Revista Brasileira de Ciência do Solo

Division - Soil Use and Management | Commission - Soil Fertility and Plant Nutrition

Optimizing application of biochar, compost and nitrogen fertilizer in soybean intercropping with *kayu putih* (*Melaleuca cajuputi*)

Taufan Alam[(1)*], **Priyono Suryanto**[(2)], **Suci Handayani**[(3)], **Dody Kastono**[(1)] **and Budiastuti Kurniasih**[(1)]

[(1)] Faculty of Agriculture, Department of Agronomy, Universitas Gadjah Mada, Indonesia.
[(2)] Faculty of Forestry, Department of Silviculture, Universitas Gadjah Mada, Indonesia.
[(3)] Faculty of Agriculture, Department of Soil, Universitas Gadjah Mada, Indonesia.

ABSTRACT: Waste resulted from the distillation of *kayu putih* leaves is a problem in almost all *kayu putih* refineries throughout Indonesia due to its enormous availability and un-utilization. It has potential to be used as an organic fertilizer source due to its nutrient content (macro and micro) which is higher than organic fertilizer from animals. The use of *kayu putih* waste is useful to complement and increase the efficiency of nitrogen fertilizer in soybean intercropping with *kayu putih*. This study aimed to determine the optimum values of *kayu putih* waste and nitrogen fertilizer based on three scenarios: economic, environmental, and eco-environmental. A two-year experiment (2018-2019) was carried out in a central composite design (CCD) with two replications as the response surface methodology (RSM) at the Menggoran Forest Resort, Playen District, Yogyakarta Forest Management, Indonesia. The treatments consist of biochar and compost levels made from *kayu putih* waste (0, 2.5, and 5.0 t ha^{-1}) and nitrogen fertilizer levels supplied by ammonium sulfate (0, 50, and 100 kg ha^{-1}) as independent variables. The observations conducted on nitrate reductase activity (NRA), total chlorophyll (TC), leaf photosynthesis rate (LPR), nitrogen loss (NL), nitrogen use efficiency (NUE), and seed yield (SY). The response variables were fitted in a full quadratic polynomial model. The results showed that the resource-based on the eco-environmental scenarios was the most favorable cropping strategy for the soybean production intercropping with *kayu putih* with the optimum value of 2.890 t ha^{-1} of biochar, 2.27 t ha^{-1} of compost, and 67.85 kg ha^{-1} of ammonium sulfate. This recommendation can reduce the use of ammonium sulfate by 32.15 % and increase of NRA, TC, LPR, NL, NUE, and SY by 12.96, 2.80, 17.18, 21.66, 7.23, and 17.29 %, respectively, compared to the single application of ammonium sulfate fertilizer.

Keywords: ammonium sulfate, biochar, compost, *Glycine max*, *Melaleuca cajuputi*.

*** Corresponding author:**
E-mail: taufan.alam@ugm.ac.id

Received: January 21, 2020
Approved: June 01, 2020

How to cite: Alam T, Suryanto P, Handayani S, Kastono D, Kurniasih B. Optimizing application of biochar, compost and nitrogen fertilizer in soybean intercropping with *kayu putih* (*Melaleuca cajuputi*). Rev Bras Cienc Solo. 2020;44:e0200003.
https://doi.org/10.36783/18069657rbcs20200003

Copyright: This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided that the original author and source are credited.

INTRODUCTION

Soybean is an important oil-producing seed crop in the world and provides 58 % of total global oilseed production (Board, 2013). It is also one of the primary commodities in Indonesia after rice and corn (Kementerian Pertanian, 2015). The consumption of soybean per year was projected to continuously rise from 8.12 Mt in 2005 to 9.46 Mt in 2020, indicating an average increase of 1.02 % per year within 2005-2020 (Sudaryanto and Swastika, 2016). Besides, the average population growth within the same period is projected to increase by 1.40 % per year. Thus, the total soybean production was projected to increase from 1.84 Mt in 2005 to 2.64 Mt in 2020, which represents a growth of 2.44 % per year (Sudaryanto and Swastika, 2016).

To avoid the soybean deficit, it is required to have a strategy to increase soybean production. One way is by the intensifying area between *kayu putih* (*Melaleuca cajuputi*) stands as well as improving the soil quality by using fertilization. Food crop production increased during the green revolution through genetic improvements and inorganic fertilization applications (Pingali, 2012). Such application of inorganic fertilizers has been carried out since the green revolution in the 1960s and proven to increase crop productivity (Stewart et al., 2005; Mora et al., 2007; Haygarth et al., 2013).

Nitrogen (N) is an essential element for plant growth. Subsequently, after the fixed carbon, N can be the limiting factor for plant growth. In a physiological process, urea is both an essential internal and external source of N converted to ammonia for N assimilation (Marschner, 2012). The addition of ammonium (NH_4^+-N) is significantly correlated with the increase of soybean yield in the rainfed areas between *kayu putih* stands (Alam et al., 2019). However, in the 1990s, productivity of food crops, especially soybean, experienced stagnation (Brisson et al., 2010; Ray et al., 2012; Grassini et al., 2013). One affecting factor was the reduction of the organic matter in the soil due to prolonged and intensive use of agrochemicals (Lal, 2004; Lipper et al., 2014).

In addition to the management of biogeochemical cycles in a sustainable manner, improvement of fertilizer efficiency is essential in agricultural systems (Rumpel et al., 2015). The remaining harvest or agricultural waste should be considered as a source of organic fertilizer useful for improving soil quality and productivity. Crop residues or waste can be converted into organic fertilizer, namely biochar and compost (Roca-Perez et al., 2009; Medina et al., 2017). Pyrolysis of the crop residues is used to produce biochar, which can be used as soil conditioners and has the potential to increase plant growth and soil C sequestration (Abiven et al., 2014).

Waste resulted from the distillation of *kayu putih* leaves is a problem in almost all *kayu putih* refineries throughout Indonesia due to its enormous availability and un-utilization (Suharto et al., 2007). The compost contents of *kayu putih* regarding its pH(H_2O), C, N, P, and K were 7.50, 200.8 g kg^{-1}, 17.9 g kg^{-1}, 12.5 g kg^{-1}, and 48.6 g kg^{-1}, respectively. It can be used as an organic fertilizer due to its nutrient content (macro and micro), which is higher than organic fertilizer sourced from animals (Rahmawati et al., 2016).

Kayu putih waste has potential to produce biochar. It is an organic waste pyrolysis product commonly used as the soil conditioner. The purpose of biochar application is to increase the crop yields (Wiedner and Glaser, 2015; Hagemann et al., 2017). A biochar produced biochar from eucalyptus (*Melaleuca leucadendron*) contained pH, C, H, N, and O of 5.65, 740.6 g kg^{-1}, 24.1 g kg^{-1}, 6.6 g kg^{-1}, and 228.7 g kg^{-1}, respectively; it also presented chemical stability, making its capacity for the release of chemical elements low, which may be highly beneficial in the environment upon retaining ions, even in acid conditions (Figueredo et al., 2017).

Biochar mixed with compost can produce a conditioner with higher agronomic quality than pure biochar applications. It can increase the concentration of NH_4^+-N and NO_3^--N in the soil and stimulate the activity of enzymes and microbes in the soil (Kammann et al., 2015). It also can increase the abundance of NH_4^+-N and NO_3^--N (Cao et al., 2017). Application of 20 t ha^{-1} of compost for *Phaseolus vulgaris* reduced by 50 % the use of NPK fertilizer (Rady et al., 2016).

This study aimed to determine the optimum value of *kayu putih* waste in the form of biochar and compost as well as the N fertilizer doses in the form of ammonium sulphate based on three scenarios: economic, environmental, and eco-environmental using response surface methodology (RSM). The results of this study will provide information to improve soil quality and soybean yield as well as to cope with the problem of *kayu putih* waste and to make it more useful.

MATERIALS AND METHODS

Characteristics of location

The experiment was conducted during dry and wet seasons within 2018-2019 in Menggoran Forest Resort, Playen District, Yogyakarta Forest Management, Indonesia. This area was located ± 43 km to the south-east of Yogyakarta City (Figure 1).

The altitude of the command area was ± 100 m, with an average air temperature of 25.60 °C, relative humidity of 84.20 %, and average rainfall of 2,005 mm yr^{-1}. Based on the USDA classification, the soil type at the study site was Lithic Haplusterts (Soil Survey Staff, 2014).

This soil corresponds to a Vertisol that has a shallow solum and rock contact of 0.50 m from the surface (Soil Survey Staff, 2014). The soil texture is dominated by clay, with very slow drainage (0.001 cm h^{-1}). The cation exchange capacity (CEC) is very high (58.83 $cmol_c$ kg^{-1}), the pH(H_2O) is classified in the alkaline category (8.18). The soil presented: 26.2 g kg^{-1} of organic matter, 117.70 mg kg^{-1} of available N, 6.87 mg kg^{-1} of P, and 0.18 mg kg^{-1} of K.

