Soybean varieties suitability in agroforestry system with *kayu putih* under influence of soil quality parameters[1]

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ABSTRACT

The existence of soybean varieties and soil type interaction causes differences in productivity of soybean varieties in agroforestry systems with *kayu putih*. Soil quality parameters (physical, chemical and biological characteristics) will affect the productivity of soybean varieties. The objective of this study was to reveal the relationship between soil quality parameters with soybean varieties suitability in agroforestry system with *kayu putih* over three locations in which their soil type were different, *i.e*. Lithic Haplusterts, Ustic Epiaquerts and Vertic Haplustalfs. The study was conducted from May to August, 2018 in Menggoran Forest Resort, Playen District, Gunungkidul Regency, Special Province of Yogyakarta, Indonesia. The highest yield of soybean per hectare on Dering I grown in Lithic Haplusterts and Ustic Epiaquerts was 1.38 and 1.27 tons.ha^{-1}, respectively, while Grobogan in Ustic Epiaquerts 1.24 tons.ha^{-1}. Dering I showed the mean of the highest yield and most suitable in all soil types, while Gema showed the mean of the lowest yield and not suitable in all soil types. Soil quality parameters that had a significant influenced on the production of soybean varieties in agroforestry systems with *kayu putih* were chemical characteristic consisting of availability of P, Mg, NH_4^+, Mn and Ca.

Keywords: soil type; soil characteristic; yield of soybean.

INTRODUCTION

Soybean is the leading commodity for food security in Indonesia. Consumption of soybean per year was projected to continuously rise from 812 thousand tons in 2005 to 946 thousand tons in 2020, indicating an average increase of 1.02% per year. Besides, the average population growth within the same period was also projected as 1.40% per year. Thus, the total soybean production was projected to increase from 1.84 million tons in 2005 to 2.64 million tons in 2020, or an average rise of 2.44% per year (Sudaryanto and Swastika, 2016).

The space between *kayu putih* stands can be used as an alternative to soybean cultivation. Soybean could be intercropped with *kayu putih* (Suryanto *et al*., 2017b). This is possible because *kayu putih* trees were pruned routinely to harvest the leaves, thus the shade factor did not affect annual crops. Agroforestry with *kayu putih* could be done continuously for 30 years (Suwignyo *et al*., 2015).

One of the easiest and cheapest technologies to increase soybean productivity is the introduction of new varieties that have high yield potential (Indonesian Agency for Agricultural Research and Development, 2007). However, varieties that have high yields in one soil type are not necessarily suitable and stable for all soil types. That is causes there is G x E interaction (Gauch, 2006; Piepho *et al*., 2016). Krisnawati & Adie (2018)

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reported that G2 and G6 genotype were considered as high yielding and stable promising lines of soybean across environments in which their soil type, seasonal rainfall, and altitude.

The sustainability of soybean varieties productivity can be done by selecting suitable and stable soybean varieties in various soil types. It can maximize the potential yield of these varieties and reduced fertilizer input (European Union, 2012). Alam *et al*., (2019) reported that Dering I and Devon I varieties had higher stability as well as higher mean of yield and Burangrang, Grobogan and Gema gave medium-high yield and poor yield with poor adaptation. However, the unknown soil quality parameters are a limiting factor for soybean production.

Soil quality is one of the three components of environmental quality in addition to air and water quality. Soil quality is an assessment of how the soil functions and prepared for the future (Andrews *et al*., 2002; Makalew, 2011). Soil quality depends on a specific soil type and the maintenance of plant and animal sustainability (Andrews *et al*., 2004). Integration of soil chemical, physical and biological attributes is the concept of soil quality that is dynamic and sensitive to soil management practices (Bilgili *et al*., 2017). Qi *et al*. (2009) stated that soil quality evaluation using soil quality measurement could reduce data and saved time and money. Soil quality affected the successful sustainable production of rice in agroforestry system with *kayu putih* (Suryanto *et al*., 2017a).

