

Ammonia Volatilization in Cocoa Farm as Affected by Sugarcane Filter Cake Supply at Different Urea and Soil Moisture Levels

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Abstract

Ammonia (NH₃) volatilization is a crucial mechanism in soil nitrogen (N) cycle. It accounts for main loss of N in cocoa farms when environment is suitable to promote the emission. A research to locate a link of several factors, namely, sugarcane filter cake (SFC), urea and soil moisture content to NH₃ volatilization, and to reveal cocoa N uptake and urea fertilizer efficiency was taken place both in a laboratory with the incubation technique, and in a greenhouse as a pot trial. The design was completely randomized design in factorial. The soil was Inceptisol from Kaliwining Experimental Station, Jember, East Java, collected from top soil of a productive cocoa farm. A closed trap system was designed to measure volatilized NH₃ from soil and SFC mixture incubated for 14 days. For the pot experiment, cocoa clone of Scavina 6 seedlings were grown for six months with treatments involving series level of SFC and series level of urea. Soil moisture content influenced volatilized NH₃ by reducing 50% emission in where it was more obvious in higher level of urea applied. It was more than 90% in average for the increase in volatilized NH₃ produced by increasing in level of urea from 0 to 0.4 g kg⁻¹ in overall level of combinations. An increase in urea level had resulted in increase in soil pH, and Pearson correlation suggested a direct link with volatilized NH₃. We found a relationship between SFC and volatilized NH₃ and their combinations with soil moisture and urea content were able to inhibit the emission. Emission decrease up to 28% was observed from 0 to 100 g SFC kg⁻¹. This inhibition may have contributed to the increase in N cocoa plant uptake by more than 70% compared to control and subsequent increase in N fertilizer supply efficiency up to 86% in the combination with 0.2 g urea kg⁻¹. The absence of SFC had made a decline in urea efficiency about 20 times.

Keywords: ammonia volatilization, sugarcane filter cake, urea, soil moisture, cocoa

INTRODUCTION

Suppling nitrogen (N) to soil, either as mineral N fertilizer or organic fertilizer is annually applied to the top soil to get sustainable production in cocoa (*Theobroma cacao* L.) farm. Nitrogen application mainly to sustain vegetative growth phase as well as to determine the quantity of pods produced for the incoming generative stage. Therefore, N availability is continuously required by cocoa trees, for

instance, to replace the loss due to in regular pruning and regrowth of new leaves, and growth of pods which occurs throughout the year (Wilson, 1999). As about 200 kg N/ha is required to build up the frame and canopy before the onset of pod production of cocoa trees (Wood & Lass, 2001), N is becoming an urgent among other nutrients.

Being varied with type, combination time application of fertilizer, a soil texture, soil

moisture content, rainfall after fertilization and evaporation rates (Ellington, 1986; Buresh, 1987; Matsushima *et al.*, 2009; Turner *et al.*, 2012), an appreciable amount of ammonium (NH_4^+) can be lost through ammonia (NH_3) volatilization which is considered to be the major loss mechanism for all N sources from agricultural soils (Buresh, 1987; He *et al.*, 2002). Application of urea accounts for 50% of the total world fertilizer N consumption (Sanz-Cobena *et al.*, 2008). Top-dressing of urea on moist soil undergoes chemical change to NH_3 and subjected to gaseous release to the atmosphere. It is estimated up to 25% of urea applied to the upland crops disappear by means of NH_3 volatilisation (Sommer & Jensen, 1994; Nieder & Benbi, 2008; Turner *et al.*, 2012), even more can be about 50% if surface application at moist soil (Ellington, 1986; Rochette *et al.*, 2009), which is the highest N loss reported among others type of N fertilizers. Subsequently, this volatilization is clearly reducing the efficiency of N supplied (Sanz-Cobena *et al.*, 2008), producing high farming cost, risking of ground and surface water from N potential contamination (He *et al.*, 2002), and negatively impacts on air quality (Liu *et al.*, 2007). Furthermore, to increase N fertilizer efficiency is becoming an urgent to establish level of both soil and plant productivity, meanwhile low status (<2%) of soil organic matter in mostly cocoa plantation now in Indonesia.

