Original Research Article

Improvement of Nitrogen Use Efficiency Derived from Ammonium Sulfate Substitute Fertilizer in Sugarcane Cultivation through the Addition of Organic Soil Amendment

ABSTRACT

For increasing nutrient use efficiency and cane yield on application of ammonium sulfate (AS) fertilizer substitution was performed through addition of soil amendment. A pot experiment was conducted for seven month of sugarcane growth. The experiment used factorial randomized complete block design with three replication. Factor I was the application of AS fertilizer and its substitution which consisted of nine levels : three treatments using AS fertilizer, three treatments of AS substitute fertilizers using the mixture of urea+gypsum and three treatments using the mixture of urea+gypsum+biocompost. Factor II was the kinds of soil amendment which consisted of three levels : calcite, boiler ash, and biochar of sugarcane trash and one control treatment. The measured variables were leaf N content and uptake, nutrient use efficiency, and yield variables. The results of this study showed that the treatment using mixture of urea+gypsum tend a higher N uptake than AS fertilizer. Application of boiler ash and biochar had the highest N nutrient upatake. The highest nutrient use efficiency was found at the lowest rate of mixture of urea+gypsum (100 kg N ha^{-1}) with application of soil amendment using biochar or boiler ash. The average increase in cane yield on this treatment compared to control by 250%. It is suggested that application of organic soil amendment is needed to increase N use efficiency of AS substitute fertilizer.

Keywords: Ammonium Sulfate fertilizer, soil amendment, N use efficiency, cane yield

1. INTRODUCTION

The change from conventional to organic farming in the sugarcane cultivation can not be done directly but requires several stages of substitution that can be started from replacing chemical fertilizers commonly used with a mixture of inorganic and organic fertilizer that is more environmental friendly. The process of these changes require more information about the characteristics and the environmental impact of conventional farming practices in the sugarcane cultivation. For example, the substitution of N fertilizer derived from Ammonium sulfate (AS) with other fertilizers requires knowledge about the negative impact of the AS fertilizer.

Overuse of AS fertilizer in the long-term can have a negative impact on the soil properties. Soil chemical changes under sugarcane is soil acidification. The major cause of soil acidification is the use of N fertilizers producing NH_4^+ such as Ammonium Sulfate (AS) [1]. Oxidation of N and S derived from AS fertilizer produced HNO_3 and H_2SO_4 by nitrifying and oxidation microorganisms [2], thereby soil pH reduced due to application of AS fertilizer [3]. To improve soil properties is required the addition of soil amendment.

Efforts in substitution of AS fertilizer as a source of Nitrogen (N) nutrient in sugarcane cultivation has been studied by several researcher using urea fertilizer [4], Ammonium Nitrate fertilizer [5], filter cake of sugar mill [6], and a combination of chemical fertilizer and organic fertilizer [7]. Substitution of ammonium sulfate fertilizer used combination of urea, gypsum, and biocompost showed a similar plant growth with the treatment using AS fertilizer [3]. However, N and S uptake in this treatment is still not optimal [8]. Thus, to increase nutrient uptake and nutrient use efficiency, soil improvement is needed through application of soil amendment.

Recently, biochar is one of organic soil amendment gets special attention by researcher. The other soil amendments suggested for improving the soil acidification of sugarcane land is sugar mill wastes such as boiler ash, filter cake, and sugar cane trash. [9] reported that the addition of boiler ash raised soil pH and increased crop yields. The effect being greater at the higher rate. Biochar is charcoal produced during pyrolisis, a process where organic material is heated under low oxygen conditions. One usage of biochar from crop residues is as soil amendment. The availability of sugarcane trash every harvest may reach 10-15% of the total potential of cane yield [10]. Thus, for an area of 1 ha with a yield of 100 tons of sugarcane, the amount of sugarcane trash as much as 10-15 ton. The great amount of sugarcane trash has the potential to be used as biochar that can be used as soil amendments. Biochar has a large surface area and porosity thereby ability adsorb or retain nutrients and water [11, 12, 13]. In addition, biochar can also improve aggregation, increase water holding capacity, and decrease soil bulk density [14, 15]. Application of biochar in the acid soils increase soil pH, base cations and CEC [13.15]) and increase crop yield [16, 17]. The objective of this study was to describe the combination effect of N fertilization derived from AS fertilizer and its substitute fertilizer and some soil amendments on sugarcane crop yield, N uptake and nitrogen use efficiency.