Several studies related to soil quality assessment showed different land evaluation parameters. Soil quality measurement was very dependent on the diversity of location, scale, land management and research objective (Rousseau *et al*., 2012). Studies related to soil quality assessment had been carried out in the same location for rice. Suryanto *et al*. (2017a) showed that soil quality parameters that play a role in rice productivity in agroforestry with *kayu putih* were amount of soil microorganisms, availability of phosphorus and exchange of potassium.

Soil quality parameters consisting of physical, chemical and biological characters in each soil types in the study location will affect the production and suitability of soybean varieties. The prediction of soil quality parameters for each soybean varieties suitability is expected for monitoring and evaluating the production of soybean varieties in different soil types. The objective of this study was to reveal the relationship between soil quality parameters with soybean varieties suitability in agroforestry system with *kayu putih*. This study would help researchers uncover critical areas of soybean cultivation on agroforestry system with *kayu putih* that many researchers could not be able to explore. Thus, a new theory on limiting factors in each soybean varieties might arise.

MATERIAL AND METHOD

The experiment was conducted in Menggoran Forest Resort, Playen District, Gunungkidul Regency, Special Province of Yogyakarta, Indonesia from May to August 2018. This area was located ±43 km to the south-east of Yogyakarta City (Figure 1).

The soybean varieties were from Indonesian Legumes and Tuber Crops Research Institute in Malang Regency, East Java Province, Indonesia. The experimental plots cover an area of 24 m^2 (6 x 4 m) in the area between *kayu putih* stands and the harvest area of 20 m^2, excluding the border rows. The plant spacing was 40 x 20 cm. No fertilization and pesticide were carried out in this study. Irrigation did not performed because the field used in this study was rainfed area.

The experiment used a Randomized Complete Block (RCB) design with five blocks as replication. The first factor was soil type in Menggoran Forest Resort consisting of Lithic Haplusterts, Ustic Epiaquerts and Vertic Haplustalfs. The second factor was soybean varieties consisting of Anjasmoro, Argomulyo, Burangrang, Demas I, Dering I, Devon I, Gema and Grobogan.

The soil quality parameters observed was soil properties (physical, chemical and biologycal characteristic) (Table 1). Soil quality parameters observation was carried out at the research site, at the General Soil and General Microbiology Laboratory, Faculty of Agriculture, Universitas Gadjah Mada, the Special Province of Yogyakarta, Indonesia. The observation of soybean yield was seed dry weight per hectare. Soybean seed was dried under sunlight to 11 % of moisture level (Suryanto *et al*., 2017a).

The models must be evaluated so that assumptions can be fulfilled. The normality test was carried out using the Kolmogorov test and Q-Q plot (Moncada *et al*., 2014). MANOVA was used to determine the significant effects on assessed physical, chemical and biological variables. F-statistics and Wiks' Lambada tests obtained from MANOVA are used to test the null hypothesis regarding overall treatment (Hatcher & Stepanski, 1994). Two-way ANOVA was used to test the yield of soybean varieties in different soil type, and the separation of means was subject to Tukey's HSD (*á* = 5%) (Hinkelman & Kempthorne, 2008).

Soybean varieties suitability were graphically analyzed for interpreting GE interaction using the PCA-Biplot. PCA-Biplot analysis, which consisted of two concepts, the biplot concept (Gabriel, 1971) was employed to visually analyze the soybean varieties in each soil type trial. The PCA-Biplot graphic was made in RStudio (RStudio Team, 2015) using pca3d package (Weiner *et al.*, 2012).