A number of research has been done to decipher N volatilization, and to set up many design to control those loss, for instance, Eriksen & Kjeldby (1987) observed a reduction of NH_3 loss by application of urea calcium nitrate; or Nieder & Benbi (2008) reported addition of water to slurry in the ratio of 3:1 slurry to reduce NH_3 losses by 44–91%. Moreover, He *et al.* (2002) observed an effectively decreasing in NH_3 emission by addition of cellulose, clinoptilolite zeolite and

the combination between those two into sandy soils. Investigation the use of urease inhibitor and nitrification inhibitor to minimize NH_3 emission were clearly reducing NH_3 emissions (Sanz-Cobena *et al.*, 2008; Soares *et al.*, 2012). Whereas, addition of Mg and Ca salts were also significantly able to reduce ammonia loss during the process of manure decomposition (Witter & Kirchmann, 1989). Moreover, urea amendment with combination of KCl, pyrite and CuSO_4 were found to decrease ammonia volatilization to 34%, compared to 48% in unamended urea (Reddy & Sharma, 2000).

Filter cake from sugar mill wastes for agriculture for long time has been considered to have a positive effect as important soil amendements and potential for use in crop production as it reduces N losses and an important C source (Roth, 1971; Dee *et al.*, 2002; Meunchang *et al.*, 2005). In Indonesia, it has been also used in several field trials to study the effects on soil properties, nutrient uptake and production of cocoa and coffee (Baon & Soenaryo, 1988; Baon & Soenaryo, 1989). Filter press cake as waste product of cane sugar mill using sulphitation process which is produced at a rate 4–5% of the total sugarcane production. In the field, it is generally disposed on land after being composted as base fertilizer before planting (Cheesman, 2004). This research aimed at quantifying ammonia volatilization and cocoa N uptake resulting from the interaction of SFC, urea and soil moisture content.

MATERIALS AND METHODS

The soil used for both laboratory and greenhouse experiment was Inceptisol based on Soil Taxonomy coming from Kaliwining Experimental Station, Indonesian Coffee and Cocoa Research Institute (ICCRI), Jember, East Java, Indonesia. The soil used was from

Table 1. Soil and sugarcane press cake characteristics prior the experiment

Sample characteristics	Values	
	Soil	SFC
Texture	clay loam	-
pH (H ₂ O)	6.80	-
pH (KCl)	4.90	-
Organic C (%)	0.96	10.75
Total N (%)	0.10	1.04
Total P ₂ O ₅ , HCl 25%, (ppm)	8.90	-
Available P ₂ O ₅ , Bray I, (ppm)	16.00	-
Exchangeable K (cmol(+) kg ⁻¹)	0.90	-
Exchangeable Na (cmol(+) kg ⁻¹)	1.25	-
Exchangeable Ca (cmol(+) kg ⁻¹)	16.75	-
Exchangeable Mg (cmol(+) kg ⁻¹)	7.05	-
Cation exchange capacity, CEC, (cmol(+) kg ⁻¹)	27.61	-
Sulphur, S, (%)	-	0.72
C/N	9.60	10.34

the surface 0–20 cm depth of productive cocoa (*Theobroma cacao* L.) farm, being maintained regularly by standard farming according to ICCRI guidelines. In addition, sugarcane filter cake (SFC) was sampled from a randomly selected sugar mill using sulphitation process in East Java, Indonesia. The preparation and routine soil and press cake analysis were performed in ICCRI Soil Laboratory and the results presented in Table 1.

To get suitable samples for handling and treatment, either the soils or SFC were provided based on ICCRI manual laboratory involving air-drying and homogenizing pass through $\phi < 2$ mm sieve. The SFC has a stable C/N ratio before the experiments set up (Table 1), as being composted for two months under the prevalent environment.

Experimental Design

This experiment was divided into two phases to reveal both N volatilization and uptake involving, (i) laboratory incubation to measure emitted NH₃ following SFC application in defined urea and soil moisture levels, and (ii) greenhouse pot trial to observe

N uptake by cocoa seedling in a series of SFC and urea doses.

The experiment was implemented in Soil Laboratory of ICCRI, Jember, East Java, Indonesia. The design of experiment for both laboratory and greenhouse trials were completely randomized design in factorial with three factors, namely dose of SFC, dose of urea and soil moisture level. The first factor was organized to four level of treatments namely as 0 g kg⁻¹; 25 g kg⁻¹; 50 g kg⁻¹; 75 g kg⁻¹ and 100 g kg⁻¹ of SFC (dry weight base). The second factor was four level urea doses, they were 0 g kg⁻¹; 0.2 g kg⁻¹; 0.4 g kg⁻¹; and 0.6 g kg⁻¹ of urea. The third factor was four levels of moisture 25%, 50%, 75%, and 100% of soil field capacity.