Experimental design based on CCD

The experiment was carried out in a central composite design (CCD) with two replications (Box and Hunter, 1957; Myers et al., 2009). For three variables, the recommended

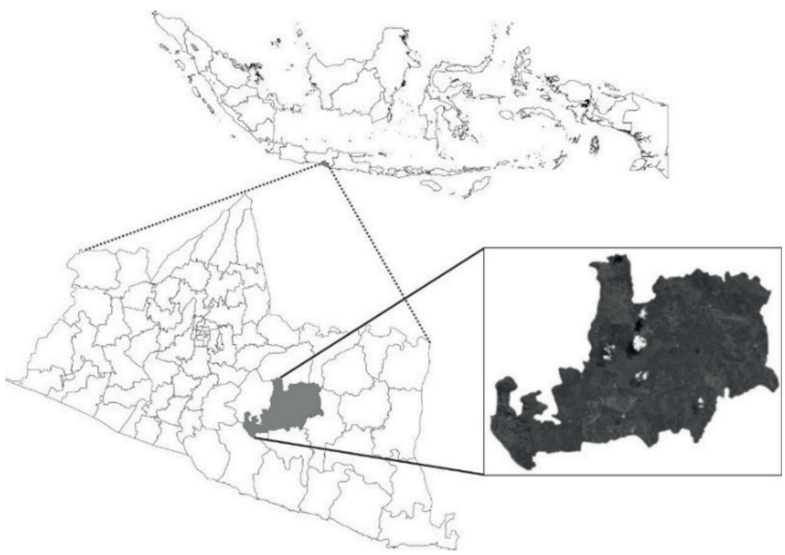

Figure 1. Geographical locations of the study area (latitude 7° 52' 59.5992" S to 7° 59' 41.1288" S and longitude 110° 26' 21.462" E to 110° 35' 7.4868" E).

number of tests at the center was six (Box and Hunter 1957; Aslan, 2007). Hence the total number of tests required for the three independent variables was (Equation 1):

$$2^k + 2k + r = 2^3 + (2 \times 3) + 6 = 20 \quad \text{Eq. 1}$$

in which: 2^k was the origin at the center; 2k was the points fixed axially at a distance from the center to generate the quadratic terms; r was the replicate runs at the center; and k was the number of variables.

The treatments consist of biochar and compost levels made from *kayu putih* waste (0, 2.5, and 5.0 t ha^{-1}) and nitrogen fertilizer levels sourced from ammonium sulfate (0, 50, and 100 kg ha^{-1}) as independent variables. The experimental design matrix resulting from the CCD (Table 1) consisted of 20 runs of coded levels expressed as actual values.

Crop management

This experiment used the Grobogan varieties obtained from the Indonesian Legumes and Tuber Crops Research Institute at Malang Regency, Province of East Java, Indonesia. The experimental plots cover 24 m^2 (6 × 4 m) of the area between *kayu putih* stands and the harvest area of 20 m^2, excluding the border rows. The plant spacing was 0.20 × 0.20 m. The experiment was in the rainfed areas and no pesticides were applied to the plots.

Biochar and compost were made from the waste of distilled *kayu putih* leaves. Biochar was made by using the Kiln Traditional Method (Emrich, 1985), and compost was made according to Misra et al. (2003). Biochar and compost were applied when planting the soybean, and ammonium sulfate was applied when the soybean reached one week after the plant (wap). Ammonium sulfate fertilizer used was from Zwavelzure Ammoniac

Table 1. Actual and coded value of experimental factors for CCD

Run	Treatment value			Coded value[1]		
	Biochar	Compost	Ammonium sulphate	Biochar	Compost	Ammonium sulphate
	t ha^{-1}	t ha^{-1}	kg ha^{-1}	X_1	X_2	X_3
1	0	0	0	-1	-1	-1
2	5	0	0	+1	-1	-1
3	0	5	0	-1	+1	-1
4	5	5	0	+1	+1	-1
5	0	0	100	-1	-1	+1
6	5	0	100	+1	-1	+1
7	0	5	100	-1	+1	+1
8	5	5	100	+1	+1	+1
9	0	2.5	50	-1	0	0
10	5	2.5	50	+1	0	0
11	2.5	0	50	0	-1	0
12	2.5	5	50	0	+1	0
13	2.5	2.5	0	0	0	-1
14	2.5	2.5	100	0	0	+1
15	2.5	2.5	50	0	0	0
16	2.5	2.5	50	0	0	0
17	2.5	2.5	50	0	0	0
18	2.5	2.5	50	0	0	0
19	2.5	2.5	50	0	0	0
20	2.5	2.5	50	0	0	0

[1] +1, -1, and 0 indicates high, low, and a medium level of each factor.

(ZA) brand. The analyses results of ZA fertilizer used in this study indicated $N\text{-}NH_4^+$ and $S\text{-}SO_4^{2-}$ of 20.93 and 23.84 %, respectively. It also showed that the $pH(H_2O)$, C, H, N, and O in the *kayu putih* biochar used in this experiment were 8.05, 738.8 g kg^{-1}, 23.2 g kg^{-1}, 1.7 g kg^{-1}, and 22.58 g kg^{-1}, respectively, while the *kayu putih* compost indicated $pH(H_2O)$, C, N, P, and K of 7.50, 220.8 g kg^{-1}, 18.9 g kg^{-1}, 13.7 g kg^{-1}, and 41.6 g kg^{-1}, respectively.

Soybean variables

The observation in this experiment was carried out based on the nitrate reductase activity (NRA) (Krywult and Bielec, 2013), total chlorophyll (TC) (Gross, 1991), leaf photosynthesis rate (LPR) (Li-Cor Bioscience Inc., 1999), nitrogen loss (NL) (Horwitz and Latimer, 2005; Jarvis et al., 2011; Fageria, 2014), nitrogen use efficiency (NUE) (Rathke et al., 2006), and seed yield (SY) per hectare. Soybean seeds were dried under the sunlight to reach 11 % of moisture level (Suryanto et al., 2017).

Mathematical modeling

The equation of response surface methodology (RSM) used in this experiment applied the uncoded independent variables as follows (Myers et al., 2009; Koocheki et al., 2014). Thus, for the three variables, the response models were fitted according to equation 2:

$$y_i = b_0 + \sum_{i=l}^{3} b_i x_i + \sum_{i=l}^{3} b_{ii} x_i^2 + \sum_{i=l}^{3} \sum_{j=i+l}^{3} b_{ij} x_i x_j \qquad \text{Eq. 2}$$

in which: y was the predicted response; b_i was the linear terms; b_{ii} was the squared terms; b_{ij} was the interaction terms; x_i and x_j were the coded independent variables.

The full quadratic polynomial equation was used the uncoded independent variables, according to equation 3:

$$y = b_0 + b_1 x_1 + b_2 x_2 + b_3 x_3 + b_{11} x_1^2 + b_{22} x_2^2 + b_{33} x_3^2 + b_{12} x_1 x_2 + b_{13} x_1 x_3 + b_{23} x_2 x_3 \qquad \text{Eq. 3}$$

in which: x_1, x_2,..., x_n were the linear terms in each of the variables; x_1^2, x_2^2,..., x_n^2 were the squared terms in each of the variables; x_1x_2, x_1x_3,..., $x_{n-i}x_n$ were the first-order interaction terms for each paired combination; b_1, b_2,..., b_n were the response model coefficients; b_0 was the intercept coefficient.

The RSM model was tested by ANOVA ($p<0.05$). The significance of the RSM model and its components (linear, squared, first-order interaction terms) tested of the full quadratic polynomial equation. The fitted model was evaluated by using the determination coefficient (R^2), root square means error (RMSE), and lack-of-fit. The F-test was used to lack-of-fit tested. The lack-of-fit tested must be less than 5 % (Myers et al., 2009).

The optimum levels of biochar, compost, and ammonium sulfate fertilizer were calculated under the three scenarios (economic, environmental, and eco-environmental). The seed yields and N loss were used to determine the economic and environmental scenarios, while N use efficiency was used to determine eco-environmental scenarios (Koocheki et al., 2014). Estimation of the three scenarios applied the ridge regression (Marquardt and Snee, 1975). All analyses were performed using the PROC RSREG in SAS 9.4 (SAS Institute, 2013).

RESULTS

The fitted models for soybean variables

The results for the RSM of the full quadratic regression for independent variables (Table 1) are presented in table 2. The lack-of-fit test was used to evaluate the quality of the fitted model. The lack-of-fit criterion used in this study was that the significance of lack-of-fit tested with an F-test should be less than 5 %. The lack-of-fit tested was not significant in nitrate reductase activity, total chlorophyll, leaf photosynthesis rate, nitrogen loss, nitrogen use efficiency, and seed yield. The regression coefficient of the fitted models for the experiment traits is presented in table 2.

Nitrate reductase activity

The highest nitrate reductase activity (NRA), equal to 3.383 μmol NO_2^- g^{-1} h^{-1}, was obtained in the treatment that received 5 t ha^{-1} of biochar and compost and 50 kg ha^{-1} of ammonium sulfate. The application of 1 t ha^{-1} of biochar and compost significantly increased the NRA by 0.078 and 0.135 mmol kg^{-1} h^{-1} NO_2^-, respectively, while the application of 1 kg ha^{-1} of ammonium sulfate significantly increased the NRA by 0.011 mmol kg^{-1} h^{-1} NO_2^- (Table 2).