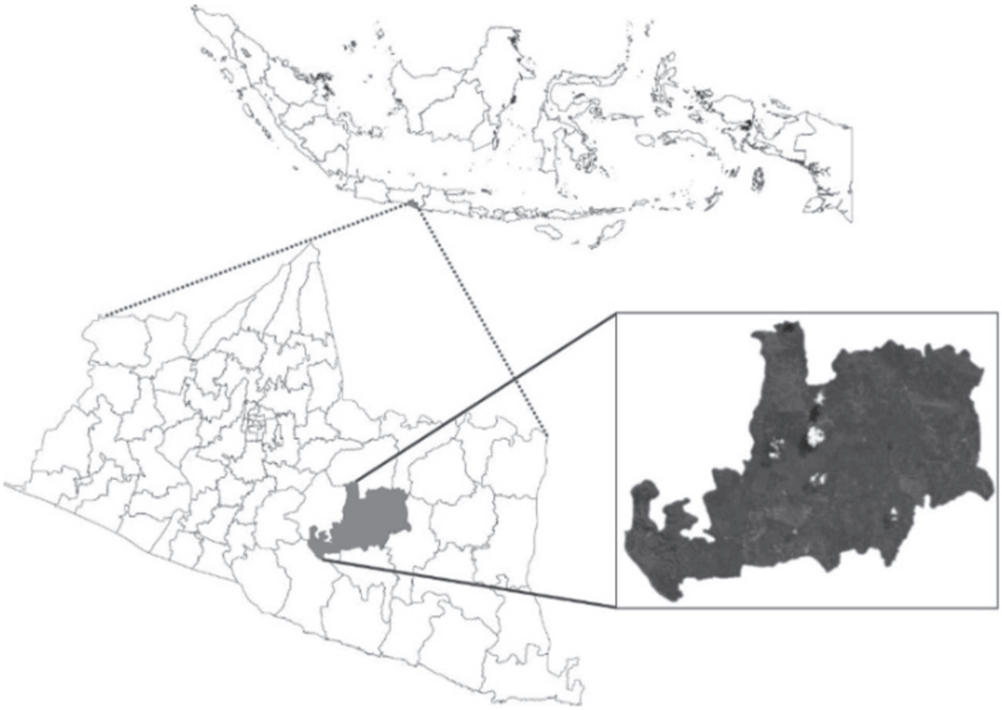

Figure 1: Geographical locations of the study area (latitude 7º 52‘ 59.5992“ S to 7º 59‘ 41.1288“ S and longitude 110º 26‘ 21.462“E to 110º 35‘ 7.4868“ E)

Table 1: Procedure methods for measurements of each indicator

Variable	Symbol	Procedures methods	Reference
Physics:			
1. Soil Texture	Silt, Sand, Clay	Robinson Pipette Method	Aubert *et al.* (1954)
2. Bulk Density	BD	Ring Sample	Blake & Hartge (1986)
3. Available Soil Moisture	ASM	Gravimetric	Alam (2014); Dwidjopuspito (1986)
4. Permeability	Perm	Permeameter	Blake & Hartge (1986)
Chemical:			
1. pH H_2O	pH	Ratio Soil : Aquadest = 1 : 2,5; pH Meter	Van Reeuwijk (1993)
2. Soil Organic Matter	SOM	Walkey and Black	Black (1965)
3. Cation Exchange Capacity	CEC	Ammonium Acetate Extraction	Hajek *et al*. (1972); Van Reeuwijk (1993)
4. Electrical Conductivity	EC	Ratio Soil : Aquadest = 1 : 2,5; EC Meter	Richards (1954)
5. Available of Nitrate and Ammonium	NO_3^- and NH_4^+	Devarda’s Alloy Method	Stenhom *et al.* (2009)
6. Available of Phosphorus	P	Olsen Extract (Spectrophotometry)	Olsen *et al*. (1954)
7. Available of Potassium and Sodium	K and Na	Ammonium Acetate Extraction; Flame Photometer	Jones Jr (2001)
8. Available of Calcium, Magnesium, Iron, Manganese, Copper and Zinc	Ca, Mg, Fe, Mn, Cu and Zn	Ammonium Acetate Extraction;Atomic Absorption Spectrophotometry(AAS)	Jones Jr (2001); Van Reeuwijk (1993)
Biology:			
1. Amounts of Bacterium	AB	Dilution-Plate	David & Davidson (2014)
2. Amounts of Fungi	AF	Dilution-Plate	David & Davidson (2014)

One-way ANOVA, factor Analysis and stepwise regression were used to relationship between the soil quality parameters with soybean varieties suitability (Andrews *et al*., 2002; Govaerts *et al*., 2006; Smith *et al*., 1993). MANOVA, ANOVA, Factor Analysis and Stepwise regression were carried out using SAS software version 9.4 for Windows. Statistical analysis was carried out by PROC GLM, MIXED, PRINCOMP, FACTOR and REG (SAS Institute Inc, 2013).

