISCUSSION

Soybean yields from the different crop rotation models

The results showed that RS resulted in the highest soybean yield during the dry season of 1.16 tons ha^{-1} compared with FS, SS, and MS, which were 1.03, 1.03, and 1.01 tons ha^{-1}, respectively. During the wet season, soybean yields were highest in MS and SS at 2.06 and 2.07 tons ha^{-1}, respectively, compared with FS and RS at 1.91 and 1.65 tons ha^{-1}, respectively (Figure 1).

Selection of key soil quality indicators affecting soybean yield

The initial screening by ANOVA ($p < 0.05$) revealed that the soil quality variables that were significantly different and had a CV of <40% were soil moisture content (SMC), total nitrogen (N), phosphorus availability (P), iron exchange (Fe), aluminum exchange (Al), total bacteria (TB), and total fungi (TF), while % silt (silt), total nitrogen (N), iron exchange (Fe), aluminum exchange (Al), total bacteria (TB), and total fungi (TF) meet these criteria during the dry and wet seasons (Table 1 and Table 2). Soil quality variables that meet the criteria were subjected to MFA with varimax rotation.

The MFA results during the dry season revealed two factors (dimensions). Factor 1 (dimension 1), with an eigenvalue of 4.26, consisted of TB, TF, and N, while factor 2 (dimension 2), with an eigenvalue of 1.76, consisted of P, SMC, and Fe (Figure 2A, 2B). The value of communality in all variables ranged from 0.84 to 1.00. The contribution values showed that TB and TF had a high contribution to soil quality during the dry season, while Fe and Al had a moderate contribution, and SMC, P, and N had low contributions (Figure 3A).

The MFA result during the wet season revealed two factors (dimensions). Factor 1 (dimension 1), with an eigenvalue of 2.93, consisted of TB, TF, Fe, and N, while factor 2 (dimension 2), with an eigenvalue of 1.52, consisted of Al (Figure 2C, 2D). The value of communality in all variables ranged from 0.83 to 0.99. TB, TF, Fe, and Al had high contributions, while N and silt had moderate and low contributions, respectively (Figure 3B).

The heatmap cluster showed that three clusters formed during the dry season, consisting of cluster 1 (FS), cluster 2 (MS) and cluster 3 (RS and SS) (Figure 4A). Three clusters also formed during the wet season consisting of cluster 1 (RS), cluster 2 (FS) and cluster 3 (MS and SS) (Figure 4B).

The results of the generalized pair plot showed that soybean yield during the dry season was significantly correlated with P (r = -0.583*) (Figure 5), while it was significantly correlated with N (r = 0.664*), Fe (r = -0.664*), TB (r = 0.946**), and TF (r = 0.975**) during the wet season (Figure 6). The generalized pair plot does not explicitly describe the contribution of each soil quality variable. This is because the correlation formed from direct and indirect effects, so standardized stepwise regression must be performed to separate the two effects.

Standardized stepwise regression was the final screening based on the MFA results. Soybean yield during the dry season was significantly affected by the increase in TB, Fe, and N according to the regression equation: $Y_{dry} = -0.678^{**} + 0.038\ TB^{**} + 0.987\ Fe^{**} + 0.430\ N^{**}$ ($R^2 = 0.968^{**}$). Soybean yield was significantly affected by TF, Fe, and the % silt during the wet season, according to the regression equation: $Y_{wet} = 5.663^{**} + 0.999\ TF^{**} + 0.857\ Fe^{**} + 0.141\ silt^{**}$ ($R^2 = 0.997^{**}$).

The strategy for improving soil quality is applying organic matter and soil amendment. Organic matter and soil amendment recommendations that meet these criteria are siam weed compost (*Chromolaena odorata*) and biochar derived from *M. cajuputi* waste.

Discussion

Crop rotation models cause differences in soybean yields in an agroforestry system with *M. cajuputi* in the dry and wet seasons. Crop rotation improves the physical, chemical, and biological properties and increases yield (Neupane et al. 2021). However, information related to variables related to the soil's physical, chemical, and biological properties that affect soybean yields is not yet known. It is essential to determine the appropriate management strategy for soil sustainability and soybean yield (Bilgili et al. 2017). In this study, soil variables that affect soybean yields are determined using a combination of univariate and multivariate techniques (Alam et al. 2020a; Andrews et al. 2002). This is because there is a high correlation between soil variables. Factor analysis is a multivariate technique to handle highly correlated environmental data (Govaerts et al. 2006; Yao et al. 2013). The final screening results show that the soil variables that affect soybean yield in the dry season are total bacteria, iron exchange, and total nitrogen, while in the wet season are total fungi, iron exchange, and % silt.