There was no interaction between biochar and compost in NRA to all ammonium sulfate treatments with an optimum value of 4.040 t ha^{-1} of biochar and 4.470 t ha^{-1} of compost with a maximum NRA value of 3.280 mmol kg^{-1} h^{-1} NO_2^- (Figure 2a). There was an interaction between biochar and ammonium sulfate in all compost treatments with an optimum value of 4.220 t ha^{-1} of biochar and 86.360 kg ha^{-1} of ammonium sulfate with a maximum NRA value of 3.320 mmol kg^{-1} h^{-1} NO_2^- (Figure 2b). There was an interaction between compost and ammonium sulfate in all biochar treatments with an optimum value of 4.240 t ha^{-1} of compost and 85.990 kg ha^{-1} of ammonium sulfate with a maximum NRA value of 3.360 mmol kg^{-1} h^{-1} NO_2^- (Figure 2c).

Total chlorophyll

The treatment that received 5 t ha^{-1} of biochar and compost and 50 kg ha^{-1} of ammonium sulfate presented the highest total chlorophyll (TC) in the leaf (0.638 kg kg^{-1}). The quadratic pattern only indicated that the application of ammonium sulfate, while the application of biochar and compost showed linear pattern in TC. Biochar and compost application as much as 1 t ha^{-1} significantly increased TC by 0.017 and 0.016 kg kg^{-1} of chlorophyll in leaf (Table 2).

No interaction occurred between biochar and compost on TC towards all ammonium sulfate treatments with an optimum value of 2.36 t ha^{-1} of biochar and 5.00 t ha^{-1} of

Table 2. Regression coefficients of the fitted model

Run	Response Variables					
	NRA	TC	LPR	NL	NUE	SY
	mmol kg^{-1} h^{-1}	kg kg^{-1}	µmol CO_2 m^{-2} s^{-1}	kg ha^{-1}	kg kg^{-1}	t ha^{-1}
b_0	2.488**	0.503**	326.908**	4.632*	2.898**	0.788**
b_1	0.078*	0.017*	1.984*	0.007*	0.381*	0.103**
b_2	0.135**	0.016*	1.525*	0.275*	0.440*	0.205**
b_3	0.011**	0.002**	0.515*	0.095**	0.075**	0.024**
$b_{11}x_1^2$	-0.014ns	-0.003ns	-0.925ns	-0.067ns	-0.051ns	-0.016ns
$b_{12}x_1x_2$	0.009ns	-0.001ns	3.44**	0.199*	0.017ns	0.011*
$b_{22}x_2^2$	-0.018ns	0.0002ns	-1.263ns	-0.088ns	-0.055ns	-0.018ns
$b_{13}x_1x_3$	0.0002*	0.000004*	0.119**	0.001*	-0.0007*	-0.0002*
$b_{23}x_2x_3$	-0.00006*	-0.0002*	0.120**	0.003*	-0.004**	-0.001**
$b_{33}x_3^2$	-0.00006**	-0.00001**	-0.005**	-0.0006**	-0.0004**	-0.0001**
R^2	0.993	0.955	0.994	0.978	0.991	0.993
RMSE	0.034	0.014	5.081	0.551	0.176	0.057
Lack-of-Fit	0.265	0.103	0.529	0.100	0.223	0.224

*, **, and ns: significant at p<0.05, significant at p<0.01, and no significant, respectively. x_1, x_2, and x_3 indicate biochar (t ha^{-1}), compost (t ha^{-1}), and ammonium sulphate (kg ha^{-1}), respectively. NRA: nitrate reductase activity; TC: total chlorophyll in leaf; LPR: leaf photosynthesis rate; NL: nitrogen loss; NUE: nitrogen use efficiency; SY: seed yield.

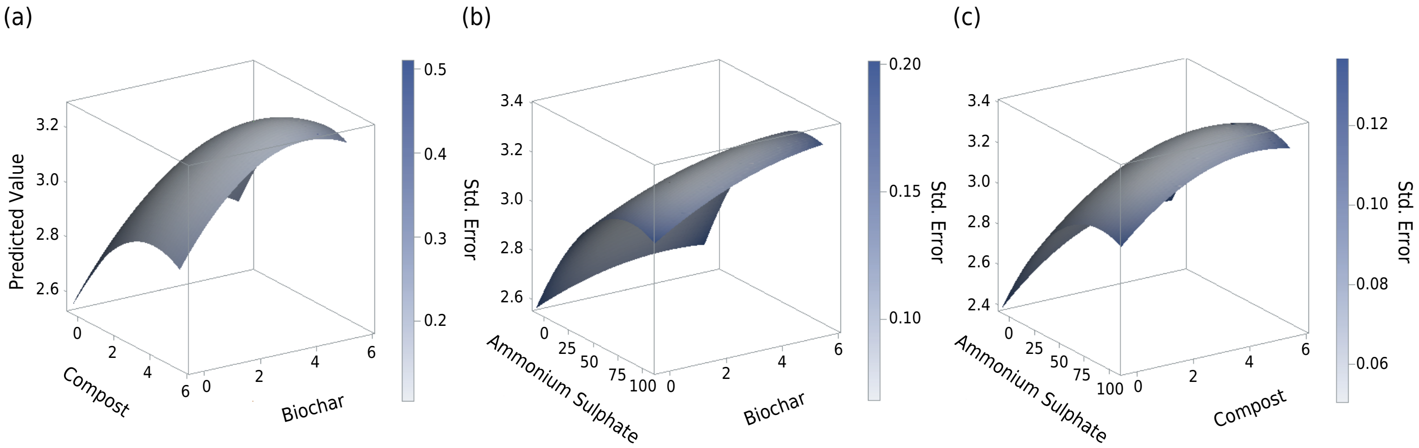

Figure 2. The NRA (mmol kg^{-1} h^{-1} NO_2^-) response to independent variable: a) biochar (t ha^{-1}) and compost (t ha^{-1}); (b) biochar (t ha^{-1}) and ammonium sulphate (kg ha^{-1}); (c) compost (t ha^{-1}) and ammonium sulphate (kg ha^{-1}).

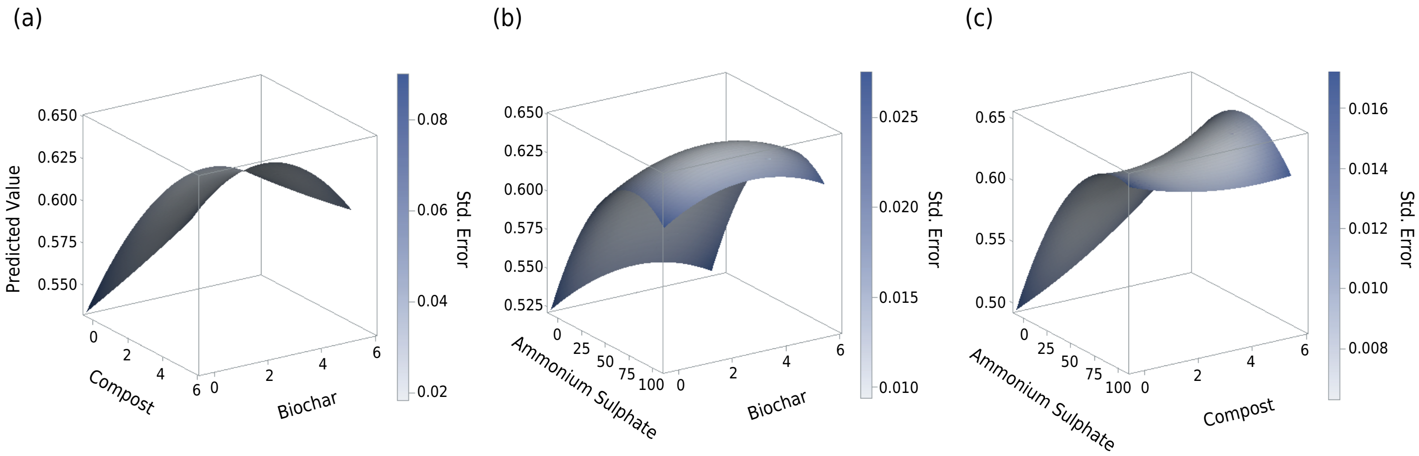

Figure 3. The TC (kg kg^{-1} of chlorophyll in leaf) response to independent variable: (a) biochar (t ha^{-1}) and compost (t ha^{-1}); (b) biochar (t ha^{-1}) and ammonium sulphate (kg ha^{-1}); (c) compost (t ha^{-1}) and ammonium sulphate (kg ha^{-1}).

compost with maximum TC value of 0.640 kg kg^{-1} of chlorophyll in leaf (Figure 3a). There was an interaction between biochar and ammonium sulfate in all compost treatments by 3.88 t ha^{-1} of biochar and 91.75 kg ha^{-1} of ammonium sulfate with a maximum TC value of 0.640 kg kg^{-1} of chlorophyll in leaf (Figure 3b). There was an interaction between compost and ammonium sulfate on all biochar treatments with an optimum value of 4.93 t ha^{-1} of compost and 61.56 kg ha^{-1} of ammonium sulfate with maximum TC value of 0.650 kg kg^{-1} of chlorophyll in leaf (Figure 3c).