2. MATERIAL AND METHODS

2.1 Study Site and Soil Characteristics

This study is a pot experiment conducted at the experimental field of Agriculture Faculty of Islamic University of Malang in January-August 2014 with an altitude of 505 m above sea level, the average temperature of 20^o-28^o C and rainfall is 1750 mm / year. Soils were collected from sugarcane land at Karangploso district , Malang regency, East Java. The soils were chosen to be representative of the group of soils from sugarcane land which have low soil pH. Samples (0-10 cm) were taken from areas under sugarcane monoculture more than 10 years. The soil had a clay content of 18.1 %, a silt content of 61.4%, and a sand content of 20.5%. The soils were analyzed for chemical properties and the results are presented in Table 1. The soil samples were used in a pot experiment in which sugarcane was grown.

Table 1. Some selected chemical properties of the soils used in this study

Soil type	pH 1:1		C-Organic (%)	N-total %	C/N	OM content %	P-Bray 1 (mg kg^{-1})	K	CEC	SO_4^{2-}
	H_2O	KCl						me/100 g		mg kg^{-1}
Inceptisols	4.9	4.5	1	0.12	8.3	1.73	60.56	0.16	18.65	6.20

2.2 Soil Amendment Preparation

The boiler ash originated from *Kebon Agung* Sugar Mill, Malang regency, East Java, while sugar cane trash came from farmers' sugarcane land. Sugarcane biochar was made in the Bioenergy Laboratory by pyrolysis process. Sugarcane trash were put in a reactor to a slow burning process (carbonation) at a temperature of 300 - 400°C for about six hours with the absence of oxygen. After the combustion, cool charcoal was taken from the combustion reactor and ready to use. The chemical characteristic of boiler ash and sugarcane trash biochar was presented in the Table 2.

Table 2. Some chemical properties of soil amendments

Soil Amendments	pH (H_2O)	Total Element Content (%)						C (%)	CEC me/100g	Water Content (%)
		N	P	K	Ca	Mg	Na			
Boiler Ash	7.85	0.05	0.57	0.51	2.27	1.22	0.18	2.24	6.24	7.46
Sugarcane Trash Biochar	8.35	0	0.16	0.18	0.46	0.42	1.4	18.42	17.52	5.42

2.3 Experimental Design

This research was a pot experiment which used factorial randomized complete block design with three replications. The first factor consisted of nine treatments as shown on the Table 3.

Table 3. Treatments used in this study for the first factor

Treatments	N rates (kg ha^{-1})	S rates (kg ha^{-1})	AS fertilizer (kg ha^{-1})	Urea fertilizer (kg ha^{-1})	Gypsum (kg ha^{-1})	Biocompost (kg ha^{-1})
T1	100	120	500	-	-	-
T2	140	168	700	-	-	-
T3	180	216	900	-	-	-
T4	100	120	-	223	522	-
T5	140	168	-	312	730	-
T6	180	216	-	400	938	-
T7	100	120	-	110	522	1950
T8	140	168	-	155	730	2750
T9	180	216	-	200	938	3550

Remarks : S content of AS Fertilizer = 24 %; N content of AS fertilizer = 20 %; S content of Gypsum = 19 %; N content of Urea fertilizer = 45%; N content in Biocompost = 2.57%. Gypsum is used as S fertilizer source and Ca content in Gypsum not calculated in the dose of the treatments

The second factor was kind of soil amendments which consisted of three levels that are calcite (A1), boiler ash of sugar industry (A2), and biochar of sugarcane trash (A3). From both factors was obtained 27 treatments and one control treatment (no fertilizer and soil amendment). Thus, the total of experimental pots used were 84 pots.