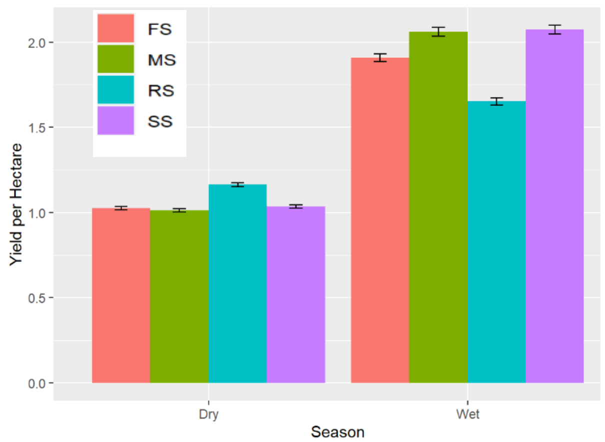

Figure 1. Least square means (LS-Means) of soybean yield (tons ha^{-1}) under the different crop rotation models during the two seasons. Error bars indicate 95% confidence intervals. FS: Soybean planting after fallow; MS: Soybean planting after maize; RS: Soybean planting after rice; SS: Continuous soybean planting

Table 1. Soil characteristics (physical, chemical, and biological) in the study area

Soil characteristics [1]	**Unit**	**Crop rotation models** [2]							
		Dry season				**Wet season**			
		FS	**MS**	**RS**	**SS**	**FS**	**MS**	**RS**	**SS**
Soil physics									
Soil Texture	-								
– Clay	%	60.25^{a}	60.15^{a}	60.26^{a}	60.30^{a}	60.30^{p}	60.32^{p}	60.26^{p}	60.30^{p}
– Sand	%	7.22^{a}	7.19^{a}	7.26^{a}	7.19^{a}	7.24^{p}	7.14^{p}	7.11^{p}	7.22^{p}
– Silt	%	32.52^{a}	32.66^{a}	32.48^{a}	32.52^{a}	32.47^{r}	32.54^{q}	32.63^{p}	32.48^{r}
Bulk Density	$g\ cm^{-3}$	1.16^{a}	1.12^{a}	1.11^{a}	1.12^{a}	1.11^{p}	1.12^{p}	1.15^{p}	1.09^{p}
Soil Moisture Content	$mm\ cm^{-1}$	16.45^{a}	17.18^{b}	19.21^{a}	19.77^{ab}	25.35^{p}	26.46^{p}	27.14^{p}	27.53^{p}
Permeability	$cm\ h^{-1}$	0.01^{a}	0.01^{a}	0.01^{a}	0.01^{a}	0.01^{p}	0.01^{p}	0.01^{p}	0.01^{p}
Soil chemistry									
pH H_2O	-	8.4^{a}	8.3^{a}	8.2^{a}	8.1^{a}	8.3^{p}	8.1^{p}	8.0^{p}	8.0^{p}
Soil Organic Carbon	%	1.6^{a}	1.5^{a}	1.6^{a}	1.4^{a}	1.7^{p}	1.6^{p}	1.6^{p}	1.5^{p}
Cation Exchange Capacity	$cmol^{(+)}\ kg^{-1}$	62.23^{a}	58.48^{a}	59.72^{a}	59.92^{a}	64.71^{p}	63.72^{p}	64.82^{p}	64.51^{p}
Electrical Conductivity	$dS\ m^{-1}$	1.682^{a}	1.689^{a}	1.614^{a}	1.647^{a}	1.711^{p}	1.742^{p}	1.691^{p}	1.708^{p}
Total Nitrogen	%	0.09^{d}	0.16^{c}	0.18^{b}	0.25^{a}	0.22^{q}	0.19^{r}	0.16^{s}	0.29^{p}
Soil Nutrient Availability:									
– Phosphorus	mg L	9^{b}	11^{a}	11^{b}	12^{b}	14^{p}	11^{p}	13^{p}	11^{p}
– Potassium	$cmol^{(+)}\ kg^{-1}$	0.18^{a}	0.12^{a}	0.15^{a}	0.11^{a}	0.26^{p}	0.22^{p}	0.22^{p}	0.24^{p}
– Sodium	$cmol^{(+)}\ kg^{-1}$	0.64^{a}	0.62^{a}	0.61^{a}	0.59^{a}	0.74^{p}	0.69^{p}	0.67^{p}	0.65^{p}
– Calcium	$cmol^{(+)}\ kg^{-1}$	29.72^{a}	24.46^{a}	25.67^{a}	24.89^{a}	23.11^{p}	23.01^{p}	21.38^{p}	22.71^{p}
– Magnesium	$cmol^{(+)}\ kg^{-1}$	1.27^{a}	1.16^{a}	1.18^{a}	1.11^{a}	1.34^{p}	1.26^{p}	1.62^{p}	1.42^{p}
– Manganese	$mg\ L^{-1}$	1.14^{a}	2.22^{a}	1.19^{a}	2.16^{a}	1.92^{p}	1.12^{p}	1.93^{p}	1.11^{p}
Soil Nutrient Exchange:									
– Fe	$mg\ L^{-1}$	1.28^{a}	1.13^{c}	1.22^{b}	1.16^{c}	1.19^{p}	1.11^{r}	1.16^{q}	1.08^{s}
– Al	$mg\ L^{-1}$	1.54^{a}	1.42^{b}	1.32^{c}	1.31^{c}	1.27^{p}	1.19^{q}	1.13^{r}	1.09^{s}
Soil biology									
Total Bacteria	cfu	1.32×10^{5d}	1.74×10^{5c}	1.92×10^{5a}	1.82×10^{5b}	1.99×10^{5r}	2.53×10^{5p}	1.64×10^{5s}	2.31×10^{5q}
Total Fungi	cfu	1.46×10^{3b}	1.61×10^{3a}	1.71×10^{3a}	1.68×10^{3a}	1.83×10^{3r}	1.94×10^{3p}	1.57×10^{3s}	1.90×10^{3q}