For pot experiment, cocoa clone of Scavina 6 seedlings was selected. Treatments were commenced two weeks after planting involving two factors, firstly series of SFC doses 0 g kg⁻¹; 25 g kg⁻¹; 50 g kg⁻¹; 75 g kg⁻¹; and 100 g kg⁻¹ and second factors of urea 0 g kg⁻¹; 0.20 g kg⁻¹; 0.40 g kg⁻¹; and 0.60 g kg⁻¹. Soil moisture was maintained in field capacity by regular manual water irrigation.

Ammonia Volatilization

To investigate NH_3 emission due to volatilization, simple experiment was designed using a closed trap system. Firstly, air-dried soil of 50 g was placed into a 100 mL glass bottle. Subsequently, SFC was added and followed by urea, and the soil mixture was blended properly. Water was added corresponded with the level of treatments. Rubber stoppers were used to close the bottles tightly to hinder the direct connection with atmosphere. On the other hand, the glass bottles were made possible to get connected with a 250 mL glass erlenmeyer by a plastic tube inserted within the hole-made on the both rubber stoppers, then sealed carefully using a parafilm to form airtight environment. Subsequently, the system was allowed to incubate at 25°C for 14 days. The erlenmeyers contained 10% H_3BO_3 + methyl red indicator to trap volatilized NH_3 from the soil mixture. By the end of observation period, the amount of NH_3 released were quantified by titrating the acid solution with 0.01 N $\text{KH}(\text{IO}_3)_2$ and the pH (H_2O) of soils were measured as well.

N Uptake and Fertilizer Efficiency

Plant biomass was harvested by the end of six months pot trial, oven-dried and weighed before grinded. The chemical analysis of N in plant tissue was performed by Kjeldahl method. N uptake values were obtained from multiplication of N concentration (%) over dry weight (g) of the plant biomass. Urea fertilizer efficiency (%) was calculated from the ratio between corrected N uptake (g/pot) and urea-N supplied (g/pot). Corrected N uptake is the difference between N uptake in treated-pot and control-pot to control bias of indigenous soil N.

All the data were compiled and statistically calculated with the analysis of variance to test the significance of both single and interactions among factors. The obtained data were tested with honestly significance difference (HSD) at 95% of the level of significance and followed by polynomial orthogonal test. Pearson correlation was used to test the relationship between volatilized NH_3 and soil pH. The analysis of statistics were performed by IBM SPSS Statistics 19.

RESULT AND DISCUSSION

The results of analysis of variance and F-test of two parameters examined, pH (H_2O) and volatilized NH_3 , were demonstrated in Table 2. Any single treatments of SFC, urea as well as moisture significantly influence the soil pH. Further analysis showed the interaction among the three factors in two or three components significantly affected soil pH after 14 days incubation experiment.

Generally, the interaction of urea and moisture in different levels of SFC contributed to the different soil pH. These relationships have been demonstrated in various pattern that clearly showed in the Figure 1. It can be seen a significant role of urea in boosting the increase in soil pH, as the obtained higher level of soil pH was in line with the higher level of urea. The models implied higher effect of urea than soil moisture.

Without addition of urea small increase soil pH over control was noticed by the input of SFC. It assumes that SFC act as liming material that may have donated more hydroxyl ion to soil solution, in which have a consistent result with a previous finding, for instance by Dee *et al.* (2002).

Various interaction effect of urea and SFC was found in application of urea 0.5 g kg^{-1} at different level of moisture. On the other hand, in addition of urea 1.0 and 1.5 g kg^{-1} ,