2.4 Experiment Procedure

For the pot experiment, the soil samples used as growing medium were air-dried and ground. 84 plastic pots (top diameter = 47 cm, bottom diameter = 40 cm, and height = 32 cm) were filled with 40 kg dry soil. Each plastic pot was perforated by 20 holes. The soil amendments were added to the soil one week before planting at rate of 5 ton ha^{-1}, equivalent to 100 g per 40 kg soil on dry weight basis. They were mixed thoroughly with the soil. Sugarcane seeds of BL-red had been the most widely planted sugarcane cultivar in East Java, were planted after seedling for 1 month, and coincided with on week after the application of soil amendments. Each pot was planted by 1 seed sugarcane by digging the soil as deep as 10 cm and then the seeds directly planted. Basal dressing of P and K (15:15) at rates 400 kg ha^{-1} were applied to each pot. The chemical fertilizer of the treatments were applied at 2 weeks after planting. Rates of chemical fertilizer were applied in accordance with the predetermined treatments. N fertilizer was applied 2 times that of the first on the plant age of 2 and 6 weeks after transplanting. All fertilizer was banded as deep as 10 cm below surface.

2.5 Measurement of Observation Variables

The variables of sugarcane yield were consisted of leaf N content, fresh weight of cane yield and total biomass, and dry weight of total biomass. Leaf samples from top of the plants were collected for analysis of leaf N content and N uptake at four months of plant age. The leaf samples were chopped, homogenized, and dried at 70^{o}C in a hot-air oven. The dried samples were ground in a stainless steel mill and wet-acid oxidation is based on a Kjeldahl oxidation in concentrated H_2SO_4 for determination of total N [18].

2.6 Calculation of Nutrient Use Efficiency

Nutrient Use Efficiency was calculated by four agronomic indices : (1) Partial factor productivity (PFP) : kg crop yield per kg nutrients applied, (2) Agronomic efficiency (AE) : kg crop yield increase per kg nutrient applied, (3) Recovery efficiency (RE) : kg nutrient taken up per kg nutrient applied), and (4) Physiological efficiency (PE) : kg yield increase per kg nutrient taken up. Crop removal effiency : removal of nutrient in harvested crop as % of nutrient applied [19].

2.7 Statistical Analysis

The collected data was statistically analyzed by using analysis of variance (ANOVA) (F-Test) at level (P≤0.05) for the factorial randomized block design and differences in each treatment were adjudged by Tukey test (P≤0.05) using program Minitab Vers.14.12. For statistical analysis of data (charts), Microsoft Excel was employed.

3. RESULTS AND DISCUSSION

3.1 Effect of Ammonium Sulfate and Its Substitute Fertilizer and Soil Amendment on Nutrient Uptake Yield.

Based on ANOVA analysis, the fertilization treatment derived from AS and its substitute fertilizer (T) and application of three soil amendments (A) significantly affected N leaf content, N uptake, cane yield, fresh weight of total biomass and dry weight of total biomass. All of treatment combinations were significantly higher than control (Table 4).

Table 4. Probabilities of F-values of fixed effects for leaf N content and N uptake, cane yield, fresh weight of total biomass, dry weight of total biomass, exposed to nine N fertilization treatments derived from AS, the mixture of urea+gypsum, and urea+gypsum+biocompost (T) and three kinds of soil amendment (A).

Fixed Effect	N Leaf Content	N Uptake	Cane Yield	Fresh Weight of Total Biomass	Dry Weight of Total Biomass
Treatments Vs.Control	43.78**	85.81**	62.02**	69.69 **	69.69**
Treatments	9.43**	16.81**	21.56**	21.41 **	21.41**
Fertilization (T)	24.29**	46.42**	55.86**	54.93 **	54.93**
Soil Amendment (A)	1.96^{ns}	13.35**	21.97**	25.47**	25.47**
T x A	2.93*	2.44*	4.36**	4.13**	4.13**