Note: [1] Soil analysis data sourced from Taryono et al. (2022); [2] Significant differences in each season based on the Tukey-Kramer test ($p < 0.05$). FS: Soybean planting after fallow; MS: Soybean planting after maize; RS: Soybean planting after rice; SS: Continuous soybean planting

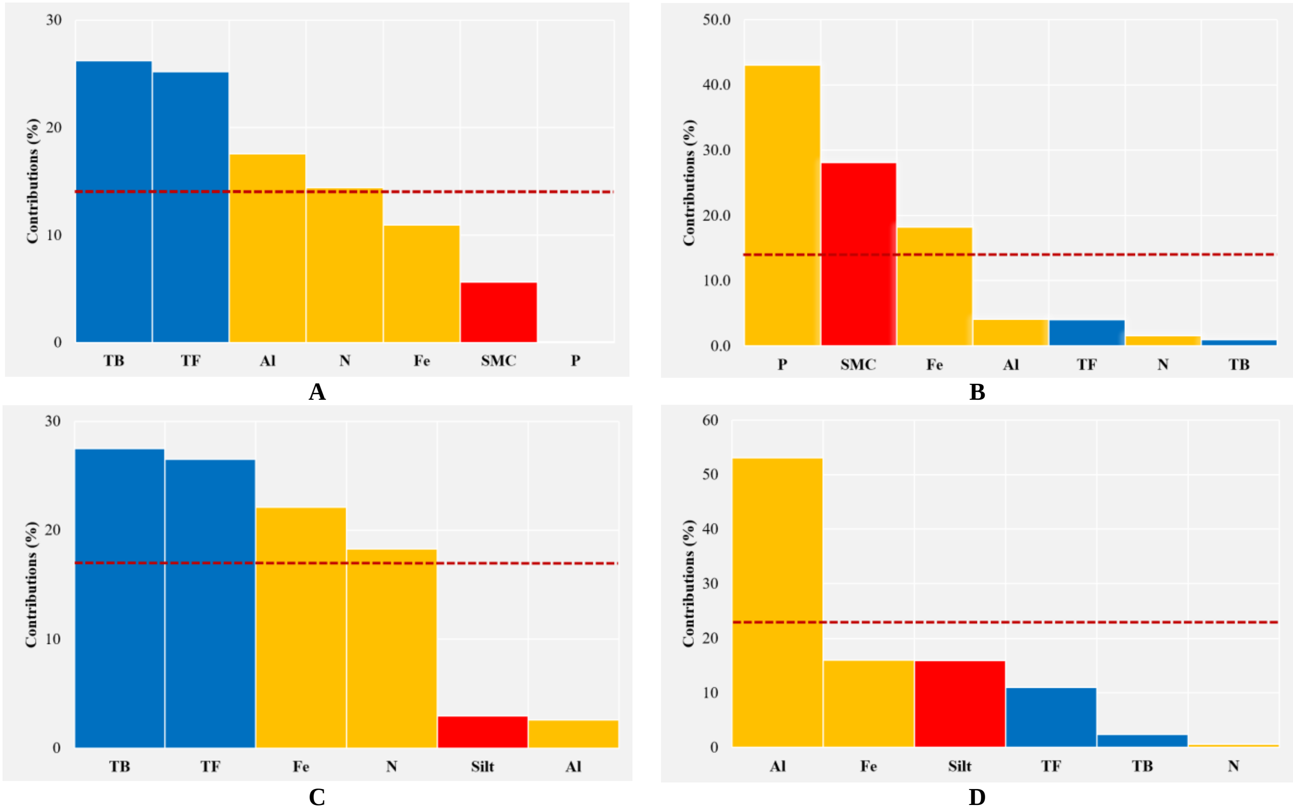

Figure 2. Multiple factor analysis (MFA) for factor 1 (dimension 1) and factor 2 (dimension 2) during the two seasons. a) MFA for factor 1 (dimension 1) during the dry season, b) MFA for factor 2 (dimension 2) during the dry season, c) MFA for factor 1 (dimension 1) during the wet season, d) MFA for factor 2 (dimension 2) during the wet season. Red, yellow, and blue represent groups of physical, chemical, and biological soil quality variables