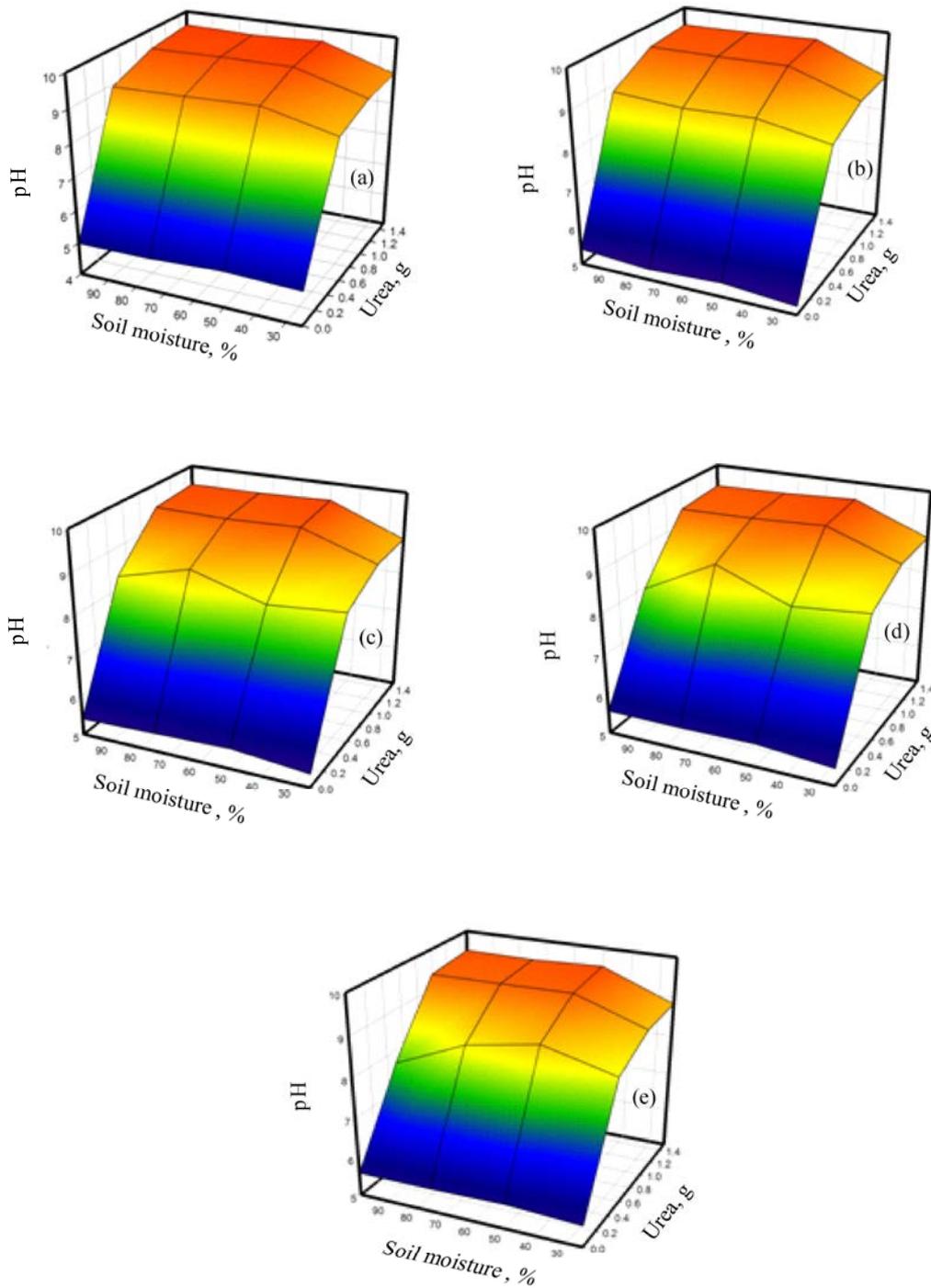


Figure 1. The interaction effect of soil moisture and urea on soil pH at 0, 25, 50, 75, and 100 g kg⁻¹ of SFC

Table 2. Analysis of variance and F-test of pH and ammonia volatilization

Treatments	Soil pH	NH ₃ volatilization
Sugarcane filter cake (SFC)	12.22 **	7.53 **
Urea (U)	74430.17 **	799.19 **
Soil moisture (M)	829.76 **	57.75 **
M x SFC	21.73 **	0.40 ^{ns}
M x U	230.05 **	34.54 **
FPC x U	155.87 **	1.68 *
M x SFC x U	22.09 **	0.16 ^{ns}

Notes: *Significant at the level of 5%; **Significant at the level of 1%; ^{ns} = not significant.

a significant difference in pH only observed in 25% field capacity, while in the higher level of 50, 75, and 100 % the values were comparable. There was no significant difference of the combination of 100 g kg⁻¹ SFC and no urea addition by the pH values resulted among different level of moisture, conversely, there were significant in the lower level of SFC of 0.25 and 50 g kg⁻¹. By increasing urea levels, there was obviously a raising in pH overall combination levels of both moisture and SFC, up to more than 70% in average. It observes more pronounced as the case in 50% and 75% field capacity, though nothing significant difference with 100%, in contrast with 25%, which suggest the higher rate of urea hydrolysis in the considerable amount of soil moisture. A proportional moisture will support hydrolysis reaction, particularly high moist soil (Mengel & Kirkby, 2001).

