Effectiveness of *Melaleuca cajuputi* Biochar as a Leaching Loss for Nitrogen Fertilizer and Intercropping in Maize

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ABSTRACT

Background: Biochar has a function for soil amendment and leaching loss for nitrogen fertilizer. The objectives of this study was to evaluate the effectiveness of *Melaleuca cajuputi* biochar as a leaching loss for nitrogen fertilizer and intercropping in maize.

Methods: The study was conducted from February to June 2019 in Menggoran Forest Resort, Playen District, Gunungkidul Regency, Special Province of Yogyakarta, Indonesia. The experimental design was a randomized complete block design (RCBD) factorial with three replications as the response surface methodology (RSM). The treatments consisted of biochar levels made from *Melaleuca cajuputi* waste (0, 5, 10, 15 tons ha⁻¹) and nitrogen fertilizer levels sourced from urea (0, 150, 300 kg ha⁻¹) as independent variables. The observation parameters were nitrate reductase activity (NRA), total chlorophyll (TC), net photosynthesis (NP), nitrogen loss (NL), nitrogen use efficiency (NUE) and seed yield per hectare (SY).

Result: The RSM revealed that the optimum value of 13,290 tons ha⁻¹ of *Melaleuca cajuputi* biochar (MCB) and 245.350 kg ha⁻¹ of nitrogen fertilizer (NF) can reduced urea by 18.22%. This recommendation increased NRA, TC, NP, NL, NUE and SY by 35.28%, 19.55%, 18.09%, -46.81%, 27.96% and 61.78%, respectively, in compare to the single application of urea.

Key words: Biochar, Intercropping, Leaching loss, Maize, *Melaleuca cajuputi*, Nitrogen fertilizer.

INTRODUCTION

The average of maize consumption in Indonesia for a year reached 8.5 million tons and only 40% fulfilled from the maize produced in the country (Ministry of Agriculture, 2018). One way is by intensifying the area between *Melaleuca cajuputi* stands and reducing nutrient loss, especially nitrogen (Alam et al., 2019; Suryanto et al., 2017; Weih et al., 2018).

Nitrogen (N) is an essential nutrient 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 problem with nutrient fertilization is low efficiency due to increase the NO₃⁻, N leaching (187.50%), NH₄⁺-N leaching (28.10%), total N leaching (217.00%), N₂O emission (202.00%), NH₃ emission (176.40%), NO emission (543.3%), N uptake (24.50%) and yield (35.70%) (Zhao et al. 2019).

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). *Melaleuca cajuputi* waste has the potential to be used as biochar. Biochar has physiochemical characteristics that are suitable for use as a soil ameliorant (Indrawati et al., 2017). The study by Coumaravel et al., (2011) showed that increases cation exchange capacity (CEC) and related soil properties.

The objectives of this study was to evaluate the effectiveness of *Melaleuca cajuputi* biochar as a leaching loss for nitrogen fertilizer and intercropping in maize. The results of this study will provide information to improve soil quality and maize yield as well as to cope with the problem of *Melaleuca cajuputi* waste and to make it more useful.

MATERIALS AND METHODS

The study was conducted from February to June 2019 in Menggoran Forest Resort, Playen District, Gunungkidul Regency, Special Province of Yogyakarta, Indonesia. The altitude of the study site was ±100 meters above sea level. Total rainfall in the study was ±407.00 mm. The average air temperature and relative humidity were 25.54°C and 83.90%. The soil moisture regime was ustic. Interpretation of the soil horizon in the soil profile was Lithic Haplusterts (Alam et al., 2019). The soil texture in the study area was dominated by clay texture with very slow drainage (0.001 cm hour⁻¹). Water availability was 9.15%. CEC included in a very high category (58.83 cmol(+1) kg⁻¹) with pH H₂O included in the alkaline category (8.18). The soil organic matters (2.62%), available of N (117.70 ppm), P (6.87 ppm) and K...
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(0.18 ppm) of the command area was classified into the low category.

The experimental design was a randomized complete block design (RCBD) factorial with three replications as the response surface methodology (RSM). The treatments consisted of biochar levels made from *Melaleuca cajuputi* waste (0, 5, 10, 15 tons ha\(^{-1}\)) and nitrogen fertilizer levels sourced from urea (0, 150, 300 kg ha\(^{-1}\)) as independent variables. Biochar made from the waste of distilled *Melaleuca cajuputi* leaves. Biochar made by using the Kiln Traditional Method (Emrich, 1985). *Melaleuca cajuputi* biochar (MCB) was applied when planting the maize and nitrogen fertilizer was applied when the maize reached one week after the plant (wap). The analysis results of urea used in this study indicated nitrate by 45.36%. Based on the laboratory analysis showed that the content of pH \(H_2O\), C, H, N and O in the MCB used in this experiment by 8.21, 72.48%, 2.32%, 0.17% and 22.44%, respectively.