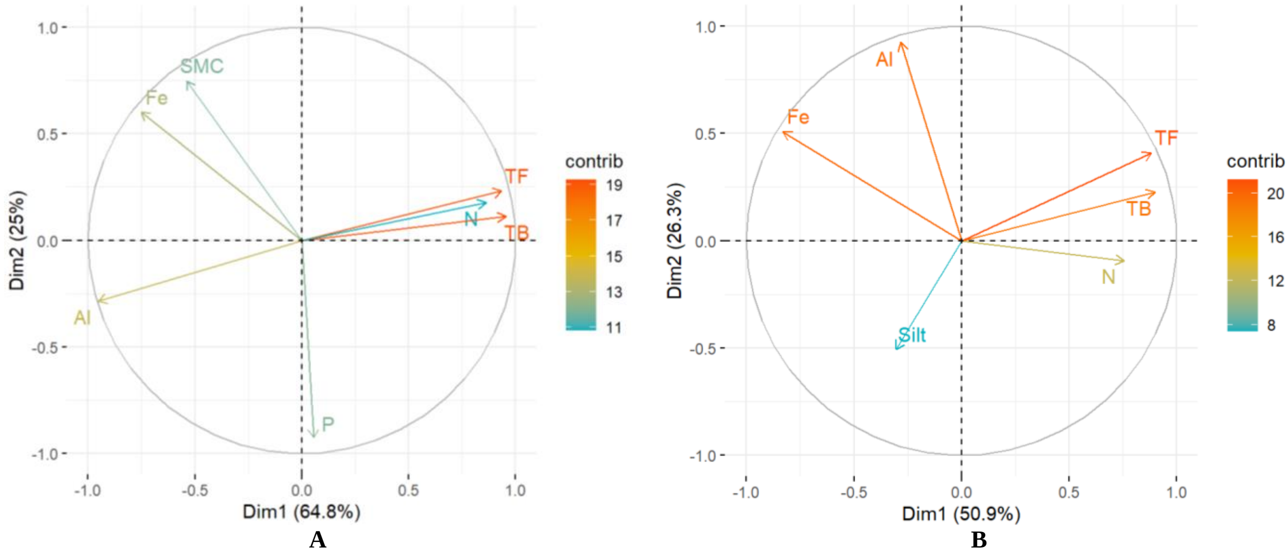

Figure 3. Contribution of soil quality variables during the two seasons. A. Dry season, B. Wet season

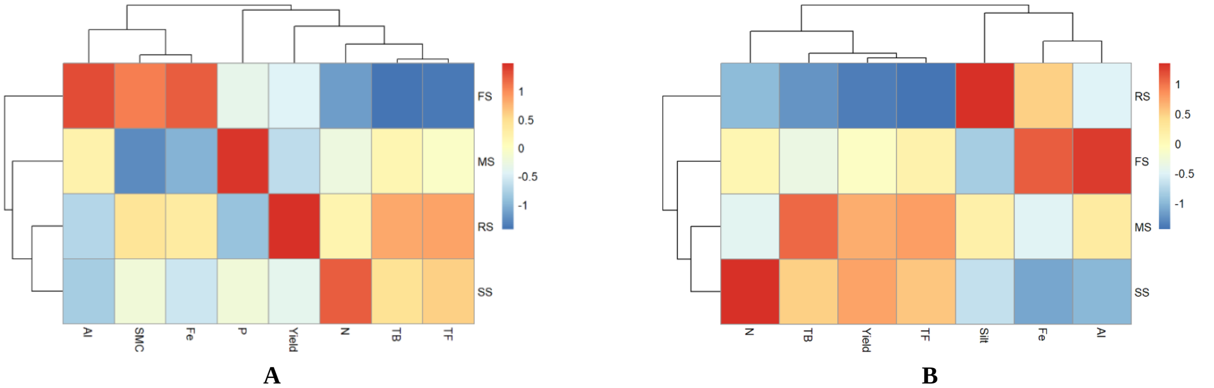

Figure 4. Heatmap clusters between soybean yield and the soil quality variables under the different crop rotation models and seasons. A) Dry season; B) Wet season

Figure 5. Generalized pair plot between soybean yield and the soil quality variables under the different crop rotation models in the dry season

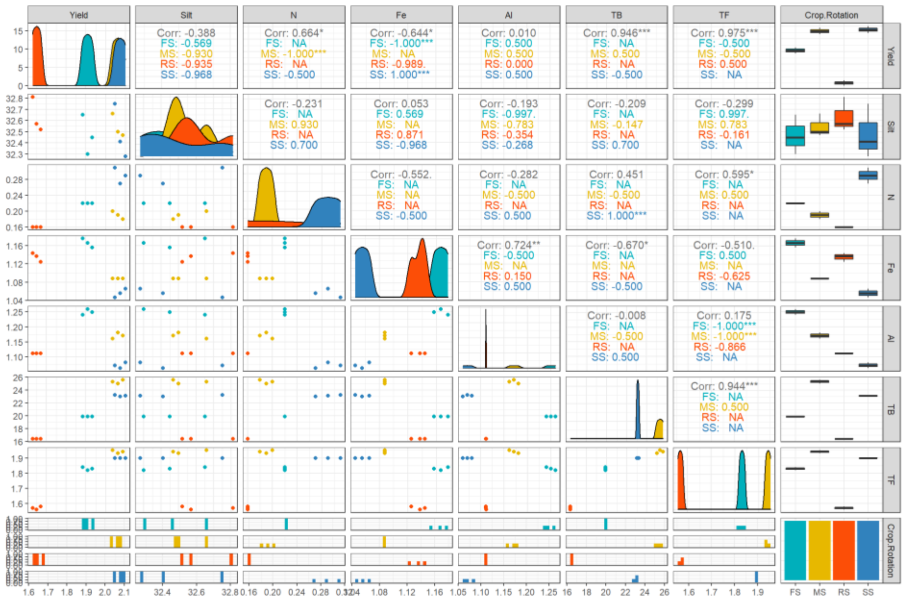

Figure 6. Generalized pair plot between soybean yield and the soil quality variables under the different crop rotation models in the wet season