Interaction of no SFC and 0.6 g kg⁻¹ increased soil pH more than 85% in 50% field capacity compared to control, but no significant difference with other levels of SFC of the same level in urea and soil moisture. In the higher level of SFC, small increase of pH generated from urea addition. In the three combination 50% moisture produced high soil pH in each level. The highest pH value, 9.62, came from the combination of no SFC, high urea and 50% moisture.

Highest dosage of SFC produced lower pH than in no addition of SFC which signified the influence of SFC to inhibit the increase

of pH following urea supply. A significant organic matter concentration in SFC (Table 1), may have linked to the buffer effect of the soil system after addition of urea, to balance -OH released from urea hydrolysis.

Ammonia Volatilization

It shows from the 3D models (Figure 2), that urea has provided to be a main key in NH₃ volatilization involving soil moisture in different level of SFC. The peak of NH₃ emission occurred immediately from the onset of soil moisture level of 25% from field capacity.

Meanwhile both combination of single factors and interactions of either moisture and urea or SFC and urea were significantly raised NH₃ loss (Table 2), on the contrary, there was no significant interaction between the moisture and SFC implying an inhibition of NH₄ that may have derived from soil organic matter to volatile. The interactions among the three factors significantly hampered NH₃ volatilization. The cumulative volatilized NH₃ were <0.15 mg in no urea addition, insignificantly varying in different level of both SFC and moisture. Furthermore, the amount of volatilized NH₃ increased about 46% when moisture content increased from 25 to 50%, but reduced gradually afterwards until 100% soil moisture field capacity.

Generally, volatilized NH₃ may have been retarded in soil moisture content more than 50% as signified by an appreciable reduced

