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

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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*. 

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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 (NH₄⁺-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(H₂O), 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 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 (Figueroedo 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 NH₄⁺-N and NO₃⁻-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, kg$^{-1}$), the pH(H$_2$O) 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
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):

\[ 2^k + 2k + r = 2^3 + (2 \times 3) + 6 = 20 \]

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 Tubers 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

<table>
<thead>
<tr>
<th>Run</th>
<th>Biochar (t ha(^{-1}))</th>
<th>Compost (kg ha(^{-1}))</th>
<th>Ammonium sulphate (kg ha(^{-1}))</th>
<th>Biochar</th>
<th>Compost</th>
<th>Ammonium sulphate</th>
</tr>
</thead>
<tbody>
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<td>0</td>
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</tr>
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<tr>
<td>13</td>
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<td>2.5</td>
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<td>0</td>
<td>0</td>
</tr>
<tr>
<td>18</td>
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<td>2.5</td>
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<td>0</td>
<td>0</td>
</tr>
<tr>
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<td>0</td>
</tr>
<tr>
<td>20</td>
<td>2.5</td>
<td>2.5</td>
<td>50</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

\(^{1}\) +1, -1, and 0 indicates high, low, and a medium level of each factor.
The analyses results of ZA fertilizer used in this study indicated N-NH$_4$$^+$ and S-SO$_4^{2-}$ of 20.93 and 23.84 %, respectively. It also showed that the pH(H$_2$O), 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$_2$O), 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:

$$y_i = b_0 + \sum_{i=1}^{3} b_i x_i + \sum_{i=1}^{3} b_{i2} x_i^2 + \sum_{i=1}^{3} \sum_{j=1}^{3} b_{ij} x_i x_j$$

Eq. 2

in which: $y$ was the predicted response; $b_i$ was the linear terms; $b_{i2}$ 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:

$$y = b_0 + b_1 x_1 + b_2 x_2 + b_3 x_3 + b_{12} x_1 x_2 + b_{23} x_2 x_3 + b_{13} x_1 x_3 + b_{13} x_2 x_3$$

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; $x_1 x_2$, $x_1 x_3$, ..., $x_{n-1} x_n$ 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 2c). 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 2a). 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 2b).

### 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 ammonia sulfate treatments with an optimum value of 3.280 mmol kg$^{-1}$ h$^{-1}$ NO$_2$ (Table 2).

### Table 2. Regression coefficients of the fitted model

<table>
<thead>
<tr>
<th>Run</th>
<th>NRA ($\text{mmol kg}^{-1} \text{h}^{-1}$)</th>
<th>TC (kg kg$^{-1}$)</th>
<th>LPR ($\mu\text{mol CO}_2 \text{m}^{-2} \text{s}^{-1}$)</th>
<th>NL (kg ha$^{-1}$)</th>
<th>NUE (kg kg$^{-1}$)</th>
<th>SY (t ha$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$b_0$</td>
<td>2.488$^*$</td>
<td>0.503$^*$</td>
<td>326.908$^*$</td>
<td>4.632$^*$</td>
<td>2.898$^*$</td>
<td>0.788$^*$</td>
</tr>
<tr>
<td>$b_1$</td>
<td>0.078$^*$</td>
<td>0.017$^*$</td>
<td>1.984$^*$</td>
<td>0.007$^*$</td>
<td>0.381$^*$</td>
<td>0.103$^*$</td>
</tr>
<tr>
<td>$b_2$</td>
<td>0.135$^*$</td>
<td>0.016$^*$</td>
<td>1.525$^*$</td>
<td>0.275$^*$</td>
<td>0.440$^*$</td>
<td>0.205$^*$</td>
</tr>
<tr>
<td>$b_3$</td>
<td>0.011$^*$</td>
<td>0.002$^*$</td>
<td>0.515$^*$</td>
<td>0.095$^*$</td>
<td>0.075$^*$</td>
<td>0.024$^*$</td>
</tr>
<tr>
<td>$b_{13}X_1$</td>
<td>-0.014$^*$</td>
<td>-0.003$^*$</td>
<td>-0.925$^*$</td>
<td>-0.067$^*$</td>
<td>-0.051$^*$</td>
<td>-0.016$^*$</td>
</tr>
<tr>
<td>$b_{12}X_2$</td>
<td>0.009$^*$</td>
<td>-0.001$^*$</td>
<td>3.44$^*$</td>
<td>0.199$^*$</td>
<td>0.017$^*$</td>
<td>0.011$^*$</td>
</tr>
<tr>
<td>$b_{22}X_2$</td>
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<td>0.002$^*$</td>
<td>-1.263$^*$</td>
<td>-0.088$^*$</td>
<td>-0.055$^*$</td>
<td>-0.018$^*$</td>
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<tr>
<td>$b_{33}X_3$</td>
<td>0.0002$^*$</td>
<td>0.00004$^*$</td>
<td>0.119$^*$</td>
<td>0.001$^*$</td>
<td>-0.0007$^*$</td>
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</tr>
<tr>
<td>$b_{13}X_3$</td>
<td>-0.00006$^*$</td>
<td>-0.0002$^*$</td>
<td>0.120$^*$</td>
<td>0.003$^*$</td>
<td>-0.004$^*$</td>
<td>-0.001$^*$</td>
</tr>
<tr>
<td>$b_{23}X_3$</td>
<td>-0.00006$^*$</td>
<td>-0.00001$^*$</td>
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<td>-0.0006$^*$</td>
<td>-0.0004$^*$</td>
<td>-0.0001$^*$</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.993</td>
<td>0.955</td>
<td>0.994</td>
<td>0.978</td>
<td>0.991</td>
<td>0.993</td>
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<tr>
<td>RMSE</td>
<td>0.034</td>
<td>0.014</td>
<td>0.051</td>
<td>0.051</td>
<td>0.176</td>
<td>0.057</td>
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<tr>
<td>Lack-of-Fit</td>
<td>0.265</td>
<td>0.103</td>
<td>0.529</td>
<td>0.100</td>
<td>0.223</td>
<td>0.224</td>
</tr>
</tbody>
</table>

$^*$, $^*$, 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.
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} CO₂ (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} CO₂ (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).
**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 Nfertilizer. 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 Nfertilizer, while the application of 1 kg ha⁻¹ ammonium sulfate significantly increased NUE by 0.075 kg kg⁻¹ grain by Nfertilizer (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 Nfertilizer (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 Nfertilizer (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 Nfertilizer (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⁻³ 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.
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 molybdenum enzymes 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$_4^+$ and NO$_3^-$ in the soil and also stimulated the activity of enzymes and microbes in the soil, which further increases the abundance of NH$_4^+$ and NO$_3^-$ (Cao et al., 2017). Increased concentrations of NH$_4^+$ and NO$_3^-$ 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 CO₂ 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 NH₄⁺ 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 %), and nitrogen uptake (24.50 %) (Zhao et al., 2019). Omar et al. (2015) reported that compost increased the NH₄⁺ 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.

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