RESULT AND DISCUSSION

The study site had an ustic moisture regime. Ustic moisture is a soil regime containing limited moisture but is suitable for plant growth when the environmental conditions favour (Boettinger *et al*., 2015). The altitude of the study site varied from 100 to 200 meters above sea level. The air temperature ranged between 24.80 to 26.40 °C. The relative humidity ranged between 81.90 % and 86.50 %. The total rainfall in the study area was 2,005 mm year^{-1}. The macro and micro climates in the study site were highly suitable for soybean cultivation (Djaenudin *et al*., 2011).

Lithic Haplusterts was included into the Vertisol soil type that had a shallow solum and rock contact of 50 cm from the surface. Vertic Haplustalfs was Alfisol soil type with vertic characteristic. Ustic Epiaquerts was Vertisol soil type that had fracture of >5 mm and thickness of >25 cm for 90 days each year in a reasonable condition when it was not irrigated (Soil Survey Staff, 2014). In general soybean was suitable to be planted in Lithic Haplusterts and Vertic Haplusterts. However, it was marginally suitable to be planted in Ustic Epiaquerts because the land was flooded during the wet season (Djaenudin *et al*., 2011).

The result of two-way ANOVA ($p < 0.05$) showed that there was an interaction between soil type and soybean varieties concerning the yield of soybean per hectare (Figure 2). The highest yields were produced by Dering I varieties cultivated at Lithic Haplusterts and Ustic Epiaquerts, namely 1.38 and 1.27 tons.ha^{-1} respectively and in Grobogan at Ustic Epiaquerts of 1.24 tons.ha^{-1}. Soybean varieties showed difference in yield per hectare when grown in Lithic Haplusterts, Ustic Epiaquerts and Vertic Haplustalfs. This was due to the G × E interaction so that each soybean varieties response differently to each soil types (Alam *et al*., 2019). The relationship between productivity and soil was very complex and highly dependent on the physical, chemical and biological nature of the soil and external factors (Adams, 2016; Sys *et al*., 1991).

Principal component analysis (PCA) Biplots of the total data set of soil quality parameters were performed with varimax rotation (orthogonal) (Ayoubi *et al*., 2009; Cox *et al*., 2003; Shukla *et al*., 2004b). The results of PCA Biplot showed that Dering I had the mean of highest yield and was suitable for all soil types. Different things were showed by Gema, which had the mean of lowest yield and was not suitable in all soil types. The position of Anjasmoro varieties in the center point. This can be interpreted that Anjasmoro had the mean of moderate yield and suitable for all soil types (Figure 3).

Xu *et al*. (2014) reported that the presence of G x E interactions gave different responses to rice yields to variations in soil types in various locations. Jandoung *et al*. (2011) reported that soybean cultivars ‘Kyado’ and ‘Sebore’ have a good performance in soil with pH ranged