** and ** sign : significant at the P= 0.05 and P= 0.01 probability levels, respectively.*

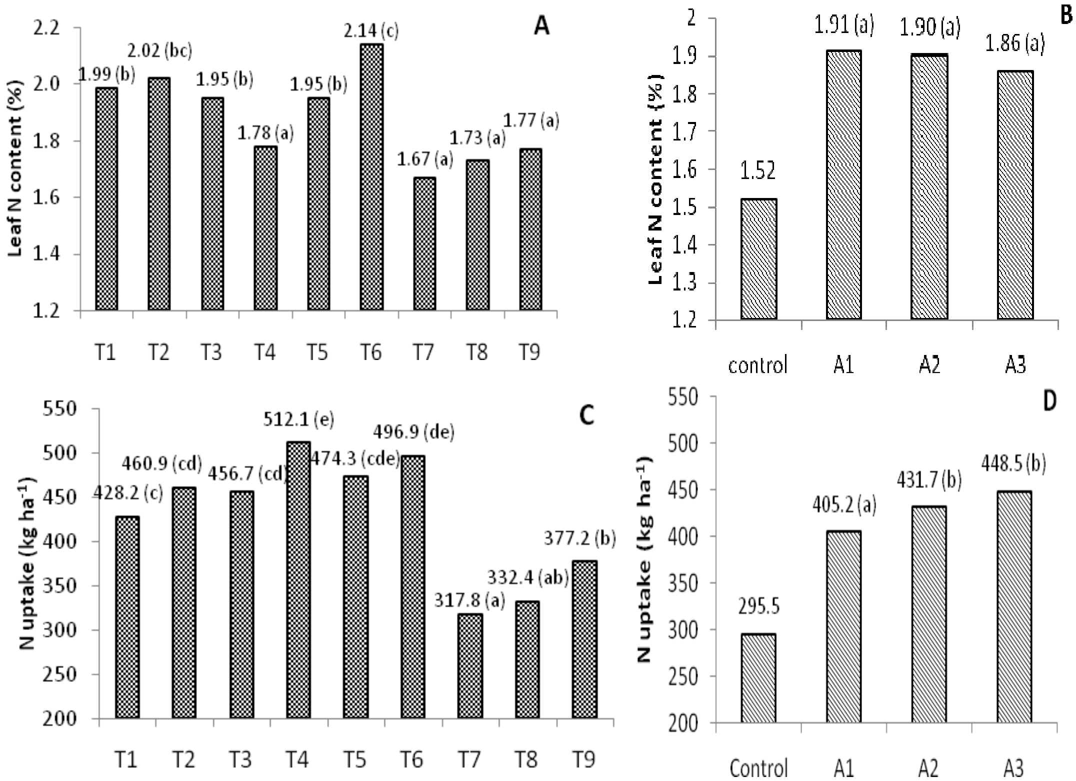

Fig.1. Effect of AS and its substitute fertilizer (A+C) (LSD=0.14 and 47.16) and soil amendments (B+D) (LSD= 0.06 and 20.24) on leaf N content and N uptake.

The T6 treatment using the mixture of 400 kg urea+938 kg gypsum per ha equivalent to 150 kg N/ha and 216 kg S/ha (Fig. 1A) had the highest leaf N content, whereas the highest N uptake was found at the T4 treatment, but not significantly different with the T5 and T6 treatments (Fig. 1C). The kind of soil amendment did not affect leaf N content (Fig. 1B) but it significantly affected N uptake (Fig.3 D). Application of biochar and boiler ash had the highest N uptake (Fig. 1D) with the average increase of the T6 treatment and biochar application by 41 % and 73 %, respectively compared to control. This results showed that application of biochar and boiler ash as soil amendment can improve soil properties, thereby it can increase nutrient availability and uptake.

3.2 Effect of Ammonium Sulfate and Its Substitute Fertilizer and Soil Amendment on Nitrogen Use Efficiency.

Based on ANOVA analysis, there was no interaction effect between fertilization treatment and soil amendment application, but the fertilization treatment derived from AS and its substitute fertilizer (T) and application of three soil amendments (A) significantly affected nutrient use efficiency that calculated by Partial Factor Productivity (PFP), Agronomic efficiency (AE), Recovery efficiency (RE), Physiological Efficiency (PE) and Crop Removal Efficiency (CRE) : removal of nutrient in harvested crop as % of nutrient applied.

Overall, the highest nutrient use efficiency was found at the T4 treatment (Tabel 5). This is caused by this treatment contains the lowest applied N rate equivalent to 100 kg N ha^{-1}. In line with this research result, [20] reported that fertilizer use efficiency can be optimized by fertilizer best management practices that apply nutrient at the right rate. The highest nutrient use efficiency always occurs at the lowest fertilizer inputs.