Leaf photosynthesis rate

The highest value of leaf photosynthesis rate (LPR) was 431.221 μmol m^{-2} s^{-1} CO_2, and it was observed in the treatment that received 5 t ha^{-1} of biochar and compost and 50 kg ha^{-1} of ammonium sulfate. Ammonium sulfate showed the quadratic pattern in LPR. Application of 1 t ha^{-1} of biochar, 1 t ha^{-1} compost, and 1 kg ha^{-1} of ammonium sulfate significantly increased LPR by 1.984, 1.525, and 0.515 μmol m^{-2} s^{-1} CO_2, respectively (Table 2).

There was an interaction between biochar and compost on the LPR towards all of the ammonium sulfate treatments with an optimum value of 4.21 t ha^{-1} of biochar and 4.32 t ha^{-1} of compost with maximum LPR value of 406.180 μmol m^{-2} s^{-1} CO_2 (Figure 4a). There was also an interaction between biochar and ammonium sulfate under all compost treatments with an optimum value of 4.23 t ha^{-1} of biochar and 86.08 kg ha^{-1}

of ammonium sulfate with maximum LPR of 406.590 µmol m^{-2} s^{-1} CO_2 (Figure 4b). There was an interaction between compost and ammonium sulfate under all biochar treatments with an optimum value of 4.25 t ha^{-1} of compost and 85.71 kg ha^{-1} of ammonium sulfate with maximum LPR value of 411.780 µmol µmol m^{-2} s^{-1} CO_2 (Figure 4c).

Nitrogen loss

The treatment of 5 t ha^{-1} of biochar and compost and 50 kg ha^{-1} of ammonium sulfate showed the highest nitrogen loss (NL) of 11.520 kg ha^{-1} N. The quadratic pattern only fitted to the treatment of ammonium sulfate application. Applying 1 t ha^{-1} of biochar and compost significantly increased NL by 0.007 and 0.0275 kg ha^{-1} N; and the application of 1 kg ha^{-1} of ammonium sulfate significantly increased NL by 0.095 kg ha^{-1} N (Table 2).

There was an interaction between biochar and compost on NL towards all ammonium sulfate treatments with an optimum value of 2.54 t ha^{-1} of biochar and 3.50 t ha^{-1} of compost with minimum NL value of 6.750 kg ha^{-1} N (Figure 5a). There was an interaction between biochar and ammonium sulfate under all compost treatments with an optimum value of 2.27 t ha^{-1} of biochar and 0.22 kg ha^{-1} of ammonium sulfate with minimum NL value of 5.210 kg ha^{-1} N (Figure 5b). There was an interaction between compost and ammonium sulfate under all biochar treatments with an optimum value of 1.95 t ha^{-1} of compost and 1.22 kg ha^{-1} of ammonium sulfate with minimum NL value of 5.310 kg ha^{-1} N (Figure 5c).

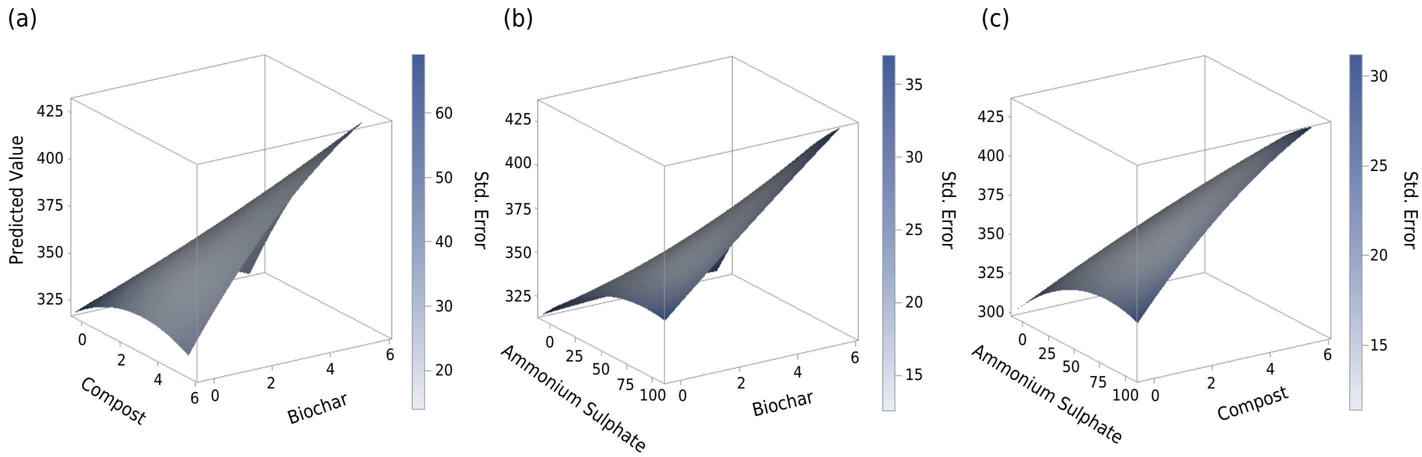

Figure 4. The LPR (µmol m^{-2} s^{-1} CO_2) response to independent variable: (a) biochar (t ha^{-1}) and compost (t ha^{-1}); (b) biochar (t ha^{-1}) and ammonium sulphate (kg ha^{-1}); (c) compost (t ha^{-1}) and ammonium sulphate (kg ha^{-1}).

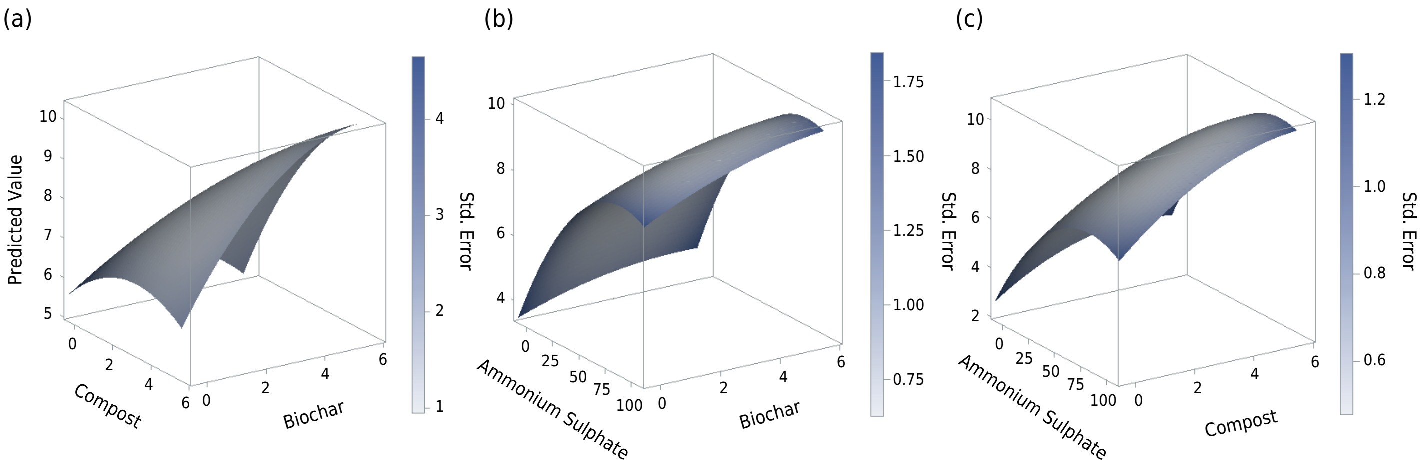

Figure 5. The NL (kg ha^{-1} N) response to independent variable: (a) biochar (t ha^{-1}) and compost (t ha^{-1}); (b) biochar (t ha^{-1}) and ammonium sulphate (kg ha^{-1}); (c) compost (t ha^{-1}) and ammonium sulphate (kg ha^{-1}).

Nitrogen use efficiency

The treatment of 2.5 t ha^{-1} of biochar, 0 t ha^{-1} of compost, and 100 kg ha^{-1} of ammonium sulfate showed the highest nitrogen use efficiency (NUE) of 6.902 kg kg^{-1} grain by $N_{fertilizer}$. The application of ammonium sulfate showed a quadratic pattern of NUE. Application of 1 t ha^{-1} of biochar and compost significantly increased NUE by 0.381 and 0.440 kg kg^{-1} grain by $N_{fertilizer}$, while the application of 1 kg ha^{-1} ammonium sulfate significantly increased NUE by 0.075 kg kg^{-1} grain by $N_{fertilizer}$ (Table 2).

There was no interaction between biochar and compost on NUE under all ammonium sulfate treatments with an optimum value of 4.87 t ha^{-1} biochar and 1.70 t ha^{-1} compost with a maximum NUE value of 6.090 kg kg^{-1} grain by $N_{fertilizer}$ (Figure 6a). There was an interaction between biochar and ammonium sulfate under all compost treatments in an optimum value of 4.47 t ha^{-1} of biochar and 80.88 kg ha^{-1} of ammonium sulfate with a maximum NUE value of 6.700 kg kg^{-1} grain by $N_{fertilizer}$ (Figure 6b). There was an interaction between compost and ammonium sulfate under biochar treatments with an optimum value of 0.70 t ha^{-1} of compost and 84.65 kg ha^{-1} of ammonium sulfate with maximum NUE value of 6.860 kg kg^{-1} grain by $N_{fertilizer}$ (Figure 6c).

Seed yield

Seed yield (SY) per hectare showed the highest value under the application of 5 t ha^{-1} of biochar and compost as well as 50 kg ha^{-1} of ammonium sulfate. Ammonium sulfate showed a quadratic pattern on SY. Application of 1 t ha^{-1} of biochar and compost and 1 kg ha^{-1} of ammonium sulfate significantly increased SY by 0.103, 0.205, and 0.024 t ha^{-1}, respectively (Table 2).