The observation parameters were nitrate reductase activity (NRA) (Krywult and Bielec, 2013), total chlorophyll (TC) (Gross, 1991), net photosynthesis (NP) (Li-Cor, 1999), nitrogen loss (NL) (Fageria, 2014), nitrogen use efficiency (NUE) (Rathke et al., 2016) and seed yield per hectare (SY). Seeds were dried under the sunlight to reach 11% of moisture levels (Suryanto et al., 2017).

The equation of response surface methodology (RSM) used in this experiment applied the uncoded independent variables as follows (kochoeki et al., 2014; Myers et al., 2009). The fitted model was an evaluation by the coefficient of determination (\(R^2\)), root square means error (RMSE) and lack-of-fit. The lack-of-fit criterion used in this study was that the significance of lack-of-fit tested with a F-test should be less than 5% (Myers et al., 2009). The optimum levels of *Melaleuca cajuputi* biochar and nitrogen fertilizer was calculated under the eco-environmental scenario used the NUE parameter (kochoeki et al., 2014). Estimation of the eco-environmental scenario applied the ridge regression (marquardt and snee, 1975). All analysis performed using PROC RSREG in SAS 9.4 (SAS Institute, 2013).

### RESULTS AND DISCUSSION

#### Fitted models for maize variables

The results for the RSM of the full quadratic regression for independent variables were presented in Table 1. The lack-of-fit test 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 a F-test should be less than 5%. The lack-of-fit tested was not significant in all soybean variables (Table 1).

#### Estimated response for maize variables of experimental factors

The application of *Melaleuca cajuputi* biochar (MCB) and nitrogen fertilizer (NF) showed a very significant increased of NRA in the maize. The NRA by 4.765 \(\mu\)mol NO\(_2\) g\(^{-1}\) h\(^{-1}\) obtained in the treatment of 15 tons ha\(^{-1}\) of MCB and 300 kg ha\(^{-1}\) of NF (Table 2). There was an interaction between MCB with NF in the NRA. The quadratic patterns showed in MCB and NF application in the NRA (Table 1). Biochar application of 20 tons ha\(^{-1}\) increased the concentration of NO\(_3^-\)-N in soil solution (Major et al., 2012). The increased concentrations of NH\(_4^+\)-N and NO\(_3^-\)-N in the soil positively correlated with the increasing NRA in the plant (Loussaert et al., 2018). NRA increases linearly with increasing nitrate fertilization (Loussaert et al., 2018). Purbajanti et al., (2019) showed that increasing N fertilization could significantly increase NRA of peanuts compared to without N fertilization.

The MCB and NF very significant increased total chlorophyll (TC) in maize. Under the treatment of 15 tons ha\(^{-1}\) of MCB and 300 kg ha\(^{-1}\) of NF, it indicated the highest TC by 0.892 g g leaf\(^{-1}\) (Table 2). There was an interaction between MCB and NF in TC. The quadratic patterns showed in MCB and NF application in TC (Table 1). Biochar application in the soil was increased chlorophyll content in chickpea by 57-126% (Macal et al., 2017). Hokmalipour and Darbandi (2012) reported that giving N fertilizer increased TC in maize.

The MCB and NF very significant increased net photosynthesis (NR). The highest value of NP due to the

### Table 1: Regression coefficients of the fitted model.

| Run | NRA (\(\mu\)mol NO\(_2\) g\(^{-1}\) h\(^{-1}\)) | TC (g g leaf\(^{-1}\)) | NP (\(\mu\)mol CO\(_2\) m\(^2\) s\(^{-1}\)) | NL (kg ha\(^{-1}\)) | NUE (kg grain kg N\(_{\text{fertilizer}}\)) | SY (tons ha\(^{-1}\)) |
|-----|--------------------------------|----------------------|--------------------------------|-----------------|--------------------------------|-------------------|
| b_0 | 2.043**                        | 0.559**              | 295.722**                      | 10.156**        | 4.171**                        | 1.234**           |
| b_1x_1 | 0.144**                      | 0.012**              | 6.204**                        | -0.493**        | 0.147**                        | 0.194**           |
| b_2x_2 | 0.011**                      | 0.002**              | 0.907**                        | 0.201**         | 0.014**                        | 0.018**           |
| b_1x_1^2 | -0.006*                      | -0.0004**            | -0.132*                        | -0.003**        | -0.003*                        | -0.006*           |
| b_2x_2^2 | -0.00001*                    | 0.000001*            | 0.004*                         | 0.00001*        | -0.00002*                      | -0.00002*         |
| R\(^2\) | 0.963                        | 0.981                | 0.964                          | 0.986           | 0.974                          | 0.950             |
| RMSE | 0.186                        | 0.017                | 13.531                         | 1.602           | 0.195                          | 0.415             |
| Lack-of-Fit | 0.092**                     | 0.116**              | 0.124**                        | 0.247**         | 0.318**                        | 0.197**           |

