Optimizing Application of Biochar Amendment for Nitrogen use Efficiency in Upland Rice under *Melaleuca cajuputi* Stands

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**ABSTRACT**

**Background:** The main problem in nitrogen fertilization for crop cultivated is the very low efficiency due to the leaching process. The purpose of this study was to the determination of the optimum levels of biochar amendment made from *Melaleuca cajuputi* biochar (MCB) and urea fertilizer (UF) for nitrogen use efficiency in upland rice under *M. cajuputi* stands.

**Methods:** The study was conducted during dry season within March to June 2019 in Menggoran Forest Resort, Playen Forest Section, Yogyakarta Forest Management District, Indonesia. The experimental design was laid out in a randomized complete block design factorial with three replications as the response surface methodology (RSM). The treatments consisted of MCB levels (0, 5, 10, 15 tons ha⁻¹) and UF levels (0, 100, 200, 300 kg ha⁻¹) as independent variables. The observation parameters were nitrate reductase activity (NRA), total chlorophyll (TC), leaf photosynthesis rate (LPR), nitrogen loss (NL), nitrogen use efficiency (NUE) and seed yield (SY). The data was analyzed using RSM approach and ridge regression.

**Result:** The optimizing applications of 11.14 tons ha⁻¹ of MCB and 281.13 kg ha⁻¹ of UF resulted in NUE and SY by 2.14 kg grain kg⁻¹ and 5.83 tons ha⁻¹ or increased by 19.07% and 13.02%, compared to a single application of UF by 300 kg ha⁻¹.

**Key words:** Amendment, *M. cajuputi* biochar, Nitrogen use efficiency, Upland rice, Urea fertilizer.

**INTRODUCTION**

Rice is the staple food for most people in Indonesia. In just one year alone from 2018 to 2019, the harvested area of rice agriculture in Indonesia shrunk by 700,000 hectares (6.15%), with rice production reduced by 4.60 million tons (7.76%) (Statistics Indonesia, 2020). One strategy to expand the areas of upland rice farming is by planting rice between *M. cajuputi* stands. Intensification of the areas among *M. cajuputi* stands for upland rice had various problems, namely low levels of N content (NH₄⁺ and NO₃⁻) in the soil and low NUE value. In general, the NH₄⁺ and NO₃⁻ contents in the soil on *M. cajuputi* forests were 39.39 and 86.18 ppm, while the NH₄⁺ and NO₃⁻ losses through the leaching process by 28.10% and 187.50% (Alam et al. 2019; Suryanto et al. 2020b; Suryanto et al. 2020c; Zhao et al. 2019).

Biochar is a product of the pyrolysis of organic materials and has several functions, such as absorbing CO₂ in the atmosphere, improving soil physical and chemical fertility and increasing fertilizer efficiency and yields (Coumaravel et al. 2011). Biochar can absorb nutrients directly to its surface by surface binding of both cation and anion due to its greater porosity and surface area (Atkinson et al. 2010). *M. cajuputi* waste can be used for soil amendment in the form of biochar. The pH H₂O, C, H, O and N contents in the MCB were 8.05, 72.48%, 2.32%, 22.44% and 0.17%, respectively (Alam et al. 2020b). The research study by Alam et al. (2020b) informed that the applications of *M. cajuputi* waste (biochar and compost) and ammonium sulfate fertilizer by 2.89 and 2.27 tons ha⁻¹ and 67.85 kg ha⁻¹, respectively, can increased NUE and soybean yield by 7.23% and 17.29%.

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rainfall during rice planting and in a year were 407 and 2,005 mm, respectively. The average air temperature and relative humidity were 25.54°C and 83.90%. The soil type was Lithic Haplusterts (Alam et al. 2019; Alam et al. 2020a; Suryanto et al. 2017; Suryanto et al. 2020a). The soil texture was dominated by clay texture with very slow drainage (0.001 cm hour⁻¹). The CEC included in a high category (57.78 cmolc⁻¹ kg⁻¹) and the pH H₂O was alkaline (8.18). SOC (1.62%), total N (0.13%), available of P (7 ppm) and available of K (0.41 cmolc⁻¹ kg⁻¹) were classified in the low category. Biochar was made from the waste of distilled M. cajuputi leaves. Biochar was made by using the Klin Traditional Method (Emrich, 1985). The laboratory analysis showed that the content of pH H₂O, C, H, N and O in the MCB was used in this experiment by 8.21, 72.48%, 2.32% and 0.17% and 22.44%, respectively.