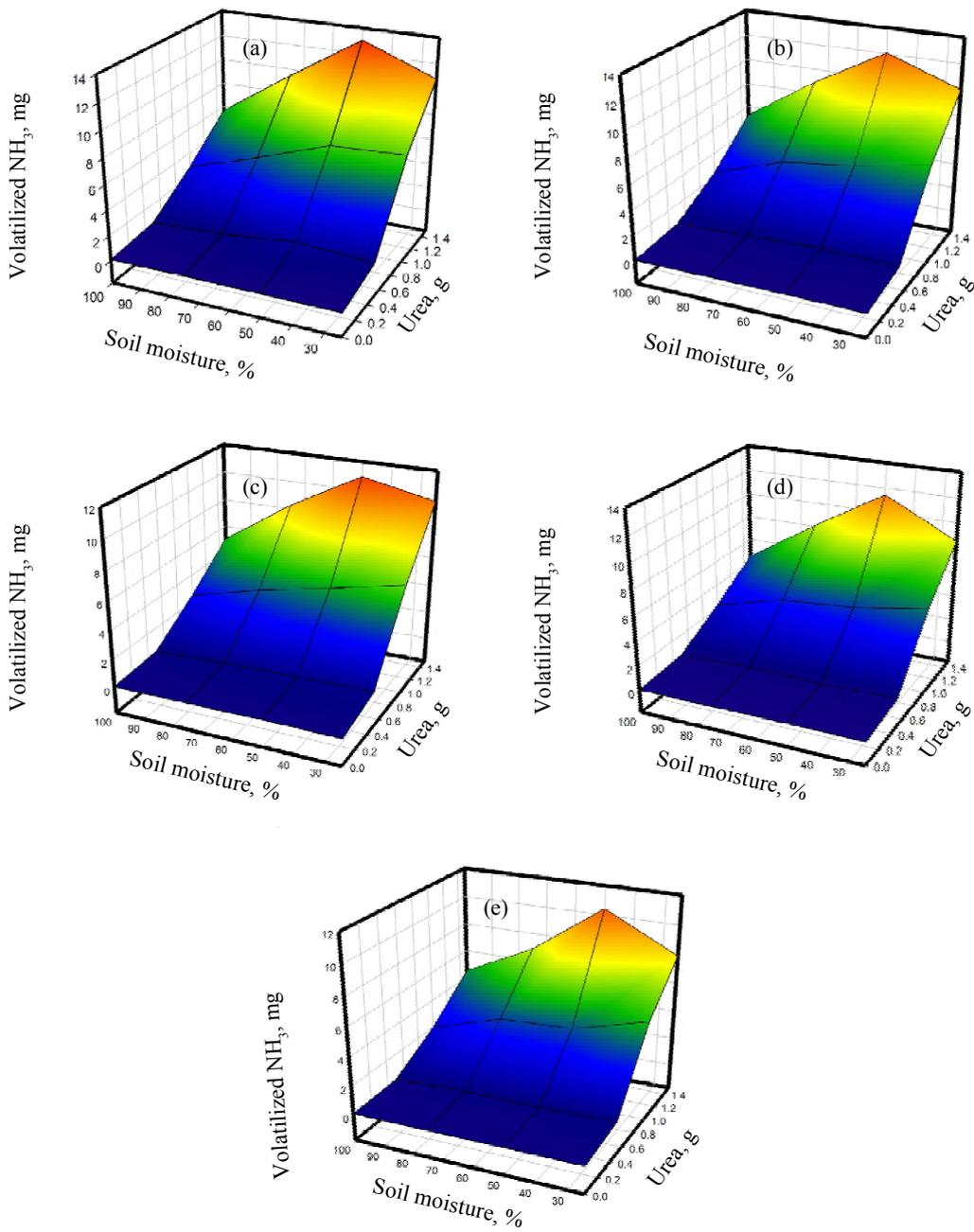


Figure 2. Interaction effect of soil moisture and urea on volatilized NH₃ at SFC level of 0 g kg⁻¹ (a), 25 g kg⁻¹ (b), 50 g kg⁻¹ (c), 75 g kg⁻¹ (d) and 100 g kg⁻¹ (e)

values through the combination of all levels. These declines were more clear in higher rate of urea supply. The average reduction in volatilized NH_3 was more than 50% from 50% to 100% field capacity. It impresses the crucial influence of moisture factor to NH_3 volatilization as it was with the pH value. A link between NH_3 volatilization and soil moisture content has been revealed in many publications elsewhere (Liu *et al.*, 2007). The addition of urea, obviously, has increased volatilized NH_3 up to more than 90% in average from 0 to 0.6 g kg^{-1} urea overall SFC levels.

Minimum volatilization was obtained in 25% field capacity in combination with no urea by which it seems all below the average value of 0.09 mg. The interaction of 0.6 g kg^{-1} urea and 50% field capacity in combination with no SFC had clearly boosted the highest volatilized NH_3 up to 13 mg. If we look back at the pH results in the previous discussions, it is clear about the same highest value obtained from this point through all combinations. By Pearson correlation, we found a significant relationship ($R = 0,622^{**}$, $n = 80$) between these two. It looks in some combinations, a contrast link where observed more constant value of pH compared to more gradient change in volatilized NH_3 in which it suggests an inhibition process of NH_3 volatilization. We supposed that there was a considerable NH_3 fixation by organic matter either indigenously from soil or SFC supplied. Fixation of NH_3 by soil organic matter has been reported in a number of publications elsewhere (Stevenson, 1994).

In the higher level of SFC, it depressed volatilized NH_3 in average 28%. In the same level of obviously decrease in volatilized NH_3 occurred with the increase of SFC. This effect was more pronounced in higher level of soil moisture content. In average, there was a reduction of volatilized NH_3 about 28% when SFC applied from 0 to 100 g kg^{-1} where this

may have attributed to the positive effect of SFC supply. Being recognized as C sources for soil amendment (Roth, 1971; Dee *et al.*, 2002; Meunchang *et al.*, 2005), SFC may have provided the improvement the soil CEC that may account for more fixed- NH_4 resulted from urea hydrolysis.

N Uptake

Relationship between urea and N uptake in different level of SFC was best represented by quadratic response curve (Figure 3). The best correlation appeared to be in the combination of urea and 25 g SFC kg^{-1} (Figure 3b). Supply of SFC increased N uptake more than 70% in the 100 g SFC kg^{-1} compared to control. The combination of no SFC and 0.2 g urea kg^{-1} has doubled the increase in N uptake before decreasing the highest urea applied. The increasing of N concentration in the soil solution from urea may have changed the balance of soil nutrients, resulting in depression of N uptake in the higher level of urea.

The highest N absorbed from soil was absorbed in application of 0.2 g urea kg^{-1} (Figure 3). In this level, the increasing N sorption by plant was 12% from control to 100 g SFC kg^{-1} implying the maximum capacity has been achieved to take more N from soil. The increase in urea applied levels in combination with 100 g SFC kg^{-1} seems potential to increase N uptake 28% in 0.4 g kg^{-1} and 77% in 0.6 g kg^{-1} . This combination may have resulted in the change in the soil nutrients balance which may enhance N uptake by plant. These results are pointing out positive effect of SFC supply to promote N uptake in the tendency of decline following higher doses of urea inputs.

Treatment of 0.2 g urea kg^{-1} resulted in highest N uptake value among different urea level treatments. The higher value was obtained in the higher concentration of SFC.

