



## Eco-friendly Production of Maize Using Struvite Recovered from Swine Wastewater as a Sustainable Fertilizer Source

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**ABSTRACT** : Magnesium ammonium phosphate (MAP) was recovered from swine wastewater and the feasibility of reutilizing it as a slowly-releasing fertilizer was evaluated. Maize growth was investigated with normal and high application rates of MAP and a fused super phosphate (FSP) fertilizer. A total of 5 treatments ( $T_0$  = control,  $T_1$  = MAP based on  $30 \text{ kg P ha}^{-1}$ ,  $T_2$  = FSP based on  $30 \text{ kg P ha}^{-1}$  + urea equivalent to nitrogen of MAP applied in  $T_1$ ,  $T_3$  = MAP based on  $40 \text{ kg P ha}^{-1}$ ,  $T_4$  = FSP based on  $40 \text{ kg P ha}^{-1}$  + urea equivalent to nitrogen of MAP applied in  $T_3$ ) were arranged with 3 replications. In the case of height and circumference, significant differences were found between controls and treated maize plants ( $p < 0.01$ ). However, no statistical differences were found between MAP- and FSP-urea treated maize. Leaf area and green biomass yield were significantly ( $p < 0.01$ ) higher in the treated group than control. Leaf area was also found significantly higher ( $p < 0.01$ ) in the higher MAP- treated group ( $2,374 \text{ cm}^2 \text{ plant}^{-1}$ ) than other treatments.  $\text{N}_2\text{O}$  emission was found to be lower in MAP treated soil than that from FSP-urea treated soil, which might be due to the slow releasing pattern of MAP. It could be assumed from the results that MAP would be an eco-friendly sustainable fertilizer source for crop production. (**Key Words** : Swine Wastewater, MAP, Struvite, Slowly-releasing Fertilizer)

### INTRODUCTION

It is estimated that the present reserves of mined phosphate rocks is 7,000 million tons as  $\text{P}_2\text{O}_5$ , in which 40 million tons of P rock is used for fertilizer production and human consumption every year (Florida Institute of Phosphate Research, 2005). It is predicted that the demand for P will increase by 1.5% each year (Steen, 1998). So, it might be stated that the mined P rocks will be exhausted within 90 years, assuming a 1.5% annual increase of utilization. Shu et al. (2006) stated that all reserved P rock will be exhausted by the year 2090 as 1.5% increasing utilization trend, and currently there is no alternative sources of P for crop production (Sharpley, 2001). So, it is essential to develop an alternative source of P fertilizer for uniform crop and animal production.

The growing demand for fodder crops comes along with the rapid development of the livestock industry. Feeding of fodder to livestock is essential for the maintenance of normal health and production, which is also an effective way to produce organic meat and milk for human consumption (Rahman et al., 2008). Presently, in world production, maize (*Zea mays*) is ranked as the third major cereal crop, behind wheat and rice, and widely considered as an ideal forage crop to feed livestock (Haque, 2003). Maize can grow quickly, produce high yields, rich in nutrients, and can be grown in spring and autumn (Sattar et al., 1994). As fodder for livestock, maize is highly nutritive, sustainable and very responsive to nitrogen fertilizer (Hukkeri et al., 1977). Fertilizer application could increase the yield and improve the quality of crop production (Hussain et al., 2002; Song et al., 2004). Normally, crop production in conventional cropping systems relies heavily on using chemical fertilizer to sustain soil fertility (Dobermann and Cassman, 2002). The chemical fertilizer may affect the soil physical environment by increasing the above ground and root biomass due to an immediate supply of plant nutrients in sufficient quantities (Lopez-perez et al., 1990). However, a long-term excessive and imbalance application of chemical fertilizer may cause many