There was an interaction between biochar and compost on SY under all ammonium sulfate treatments with an optimum value of 3.47 t ha^{-1} of biochar and 4.80 t ha^{-1} of compost with a maximum SY value of 2.180 t ha^{-1} (Figure 7a). There was an interaction between biochar and ammonium sulphate in all compost treatments with optimum values of 4.49 t ha^{-1} of biochar and 80.37 kg ha^{-1} of ammonium sulphate and maximum SY value of 2.230 t ha^{-1} (Figure 7b). There was an interaction between compost and ammonium sulphate under all biochar treatments with an optimum value of 4.71 t ha^{-1} of compost and 73.28 kg ha^{-1} of ammonium sulphate and maximum SY value of 2.310 t ha^{-1} (Figure 7c).

Determining the optimum scenarios for nitrogen fertilizer efficiency

Determining the optimum level of biochar, compost, and ammonium sulphate were carried out based on three scenarios: economic, environmental, and eco-environmental

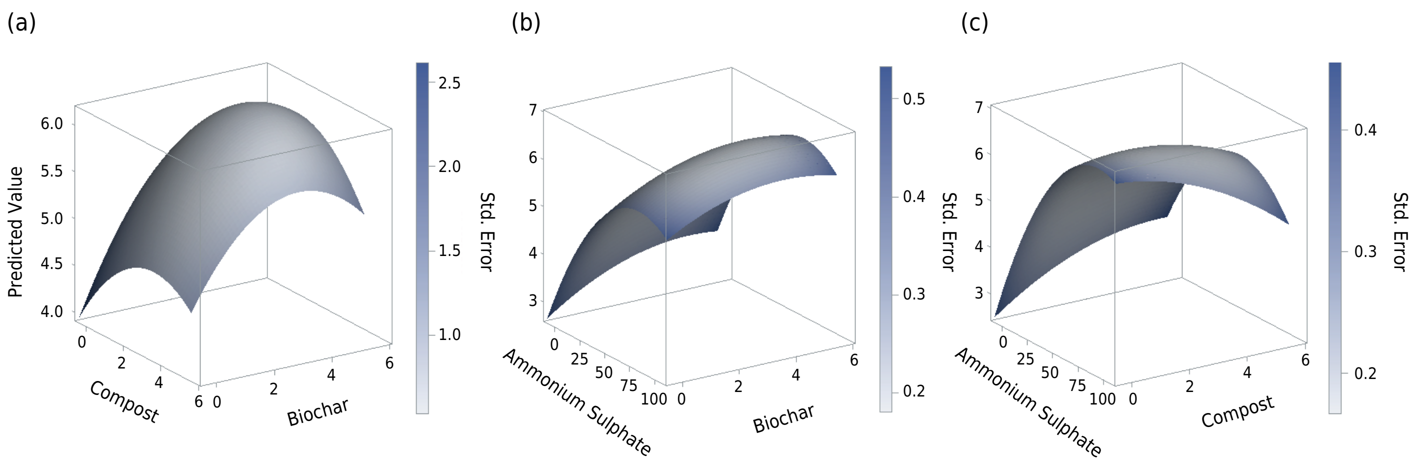

Figure 6. The NUE (kg kg^{-1} grain by $N_{fertilizer}$) response to independent variable: (a) biochar (t ha^{-1}) and compost (t ha^{-1}); (b) biochar (t ha^{-1}) and ammonium sulphate (kg ha^{-1}); (c) compost (t ha^{-1}) and ammonium sulphate (kg ha^{-1}).

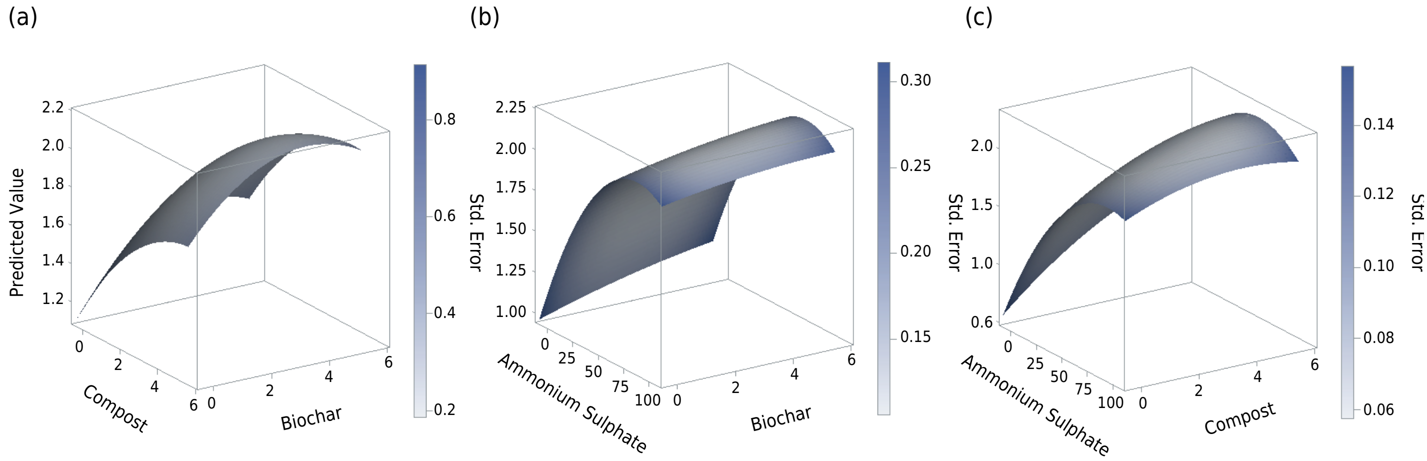

Figure 7. The SY (t ha^{-1}) response to independent variable: (a) biochar (t ha^{-1}) and compost (t ha^{-1}); (b) biochar (t ha^{-1}) and ammonium sulphate (kg ha^{-1}); (c) compost (t ha^{-1}) and ammonium sulphate (kg ha^{-1}).

Table 3. Optimized value of *kayu putih* waste and nitrogen fertilizer applications for response variables

Variable and Treatments		Scenarios		
		Economic	Environmental	Eco-Environmental
Response Variables	NRA (mmol kg^{-1} h^{-1} NO_2^-)	3.44	2.84	3.33
	TC (kg kg^{-1} of chlorophyll in leaf)	0.65	0.56	0.64
	LPR (µmol m^{-2} s^{-1} CO_2)	454.74	332.45	388.01
	NL (kg ha^{-1} N)	12.20	5.52	9.84
	NUE (kg kg^{-1} grain by $N_{fertilizer}$)	6.25	4.33	6.87
	SY (t ha^{-1})	2.43	1.36	2.26
Independent Variables	Biochar (t ha^{-1})	4.79	2.39	2.89
	Compost (t ha^{-1})	5.38	2.02	2.27
	Ammonium sulphate (kg ha^{-1})	70.21	0.97	67.85

NRA: nitrate reductase activity; TC: total chlorophyll; LPR: leaf photosynthesis rate; NL: nitrogen loss; NUE: nitrogen use efficiency; SY: seed yield.

(Table 3). Within the optimum economic scenario, the level of treatments for biochar, compost, and ammonium sulphate were 3.82 t ha^{-1}, 4.32 t ha^{-1}, and 72.11 kg ha^{-1}, respectively, that produced a maximum SY of 2.43 t ha^{-1}. The decreasing of seed yield in the environmental and eco-environmental scenarios occurred by 44.00 and 6.98 %, respectively. The optimum levels of treatments for biochar, compost, and ammonium sulphate in environmental scenarios were 2.39 t ha^{-1}, 2.02 t ha^{-1}, and 0.97 kg ha^{-1}, respectively, with a minimum NL of 5.52 kg ha^{-1} N. The increasing NL for economic and eco-environmental scenarios occurred were 120.89 and 78.20 %, respectively. The optimum levels of treatments in the eco-environmental scenario were 2.89 t ha^{-1} of biochar, 2.27 t ha^{-1} of compost, and 67.85 kg ha^{-1} of ammonium sulphate with maximum NUE of 6.87 kg kg^{-1} grain by $N_{fertilizer}$. Decreasing NUE in economic and environmental scenarios occurred by 9.00 and 36.97 %, respectively.

DISCUSSION

The objective of this experiment was to determine the optimum doses of *kayu putih* waste in the form of biochar and compost as well as the N fertilizer in the form of ammonium sulfate. If this study would have used a full factorial design, it would be complicated, very costly, and time-consuming and it would present a considerable experimental error. Hence, the use of RSM and CCD was the choice for this experiment (Koocheki et al., 2014). The RSM is one of the statistical methodologies useful for getting optimal results

(Myers et al., 2009). This model is reliable, produces an appropriate mathematical model, and can determine the optimum value of independent variables that can provide maximum or minimum responses (Montgomery, 2001).

Compared to factorial design, CCD can reduce the combination of the treatments (Obeng et al., 2005; Aslan, 2007; Myers et al., 2009; Koocheki et al., 2014). The CCD is used to predict the dependent variable (Y) at various points of the independent variable (X) which is a function of the distance from the point to the design center (Clarke and Kempson, 1997; Kalavathy et al., 2009; Myers et al., 2009; Koocheki et al., 2014).