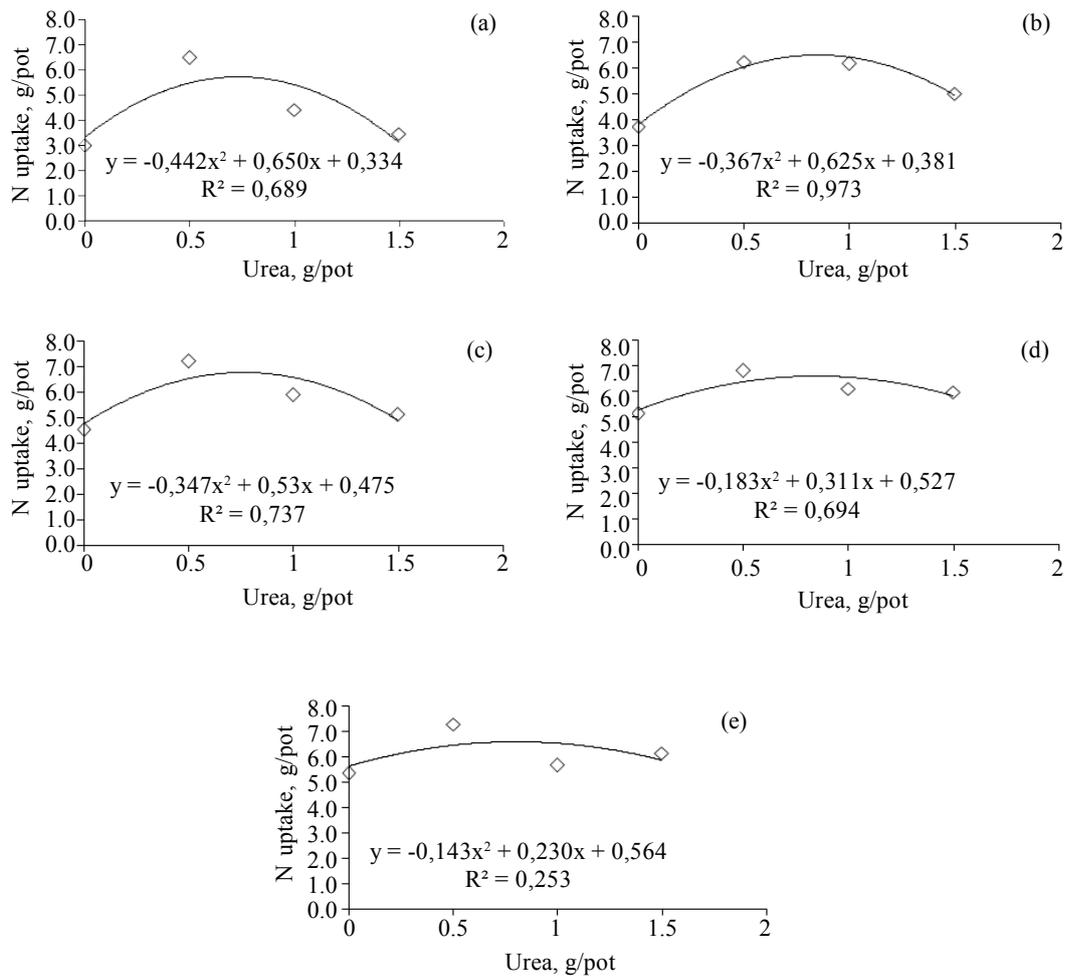


Figure 3. Nitrogen uptake after urea addition in each level treatments of filter press cake 0 g kg⁻¹ (a), 25 g kg⁻¹ (b), 50 g kg⁻¹ (c), 75 g kg⁻¹ (d) and 100 g kg⁻¹ (e)

This is also implying N plant sorption promotion by SFC. As an organic material, SFC may have been sources of some nutrients (Table 1), that may affect initial nutrient balance. Moreover, an increase in soil pH as reported the incubation experiment, it clearly explains the contribution of change in nutrients balance following SFC supply. SFC has been reported to increase N mineralised during incubation (Dee *et al.*, 2002), implying good nutrient environment resulted by its supply.