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environmental problems, such as odor, soil erosion, reduction of soil biodiversity, and ground water pollution (Porazinska et al., 1999), and these might affect a sustainable development of agriculture. It is known that urea is widely used as a chemical fertilizer that can release nitrogen rapidly into the soil, from which only 40% is recovered by plants and the remaining 60% is lost in different ways (Liang et al., 2007). Nitrogen fertilization is the chief source of nitrous oxide (N<sub>2</sub>O) emission from soil (Perala et al., 2006; Chu et al., 2007). N<sub>2</sub>O plays an important role in the recent global warming trend and participates in the destruction of stratospheric ozone (O<sub>3</sub>) (IPCC, 2007). Moreover, nitrogen fertilizer may affect N<sub>2</sub>O emission in several ways depending on the type of N source (NO<sub>3</sub><sup>-</sup>, NH<sub>4</sub><sup>+</sup> or organic N) (Dambreville et al., 2008). To overcome both the nutrient supply and the adverse effect of chemical fertilizer, applying slow-release fertilizers may be an important alternative to control environmental pollution.

MAP is a slow releasing fertilizer with a chemical formula of MgNH<sub>4</sub>PO<sub>4</sub>·6H<sub>2</sub>O and a mixed fertilizer that contains 13% P, 7% N and 10% Mg, which can be treated as phosphorus fertilizer. Chirmuley (1994) stated that MAP is a white crystalline powder in its pure form. It is highly soluble at acidic pH and highly insoluble at alkaline pH. MAP could be successfully recovered from different kinds of waste or wastewaters, such as swine wastewater (Suzuki et al., 2007), wasted sludge (Jaffer et al., 2002), industrial wastewater (Diwani et al., 2007) and poultry manure wastewater (Yetilmezsoy and Zengin, 2009). Lee et al. (2009) and Rahman et al. (2011) reported that an effective application of MAP fertilizer for crop production can help make an eco-friendly environment. Also, the utilization of MAP as fertilizer would help to reduce the application of rock phosphate in the agricultural sector. Thus, MAP could help to create an eco-friendly environment by reducing the need for rock phosphate. According to our previous study (Rahman et al., 2011) and Bashan and Bashan (2004), MAP may have a low leaching rate and slowly release nutrients during the plant-growing season. In this study, the efficiency of MAP recovered from swine wastewater as a sustainable fertilizer was tested by investigating the influence of MAP on the growth, biomass yield, nutrient content, chemical composition and energy content of maize fodder and further by calculating N<sub>2</sub>O emission under the maize growth.

## MATERIALS AND METHODS

### Investigation of maize growth on pot culture

Pot cultivation of maize (*Zea mays* L.) variety Barnali (used for grain production) was performed from May to July of 2009 at a trial site having latitude of +127° 59' 49.03" E and longitude of +37° 59' 51.87" N in south Korea.

**Table 1.** Layout of the experiment

Treatments	Fertilizer source (g pot <sup>-1</sup> )			
	MAP	FSP	Urea	KCl
T <sub>0</sub>	-	-	-	0.362
T <sub>1</sub>	0.877	-	-	0.362
T <sub>2</sub>	-	0.57	0.115	0.362
T <sub>3</sub>	1.169	-	-	0.362
T <sub>4</sub>	-	0.76	0.152	0.362

T<sub>0</sub> = Control, T<sub>1</sub> = MAP based on 30 kg P ha<sup>-1</sup>, T<sub>2</sub> = FSP based on 30 kg P ha<sup>-1</sup>+Urea equivalent to nitrogen of MAP, T<sub>3</sub> = MAP based on 40 kg P ha<sup>-1</sup>, T<sub>4</sub> = FSP based on 40 kg P ha<sup>-1</sup>+Urea equivalent to nitrogen of MAP; MAP = Magnesium ammonium phosphate.

After recovering MAP from swine wastewater (Rahman et al., 2011), its effect on the growth of maize plant was tested and compared with that of a general chemical fertilizer such as fused super phosphate (20% P<sub>2</sub>O<sub>5</sub>) and urea (46% N). During the experimental period, plant height and diameter, leaf number and area, biomass yield and nutritional composition of maize plant were investigated.