Nitrate reductase activity (NRA) is the molybdoenzymes responsible to reduce nitrate (NO_3^-) to nitrite (NO_2^-). This process is essential for protein production in most plants (Marschner, 2012). The application of biochar made from *kayu putih* waste promoted a significant increase in NRA in the soybean. Biochar is defined as carbonized organic material produced from animal and crop residues for soil amendments. The release of nitrate by the biochar may prevent the washing of nitrate so that it can be available for the plants in a longer period (Haider et al., 2016). Biochar increased the concentration of NH_4^+-N and NO_3^--N in the soil and also stimulated the activity of enzymes and microbes in the soil, which further increases the abundance of NH_4^+-N and NO_3^--N (Cao et al., 2017). Increased concentrations of NH_4^+-N and NO_3^--N in the soil was positively correlated with the increase of NRA in the plants (Loussaert et al., 2018).

Compost made from *kayu putih* waste significantly increased NRA in the soybean. Soil fertility increased by applying an organic substance. It provides beneficial compounds that play an important role in improving the soil physical, chemical, and biological properties by increasing the water holding capacity, N content in the soil, and soil microbial population (Zhong et al., 2010).

The application of ammonium sulfate significantly increased the NRA in soybean. The assimilation of N involves the NRA, and its activity seems to be dependent on the N availability in the soil (Cazzeta and Villela, 2004). Application of ammonium sulfate as much as 100 kg ha^{-1} to corn significantly increases NRA by 79.430 mmol kg^{-1} h^{-1} FW in comparison to the without ammonium sulfate, with NRA value of 35.96 mmol kg^{-1} h^{-1} FW (Purbajanti et al., 2016).

Chlorophyll pigmented with green color is found in diverse plants, algae, and cyanobacteria functioning to converse the solar energy to chemical energy for building important carbohydrate molecules useful as the food source for the whole plant (Hynninen and Leppakases, 2002). Biochar and compost made from *kayu putih* waste significantly increased TC. Ngulube et al. (2018) reported that the application of biochar significantly increased the TC in the groundnut. Such an increase occurred in all stages of groundnut (V3, R1, and R3). Biochar positively influences the chlorophyll content and related parameters such as increasing PS II activity and facilitate the electron transport, which then increases the photosynthesis rate of the plant (Lyu et al., 2016). A study by Shaheen et al. (2017) indicated that organic fertilizer significantly increased the TC in soybean in comparison to the control (without fertilizer). The content of TC in organic fertilizing and control was 2.913 and 1.852 mg cm^{-2}, respectively.

The application of ammonium sulfate significantly increased TC in soybean. Gai et al. (2017) reported that giving N fertilizer to soybean, it increased TC during phase V4 and R2. The increase of TC in soybean was due to the integration between organic and inorganic fertilizer in comparison to without fertilizer and a single application of inorganic fertilizer (Solanki et al., 2018). Alam et al. (2009) informed that low chlorophyll content correlated with a decrease in the rate of photosynthesis and soybean yields.

Biochar and compost made from *kayu putih* waste significantly increased LPR. Xu et al. (2014) reported that the application of biochar as an amendment for red Ferrosol increased leaf photosynthetic rate and peanut yield. Sarfraz et al. (2017) reported that vapor pressure deficit (VPD), stomatal conductance, photosynthetic rate, and WUE of corn crop significantly increased when biochar was applied to the soil. Efthimiadou et al. (2010) reported that the use of organic wastes in corn plants increased the photosynthesis rate by 49.65 % compared to the treatment without organic matter.

The increase of LPR in soybean was significantly affected by ammonium sulfate fertilization. The N fertilization increased the LPR when soybean entered phase V4 and R2. Such increasing of the photosynthesis rate is an essential way to raise the soybean yield (Gai et al., 2017). Zhang et al. (2013) showed that there was a positive correlation between increasing N dose and photosynthesis, stomatal conductance, transpiration, and intercellular CO_2 concentration on soybean growth.

Biochar from *kayu putih* waste significantly reduced NL in soybean. The addition of 15.00 % of biochar in organic fertilizer significantly reduced the N loss by 27.00 % (Wang et al., 2017). Simultaneously, applying biochar and compost can release NH_4^+ slowly to be utilized by plants (Kammann et al., 2015). Increasing the ammonium sulphate fertilization dose significantly increased NL. Increasing N fertilizer in the soil increased the nitrate leaching (187.50 %), ammonium leaching (28.10 %), total nitrogen leaching (217.00 %), nitrous oxide emission (202.00 %), ammonia emission (176.40 %), nitric oxide emission (543.3 %), yield (35.70 %), and nitrogen uptake (24.50 %) (Zhao et al., 2019). Omar et al. (2015) reported that compost increased the NH_4^+ content in soils compared to without compost applications. Biochar has the potential to increase N content and reduce environmental pollution due to N loss in the soil (Clough et al., 2013).

Nitrogen use efficiency (NUE) is the basis for economic and environmental efficiency and effective agroecosystem management practices that also increases the efficiency of nutrient use (Montemurro et al., 2016). Biochar can increase plant growth and yield, as well as the N use efficiency (NUE) by raising the CEC and sustain the water holding capacity in the soil (Atkinson et al., 2010; Hagner et al., 2016). A research conducted by Sarfraz et al. (2017) showed that the addition of biochar by 1 % w w^{-1} in the soil could streamline the use of N fertilizer by 50.00 % and increase NUE by 65.00 %. A positive relationship between the addition of a dose of N fertilizer to the increase of NUE was established. The low NUE was due to the small amount of N fertilizer application carried out by the farmers (Abebe et al., 2017). A study conducted in southern China showed that NPK + biochar fertilization increased corn biomass by 75 % compared to a single NPK application. Gathorne-Hardy et al. (2009) also reported an increase of more than 30 % in barley yield when biochar and N fertilizer were applied together.

The application of biochar made from *kayu putih* waste to the soil affects various physical-chemical properties of the soil. Biochar can increase nutrient retention and availability for the plants (Pietikainen et al., 2000; Glaser et al., 2002). The potential of biochar to improve soil fertility can increase yields on previously degraded soils (Kanouo et al., 2017). Legumes generally show a higher positive response than other plants (grains, vegetables, and grass) with an average increase of 40 % for seed yield and 25 % for total biomass (Liu et al., 2013).

The interaction between biochar and N has shown to be efficient in increasing plant growth. Nitrogen is released slowly, so it is utilized by the plants (Haider et al., 2016). Biochar mixed with compost can produce a conditioner with higher agronomic quality if compared to pure biochar (Kammann et al., 2015). Ammonium contained in the surface of biochar was due to the exchange of cation released with the extraction of KCl (Saleh et al., 2012).

CONCLUSIONS

The optimum levels of treatments based on environmental scenarios were 2.39 t ha^{-1} of biochar, 2.02 t ha^{-1} of compost, and 0.97 kg ha^{-1} of ammonium sulfate, respectively. The economic scenario showed that it was required to use 4.79 t ha^{-1} of biochar, 5.38 t ha^{-1} of compost, and 72.21 kg ha^{-1} of ammonium sulfate, respectively. Amounts 2.89 t ha^{-1} of biochar, 2.27 t ha^{-1} of compost, and 67.85 kg ha^{-1} of ammonium sulfate found as the optimum levels for the eco-environmental scenario.

The resource-based on the eco-environmental scenario was the most favorable cropping strategy for the soybean production intercropped with *kayu putih*. That scenario reduced the use of ammonium sulfate by 32.15 % and increased NRA, TC, LPR, NL, NUE, and SY by 12.96, 2.80, 17.18, 21.66, 7.23, and 17.29 %, respectively, compared to the single application of ammonium sulfate fertilizer.

AUTHOR CONTRIBUTIONS

Conceptualization: Taufan Alam (lead), Budiastuti Kurniasih (supporting), Priyono Suryanto (supporting), and Dody Kastono (supporting).

Methodology: Taufan Alam (lead), Budiastuti Kurniasih (supporting), Priyono Suryanto (supporting), Suci Handayani (supporting), and Dody Kastono (supporting).

Software: Taufan Alam (lead).

Validation: Taufan Alam (lead), Budiastuti Kurniasih (supporting), Priyono Suryanto (supporting), Suci Handayani (supporting), and Dody Kastono (supporting).

Formal analysis: Taufan Alam (lead).

Investigation: Taufan Alam (lead), Budiastuti Kurniasih (supporting), Priyono Suryanto (supporting), Suci Handayani (supporting), and Dody Kastono (supporting).

Writing-original draft preparation: Taufan Alam (lead).

Writing-review and editing: Taufan Alam (lead), Budiastuti Kurniasih (supporting), Priyono Suryanto (supporting), Suci Handayani (supporting), and Dody Kastono (supporting).

Visualization: Taufan Alam (lead).

Supervision: Taufan Alam (lead), Budiastuti Kurniasih (supporting), Priyono Suryanto (supporting), Suci Handayani (supporting), and Dody Kastono (supporting).

Project administration: Taufan Alam (lead).

Funding acquisition: Taufan Alam (lead), Budiastuti Kurniasih (supporting), and Priyono Suryanto (supporting).