N Urea Fertilization Efficiency

We find a positive effect SFC to increase N uptake as clearly depicted in Figure 3, subsequently linked to the improvement of urea fertilization efficiency. The absence of SFC resulted in 20 times decline in urea efficiency by increasing urea concentration from 0.2 to 0.6 g kg⁻¹. Nitrogen fertilizer efficiency value increased both in application of urea 0.2 and 0.6 g kg⁻¹, generally, correspond to

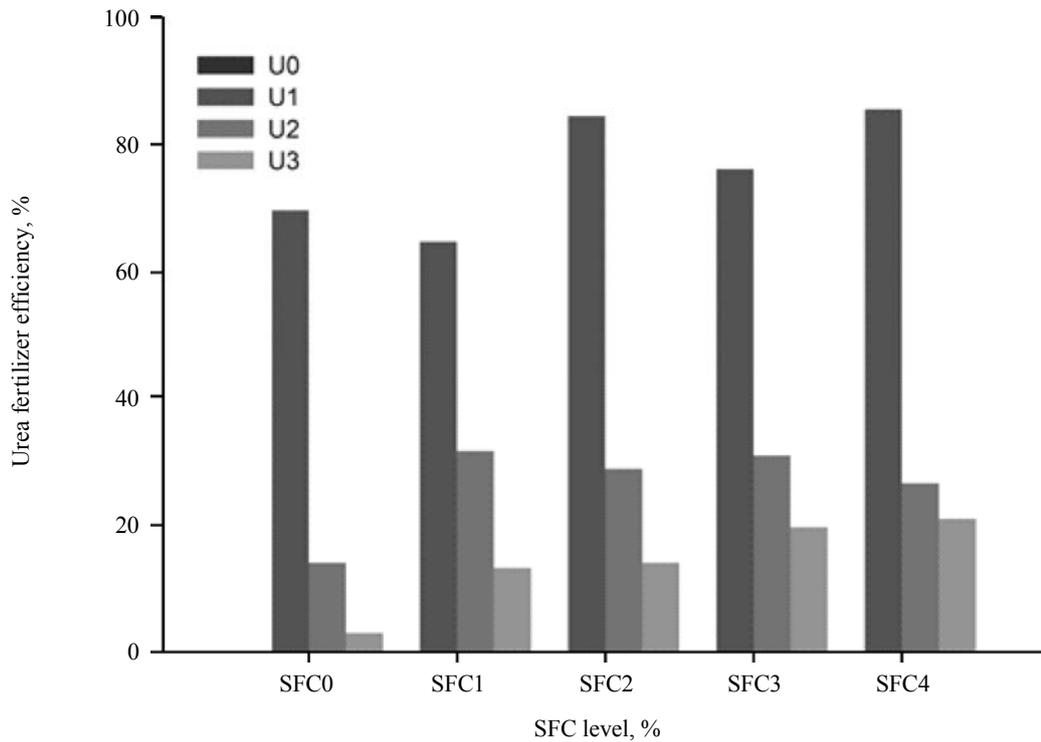


Figure 4. Urea fertilization efficiency as affected by different level of FPC. The bar of U0 does not emerge as the efficiency of urea zero

the increasing level of SFC. These data obviously showed a decrease in the N fertilizer efficiency with increasing level of urea as demonstrated in Figure 4. The N uptake data (Figure 3) may explain that this tendency was resulted from the increase in N loss with urea increment doses.

The highest urea efficiency was obtained from application of urea 0.2 g kg^{-1} (Figure 4). In the combination of urea 0.2 g kg^{-1} and SFC 100 g kg^{-1} , efficiency was observed. Although, in addition of urea 0.6 g kg^{-1} the obtained fertilizer efficiency was the smallest, but the increasing value from control to application of SFC 100 g kg^{-1} was the highest among other combinations. Nitrogen fertilizer efficiency increased in the addition of urea

0.6 g kg^{-1} when SFC applied increased from 0 to 100 g kg^{-1} , meanwhile the efficiency was less when urea applied also less.

CONCLUSIONS

Single component as, urea, moisture and sugarcane filter cake and the interactions of either urea and moisture or sugarcane filter cake and urea significantly affected soil pH, and furthermore have boosted volatilized NH_3 . Urea supply has contributed to the increasing soil pH in all levels of combination. Pearson correlation ($R = 0,622^{**}$) suggested a direct link between soil pH and volatilized NH_3 . Soil moisture increase from 50% to 100% reduced 50% of NH_3 emission. This effect was more obvious in higher levels of urea

applied. Urea produced more volatilized NH_3 when urea applied in higher dosage and it was able to reduce volatilized NH_3 about 28% if applied in higher dosage. Inhibition of NH_3 volatilization may have contributed to the increase in N uptake by more than 70% in the highest level of SFC in compared to control. This increase may have resulted in increase in N fertilizer efficiency. The absence of SFC has made a decline in urea efficiency when urea applied in higher dosage. A decrease in efficiency value with increasing level of urea may be related with increase in N loss with urea increment doses.

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