Pot cultivation of maize plants was performed with normal (30 kg P ha<sup>-1</sup>) and high (40 kg P ha<sup>-1</sup>) application rates (Kogbe and Adediran, 2003) of fertilizer sources (MAP and FSP fertilizer). A total of 5 treatments were arranged with 3 replications (Table 1). KCl was applied as a source of K<sub>2</sub>O at a rate of 57 kg ha<sup>-1</sup> in all treatments. Practically, N application rate was kept low in this experiment to determine the efficiency of MAP. A total of 15 soil pots were prepared with well-mixed experimental soil collected from the farming area. Detailed physicochemical properties of the soil were investigated before starting the experiment (Table 2). The height of the experimental pots was 28 cm and the diameter was 22 and 19 cm at the top and bottom, respectively. The area of the soil surface was 0.038 m<sup>2</sup> in all pots. Eight kg of soil were placed in each pot and MAP or FSP-urea was thoroughly mixed with soil in the upper 5 cm. Fertilizer and struvite

**Table 2.** Physico-chemical properties of the experimental soil

Parameter	Mean±standard deviation
pH	6.04±0.049
EC (dS m <sup>-1</sup> )	0.144±0.031
Organic Carbon (g kg <sup>-1</sup> )	14.82±2.091
TN (g kg <sup>-1</sup> )	0.622±0.016
Total P (mg kg <sup>-1</sup> )	12.35±0.251
Total K (mol kg <sup>-1</sup> )	0.285±0.005
Total Mg (mol kg <sup>-1</sup> )	1.414±0.064
Mechanical composition	
Clay (%)	15.33±2.31
Silt (%)	18.87±3.57
Sand (%)	65.79±1.27
Textural class	Sandy loam

**Table 3.** Average temperature and precipitation for the past 30 years (1981-2011)

Parameters	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Average
Temperature (°C)	-4.6	-1.3	4.5	11.6	17.1	21.7	24.5	24.6	19.4	12.5	5.0	-1.7	11.1
Precipitation (mm)	20.3	23.8	41.7	62.3	104.0	123.1	383.8	317.5	160.9	44.3	44.7	20.9	112.2

were applied according to the surface area of the experimental pots. The pot-to-pot distance was maintained at 40 cm. Maize seeds of local variety were sowed at a depth 3 cm in the experimental pots (3 seeds in each pot). Two maize seedlings were removed from each pot after germinating the grains, and only one maize seedling was grown on each pot. During the experimental period, the average temperature was 20-30°C and the average monthly rainfall was 171 mm and average temperature and precipitation of the area for 30 years is shown in Table 3. There was an even distribution of rainfall throughout the growing season. Moreover, the pots were watered to field capacity level when necessary, and intercultural operations were performed periodically without applying any pesticides. The height and circumference of the maize plants were measured every alternate week. The green biomass yield, leaf number, leaf area, and other nutrient compositions of the plants were measured after harvesting them as fodder.

#### Calculation of N<sub>2</sub>O emission

To identify the amount of N<sub>2</sub>O emitted from different treatments of fertilizer, the N leaching loss was studied as in our previous study (Rahman et al., 2011). As described by Nevison (2000), N<sub>2</sub>O production lost from the field through leaching and runoff is defined as follows in the IPCC methodology:

$$N_2O (L) = N-LEACH \times EF5$$

Where, N-LEACH (kg N) is the amount of fertilizer N lost through leaching and runoff, N<sub>2</sub>O (L) is the N<sub>2</sub>O emissions associated with agricultural nitrogen lost through leaching and runoff and EF5 (kg N<sub>2</sub>O-N/kg N) is the emission factor for leaching/runoff, EF5 = 0.001.

