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Interactions of Biochar Briquette with Ammonium Sulfate Fertilizer for Controlled Nitrogen Loss in Soybean Intercopping with *Melaleuca cajuputi*

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ABSTRACT

Background: Nutrient briquette and biochar are used to reduce nitrogen loss and improve soil fertility. This study aimed to evaluate the interaction of biochar briquette with ammonium sulfate fertilizer for controlled nitrogen loss in soybean intercropping with *Melaleuca cajuputi*.

Methods: The study was conducted in the wet season from November to February 2020 at Menggoran Forest Resort, Playen Forest Section, Yogyakarta Forest Management District, Indonesia. The experiment was using a randomized complete block design factorial with three blocks as the response surface methodology. The treatments included different levels of biochar briquette from *Melaleuca cajuputi* waste (0, 2 and 4 grain plant^{-1} or 0, 5 and 10 tons ha^{-1}) and nitrogen fertilizer supplied by ammonium sulfate (0, 50 and 100 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).

Result: The optimum values of 3.70 grain plant^{-1} or 9.25 tons ha^{-1} biochar briquette with 76.31 kg ha^{-1} ammonium sulfate fertilizer decreased NL by 38.25% and increased SY by 13.02% compared with single ammonium sulfate fertilizer.

Key words: Ammonium sulfate, Biochar briquette, Intercropping, *Melaleuca cajuputi*, Nitrogen loss, Soybean.

INTRODUCTION

Soybean is a valuable food commodity in Indonesia after rice and maize (Ministry of Agriculture, 2015). The average volume and value of soybean imports over the 6 years (2013-2018) in Indonesia were 1.9 million tons and US$ 1.09 billion, respectively and the conversion of agricultural areas to non-agricultural areas was 96,512 ha year^{-1} (Mulyani *et al*. 2017, Statistics Indonesia, 2018). Alternative strategies are to intensify the areas between *Melaleuca cajuputi* stands and reduce nitrogen loss (NL) (Alam *et al*. 2020, Suryanto *et al*. 2020).

Nitrogen plays a role in chlorophyll formation in leaves (Marschner, 2012). The problem with nitrogen fertilization is the low efficiency due to high NL (Zhao *et al.* 2019). Biochar is an organic material formed from pyrolysis. Biochar can absorb CO_2 in the atmosphere, improve soil physical and chemical properties and increase inorganic fertilizer efficiency and crop yields (Coumaravel *et al*. 2011). Waste from the distillation of *M. cajuputi* leaves is a problem in Indonesia because of its enormous availability and un-utilization. *M. cajuputi* has the potential to be used as biochar and compost (Alam *et al*. 2020). Nurmalasari *et al*. (2020) reported that *M. cajuputi* biochar could increase the efficiency of urea fertilization by 18.22% while reducing N loss and increasing maize yield by 46.81% and 61.78%, respectively, compared with single urea application.

The deep placement application of 10 tons ha^{-1} biochar made from *M. cajupti* waste of 100 kg ha^{-1} ammonium sulfate produces soybean yield by 1.42 tons ha^{-1} (Alam *et al*. 2020). This value is still lower than the potential and actual yield of Grobogan varieties, which are 3.40 and 2.77 tons ha^{-1}, respectively (Indonesian Legumes and Tuber Crops Research Institute, 2016). The release rate of nutrients from fertilizers must be slower than that from fertilizers in which the nutrients are readily available for plant uptake. Use of nutrient briquette has the potential to increase fertilization efficiency and yield and reduce soil nutrient loss (Torne *et al*. 2017).

This study aims to evaluate the interaction of biochar briquette (BB) with ammonium sulfate fertilizer (ASF) for controlled NL in soybean intercropping with *M. cajuputi*.

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MATERIALS AND METHODS

The study was conducted in the wet season from November to February 2020 at Menggoran Forest Resort, Playen Forest Section, Yogyakarta Forest Management District, Indonesia. The average air temperature and relative humidity were 29.50 °C and 85.90%, respectively. The soil type was Lithic Haplusterts (Alam *et al*. 2019, Suryanto *et al.* 2020). The soil texture was dominated clay texture. CEC and pH H_2O were included in a very high category (58.78 $cmol^{(+)}$ kg^{-1}) and alkaline category (8.16). The SOM (2.62%), total N (0.13%), available of P (7 ppm) and available of K (0.41 $cmol^{(+)}$ kg^{-1}) were classified into the low category.

Experimental design

The experimental design was a randomized complete block design factorial with three blocks as the response surface methodology (RSM). The treatments included different levels of biochar briquette from *M. cajuputi* waste (0, 2 and 4 grain $plant^{-1}$ or 0, 5 and 10 tons ha^{-1}) and nitrogen fertilizer supplied by ammonium sulfate (0, 50 and 100 kg ha^{-1}) as independent variables.