Table 2. Mean squares treatment of ANOVA

Soil quality variables		Mean squares treatment of ANOVA[1]	
		Dry season	Wet season
Physics	% Clay	0.012^{ns}	0.002^{ns}
	% Sand	0.004^{ns}	0.011^{ns}
	% Silt	0.017^{ns}	0.017*
	Bulk density	0.003^{ns}	0.014^{ns}
	Soil moisture content	0.043*	0.017^{ns}
	Permeability	0.000^{ns}	0.000^{ns}
Chemistry	Ph H_2O	0.010^{ns}	0.057^{ns}
	Soil organic carbon	0.003^{ns}	0.003^{ns}
	Cation exchange capacity	11.502^{ns}	1.848^{ns}
	Electrical conductivity	0.002^{ns}	0.0008^{ns}
	Total nitrogen	0.013**	0.009**
	Phosphorus availability	17.889**	4.972^{ns}
	Potassium availability	0.001^{ns}	0.001^{ns}
	Calcium availability	3.705^{ns}	1.594^{ns}
	Magnesium availability	0.0002^{ns}	0.00005^{ns}
	Sodium availability	0.002^{ns}	0.003^{ns}
	Manganese availability	0.0002^{ns}	0.005^{ns}
	Iron exchange	0.013**	0.007**
	Aluminum exchange	0.035**	0.018**
Biologicy	Total bacteria	2.09×10^{9}**	4.52×10^{9}**
	Total fungi	3.73×10^{4}**	8.30×10^{4}**

Note: [1] ns and * not significant and significant at ($p < 0.05$). ** significant at ($p < 0.01$)

Rotating crops increases the abundance and heterogeneity of bacteria and fungi in the soil, thereby increasing the yield (Ai et al. 2018; Bowles et al. 2020). The sustainability of soybean production in the tropic is influenced by the interaction between soybean and bacteria in the soil. The higher soybean yields on the maize-maize-soybean rotation than on the soybean-maize-soybean rotation in many irrigated lands. This is related to the biological nitrogen fixation process (Carciochi et al. 2019). In addition, the increase in soybean yield in various crop rotations was due to an increase in root function and a decrease in pathogenic soil microorganisms or parasites that affect root growth (Grabau and Chen 2016; Li et al. 2018; Neupane et al. 2021).

The interaction between soybean and fungi has a positive impact on increasing soybean yield. Pop-Moldovan et al. (2021) informed that former maize plantations had a high abundance of mycorrhizal fungi. Mycorrhizae help plants to grow and develop, thus facilitating the absorption of nutrients, especially phosphorus. Fungi receive carbon from plants due to photosynthesis and plants receive nutrients that their roots do not have access to from fungi (Chen et al. 2018).

An increase in the Fe content in the soil increased soybean yield. Legumes in symbiosis with N-fixing bacteria require high Fe. The function of Fe is related to protein synthesis, and the formation of leghemoglobin, nitrogenase, and cytochromes. Fe deficiency affects the initiation and development of root nodules (Ivanov et al. 2012; Stein and Waters 2012). In this study, the Fe content in the soil was very low. This is because the soil at the study site had lime as the parent material containing bicarbonate and carbonate ions, causing the soil pH to be alkaline (Waters et al. 2018). Fe is oxidized as insoluble iron oxides in alkaline soils (Morrissey and Guerinot 2009). Moreover, the role of the microbiology of iron cycling, such as nitrate-reducing Fe (II)-oxidizing bacteria, can enhance the availability of ammonium in soil which indirectly can be absorbed by plants (Kappler et al. 2021).

An increase in soil N during the dry season was followed by an increase in soybean yield. This is because the soil was in the order Vertisol, so the soil temperature increased during the dry season and caused N to be lost through the volatilization of NH_3 (Lu et al. 2020). The increase in the % silt during the wet season affected soybean yield. Soybeans require good drainage and the increased percentage of silt increases permeability and the soil infiltration rate (Radocaj et al. 2020).

The application of organic matter and soil amendment improves soil quality as the key to increasing soybean yield. Siam weed (*Chromolaena odorata*) compost and biochar sourced from *M. cajuputi* waste are recommended for organic matter and soil amendment. Siam weed compost is a weed with an annual life cycle that grows wild in *M. cajuputi* forests and has the potential as an alternative source of organic matter (Suryanto et al. 2020b; Zachariades et al. 2009). Suryanto et al. (2020b) reported that the siam weed (*Chromolaena odorata*), which grows in *M. cajuputi* forests, can be used as an alternative source of organic fertilizer. Applying 10 and 15 tons ha^{-1} of siam weed compost produced soybean yields of 0.90 and 1.70 tons ha^{-1} compared with 0.20 tons ha^{-1} without siam weed compost.

Biochar sourced from *M. cajuputi* waste can be used as a soil amendment to increase the annual crop yield (Alam et al. 2020b; Faridah et al. 2021; Kastono et al. 2022). Applying 9.25 tons·ha^{-1} of *M. cajuputi* biochar and 76.31 kg·ha^{-1} of ammonium sulfate increased soybean yield by 13.02% and reduced nitrogen loss by 38.25% compared with a single application of 100 kg ha^{-1} ammonium sulfate (Alam et al. 2021). Suryanto et al. (2022) reported a significant impact of *M. cajuputi* biochar 3 years after regular application. The increase occurred in water holding capacity, soil organic carbon, total nitrogen, bacteria, and fungi in the soil.