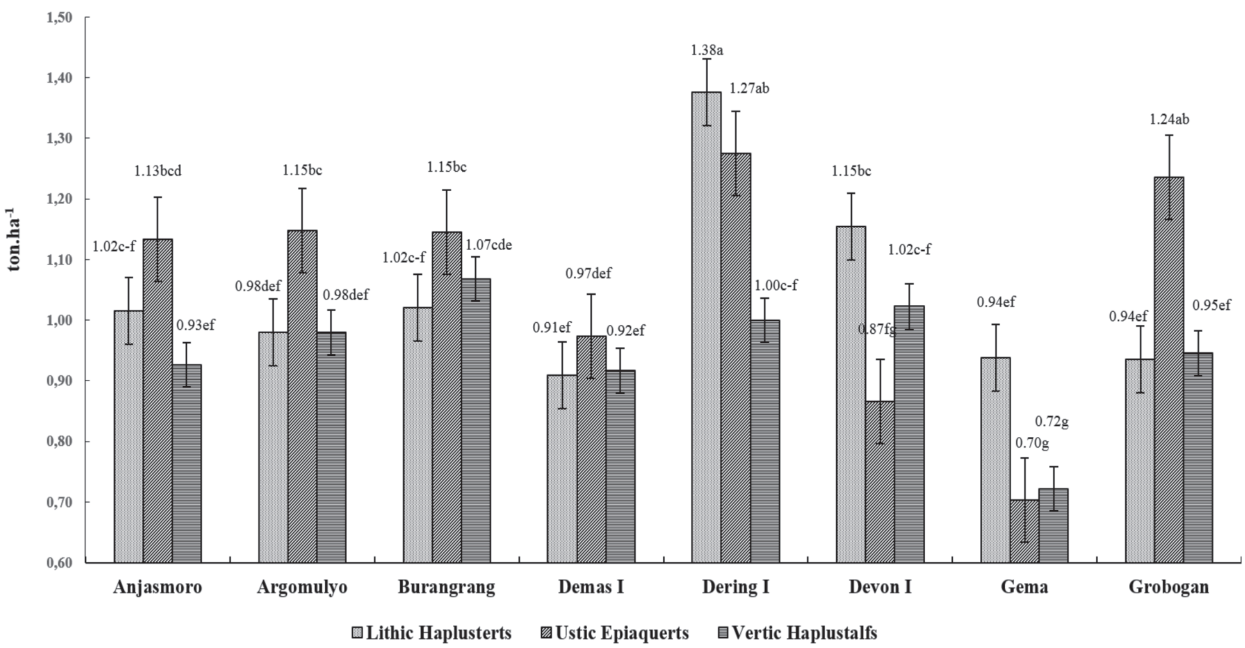

Figure 2: Yield of soybean varieties per hectare on the various of soil types.

Tabel 2: One way analysis of variance (ANOVA) of soil quality parameters

No.	Soil Quality Parameters	Unit	Soil Type			CV (%)
			Lithic Haplusterts	Ustic Epiaquerts	Vertic Haplustalf	
1.	Clay	%	60.34 ± 2.86^{b}	53.59 ± 1.63^{b}	78.50 ± 2.01^{a}	8.78
2.	Silt	%	32.58 ± 2.37^{a}	35.71 ± 1.18^{a}	16.17 ± 1.49^{b}	14.32
3.	Sand	%	7.08 ± 0.55^{ab}	10.70 ± 1.65^{a}	5.33 ± 0.70^{b}	36.37
4.	Bulk Density	$g\ cm^{-3}$	1.15 ± 0.03^{a}	1.08 ± 0.04^{a}	1.14 ± 0.04^{a}	6.32
5.	Available Soil Moisture	$mm\ cm^{-1}$	3165.00 ± 364.92^{a}	2002.20 ± 138.44^{b}	3094.10 ± 275.42^{a}	12.33
6.	Permeability	$cm\ h^{-1}$	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}	0.00
7.	pH H_2O	-	8.18 ± 0.04^{a}	7.80 ± 0.06^{b}	7.69 ± 0.05^{b}	1.63
8.	Cation Exchange Capacity	$cmol(+1).kg^{-1}$	58.83 ± 0.16^{b}	65.30 ± 0.90^{a}	32.65 ± 0.20^{c}	2.19
9.	Electrical Conductivity	$\mu S\ cm^{-1}$	1689.90 ± 63.32^{b}	1870.50 ± 27.92^{a}	1154.80 ± 61.07^{c}	6.13
10.	Soil Organic Matters	%	2.62 ± 0.03^{a}	2.75 ± 0.09^{a}	2.73 ± 0.07^{a}	5.23
11.	Ammonium	ppm	39.39 ± 3.91^{b}	56.76 ± 7.21^{a}	$51.00 \pm 1.54a^{b}$	18.87
12.	Nitrate	ppm	86.18 ± 14.42^{a}	143.21 ± 33.65^{a}	82.73 ± 10.24^{a}	39.70
13.	Phosphorus	ppm	6.87 ± 0.57^{b}	18.76 ± 2.58^{a}	2.46 ± 0.36^{b}	33.76
14.	Potassium	me %	0.78 ± 0.01^{a}	0.94 ± 0.04^{a}	0.93 ± 0.11^{a}	15.52
15.	Sodium	me %	0.75 ± 0.04^{a}	0.79 ± 0.12^{a}	0.72 ± 0.07^{a}	23.68
16.	Calcium	me %	5.85 ± 0.00^{a}	5.83 ± 0.01^{a}	5.70 ± 0.01^{b}	0.34
17.	Magnesium	me %	0.28 ± 0.00^{a}	0.28 ± 0.00^{a}	0.27 ± 0.00^{b}	1.13
18.	Iron	ppm	12.22 ± 0.11^{a}	12.58 ± 0.21^{a}	9.21 ± 0.33^{b}	5.49
19.	Manganese	ppm	32.52 ± 0.27^{b}	32.90 ± 0.59^{b}	35.17 ± 0.18^{a}	2.80
20.	Copper	ppm	3.20 ± 0.07^{b}	3.44 ± 0.05^{a}	1.72 ± 0.08^{c}	4.78
21.	Zinc	ppm	1.43 ± 0.04^{b}	$1.51 \pm 0.80b$	4.16 ± 0.08^{a}	46.24
22.	Amounts of Bacterium	colony	$3.44x10^{6} \pm 2.45x10^{4a}$	$3.52x10^{6} \pm 6.63x10^{4a}$	$3.48x10^{6} \pm 3.74x10^{4a}$	2.13
23.	Amounts of Fungi	colony	$2.54x10^{5} \pm 2.45x10^{3a}$	$2.62x10^{5} \pm 6.63x10^{3a}$	$2.60x10^{5} \pm 3.74x10^{3a}$	2.34