* and ** significant at (p<0.05) and (p<0.01). x_1 and x_2 indicates *Melaleuca cajuputi* biochar (tons ha\(^{-1}\)) and nitrogen fertilizer (kg ha\(^{-1}\)). NRA - Nitrate reductase activity; TC - Total chlorophyll; NP - Net photosynthesis; NL - Nitrogen loss; NUE - Nitrogen use efficiency; SY - Seed yield.
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application of 15 tons ha\(^{-1}\) of MCB and 300 kg ha\(^{-1}\) of NF was 494.219 \(\mu\)mol CO\(_2\) m\(^{-2}\) s\(^{-1}\) (Table 2). There was an interaction between MCB and NF in the NP. The quadratic patterns showed in MCB and NF application in NP (Table 1). Xu et al., (2015) showed that biochar improves photosynthesis rate and electron transport rate in peanuts. NF is needed to increase the maize production. Zhang et al., (2013) showed that there was a positive relationship between the increasing dose of N with photosynthesis, stomatal conductance, transpiration and CO\(_2\) concentrations among cells in soybean.

The MCB significant reduced NL in maize, while NF very significant increased NL. The treatment of 0 tons ha\(^{-1}\) of MCB and 300 kg ha\(^{-1}\) of NF showed the highest nitrogen loss (NL) by 41.461 kg ha\(^{-1}\) N (Table 2). There was an interaction between MCB with NF in NL. The quadratic pattern was only showed in NF applications in NL (Table 1). The used of biochar of 2\% and 4\% in clay texture of soil can reduce N loss and NO\(_3^--\)N by 29.19% and 28.65%. Increasing the NF very significant increased NL in vegetable commodities (Zhao et al. 2019).

The highest value of nitrogen use efficiency (NUE) due

**Table 2:** Actual values of experimental factors and estimated response for maize variables.

| Run | MCB (tons ha\(^{-1}\)) | NF (kg ha\(^{-1}\)) | NRA (\(\mu\)mol NO\(_2^-\) g \(^{-1}\) hour\(^{-1}\)) | TC (g g leaf\(^{-1}\)) | NP (\(\mu\)mol CO\(_2\) m\(^{-2}\) s\(^{-1}\)) | NL (kg ha\(^{-1}\)) | NUE (kg grain kg N\(_{\text{fertilizer}}\)^{-1}) | SY (tons ha\(^{-1}\)) |
|-----|------------------------|---------------------|---------------------------------|-------------------|---------------------|------------------|-----------------|------------------|
| 1   | 0                      | 0                   | 2.043                           | 0.559             | 295.722             | 10.156           | 4.171           | 1.235            |
| 2   | 0                      | 150                 | 3.209                           | 0.722             | 392.865             | 33.053           | 5.596           | 3.237            |
| 3   | 0                      | 300                 | 3.466                           | 0.739             | 412.247             | 41.461           | 5.671           | 3.800            |
| 4   | 5                      | 0                   | 2.619                           | 0.609             | 323.441             | 7.697            | 4.831           | 2.063            |
| 5   | 5                      | 150                 | 3.858                           | 0.781             | 423.690             | 27.943           | 6.264           | 4.250            |
| 6   | 5                      | 300                 | 4.188                           | 0.809             | 446.179             | 33.699           | 6.346           | 4.998            |
| 7   | 10                     | 0                   | 2.906                           | 0.640             | 344.552             | 5.256            | 5.341           | 2.609            |
| 8   | 10                     | 150                 | 4.218                           | 0.822             | 447.907             | 22.851           | 6.781           | 4.982            |
| 9   | 10                     | 300                 | 4.621                           | 0.860             | 473.503             | 25.956           | 6.871           | 5.915            |
| 10  | 15                     | 0                   | 2.903                           | 0.652             | 359.055             | 2.832            | 5.701           | 2.874            |
| 11  | 15                     | 150                 | 4.289                           | 0.845             | 465.517             | 17.776           | 7.149           | 5.432            |
| 12  | 15                     | 300                 | 4.765                           | 0.892             | 494.219             | 18.229           | 7.246           | 6.550            |

MCB - *Melaleuca cajuputi* biochar; NF - Nitrogen fertilizer; NRA - Nitrate reductase activity; TC - Total chlorophyll; NP - Net photosynthesis; NL - Nitrogen loss; NUE - Nitrogen use efficiency; SY - Seed yield.