#### Analytical method

Soil properties were analyzed according to the principles of Margeson and Schinner (2005). Number of green leaves was counted at the time of harvesting and the leaf area was measured according to Yang and Alley (2005). For biomass yield, representative samples of fresh fodder were oven dried at 105°C for 24 h and oven dried samples were ground to a size of 1.0 mm for the nutrient composition analysis. For dry matter (DM), ash, crude protein (CP), and crude fibre (CF) were estimated according to the methods of AOAC (2003). Neutral detergent fibre (NDF) and acid detergent fibre (ADF) were estimated in accordance with the principles of Cherney (2000) and Faichney and White (1983). The data were analyzed using the Statistical Package for the Social Sciences (SPSS, Version 12.0, 2003) with one way analysis of variance (ANOVA). Differences among the treatment means were determined by values for Duncan's Multiple Range Test (DMRT) (Steel and Torrie, 1980).

## RESULTS AND DISCUSSION

#### Maize growth (height and circumference)

The growth patterns of potted maize given different treatments are shown in Table 4 and 5. A significant difference was found in plant height and stem circumference between control and treated groups during the whole growth period ( $p < 0.01$ ). However, there was no significant difference between MAP and FSP-urea-treated groups. These results might indicate that the two types of fertilizers had no significantly different effects on maize growth. A comparatively greater height (68.33 cm) was observed for maize given the higher level of MAP (T<sub>3</sub>) at 56 days (the time at which cob formation begins), although there was no significant difference overall between MAP and FSP-urea-treated maize. The height was lowest in T<sub>0</sub>

**Table 4.** Mean height of maize plants

Day	Height (cm)					SEM	Level of sig.
	T <sub>0</sub>	T <sub>1</sub>	T <sub>2</sub>	T <sub>3</sub>	T <sub>4</sub>		
14	8.67 <sup>b</sup>	11.00 <sup>ab</sup>	12.00 <sup>a</sup>	13.00 <sup>a</sup>	11.33 <sup>a</sup>	0.488	*
28	22.00 <sup>b</sup>	28.00 <sup>a</sup>	29.67 <sup>a</sup>	31.00 <sup>a</sup>	29.33 <sup>a</sup>	0.931	**
42	29.67 <sup>b</sup>	45.67 <sup>a</sup>	49.33 <sup>a</sup>	49.33 <sup>a</sup>	45.67 <sup>a</sup>	2.085	**
56	40.00 <sup>b</sup>	60.67 <sup>b</sup>	64.33 <sup>ab</sup>	68.33 <sup>a</sup>	64.67 <sup>ab</sup>	2.798	**

Different superscripts in the same row means significantly differ (\*\* Significance at 1% level, \* Significance at 5% level).

T<sub>0</sub> = Control, T<sub>1</sub> = MAP based on 30 kg P ha<sup>-1</sup>, T<sub>2</sub> = FSP based on 30 kg P ha<sup>-1</sup>+Urea equivalent to nitrogen of MAP, T<sub>3</sub> = MAP based on 40 kg P ha<sup>-1</sup>, T<sub>4</sub> = FSP based on 40 kg P ha<sup>-1</sup>+Urea equivalent to nitrogen of MAP; MAP = Magnesium ammonium phosphate.

**Table 5.** Mean circumference of the stems

Day	Stem circumference (cm)					SEM	Level of sig.
	T <sub>0</sub>	T <sub>1</sub>	T <sub>2</sub>	T <sub>3</sub>	T <sub>4</sub>		
14	1.03 <sup>d</sup>	1.17 <sup>cd</sup>	1.23 <sup>bc</sup>	1.40 <sup>ab</sup>	1.43 <sup>a</sup>	0.042	**
28	2.60 <sup>c</sup>	3.53 <sup>b</sup>	3.90 <sup>ab</sup>	4.33 <sup>a</sup>	4.33 <sup>a</sup>	0.176	**
42	3.17 <sup>c</sup>	4.00 <sup>b</sup>	4.63 <sup>a</sup>	4.53 <sup>ab</sup>	4.80 <sup>a</sup>	0.165	**
56	4.03 <sup>b</sup>	5.17 <sup>a</sup>	5.00 <sup>a</sup>	5.20 <sup>a</sup>	5.07 <sup>a</sup>	0.124	**

Different superscripts in the same row means significantly differ (\*\* Significance at 1% level).