Table 5. Effect of AS and its substitute fertilizer (T) and soil amendments (A) on Nitrogen use efficiency

Treatments	PFP		AE		RE		PE		CRE	
T1	519.44	c	173.61	bcd	1.67	b	40.66	ab	0.83	a
T2	481.15	bc	234.13	d	1.44	b	68.67	bc	1.06	ab
T3	387.35	abc	195.22	cd	1.10	a	76.61	cd	0.79	ab
T4	861.39	d	515.56	e	2.53	c	100.93	d	1.68	bc
T5	511.90	c	264.88	d	1.53	b	76.88	cd	1.85	c
T6	371.91	abc	179.78	bcd	1.32	b	65.35	bc	0.86	ab
T7	441.67	abc	95.83	abc	0.58	a	29.45	a	0.41	a
T8	314.48	ab	67.46	a	0.52	a	28.31	a	0.35	a
T9	285.49	a	93.36	ab	0.65	a	43.96	ab	0.42	a
LSD (*P*=0.05)	180.31		100.84		0.58		28.62		0.78	
A1	431.32	a	169.66	a	1.09	a	52.55	a	0.97	a
A2	456.98	a	195.32	a	1.30	ab	57.84	ab	0.82	a
A3	503.30	a	241.63	b	1.39	b	66.56	b	0.96	a
LSD (*P*=0.05)	77.39		43.28		0.24		12.28		0.54	

Means followed by different letters in the same column for each treatment of T and A are statistically significant different at Tukey- test, P=0.05

The highest nutrient use efficiency was found at the application soil amendment using biochar and boiler ash. The beneficial effect of soil amendments was due to rise in the soil reaction up to 6.5 (unpublished data of this experiment) with an initial pH value of the soil by 4.9, boiler ash by 7.85 and sugarcane trash biochar by 8.35 (Table 2), thereby it increase availability and N uptake although N applied at a low rate. [21] reported NUE not only depends on the ability to efficiently take up the nutrient from the soil, but also on transport, storage, mobilization, usage within the plant and even on the environment. If a plant is grown at the condition of nutrient deficiency stress, it will be efficiently take up the nutrient from the soil. However, the effectiveness of fertilizers in increasing crop yields and optimizing farmer profitability should not sacrificed for efficiency alone. There must be a balance optimal nutrient use efficiency and optimal crop productivity.

3.3 Effect of Ammonium Sulfate and Its Substitute Fertilizer and Soil Amendment on Yield of Sugarcane.

The T4 treatment using the mixture of 223 kg urea+ 522 kg gypsum per ha equivalent to 100 kg N/ha and 120 kg S/ha (Fig. 2A) and application of biochar had the highest cane yield (Fig. 2B) with the average increase of the T4 treatment and biochar application by 250 % and 95 %, respectively compared to control.

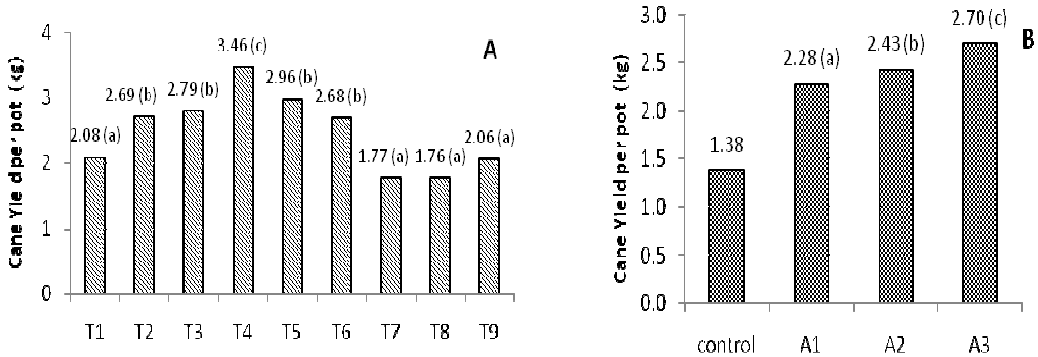

Fig 2. Effect of AS and its substitute fertilizer (A) (LSD=0.36) and soil amendments (B) (LSD=0.14) on cane yield at seven months of plant age.