The experimental design was laid out in a randomized complete block design factorial with three replications as the response surface methodology (RSM). The treatments consisted of MCB levels (0, 5, 10, 15 tons ha⁻¹) and UF levels (0, 100, 200, 300 kg ha⁻¹) as independent variables. Biochar was applied during rice planting, while urea applied in 2, 4 and 8 week after planting (wap). The observation parameters were nitrate reductase activity (NRA) (Krywult and Bielec, 2016) and seed yield (SY) (Suryanto et al. 2017; Suryanto et al. 2020a). The observations of NRA, TC and LPR were carried out during the maximum vegetative phase, while NL, NUE and SY in the harvest time. The RSM equation used in this experiment applied the uncoded independent variables (Koocheki et al. 2014, Myers et al. 2009). The fitted model were an evaluation by the R², 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 MCB and UF levels were calculated under the economy scenario using the SY parameter and estimation with ridge regression (Koocheki et al. 2014, Marquardt and Sne, 1975). All analysis was performed using PROC RSREG in SAS 9.4 software (SAS Institute, 2013).

RESULTS AND DISCUSSION

Evaluation of the fitted models for upland rice parameters

The R², RMSE and the lack-of-fit test was used to evaluate the quality of the fitted model. Based on the regression equations showed that R² dan RMSE indicated that all models showed fitted (Table 1). The lack-of-fit tested was not significant in all soybean parameters (Table 1).

Estimated response for upland rice parameters of experimental factors

The MCB and UF applications very significantly influenced NRA (Table 1). The highest NRA by 4.46 μmol NO₃⁻ g⁻¹ hour⁻¹ obtained in the treatments of 10 tons ha⁻¹ of MCB and 300 kg ha⁻¹ of UF (Table 2). There was no interaction between MCB with UF in the NRA. The MCB and UF showed linear and quadratic patterns (Table 1). The increase of N levels has a significant effect on NH₄⁺ and NO₃⁻ concentrations in the soil and NRA in the rice (Nascente and Lanna, 2016). The applications of 13.29 tons ha⁻¹ of MCB and 245.35 tons ha⁻¹ of UF increased the NRA content by 35.28%, compared to a single UF application by 300 kg ha⁻¹ (Nurmalasari et al. 2020).

The treatments of MCB and UF in the soil gave significantly and very significantly influenced TC (Table 1). The applications of 10 tons ha⁻¹ of MCB and 300 kg ha⁻¹ of UF showed the highest TC by 0.94 g g leaf⁻¹ (Table 2). There was no interaction between MCB with UF in TC. The MCB and UF showed a linear pattern (Table 1). The N fertilization of 120 kg ha⁻¹ combined with biochar of 9 ton ha⁻¹ significantly increased TC in rice (Lai et al. 2017).

The applications of MCB and UF significantly and very significantly influenced LPR (Table 1). The LPR showed the highest value by 415.71 μmol CO₂ m⁻² s⁻¹ in the applications of 10 tons ha⁻¹ of MCB and 300 kg ha⁻¹ of UF (Table 2). There was no interaction between MCB with UF in LPR. The UF showed a quadratic pattern, while MCB showed a linear pattern (Table 1). In general, the amendments using biochar on crops significantly increased the photosynthesis rate, stomatal conductance, transpiration rate, water use efficiency and chlorophyll content by 27.1%, 19.6%, 26.9%, 26.8% and 16.1%, respectively (He et al., 2020). The effect of N supply in rice can increase flag leaf photosynthesis, slow down the aging of flag leaves and prolong photosynthesis times (Sun et al. 2014).

The MCB and UF treatments very significantly influenced NL (Table 1). The treatments of 15 tons ha⁻¹ of MCB and 0 kg ha⁻¹ of UF showed the lowest NL by 3.25 kg ha⁻¹, while the highest NL by 54.00 kg ha⁻¹ in the applications of 0 tons ha⁻¹ of MCB and 300 kg ha⁻¹ of UF (Table 2). There was an interaction between MCB and UF in NL. The quadratic patterns showed in MCB and UF treatments (Table 1). The addition of biochar to the soil can increase water-holding capacity, thus reducing N loss risk through the leaching process (Zheng et al. 2013).