ACKNOWLEDGEMENTS

Authors acknowledge the financial support given by the Directorate of Research of Universitas Gadjah Mada, grant number 3943/UN1/DITLIT/DIT-LIT/LT/2019. Authors thank the technical assistance of the field technicians of Mr. Teguh Widodo, and the Lab technicians of Soil Laboratory and Crop Production and Management Laboratory, Faculty of Agriculture of the Universitas Gadjah Mada, Indonesia.

REFERENCES

Abebe Z, Feyisa H. Effects of nitrogen rates and time of application on yield of maize: Rainfall variability influenced time of N application. Int J Agron. 2017;2017:1545280. https://doi.org/10.1155/2017/1545280

Abiven S, Schmidt MWI, Lehmann J. Biochar by design. Nat Geosci. 2014;7:326-7. https://doi.org/10.1038/ngeo2154

Alam MA, Siddiqua A, Chowdhury MAH, Prodhan MY. Nodulation, yield and quality of soybean as influenced by integrated nutrient management. J Bangladesh Agril Univ. 2009;7:229-34. https://doi.org/10.3329/jbau.v7i2.4723

Alam T, Kurniasih B, Suryanto P, Basunanda P, Supriyanta, Ambarwati E, Widyawan MH, Handayani S, Taryono. Stability analysis for soybean in agroforestry system with *kayu putih*. SABRAO J Breed Genet. 2019;51:405-18.

Aslan N. Application of response surface methodology and central composite rotatable design for modeling the influence of some operating variables of a Multi-Gravity Separator for coal cleaning. Fuel. 2007;86:769-76. https://doi.org/10.1016/j.fuel.2006.10.020

Atkinson CJ, Fitzgerald JD, Hipps NA. Potential mechanisms for achieving agricultural benefits from biochar application to temperate soils: a review. Plant Soil. 2010;337:1-18. https://doi.org/10.1007/s11104-010-0464-5

Board JE. A comprehensive survey of international soybean research: genetics, physiology, agronomy and nitrogen relationships. Rijeka: InTech; 2013.

Box GEP, Hunter JS. Multi-factor experimental designs for exploring response surfaces. Ann Math Stat. 1957;28:195-241.

Brisson N, Gate P, Gouache D, Charmet G, Oury FX, Huard F. Why are wheat yields stagnating in Europe? A comprehensive data analysis for France. Field Crops Res. 2010;119:201-12. https://doi.org/10.1016/j.fcr.2010.07.012

Cao T, Meng J, Liang H, Yang X, Chen W. Can biochar provide ammonium and nitrate to poor soils? Soil column incubation. J Soil Sci Plant Nut. 2017;17:253-65. https://doi.org/10.4067/S0718-95162017005000020

Cazzeta JO, Villela LCV. Nitrate reductase activity in leaves and stems of tanner grass (*Brachiaria radicans* Napper.). Sci Agric. 2004;61:640-8. https://doi.org/10.1590/S0103-90162004000600012

Clarke GM, Kempson RE. Introduction to the design and analysis of experiments. London: Arnold; 1997.

Clough TJ, Condron LM, Kammann C, Müller C. A review of biochar and soil nitrogen dynamics. Agron. 2013;2013:275-93. https://doi.org/10.3390/agronomy3020275

Efthimiadou A, Bilalis D, Karkanis A, Williams BF. Combined organic/inorganic fertilization enhance soil quality and increased yield, photosynthesis and sustainability of sweet maize crop. Aust J Crop Sci. 2010;4:722-9.

Emrich W. Handbook of charcoal making: the traditional and industrial methods. Luxembourg: Commission of the European Communities Directorate; 1985.

Fageria NK. Nitrogen management in crop production. New York: CRC Press; 2014.

Figueredo NAD, Costa LMD, Melo LCA, Siebeneichlerd EA, Tronto J. Characterization of biochars from different sources and evaluation of release of nutrients and contaminants. Rev Cienc Agron. 2017;48:395-403. https://doi.org/10.5935/1806-6690.20170046

Gai Z, Zhang J, Li C. Effects of starter nitrogen fertilizer on soybean root activity, leaf photosynthesis and grain yield. PLoS ONE. 2017;12:e0174841. https://doi.org/10.1371/journal.pone.0174841

Gathorne-Hardy A, Knight J, Woods J. Biochar as a soil amendment positively interacts with nitrogen fertilizer to improve barley yields in the UK. IOP Conf Ser Earth Environ Sci. 2009;6:372052. https://doi.org/10.1088/1755-1307/6/7/372052

Glaser B, Lehmann J, Zech W. Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal: a review. Biol Fertil Soils. 2002;35:219-30. https://doi.org/10.1007/s00374-002-0466-4

Grassini P, Eskridge KM, Cassman KG. Distinguishing between yield advances and yield plateaus in historical crop production trends. Nature Commun. 2013;4:2918. https://doi.org/10.1038/ncomms3918

Gross J. Pigmentin vegetable, chlorophyl and caretinoids. New York: Van Nonstrand Reinhold; 1991.

Hagemann N, Kammann CI, Schmidt HP, Kappler A, Behrens S. Nitrate capture and slow release in biochar amended compost and soil. PLoS ONE. 2017;12:e0171214. https://doi.org/10.1371/journal.pone.0171214

Hagner M, Kemppainen R, Jauhiainen L, Tiilikkala K, Setälä H. The effects of birch (*Betula* spp.) biochar and pyrolysis temperature on soil properties and plant growth. Soil Till Res. 2016;163:224-34. https://doi.org/10.1016/j.still.2016.06.006

Haider G, Steffens D, Müller C, Kammann CI. Standard extraction methods may underestimate nitrate stocks captured by field aged biochar. J Environ Qual. 2016;45:1196-204. https://doi.org/10.2134/jeq2015.10.0529

Haygarth PM, Bardgett RD, Condron LM. Soil conditions and plant growth. West Sussex: Wiley-Blackwell; 2013.

Horwitz W, Latimer GW. Official methods of analysis of AOAC international. Maryland: Association of Official Analytical Chemistry International; 2005.

Hynninen PH, Leppakases TS. Encyclopedia of life support system. Oxford: EOLSS; 2002.

Jarvis S, Hutchings N, Brentrup F, Olesen JE, Van Der Hock KW. The European nitrogen assessment: source, effects and policy perspectives. London: Cambridge University Press; 2011.

Kalavathy HM, Regupathib I, Pillai MG, Miranda LR. Modelling, analysis and optimization of adsorption parameters for H_3PO_4 activated rubber wood sawdust using response surface methodology (RSM). Colloid Surfaces B: Biointerfaces. 2009;70:35-45. https://doi.org/10.1016/j.colsurfb.2008.12.007

Kammann CI, Schmidt HP, Messerschmidt N, Linsel S, Steffens D, Mueller C. Plant growth improvement mediated by nitrate capture in co-composted biochar. Sci Rep. 2015;5:11080. https://doi.org/10.1038/srep11080

Kanouo BMD, Allaire SE, Munson DA. Quality of biochars made from eucalyptus tree bark and corncob using a pilot-scale retort kiln. Was Biomass Valor. 2017;9:899-909. https://doi.org/10.1007/s12649-017-9884-2

Kementerian Pertanian. Rencana strategis tahun 2015-2019 [internet]. Jakarta, Indonesia: Kementerian Pertanian; 2015 [cited 2020 Jan 06]. Available from: http://sakip.pertanian.go.id/admin/file/RENSTRA%20BPPSDMP%202015-2019.pdf.

Koocheki A, Mahallati MN, Moradi R, Mansoori H. Optimizing water, nitrogen and crop density in canola cultivation using response surface methodology and central composite design. Soil Sci Plant Nutrit. 2014;60:286-98. https://doi.org/10.1080/00380768.2014.893535

Krywult M, Bielec D. Method of measurement of nitrate reductase activity in field conditions. J Ecol Eng. 2013;14:7-11. https://doi.org/10.5604/2081139X.1031524

Lal R. Soil carbon sequestration to mitigate climate change. Geoderma. 2004;123:1-22. https://doi.org/10.1016/j.geoderma.2004.01.032

Li-Cor Bioscience Inc. Using the Li-6400: Portable photosynthesis system. Lincoln: Li-Cor Inc.; 1999.

Lipper L, Thornton P, Campbell BM, Baedeker T, Braimoh A, Bwalya M, Caron P, Cattaneo A, Garrity D, Henry K, Hottle R, Jackson L, Jarvis A, Kossam F, Mann W, McCarthy N, Meybeck A, Neufeldt H, Remington T, Sen PT, Sessa R, Shula R, Tibu A, Torquebiau EF. Climate-smart agriculture for food security. Nat Clim Chang. 2014;4:1068-72. https://doi.org/10.1038/nclimate2437

Liu XY, Zhang AF, Ji CY, Joseph S, Bian RJ, Li LQ, Pan GX, Paz-Ferreiro J. Biochar's effect on crop productivity and the dependence on experimental conditions-A meta-analysis of literature data. Plant Soil. 2013;373:583-94. https://doi.org/10.1007/s11104-013-1806-x

Loussaert D, Clapp J, Mongar N, O'Neill DP, Shen B. Nitrate assimilation limits nitrogen use efficiency (NUE) in maize (*Zea mays* L.). Agronomy. 2018;8:110. https://doi.org/10.3390/agronomy8070110

Lyu S, Du G, Liu L, Zhao L, Lyu D. Effects of biochar on photosystem function and activities of protective enzymes in *Pyrus ussuriensis* Maxim. under drought stress. Acta Physiol Plant. 2016;38:220. https://doi.org/10.1007/s11738-016-2236-1

Marquardt DW, Snee RD. Ridge regression in practice. Am Stat. 1975;29:3-20. https://doi.org/10.1080/00031305.1975.10479105

Marschner H. Mineral nutrition of higher plants. London: Academic Press; 2012.