Number followed by the same letter in the same column were not significantly different by Tukey's HSD test ($p<0.05$). The bars was indicated Standard Error of Mean (SEM).

from 5.5 to 6.5 and have a relative tolerance to moderate acidic soil. It depended on the genetics of each plant (Klee & Tieman, 2013). Giller *et al*. (2011) suggested that each plant had a different response in absorbing nutrients, fertilizers and lime applications on a site. This showed that the soil had high heterogeneity that affected plant growth.

The result of MANOVA with physical and chemical properties showed a very significant difference and significant difference of (< 0.000**) and (0.019*) respectively but the biological property showed no significant difference (0.508^{ns}). These indices represent the cumulative effects of different soil properties (physical, chemical and biology) as an index from the role of each indicator in soil quality (Drury *et al*., 2003).

One-way ANOVA was applied on the twenty-four parameters used at different land effecting soil quality parameters (Table 2). The result of ANOVA on the soil quality parameters showed a significant difference ($p < 0.05$) and had a coefficient of variance of <40% consisting of % clay, % silt, % sand, ASM, CEC, pH H_2O, EC, available NH_4^+, P, Ca, Mg, Fe, Mn and Cu (Table 2). Those parameters were maintained for continued 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 (Andrews *et al*., 2002).

Factor analysis was provided to classify the soil quality parameters into a small set of independent factors and reduced the original data set. The result of the factor analysis showed three sets of soil quality factors formed (Table 3). Factor 1 consisted of % clay, % silt, % sand, CEC, EC, P, Ca, Fe, Mn and Cu. Factor 2 consisted of P and Mg. Factor 3 consisted of % sand and NH_4^+ (Table 3).

The final result of the factor analysis showed that % clay, % silt, % sand, CEC, EC, P, Ca, Fe, Mn, Cu, Mg and NH_4^+ were suitable to proceed to the stepwise regression analysis since it had a communality value of higher than 0.5.

Factor analysis is widely considered as a suitable method for highly correlated environmental data (Shukla *et al*., 2004a; Govaerts *et al*., 2006; Yao *et al*., 2013). Varimax rotation enhances the interpretability of the uncorrelate components. The derived factors are designated as soil quality indices or complex indicators.

Stepwise regression analysis was used for screening soil quality parameters that affect the production of soybean varieties suitability (Andrews *et al*., 2002; Govaerts *et al*., 2006; Makalew, 2011; Smith *et al*., 1993; Suryanto *et al*., 2017a).