The additions of MCB not significantly increased NUE, while UF showed very significantly increased NUE (Table 1). The applications of 15 tons ha⁻¹ of MCB and 100 kg ha⁻¹ of UF gave the highest NUE by 2.21 kg grain kg⁻¹ N (Table 2). There was no interaction between MCB and UF in NUE. The MCB showed a linear pattern, whereas UF showed a quadratic pattern (Table 1). Based on the eco-environmental scenario, it showed that the applications of M. cajuputi waste in the form of biochar and compost by 2.89 and 2.27 tons ha⁻¹ and ammonium sulfate by 67.85 kg ha⁻¹ resulted in NUE maize by 6.87 kg kg⁻¹ grain by Ncrit = 2 or increased by 7.23%, compared to the single application of ammonium sulfate fertilizer (Alam et al. 2020b).
Table 1: Regression coefficients of the fitted model.

| Run | NRA (μmol NO₃⁻ g⁻¹ h⁻¹) | TC (g g leaf⁻¹) | LPR (μmol CO₂ m⁻² s⁻¹) | NL (kg ha⁻¹) | NUE (kg grain kg N fertilizer⁻¹) | SY (tons ha⁻¹) |
|-----|--------------------------|-----------------|------------------------|--------------|-------------------------------|----------------|
| b₀   | 2.12**                   | 0.32**          | 202.44**                | 6.77**       | -0.05**                       | 1.65           |
| b₁x₁ | 0.05**                   | 0.01*           | 3.9                     | -1.08**      | 0.02 ns                       | 0.06           |
| b₂x₂ | 0.01**                   | 0.002**         | 0.75**                  | 0.12**       | 0.02**                        | 0.01           |
| b₃x₁² | -0.0005**                | -0.0003**       | -0.03**                 | 0.06**       | 0.0001**                      | -0.0004        |
| b₄x₂² | -0.000002**              | -0.000009**     | -0.0006*                | -0.0001**    | -0.00005**                    | -0.00002       |
| R²   | 0.99**                   | 0.96**          | 0.96**                  | 0.99**       | 0.90**                        | 0.97**         |
| RMSE | 0.09                      | 0.05            | 14.91                   | 1.48         | 0.27                          | 0.28           |
| Lack-of-Fit | 0.083**               | 0.128**        | 0.135**                 | 0.268**      | 0.339**                       | 0.207**        |

* and ** significantly and no significantly at (p<0.05), ** significantly at (p<0.01). x₁ and x₂ indicates M. cajuputi biochar (tons ha⁻¹) and urea fertilizer (kg ha⁻¹). NRA- Nitrate reductase activity; TC- Total chlorophyll; LPR- Leaf photosynthesis rate; NL- Nitrogen loss; NUE- Nitrogen use efficiency; SY- Seed yield.

Table 2: Actual values of experimental factors and estimated response for upland rice variables.

| Run | MCB | UF | NRA (μmol NO₃⁻ g⁻¹ h⁻¹) | TC (g g leaf⁻¹) | LPR (μmol CO₂ m⁻² s⁻¹) | NL (kg ha⁻¹) | NUE (kg grain kg N fertilizer⁻¹) | SY (tons ha⁻¹) |
|-----|-----|----|--------------------------|-----------------|------------------------|--------------|-------------------------------|----------------|
| 1   | 0   | 0  | 2.16                     | 0.33            | 213.88                 | 6.25         | 0.00                          | 1.79           |
| 2   | 0   | 100| 3.05                     | 0.48            | 264.69                 | 18.00        | 1.48                          | 2.88           |
| 3   | 0   | 200| 3.70                     | 0.62            | 326.50                 | 36.00        | 1.25                          | 3.95           |
| 4   | 0   | 300| 3.94                     | 0.74            | 367.68                 | 54.00        | 1.09                          | 4.67           |
| 5   | 5   | 0  | 2.36                     | 0.39            | 226.54                 | 4.38         | 0.00                          | 2.04           |
| 6   | 5   | 100| 3.24                     | 0.51            | 270.32                 | 12.60        | 1.65                          | 3.16           |
| 7   | 5   | 200| 3.84                     | 0.68            | 348.10                 | 25.20        | 1.44                          | 4.29           |
| 8   | 5   | 300| 4.12                     | 0.83            | 398.77                 | 37.80        | 1.31                          | 5.25           |
| 9   | 10  | 0  | 2.52                     | 0.42            | 233.35                 | 3.75         | 0.00                          | 2.16           |
| 10  | 10  | 100| 3.42                     | 0.55            | 295.73                 | 10.80        | 1.88                          | 3.36           |
| 11  | 10  | 200| 4.02                     | 0.78            | 383.88                 | 21.60        | 1.74                          | 4.90           |
| 12  | 10  | 300| 4.45                     | 0.94            | 415.71                 | 32.40        | 1.56                          | 5.98           |
| 13  | 15  | 0  | 2.68                     | 0.45            | 257.87                 | 3.25         | 0.00                          | 2.48           |
| 14  | 15  | 100| 3.61                     | 0.58            | 313.38                 | 9.36         | 2.21                          | 3.78           |
| 15  | 15  | 200| 4.23                     | 0.91            | 412.39                 | 18.72        | 2.13                          | 5.84           |
| 16  | 15  | 300| 4.25                     | 0.88            | 403.06                 | 28.08        | 1.46                          | 5.59           |