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REFERENCES

Ai C, Zhang S, Zhang X, Guo D, Zhou W, Huang S. 2018. Distinct responses of soil bacterial and fungal communities to changes in fertilization regime and crop rotation. Geoderma 319: 156-166. DOI: 10.1016/j.geoderma.2018.01.010.

Alam T, Kurniasih B, Suryanto P, Basunanda P, Supriyanta, Ambarwati E, Widyawan MH, Handayani S, Taryono. 2019. Stability analysis for soybean in agroforestry system with *kayu putih*. SABRAO J Breed Genet 51: 405-418.

Alam T, Muhartini S, Suryanto P, Ambarwati E, Kastono D, Nurmalasari AI, Kurniasih B. 2020a. Soybean varieties suitability in agroforestry system with *kayu putih* under influence of soil quality parameters. Rev Ceres 67: 410-418. DOI: 10.1590/0034-737X202067050009.

Alam T, Suryanto P, Handayani S, Kastono D, Kurniasih B. 2020b. Optimizing application of biochar, compost and nitrogen fertilizer in soybean intercropping with kayu putih (*Melaleuca cajuputi*). Rev Bras Ciênc Solo 44: e0200003. DOI: 10.36783/18069657rbcs20200003.

Alam T, Suryanto P, Kastono D, Putra ETS, Handayani S, Widyawan MH, Muttaqin AS, Kurniasih B. 2021. Interactions of biochar briquette with ammonium sulfate fertilizer for controlled nitrogen loss in soybean intercopping with *Melaleuca cajuputi*. Legume Res 4: 339-343. DOI: 10.18805/LR-586.

Alam T, Suryanto P, Susyanto N, Kurniasih B, Basunanda P, Putra ETS, Kastono D, Respatie DW, Widyawan MH, Nurmansyah, Ansari A, Taryono. 2022. Performance of 45 non-linear models for determining critical period of weed control and acceptable yield loss in soybean agroforestry systems. Sustain 14: 7636. DOI: 10.3390/su14137636.

Ambarwati E, Arwiyanto T, Widada J, Alam T, Andika IP, Taryono. 2022. The genes associated with jasmonic acid and salicylic acid are induced in tropical chili pepper against *Ralstonia solanacearum* by applying arbuscular mycorrhizal fungi. Horticulturae 8: 876. DOI: 10.3390/horticulturae8100876.

Andrews SS, Karlen DL, Mitchell JP. 2002. A comparison of soil quality indexing methods for vegetable production system in Northern California. Agric Ecosyst Environ 90: 25-45. DOI: 10.1016/S0167-8809(01)00174-8.

Arslan S. 2017. Assessment of groundwater and soil quality for agricultural purposes in Kopruoren basin, Kutahya, Turkey. J Afr Earth Sci 131: 1-13. DOI: 10.1016/j.jafrearsci.2017.04.004.

Bandyopadhyay KK, Aggarwal P, Chakraborty D, Pradhan S, Garg RN, Singh R. 2012. Practical Manual on Measurement of Soil Physical Properties. Division of Agricultural Physics, Indian Agricultural Research Institute, New Delhi, India.

Bilgili AV, Kucuk C, van Es HM. 2017. Assessment of the quality of the Harran Plain soils under long-term cultivation. Environ Monit Assess 189: 460. DOI: 10.1007/s10661-017-6177-y.

Boettinger J, Chiaretti J, Ditzler C, Galbraith J, Kerschen K, Loerch C, McDanie P, McVey S, Monger C, Owens P, Ransom M, Scheffe K, Shaw J, Stolt M, Weindorf D. 2015. Illustrated Guide to Soil Taxonomy. Version 2. U.S. Department of Agriculture, Natural Resources Conservation Service, National Soil Survey Center, Lincoln, Nebraska, USA. DOI: 10.2136/sh2015-56-2-rc3.

Bowles TM, Mooshammer M, Socolar Y, Calderón F, Cavigelli MA, Culman SW, Deen W, Drury CF, Garcia AGY, Gaudin ACM, Harkcom WS, Lehman RM, Osborne SL, Robertson GP, Salerno J, Schmer MR, Strock J, Grandy AS. 2020. Long-term evidence shows that crop-rotation diversification increases agricultural resilience to adverse growing conditions in North America. One Earth 2: 284-293. DOI: 10.1016/j.oneear.2020.02.007.

Carciochi WD, Rosso LHM, Secchi MA, Torres AR, Naeve S, Casteel SN, Kovács P, Davidson D, Purcell LC, Archontoulis S, Ciampitti IA. 2019. Soybean yield, biological N_2 fixation and seed composition responses to additional inoculation in the United States. Sci Rep 9: 19908. DOI: 10.1038/s41598-019-56465-0.

Chen M, Arato M, Borghi L, Nouri E, Reinhardt D. 2018. Beneficial services of arbuscular mycorrhizal fungi; from ecology to application. Front Plant Sci 9: 1270. DOI: 10.3389/fpls.2018.01270.

Cheng J, Ding C, Li X, Zhang T, Wang X. 2016. Soil quality evaluation for navel orange production systems in central subtropical China. Soil Till Res 155: 225-232. DOI: 10.1016/j.still.2015.08.015

David AB, Davidson CE. 2014. Estimation method for serial dilution experiments. J Microbiol Met 107: 214-221. DOI: 10.1016/j.mimet.2014.08.023.