T<sub>0</sub> = Control, T<sub>1</sub> = MAP based on 30 kg P ha<sup>-1</sup>, T<sub>2</sub> = FSP based on 30 kg P ha<sup>-1</sup>+Urea equivalent to nitrogen of MAP, T<sub>3</sub> = MAP based on 40 kg P ha<sup>-1</sup>, T<sub>4</sub> = FSP based on 40 kg P ha<sup>-1</sup>+Urea equivalent to nitrogen of MAP; MAP = Magnesium ammonium phosphate.

(40 cm) at the final stage of growth, and cob development had not yet begun at 56 days. Normally, cob development occurs at 50-55 days during maize growth (Rahman et al., 2008). The slower-than-normal plant growth (Subedi and Ma, 2005) observed here could be due to the pot culture and other factors including the genetic constituency of the maize. According to Rahman et al. (2008) factors responsible for plant growth are genetic constitution, soil fertility, climatic condition, day length, light intensity, since the experiment was conducted during the month of May-July, climatic condition, day length, light intensity were favorable. Subedi and Ma (2005) had stated that the height above the ear-node was 52% of the total plant height. Those internodes of hybrid maize are larger than those of local variety; this also might have contributed to the lower height in the experiment. Also, other factors such as genetic makeup, soil fertility, climatic conditions, day length, light intensity, and season could have affected the maize plant height.

#### Leaf number, leaf area and biomass yield

The green biomass yield and nutritional state of the potted maize are shown in Table 6. Leaf number was significantly different between control and treated groups

( $p < 0.05$ ), but no significant differences were found among the treated groups. The leaf number is dependent on several environmental factors including nutrient levels in the soil. The low number of leaves in T<sub>0</sub> (9.33) might be due to senescence, which is also caused by the low nutrient status of the soil (Gungula et al., 2005). An optimum level of NPK maintains the activity of plant cells and tissues, delaying senescence and ultimately increasing the final leaf number and leaf area.

The leaf area was also significantly different between control and treated groups ( $p < 0.01$ ). Among the treated groups, T<sub>3</sub> showed significantly higher leaf area relative to the other groups ( $p < 0.01$ ). Although the same amount of NPK was applied in T<sub>3</sub> and T<sub>4</sub>, the estimated leaf area was significantly different, being 2,374 and 1,887 cm<sup>2</sup> plant<sup>-1</sup>, respectively. Similarly, the estimated leaf area for T<sub>1</sub> and T<sub>2</sub> was 1,873 and 1,684 cm<sup>2</sup> plant<sup>-1</sup>, respectively. This phenomenon might be explained by the gradual and slowly-releasing pattern of MAP. Nitrogen losses occurring rapidly after application of urea to the soil (Liang et al., 2007) might have caused N deficiency in T<sub>2</sub> and T<sub>4</sub>, leading to reduced yield. In addition, comparing T<sub>1</sub> and T<sub>3</sub>, higher MAP application led to a significantly higher photosynthetic area (leaf area of the plants), which