**Fig 1:** The variables response to the *Melaleuca cajuputi* biochar (MCB) (tons ha\(^{-1}\)) and nitrogen fertilizer (NF) (kg ha\(^{-1}\)). a). NRA - Nitrate reductase activity (\(\mu\)mol NO\(_2^-\) g \(^{-1}\) h\(^{-1}\)); b). TC - Total chlorophyll (g g leaf\(^{-1}\)); c). NP - Net photosynthesis (\(\mu\)mol CO\(_2\) m\(^{-2}\) s\(^{-1}\)); d). NL - Nitrogen loss (kg ha\(^{-1}\) N); e). NUE - Nitrogen use efficiency (kg grain kg N\(_{\text{fertilizer}}\)^{-1}); f). SY - Seed yield (tons ha\(^{-1}\)).
to the application of 15 tons ha\(^{-1}\) of MCB and 300 kg ha\(^{-1}\) of NF was 7.246 kg grain kg N\(_{\text{MBC}}\)\(^{-1}\) (Table 2). There was an interaction between MCB and NF in the NUE. The quadratic patterns showed in MCB and NF application in NUE (Table 1). Biochar can increase plant growth and yield, as well as the NUE by rising the CEC and sustain the water holding capacity in the soil (Hagner et al., 2016). Low NUE values positively correlated with low N fertilizer application in farmers level. The N application of 330 kg ha\(^{-1}\) increased N uptake, NUE and ANUE compared to without N fertilizer (Abebe et al., 2017).

Seed yield (SY) showed the highest value under the application of 15 tons ha\(^{-1}\) of MCB as well as 300 kg ha\(^{-1}\) of NF showed the SY by 6.550 tons ha\(^{-1}\) (Table 2). There was an interaction between MCB and NF in SY. The quadratic patterns showed in MCB and NF application in SY (Table 1). The RSM revealed that application of 13.290 tons ha\(^{-1}\) of MCB and 245.350 kg ha\(^{-1}\) of NF produced a maximum NRA, TC, NP, NL, NUE and SY by 4.689 mol NO\(_2\) g\(^{-1}\) h\(^{-1}\), 0.884 g g leaf\(^{-1}\), 486.811 mol CO\(_2\) m\(^{-2}\) s\(^{-1}\), 22.052 kg ha\(^{-1}\) N, 7.256 kg grain kg N\(_{\text{MBC}}\)\(^{-1}\) and 6.147 tons ha\(^{-1}\), respectively (Fig 1a, 1b, 1c, 1d, 1e, 1f).

That recommendation was reduced use of urea by 15.75%, while to an increased NRA, TC, NP, NL, NUE and SY by 35.56%, 19.45%, 17.97%, -45.33%, 27.44% and 61.92%, respectively, in compare to the single application of urea.

The research related to the used of biochar conducted under tropical conditions reported an increase in maize yield (Major et al., 2010). These studies report that biochar has positive interactions with tropical soils to increase maize productivity and soil fertility (Coumaravel et al., 2015).

CONCLUSION

*Melaleuca cajuputi* biochar can be decrease of the leaching loss for nitrogen fertilizer and intercropping in maize as well as to improve maize yield and cope with the problem of *Melaleuca cajuputi* waste and to make it more useful. The RSM revealed that application of 13.290 tons ha\(^{-1}\) of MCB and 245.350 kg ha\(^{-1}\) of NF produced a maximum nitrate reductase activity (NRA), total chlorhyl (TC), net photosynthesis (NP), nitrogen loss (NL), nitrogen use efficiency (NUE) and seed yield (SY) by 4.689 mol NO\(_2\) g\(^{-1}\) h\(^{-1}\), 0.884 g g leaf\(^{-1}\), 486.811 mol CO\(_2\) m\(^{-2}\) s\(^{-1}\), 22.052 kg ha\(^{-1}\) N, 7.256 kg grain kg N\(_{\text{MBC}}\)\(^{-1}\) and 6.147 tons ha\(^{-1}\), respectively. That recommendation was reduced use of urea by 15.75%, while to an increased NRA, TC, NP, NL, NUE and SY by 35.56%, 19.45%, 17.97%, -45.33%, 27.44% and 61.92%, respectively, in compare to the single application of urea.

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