De Royer S, Van Noordwijk M, Roshetko JM. 2018. Does community-based forest management in Indonesia devolve social justice or social costs?. Intl For Rev 20 (2): 167-180. DOI: 10.1505/146554818823767609.

FAO. 2015. Agroforestry. http://www.fao.org/forestry/agroforestry/80338/en/.

Faridah E, Suryanto P, Nurjanto HH, Putra ETS, Falah MD, Widyawan MH, Alam T. 2021. Optimizing application of biochar amendment for nitrogen use efficiency in upland rice under *Melaleuca cajuputi* stands. Indian J Agric Res 55: 105-109. DOI: 10.18805/IJARe.A-601.

Firdous S, Begum S, Yasmin A. 2016. Assessment of soil quality parameters using multivariate analysis in the Rawal Lake watershed. Environ Monit Assess 188: 533. DOI: 10.1007/s10661-016-5527-5.

Govaerts B, Sayre KD, Deckers J. 2006. A minimum data set for soil quality assessment of wheat and maize cropping in the highlands of Mexico. Soil Till Res 87: 163-174. DOI: 10.1016/j.still.2005.03.005.

Grabau ZJ, Chen S. 2016. Determining the role of plant-parasitic nematodes in the corn-soybean crop rotation yield effect using nematicide application; II. soybean. Agron J 108: 1168-1179. DOI: 10.2134/agronj2015.0432.

Ivanov R, Brumbarova T, Bauer P. 2012. Fitting into the harsh reality; regulation of iron-deficiency responses in dicotyledonous plants. Mol Plant 5: 27-42. DOI: 10.1093/mp/ssr065.

Jiang M, Xu L, Chen X, Zhu H, Fan H. 2020. Soil quality assessment based on a minimum data set; a case study of a county in the typical river delta wetlands. Sustain 12: 9033. DOI: 10.3390/su1221903.

Kappler A, Bryce C, Mansor M, Lueder U, Byrne JM, Swanner ED. 2021. An evolving view on biogeochemical cycling of iron. Nat Rev Microbiol 19: 360-374. DOI: 10.1038/s41579-020-00502-7.

Kastono D, Suryanto P, Rogomulyo R, Handayani S, Supriyanta, Widyawan MH, Alam T. 2022. Differences in biochar sources for controlled nitrogen loss in a hybrid maize agroforestry system with *Melaleuca cajuputi*. J Eng Tech Sci 54: 122-134. DOI: 10.5614/j.eng.technol.sci.2022.54.1.9.

Li J, Liu K, Zhang J, Huang L, Coulter JA, Woodburn T, Li L, Gan Y. 2018. Soil-plant indices help explain legume response to crop rotation in a semiarid environment. Front Plant Sci 9: 1488. DOI: 10.3389/fpls.2018.01488.

Lin Y, Deng H, Du K, Li J, Lin H, Chen C, Fisher L, Wu C, Hong T, Zhang G. 2017. Soil quality assessment in different climate zones of China's Wenchuan earthquake affected region. Soil Till Res 165: 315-324. DOI: 10.1016/j.still.2016.09.009.

Lu J, Wang D, Liu K, Chu G, Huang L, Tian X, Zhang Y. 2020. Inbred varieties outperformed hybrid rice varieties under dense planting with reducing nitrogen. Sci Rep 10: 8769. DOI: 10.1038/s41598-020-65574-0.

Ministry of Agriculture. 2021. Indonesian soybean production projection (2020-2024). Ministry of Agriculture, Jakarta, Indonesia. https://databoks.katadata.co.id/datapublish/2021/06/04/produksi-kedelai-diproyeksi-turun-hingga-2024. [Indonesian]

Morrissey J, Guerinot ML. 2009. Iron uptake and transport in plants; the good, the bad and the ionome. Chem Rev 109: 4553-4567. DOI: 10.1021/cr900112r.

Mulyani A, Nursyamsi D, Syakir M. 2017. Strategi pemanfaatan sumberdaya lahan untuk pencapaian swasembada beras berkelanjutan. Jurnal Sumberdaya Lahan 11: 11-22. DOI: 10.21082/jsdl.v11n1.2017.11-22. [Indonesian]

Neupane A, Bulbul I, Wang Z, Lehman RM, Nafziger E, Marzano SYL. 2021. Long term crop rotation effect on subsequent soybean yield explained by soil and root-associated microbes and soil health indicators. Sci Rep 11: 9200. DOI: 10.1038/s41598-021-88784-6.

Peters J. 2013. Wisconsin Procedures for Soil Testing, Plant Analysis and Feed & Forage Analysis. University of Wisconsin, Madison, USA. https://datcp.wi.gov/Documents/NMProcedures.pdf.

Pop-Moldovan V, Vârban R, Corcoz L, Pleșa A, Stoian V, Vidican R. 2021. Divergence in corn mycorrhizal colonization patterns due to organic treatment. Plants 10: 2760. DOI: 10.3390/plants10122760.

Putra ETS, Purwanto BH, Wulandari C, Alam T. 2021. Metabolic activities of eight oil palm progenies grown under aluminum toxicity. Biodiversitas 22: 3146-3155. DOI: 10.13057/biodiv/d220808.