Biochar was made from the waste of distilled *M. cajupti* leaves using the Kiln Traditional Method (Emrich, 1985). The process of making BB consisted of mixing, molding and drying. Each briquette weighed 10 g. The ASF used was from *Zwavelzure Ammoniac* (ZA) brand. The ZA fertilizer used in this study contained 20.93% N-NH_4^+ and 23.84% S-SO_4^{2-}. The pH(H_2O), C, H, N and O in the biochar briquette 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 (Alam *et al*. 2020).

Soybean variables

The observation parameters were nitrate reductase activity (NRA) (Krywult and Bielec, 2013), total chlorophyll (TC) (Gross, 1991), leaf photosynthesis rate (LPR) (Li-Cor, 1999), nitrogen loss (NL) (Fageria, 2014), nitrogen use efficiency (NUE) (Rathke *et al*. 2016) and seed yield (SY) (Alam *et al*. 2019, Suryanto *et al*. 2020).

Statistical analysis

The RSM equation used in this experiment applied the uncoded independent variables as follows (Koocheki *et al*. 2014, Myers *et al*. 2009). The fitted model was an evaluation by the R^2, 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 BB with ASF were calculated under the economy scenario using the SY variable and estimation with ridge regression (Koocheki *et al*. 2014, Marquardt and Snee, 1975). All analyses were performed using PROC RSREG in SAS 9.4 (SAS Institute, 2013).

RESULTS AND DISCUSSION

Fitted models for soybean variables

RSM is one of the statistical methodologies used to obtain optimum results (Myers *et al.* 2009). The lack-of-fit test was used to evaluate the quality of the fitted model. The lack-of-fit test was not significant for all soybean variables so that all models were fitted to use (Table 1).

Estimated response for soybean variables of experimental factors

An interaction was found between BB with ASF in all soybean variables (Table 1). The applications of BB and ASF significantly increased NRA. BB showed a linear pattern, whereas ASF showed a quadratic pattern (Table 1). The applications of 4 grain $plant^{-1}$ BB with 100 kg ha^{-1} ASF produced the highest NRA by 3.86 µmol NO_2^- g^{-1} h^{-1} (Table 2). NRA showed a positive correlation with ammonium and nitrate content in the soil (Loussaert *et al*. 2018). Purbajanti *et al*. (2016) reported that 100 kg ha^{-1} ASF increases NRA content by 120.88% compared with that without ASF.

The applications of BB and ASF significantly increased TC. The BB showed a linear pattern, whereas the ASF showed a quadratic pattern (Table 1). The treatments of 4 grain $plants^{-1}$ BB with 100 kg ha^{-1} ASF produced the highest

Table 1: Regression coefficients and the fitted model.

Runs	Regression coefficient of independence variables					
	NRA (µmol NO_2^- g^{-1} h^{-1})	TC (g g $leaf^{-1}$)	LPR (µmol CO_2 m^{-2} s^{-1})	NL (kg ha^{-1})	NUE (kg grain kg $N_{fertilizer}^{-1}$)	SY (tons ha^{-1})
b_0	2.612**	0.528**	331.948**	6.504**	1.191**	0.676**
b_1x_1	0.155**	0.013**	4.302*	-2.278*	0.115^{ns}	0.045**
b_2x_2	0.015**	0.002**	1.301**	0.270**	0.058**	0.011**
$b_{11}x_1^2$	0.002^{ns}	0.001^{ns}	1.551**	0.768**	0.086**	0.012*
$b_{12}x_1x_2$	-0.001*	-0.00006*	-0.037**	-0.030**	-0.0004**	-0.0004**
$b_{22}x_2^2$	-0.00006**	-0.00001**	-0.005**	0.0001**	-0.0002**	-0.00005**
R^2	**0.97****	**0.99****	**0.99****	**0.98****	**0.99****	**0.99****
RMSE	**0.07**	**0.01**	**2.57**	**1.66**	**0.11**	**0.02**
Lack-of-fit	**0.27^{ns}**	**0.15^{ns}**	**0.48^{ns}**	**0.19^{ns}**	**0.21^{ns}**	**0.22^{ns}**

* and ^{ns} significant and no significant at ($p < 0.05$). ** significant at ($p < 0.01$). x_1 and x_2 indicates biochar briquette (grain $plant^{-1}$) and ammonium sulfate 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.

TC value by 0.69 g g leaf^{-1} (Table 2). Solanki *et al*. (2018) informed that integration between organic with inorganic fertilizer increases the chlorophyll content in leaves compared with that without fertilizer and a single application of inorganic fertilizer.