The result of stepwise regression showed that each soybean varieties had a different soil quality parameters limiting factors (Table 4). Each soybean varieties showed a different response to the availability of nutrients in the soil. The soil quality parameters affecting the yield of Argomulyo also showed P (1.094**) and Mg (-0.692*), Burangrang NH_4^+ (0.569*), Dering I Mn (-0.684**), Devon I Mg (-1.001**) and Ca (0.648*), Gema Mg (-0.902**), while Grobogan NH_4^+ (0.5328), and P (0.471*). Specifically for Anjasmoro and Demas I, there was no soil quality parameters limiting factors for these varieties.

Positive response was shown by Argomulyo and Grobogan for the availability of P, Burangrang and Grobogan for NH_4^+ and Devon I for Ca. The increased availability of P in the soil was very significant and significantly increased the yield of Argomulyo and Grobogan. The deficiency of P caused a significant decrease in net photosynthetic rate in rice (Xu *et al*., 2007).

Table 3: Factor analysis with varimax rotation of physical, chemical and biological properties of soil

Parameter	Factor 1	Factor 2	Factor 3	Communality
% Clay	-0.908 *	-0.214	-0.137	0.999
% Silt	0.923 *	0.240	-0.065	0.999
% Sand	0.586 *	0.071	0.696 *	0.999
Available Soil Moisture	-0.262	-0.059	-0.187	0.974
pH H_2O	0.357	-0.030	-0.199	0.979
CEC	0.851 *	0.371	0.095	0.999
Electrical Conductivity	0.936 *	0.176	0.158	0.996
Ammonium	-0.051	-0.024	0.976 *	0.995
Phosphorus	0.661 *	0.520 *	0.154	0.991
Calcium	0.873 *	0.194	-0.003	0.998
Magnesium	0.436	0.889 *	-0.040	0.988
Iron	0.761 *	0.380	0.119	0.994
Manganese	-0.663 *	-0.228	-0.240	0.980
Copper	0.880 *	0.299	-0.004	0.993
Eigen-Value	**9.120**	**2.095**	**1.153**	

* Significant soil's parameters in each soil set factor.

The increased availability of NH_4^+ in soil was very significant to the increased yield of Grobogan and Burangrang. Nitrogen could be a limiting factor for plant growth after fixed carbon (Marschner, 2011). In a physiological process, urea was an essential internal and external source of N converted to ammonia for N assimilation (Marschner, 2011). Faustino *et al*. (2015) informed that NH_4^+ fertilization could increase the root growth of *Pinus taeda* in drought stress.

Higher increased availability of Ca in soil significantly increased the yield of Devon I varieties. The result of the research conducted by Domingues *et al*. (2016) described that common bean plants with higher Ca concentrations had a high dry weight of shoots and roots, grain yields and Ca concentrations in leaves and seeds.

Negative response was shown by Argomulyo, Devon I and Grobogan against the availability of Mg nutrients; Mn was available in Dering I. The increased availability of Mg was negatively correlated with K availability and the high concentration of Mg caused a decrease in soil calcium content (Venkatesan & Jayaganesh, 2010). The high concentration of Mg^{2+} in cytoplasm could block K^+ channel in the inner envelope membrane of chloroplasts and thus inhibited the removal of H^+ ions from the chloroplast stroma (Wu *et al*., 1991).