MCB- M. cajuputi biochar (tons ha⁻¹); UF- Urea fertilizer (kg ha⁻¹). NRA- Nitrate reductase activity (μmol NO₃⁻ g⁻¹ h⁻¹); TC- Total chlorophyll (g g leaf⁻¹); LPR- Leaf photosynthesis rate (μmol CO₂ m⁻² s⁻¹); NL- Nitrogen loss (kg ha⁻¹); NUE- Nitrogen use efficiency (kg grain kg N fertilizer⁻¹); SY- Seed yield (tons ha⁻¹).

The MCB and UF applications significantly and very significantly influenced SY (Table 1). The SY showed the highest value by 5.98 tons ha⁻¹ in the applications of 10 tons ha⁻¹ of MCB and 300 kg ha⁻¹ of UF (Table 2). There was no interaction between MCB and UF in SY. The MCB showed a linear pattern, while UF showed a quadratic pattern (Table 1). A biochar amendment of <30 ton ha⁻¹ can increase plant productivity by 11% (Liu et al. 2013). Nitrogen fertilization of 240 kg ha⁻¹ with a schedule of 30% at basal, 20% at 10 days after transplanting (DAT) and 50% at 36 DAT resulted in average rice productivity of 10.20 tons ha⁻¹ or an increase of 46.87%, compared to without N fertilizer (Pan et al. 2012).

Based on economic scenario showed that the optimum values of 11.14 tons ha⁻¹ of MCB and 281.13 kg ha⁻¹ of UF produced a maximum NRA, TC, LPR, NL, NUE and SY by 3.91 μmol NO₃⁻ g⁻¹ h⁻¹, 0.95 g g leaf⁻¹, 411.85 μmol CO₂ m⁻² s⁻¹, 12.36 kg ha⁻¹, 2.14 kg grain kg N fertilizer⁻¹ and 14.13 tons ha⁻¹, respectively (Fig 1a, 1b, 1c, 1d, 1e, 1f). This recommendation reduced use of UF by 15.75%, while to an increased NRA, TC, LPR, NL, NUE and SY by 17.72%, 12.98%, 10.29%, -63.41%, 47.45% and 44.76%, respectively, in comparison to the single application of UF by 300 kg ha⁻¹.

The research was conducted by Dong et al. (2015) in 2009 and 2010 provides information that the addition of biochar to soil can increased rice yields by 11.30% and
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Coumaravel et al. (2015) informed that the application of biochar combined with NPK fertilizer can increase the sustainability of soil fertility and maize productivity.

**CONCLUSION**

The optimum values of 11.14 tons ha\(^{-1}\) of MCB and 281.13 kg ha\(^{-1}\) of UF produced a maximum NRA, TC, LPR, NL, NUE and SY by 3.91 μmol NO\(_2\)-g\(^{-1}\)-h\(^{-1}\), 0.95 g g leaf\(^{-1}\), 411.85 μmol CO\(_2\)-m\(^2\)-s\(^{-1}\), 12.36 kg ha\(^{-1}\), 2.14 kg grain kg N\(_{fertilizer}\)-1, and 14.13 tons ha\(^{-1}\), respectively. This recommendation reduced use of UF by 15.75%, while to an increased NRA, TC, NP, NL, NUE and SY by 17.72%, 12.98%, 10.29%, -63.41%, 47.45% and 44.76%, respectively, in comparison to the single application of UF by 300 kg ha\(^{-1}\).

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