The applications of BB and ASF significantly and very significantly increased the LPR. The BB and ASF showed quadratic patterns (Table 1). Treatments of 4 grain plant^{-1} BB with 100 kg ha^{-1} ASF showed the highest LPR of 437.72 µmol CO_2 m^{-2} s^{-1} (Table 2). Increased photosynthesis capacity contributed to an increase in biomass and yield. The application of biochar increased the photosynthesis rate and the WUE in potatoes (Akhtar *et al*. 2014). Increased N fertilization into the soil significantly increases stomatal conductance, transpiration rate, intercellular CO_2 concentration and soybean growth (Zhang *et al*. 2013).

BB significantly increased NL, whereas ASF very significantly increased NL. The regression patterns of BB and ASF were quadratic (Table 1). The applications of 0 grain plant^{-1} BB with 100 kg ha^{-1} ASF showed the highest NL of 35.60 kg ha^{-1} (Table 2). The integration between organic and inorganic fertilizers is useful for increasing N uptake, NL and maize yield (Dunjana *et al*. 2012). Increased N fertilization showed a significantly positive correlation with

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

Runs	Dependent variables		Estimates response of independent variables					
	BB (grain plant^{-1})	ASF (kg ha^{-1})	NRA (µmol NO_2^- g^{-1} h^{-1})	TC (g g leaf^{-1})	LPR (µmol CO_2 m^{-2} s^{-1})	NL (kg ha^{-1})	NUE (kg grain kg $N_{fertilizer}^{-1}$)	SY (tons ha^{-1})
1	0	0	2.56	0.53	332.24	5.13	1.22	0.68
2	2	0	2.95	0.55	344.29	7.35	1.67	0.79
3	4	0	3.30	0.60	376.14	8.72	3.09	1.08
4	0	50	3.31	0.61	384.32	20.77	3.50	1.15
5	2	50	3.38	0.64	397.70	15.68	4.21	1.26
6	4	50	3.62	0.68	415.26	17.01	5.19	1.40
7	0	100	3.43	0.65	408.50	35.60	4.81	1.34
8	2	100	3.69	0.68	416.49	24.90	5.26	1.41
9	4	100	3.86	0.69	437.72	27.05	6.53	1.57

BB= Biochar briquette, ASF= Ammonium sulfate fertilizer, NRA= Nitrate reductase activity, TC= Total chlorophyll, LPR= Leaf photosynthesis rate, NL= Nitrogen loss, NUE= Nitrogen use efficiency, SY= Seed yield.