The same results were found on the variables of fresh and dry weight total biomass, which the T4 treatment had the highest fresh and dry weight of total biomass, whereas the treatment of soil amendments showed that the application biochar had the highest of fresh and dry weight of total biomass but not significantly different with the application of boiler ash (Fig.3). Nitrogen is the primary nutrient limiting sugarcane production. It greatly determines the cane yield level achieved as this nutrient can affect tiller formation and stem growth [22]). However, sugarcane response to N fertilization was affected by soil condition such as soil moisture [22]. and soil pH [23]. Application of biochar can improve soil properties such as water holding capacity, soil pH, base cations and CEC [13, 14, 15]. The soil improvement can increase plant growth and yield [16, 17, 15].

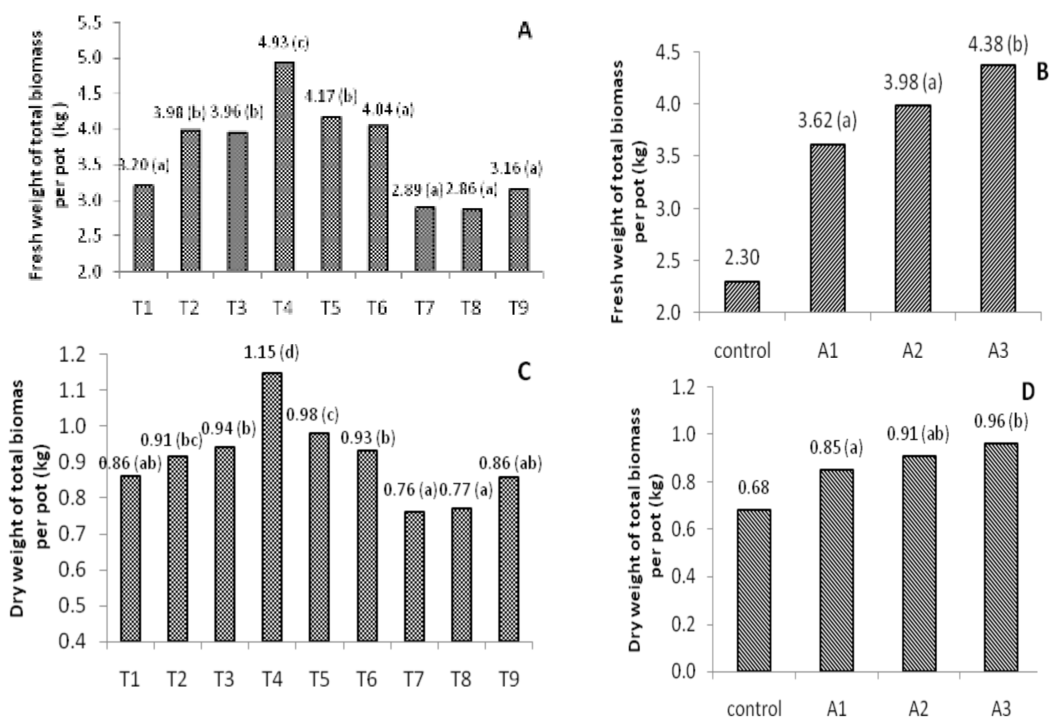

Fig.3. Effect of AS and its substitute fertilizer (A+C) (LSD=0.43 and 0.1) and soil amendments (B+D) (LSD= 0.39 and 0.1) on fresh weight and dry weight of total biomass at seven months of plant age.

4. CONCLUSION

Application of biochar and boiler ash increased N uptake and N use efficiency in the application of urea+gypsum mixture as AS substitute fertilizer. This increase had a positive impact on the sugarcane yield when compared with the control and use of AS fertilizer. The highest nitrogen use efficiency and yield improvement were found at the treatments using urea+gypsum mixture at the lowest rate by 223 kg urea + 522 kg gypsum equivalent to 100 kg N and 120 kg S per ha with the addition of biochar or boiler ash. This result suggested that the addition of biochar and boiler ash as organic soil amendment in sugarcane cultivation is recommended to optimize the use of AS substitute fertilizer.

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