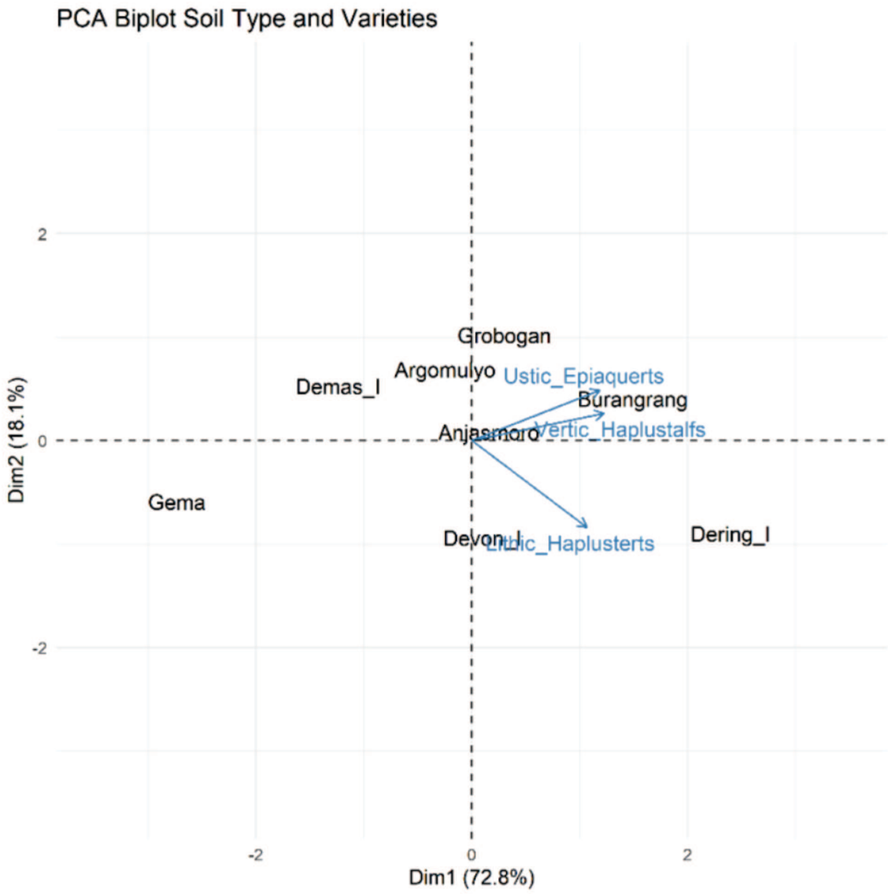

Figure 3: Principal component analysis (PCA) Biplot for soybean varieties and soil types.

Table 4: Stepwise regression analysis of relationship between soil quality parameters with yield of soybean varieties

Varieties	Regression Equation	R^2
Anjasmoro	–	-
Argomulyo	Y = 6.199* + 1.094 P** – 0.692 Mg*	0.852**
Burangrang	Y = 0.854** + 0.569 NH_4^+*	0.824*
Demas I	–	-
Dering I	Y = 5.802** – 0.684 Mn**	0.868**
Devon I	Y = 3.982^{ns} – 1.001 Mg** + 0.648 Ca*	0.828*
Gema	Y = 25.884** – 0.902 Mg**	0.814**
Grobogan	Y = 0.496** + 0.532 NH_4^+* + 0.471 P*	0.706**

*Significant at á 5%. **Significant at á 1%.

The yield of Dering I decreased in line with the increased availability of Mn in the soil. Silva *et al*. (2017) reported that Mn poisoning in corn might reduce chlorophyll content, plant biomass and plant antioxidant. The translocation of Mn from the root to leaf triggers decreased in chlorophyll content. High Mn concentration caused the increase in ROS accompanied by a higher level of antioxidant enzyme activity and lipid peroxidation (Rao *et al*., 2016).

Based on the result of the study it is recommended for soybean varieties that had high yield in each soil type and the fertilizer used, depending on the limiting factors in each soybean varieties. The suggestion for future study is that an optimum dose for soil quality parameters affecting soybean varieties is determined.

CONCLUSION

The highest yield of soybean per hectare on Dering I grown in Lithic Haplusterts and Ustic Epiaquerts was 1.38 and 1.27 tons.ha^{-1} respectively while Grobogan in Ustic Epiaquerts 1.24 tons.ha^{-1}.

Dering I showed the mean of the highest yield and most suitable in all soil types, while Gema showed the mean of the lowest yield and not suitable in all soil types.

Soil quality parameters that had a significant influenced on the production of soybean varieties in agroforestry systems with kayu putih were chemical characteristic consisting of availability of P, Mg, NH_4^+, Mn and Ca.

CONFLICT OF INTERESTS

There is no conflict of interests in carrying the research and publishing the manuscript.

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