Medina M, Monreal C, Chabot D, Meier S, Gonza´lez ME, Morales E, Parillo R, Borie F, Cornejo P. Microscopic and spectroscopic characterization of humic substances from a compost amended copper contaminated soil: Main features and their potential effects on Cu immobilization. Environ Sci Pollut Res. 2017;24:14104-16. https://doi.org/10.1007/s11356-017-8981-x

Misra RV, Roy RN, Hiroka N. On-farm composting methods [internet]. Rome, Italy: Food and Agriculture Organization of the United Nations; 2003 [cited 2020 Jan 06]. Available from: http://www.fao.org/3/y5104e/y5104e00.htm.

Montemurro F, Diacono M. Towards a better understanding of agronomic efficiency of nitrogen: assessment and improvement strategies. Agronomy. 2016;6:31. https://doi.org/10.3390/agronomy6020031

Montgomery DC. Design and analysis of experiments. New York: John Wiley and Sons; 2001.

Mora ML, Cartes P, Nu´n˜ez P, Salazar M, Demanet R. Movement of NO_3^--N and NH_4^+-N in an Andisol and its influence on ryegrass production in a short term study. RC Suelo Nutr Veg. 2007;7:46-64. https://doi.org/10.4067/S0718-27912007000200005

Myers RH, Montgomery DC, Cook CMA. Response surface methodology: Process and product optimization using designed experiments. New Jersy: John Wiley and Sons; 2009.

Ngulube M, Mweetwa AM, Phiri E, Njoroge SCM, Chalwe H, Shitumbanuma V, Brandenburg RL. Effects of biochar and gypsum soil amendments on groundnut (*Arachis hypogaea* L.) dry matter yield and selected soil properties under water stress. Afr J Agric Res. 2018;13:1080-90. https://doi.org/10.5897/AJAR2018.13123

Obeng DP, Morrell S, Munn TJN. Application of central composite rotatable design to modelling the effect of some operating variables on the performance of the three-product cyclone. Int J Miner Process. 2005;76:181-92. https://doi.org/10.1016/j.minpro.2005.01.002

Omar L, Ahmed OH, Majid NMA. Improving ammonium and nitrate release from urea using clinoptilolite zeolite and compost produced from agricultural wastes. Sci World J. 2015;2015:574201. https://doi.org/10.1155/2015/574201

Pietikainen J, Kiikkila O, Fritze H. Charcoal as a habitat for microbes and its effect on the microbial community of the underlying humus. Oikos. 2000;89:231-42. https://doi.org/10.1034/j.1600-0706.2000.890203.x

Pingali PL. Green revolution: Impacts, limits, and the path ahead. PNAS. 2012;109:12302-8. https://doi.org/10.1073/pnas.0912953109

Purbajanti ED, Kusmiyati F, Slamet W, Darmawati A, Roessali W. Differences in crop growth rate, chlorophyll content index and nitrate reductase in source N of sweet corn. Int Proc Chem Biol Environ Eng. 2016;92:23-36. https://doi.org/10.7763/IPCBEE

Rady MM, Semida WM, Hemida KA, Abdelhamid MT. The effect of compost on growth and yield of *Phaseolus vulgaris* plants grown under saline soil. Int J Recycl Org Was Agric. 2016;5:311-21. https://doi.org/10.1007/s40093-016-0141-7

Rahmawati A, Alberto E, Soemarno. Pengaruh kompos limbah daun minyak kayu putih untuk pertumbuhan semai tanaman kayu putih. Jurnal Tanah dan Sumberdaya Lahan. 2016;3:293-301.

Rathke GW, Behrens T, Diepenbrock W. Integrated nitrogen management strategies to improve seed yield, oil content and nitrogen efficiency of winter oilseed rape (*Brassica napus* L.): a review. Agr Eco Environ. 2006;117:80-108. https://doi.org/10.1016/j.agee.2006.04.006

Ray DK, Ramankutty N, Mueller ND, West PC, Foley A. Recent patterns of crop yield growth and stagnation. Nat Commun. 2012;3:1293. https://doi.org/10.1038/ncomms2296

Roca-Perez L, Martı´nez C, Marcilla P, Boluda R. Composting rice straw with sewage sludge and compost effects on the soil-plant system. Chemosphere. 2009;75:781-7. https://doi.org/10.1016/j.chemosphere.2008.12.058

Rumpel C, Baumann K, Remusat L, Dignac MF, Barre P, Deldicque D, Glasser G, Lieberwirth I, Chabbi A. Nano scale evidence of contrasted processes for root-derived organic matter stabilization by mineral interactions depending on soil depth. Soil Biol Biochem. 2015;85:82-8. https://doi.org/10.1016/j.soilbio.2015.02.017

Saleh ME, Mahmoud AH, Rashad M. Peanut biochar as a stable adsorbent for removing NH_4^+-N from waste water: A preliminary study. Adv Environ Biol. 2012;6:2170-6.

Sarfraz R, Shakoor A, Abdullah M, Arooj A, Hussain A, Xing S. Impact of integrated application of biochar and nitrogen fertilizers on maize growth and nitrogen recovery in alkaline calcareous soil. Soil Sci Plant Nutr. 2017;63:488-98. https://doi.org/10.1080/00380768.2017.1376225

Shaheen A, Tariq R, Khaliq A. Comparative and interactive effects of organic and inorganic amendments on soybean growth, yield and selected soil properties. Asian J Agric Biol. 2017;5:60-9.

Soil Survey Staff. Keys to soil taxonomy. 12th ed. Washington, DC: United States Department of Agriculture, Natural Resources Conservation Service; 2014.

Solanki AC, Solanki MK, Nagwanshi A, Dwivedi AK, Dwivedi BS. Nutrient uptake and grain yield enhancement of soybean by integrated application of farmyard manure and NPK. Int J Curr Microbiol App Sci. 2018;7:1093-102. https://doi.org/10.20546/ijcmas.2018.709.130

Statistical Analysis Systems - SAS. Statistical analysis for windows 9.4. North Carolina: SAS Institute, Inc.; 2013.

Stewart WM, Dibb DW, Johnston AE, Smyth TJ. The contribution of commercial fertilizer nutrients to food production. Agron J. 2005;97:1442-52. https://doi.org/10.2134/agronj2005.0001

Sudaryanto T, Swastika KS. Ekonomi kedelai di Indonesia [internet]. Malang, Indonesia: Ekonomi Kedelai di Indonesia; 2016 [cited 2020 Jan 06]. Available from: http://balitkabi.litbang.pertanian.go.id/wp-content/uploads/2016/03/dele_1.tahlim-1.pdf.

Suharto SD, Wahono SK, Julendra H. Kajian pemanfaatan limbah penyulingan minyak kayu putih sebagai sumber energi alternatif untuk UMKM industri tahu di Gunungkidul Yogyakarta. In: Proceedings of seminar on community empowerment through utilization of local materials; December 2007; Yogyakarta. Yogyakarta: Indonesian Institute of Science; 2007. p. 7039.

Suryanto P, Tohari, Sulistyaningsih E, Putra ETS, Kastono D, Alam T. Estimation of critical period for weed control in soybean on agro-forestry system with kayu putih. Asian J Crop Sci. 2017;9:82-91. https://doi.org/10.3923/ajcs.2017.82.91

Wang XQ, Zhao Y, Wang H, Zhao XY, Cui HY, Wei ZM. Reducing nitrogen loss and phytotoxicity during beer vinasse composting with biochar addition. Was Man. 2017;61:150-6. https://doi.org/10.1016/j.wasman.2016.12.024

Wiedner K, Glaser B. Biochar for environmental management: Science, technology and implementation. London: Routledge; 2015.

Xu CY, Hosseini-Bay S, Hao Y. Effect of biochar amendment on yield and photosynthesis of peanut on two types of soils. Environ Sci Pollut Res. 2014;22:6112-25. https://doi.org/10.1007/s11356-014-3820-9

Zhang X, Huang G, Bian X, Zhao Q. Effects of root interaction and nitrogen fertilization on the chlorophyll content, root activity, photosynthetic characteristics of intercropped soybean and microbial quantity in the rhizosphere. Plant Soil Environ. 2013;59:80-8. https://doi.org/10.17221/613/2012-PSE

Zhao H, Li X, Jiang Y. Response of nitrogen losses to excessive nitrogen fertilizer application in intensive greenhouse vegetable production. Sustain. 2019;11:1513. https://doi.org/10.3390/su11061513

Zhong W, Gu T, Wang W, Zhang B, Lin X, Huang Q, Shen W. The effects of mineral fertilizer and organic manure on soil microbial community and diversity. Plant Soil. 2010;326:511-22. https://doi.org/10.1007/s11104-009-9988-y