Qi YB, Darilek JL, Huang B, Zhao YC, Sun WX, Gu ZQ. 2009. Evaluating soil quality indices in an agricultural region of Jiangsu Province, China. Geoderma 149: 325-334. DOI: 10.1016/j.geoderma.2008.12.015.

R Core Team. 2017. R; A Language and Environment for Statistical Computing.

Radocaj D, Jurisic M, Zebec V, Plascak I. 2020. Delineation of soil texture suitability zones for soybean cultivation; a case study in continental Croatia. Agron 10: 823. DOI: 10.3390/agronomy10060823.

Rousseau GX, Deheuvels O, Arias IR, Somarriba E. 2012. Indicating soil quality in cacao-based agroforestry systems and old-growth forests;

the potential of soil macrofauna assemblage. Ecol Ind 23: 535-543. DOI: 10.1016/j.ecolind.2012.05.008.

Ruslanjari D, Suryanto P, Alam T. 2020. Optimization management for chili (*Capsicum annum* L.) production in agroforestry system with coconut (*Cocos nucifera* L.) on local protected coastline areas. Indonesian J Geogr 52: 397-401. DOI: 10.22146/ijg.55241.

SAS Institute. 2013. SAS System for Windows 9.4. SAS Institute Inc., North Carolina, USA.

Stein RJ, Waters BM. 2012. Use of natural variation reveals core genes in the transcriptome of iron-deficient *Arabidopsis thaliana* roots. J Exp Bot 63: 1039-1055. DOI: 10.1093/jxb/err343.

Sunanto H. 2003. Budi Daya dan Penyulingan Kayu Putih. Kanisius, Yogyakarta. [Indonesian]

Suryanto P, Faridah E, Nurjanto HH, Putra ETS, Kastono D, Handayani S, Boy R, Widyawan MH, Alam T. 2022. Short-term effect of in situ biochar briquettes on nitrogen loss in hybrid rice grown in an agroforestry system for three years. Agron 12: 564. DOI: 10.3390/agronomy12030564.

Suryanto P, Faridah E, Triyogo A, Kastono D, Suwignyo B, Nurmalasari AI, Alam, T. 2020a. Designing of soil quality and climate assessment tool for sustainable production of signalgrass (*Brachiaria brizantha*) silvopasture system in mountain ecosystems. Aust J Crop Sci 14: 614-621. DOI: 10.21475/ajcs.20.14.04.p2147.

Suryanto P, Kurniasih B, Faridah E, Nurjanto HH, Rogomulyo R, Handayani S, Kastono D, Muttaqien AS, Alam T. 2020b. Influence of furrow with organic material and *Chromolaena odorata* compost on upland rice productivity in an agroforestry system with *Melaleuca cajuputi*. Biodiversitas 21: 780-791. DOI: 10.13057/biodiv/d210246.

Suryanto P, Taryono, Supriyanta, Kastono D, Putra ETS, Widyawan MH, Alam T. 2020c. Assessment of soil quality parameters and yield of rice cultivars in *Melaleuca cajuputi* agroforestry system. Biodiversitas 21: 3463-3470. DOI: 10.13057/biodiv/d210807.

Suryanto P, Tohari, Putra ETS, Alam T. 2017. Soil quality assessment for yield improvement of clove, cacao and cardamom agro-forestry system in Menoreh Mountains Area, Indonesia. J Agron 16: 160-167. DOI: 10.3923/ja.2017.160.167.

Taryono, Suryanto P, Supriyanta, Basunanda P, Wulandari RA, Handayani S, Nurmansyah, Alam T. 2022. Soybean crop rotation stability in rainfed agroforestry system through GGE Biplot and EBLUP. Agron 12: 2012. DOI: 10.3390/agronomy12092012.

Waters BM, Amundsen K, Graef G. 2018. Gene expression profiling of iron deficiency chlorosis sensitive and tolerant soybean indicates key roles for phenylpropanoids under alkalinity stress. Front Plant Sci 9: 10. DOI: 10.3389/fpls.2018.00010.

Welham SJ, Gezan SA, Clark SJ, Mead A. 2015. Statistical Methods in Biology; Design and Analysis of Experiments and Regression. CRC Press, Boca Raton, Florida, USA. DOI: 10.1201/b17336.

Widyawan MH, Hasanah A, Sayekti RRRS, Wulandari RA, Alam T, Taryono, Pramana AAC. 2020. Multivariate analysis unravel genetic diversity and relationship between agronomic traits, protein and dietary fiber in yardlong bean (*Vigna unguiculata* subsp. sesquipedalis Verdc.). Biodiversitas 21: 5662-5671. DOI: 10.13057/biodiv/d211211.

Yao R, Yang J, Gao P, Zhang J, Jin W. 2013. Determining minimum data set for soil quality assessment of typical salt affected farmland in the coastal reclamation area. Soil Till Res 128: 137-148. DOI: 10.1016/j.still.2012.11.007.

Zachariades, Day CM, Muniappan R, Reddy GVP. 2009. *Chromolaena odorata* (L.) King and Robinson (*Asteraceae*). In: Muniappan R, Reddy GVP, Raman (eds). A Biological Control of Tropical Weeds using Arthropods. Cambridge University Press, Cambridge, USA. DOI: 10.1017/CBO9780511576348.008.