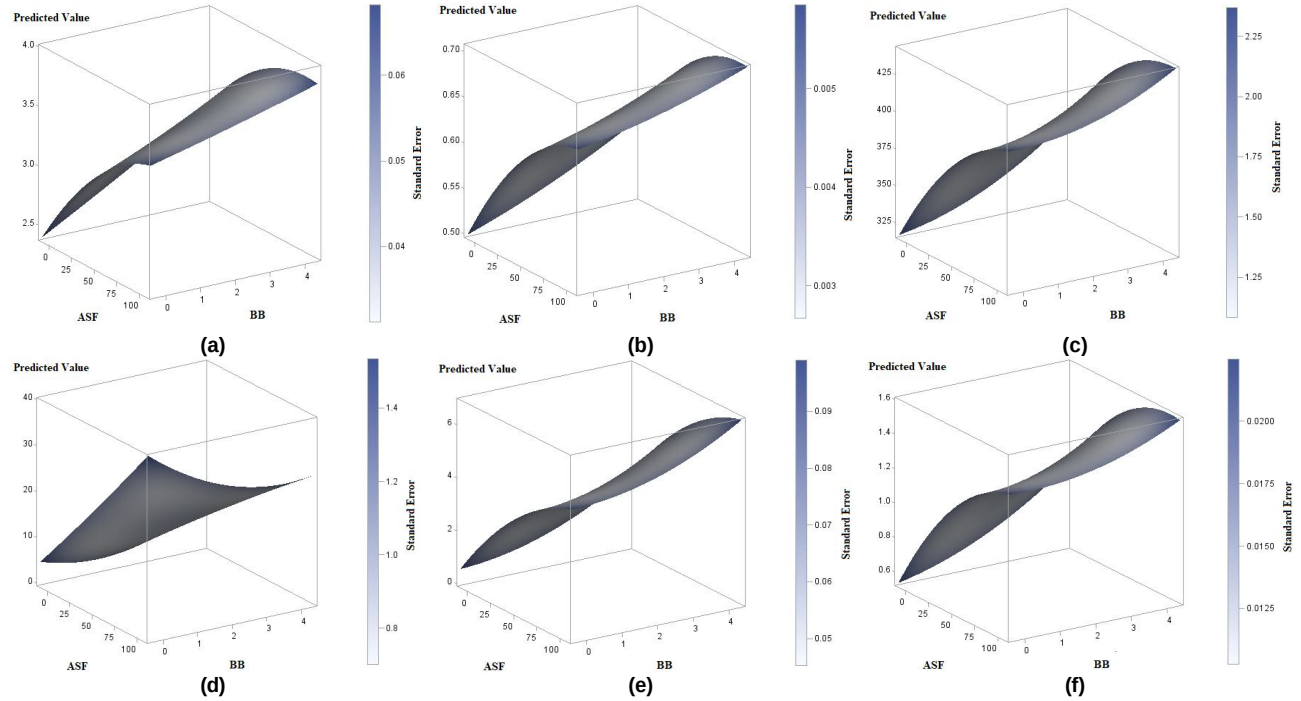


Fig 1: The variables response to the biochar briquette (BB) (grain plant^{-1}) and ammonium sulfate fertilizer (ASF) (kg ha^{-1}). **a).** NRA= Nitrate reductase activity (µmol NO_2^- g^{-1} h^{-1}), **b).** TC= Total chlorophyll (g g leaf^{-1}), **c).** LPR= Leaf photosynthesis rate (µmol CO_2 m^{-2} s^{-1}), **d).** NL= Nitrogen loss (kg ha^{-1}), **e).** NUE= Nitrogen use efficiency (kg grain kg $N_{fertilizer}^{-1}$), **f).** SY= Seed yield (tons ha^{-1}).

increased N loss through the leaching process, namely, 187.50% nitrate and 28.10% ammonium (Zhao *et al*. 2019).

The BB treatment did not significantly increase NUE, whereas ASF very significantly increased NUE. BB and ASF showed quadratic patterns (Table 1). The applications of 4 grain plant^{-1} with 100 kg ha^{-1} showed the highest NUE of 6.53 kg grain kg $N_{fertilizer}^{-1}$ (Table 2). Biochar can increase plant growth and yield, as well as NUE, by rising the CEC and sustaining the water holding capacity in the soil (Hagner *et al*. 2016). A positive relationship was established between N fertilizer and increased NUE. Biochar exerts a positive influence on plant growth by increasing NUE (Clough and Condron, 2010). NUE has a positive correlation with N application in the soil. Fertilization of N under optimum conditions maximizes NUE (Abebe *et al*. 2017).

The applications of BB and ASF very significantly increased SY. The treatments of BB and ASF showed quadratic patterns (Table 1). Under the treatments of 4 grain plant^{-1} of BB with 100 kg ha^{-1} ASF showed the highest SY of 1.568 ton ha^{-1} (Table 2). Kanouo *et al*. (2018) reported that biochar has the potential as a soil amendment on degraded soil while increasing the legume yield by 40% and total biomass by 25%. The addition of NH_4^+-N is significantly correlated with the increased soybean yield intercropping with *kayu putih* (Alam *et al*. 2019).

RSM revealed that the optimum dose of 3.70 grain plant^{-1} or 9.25 tons ha^{-1} BB with 76.31 kg ha^{-1} ASF yielded the maximum NRA, TC, LPR, NL, NUE and SY values of 3.73 µmol NO_2^- g^{-1} h^{-1}, 0.67 g g leaf^{-1}, 428.82 µmol CO_2 m^{-2} s^{-1}, 21.31 kg ha^{-1}, 5.93 kg grain kg $N_{fertilizer}^{-1}$ and 1.44 tons ha^{-1}, respectively (Figs 1a, 1b, 1c, 1d, 1e, 1f). Coumaravel *et al.* (2015) informed that the application of biochar combined with NPK fertilizer can increase the sustainability of soil fertility and maize productivity.

The theory behind the briquette is that a smaller surface area to volume ratio of briquette can significantly reduce N loss through ammonia volatilization (Torne *et al*. 2017). Urea applied on the surface can reach N loss as high as 35%. However, buried briquette only lose approximately 4% N, which is a considerable improvement in NUE (IFCD, 2013).

CONCLUSION

A positive interaction was found between BB from *M. cajuputi* waste with ASF for all soybean variables. The optimum values were 3.70 grain plant^{-1} or 9.25 tons ha^{-1} BB and 76.31 kg ha^{-1} ASF reduced the use of ASF by 23.69% and increased NRA, TC, LPR, NL, NUE and SY by 6.09%, 6.25%, 4.07%, -38.25%, 19.07% and 13.02%, respectively, compared with the single application of ASF.

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