**Table 6.** Biomass yield and nutritional state of maize fodder

Parameter	Treatments					SEM	Level of sig.
	T <sub>0</sub>	T <sub>1</sub>	T <sub>2</sub>	T <sub>3</sub>	T <sub>4</sub>		
Leaf number	9.33 <sup>b</sup>	11.67 <sup>a</sup>	10.67 <sup>a</sup>	11.67 <sup>a</sup>	10.67 <sup>a</sup>	0.262	*
Leaf area (cm <sup>2</sup> plant <sup>-1</sup> )	999 <sup>c</sup>	1,887 <sup>b</sup>	1,684 <sup>b</sup>	2,374 <sup>a</sup>	1,873 <sup>b</sup>	123.96	**
Yield (MT ha <sup>-1</sup> )	9.02 <sup>c</sup>	29.54 <sup>ab</sup>	26.22 <sup>b</sup>	32.48 <sup>a</sup>	27.99 <sup>b</sup>	2.267	**
DM (%)	17.91 <sup>b</sup>	22.09 <sup>a</sup>	20.83 <sup>ab</sup>	22.37 <sup>a</sup>	21.94 <sup>a</sup>	0.618	*
Ash (%)	1.07 <sup>b</sup>	1.32 <sup>a</sup>	1.19 <sup>ab</sup>	1.34 <sup>a</sup>	1.25 <sup>a</sup>	0.032	*
CP (%)	3.39 <sup>b</sup>	4.62 <sup>ab</sup>	3.61 <sup>ab</sup>	6.26 <sup>a</sup>	4.64 <sup>ab</sup>	0.410	*
CF (%)	29.26 <sup>a</sup>	25.21 <sup>b</sup>	25.48 <sup>b</sup>	24.12 <sup>b</sup>	25.58 <sup>b</sup>	0.533	*
ADF (%)	31.05	30.64	30.02	28.85	30.13	0.333	NS
NDF (%)	64.57 <sup>a</sup>	56.71 <sup>b</sup>	59.14 <sup>b</sup>	56.19 <sup>b</sup>	57.94 <sup>b</sup>	1.157	*

Different superscripts in the same row means significantly differ (\*\* Significance at 1% level, \* Significance at 5% level, NS = Not significant).

T<sub>0</sub> = Control, T<sub>1</sub> = MAP based on 30 kg P ha<sup>-1</sup>, T<sub>2</sub> = FSP based on 30 kg P ha<sup>-1</sup>+Urea equivalent to nitrogen of MAP, T<sub>3</sub> = MAP based on 40 kg P ha<sup>-1</sup>, T<sub>4</sub> = FSP based on 40 kg P ha<sup>-1</sup>+Urea equivalent to nitrogen of MAP; MAP = Magnesium ammonium phosphate.

ultimately increased the vegetative growth and yield of the maize (Aluko and Fischer, 1987). The leaf area of the group treated with lower MAP ( $T_1$ ) has statistically no difference with that of the group treated with higher FSP-urea ( $T_4$ ). However, the lowest leaf area observed in control group ( $999 \text{ cm}^2 \text{ plant}^{-1}$ ) could be due to a lack of N and P. A higher leaf area ensures higher photosynthetic activity, which in turn increases the biomass yield (Subedi and Ma, 2005; Yang and Alley, 2005). N levels in the soil are responsible for the green coloration and chlorophyll content of leaves, and N deficiency greatly affects yield (Hageman, 1986). In this experiment, MAP was evaluated as an alternative to chemical fertilizer. Hence, no additional N fertilizer was added with MAP.  $T_1$  and  $T_3$  contained only 14 and 18 kg N  $\text{ha}^{-1}$ , respectively, as MAP in crystal form.  $T_2$  and  $T_4$  contained an equivalent amount of urea-nitrogen besides FSP fertilizer. Under these low application rate conditions, N deficiencies might occur during later stages of growth in  $T_2$  and  $T_4$  due to higher leaching losses of N. However, there might have been no N deficiency in  $T_1$  and  $T_3$  due to the slowly-releasing property of the MAP crystal. Our previous study (Rahman et al., 2011) showed that the leaching property of urea was more than 3 fold higher than that from MAP. Due to this slow leaching property a plant might absorb most of the N from MAP.

In the case of green biomass yield, a clearly significant difference was observed between MAP- and FSP-urea-treated groups, as well as between control and treated groups ( $p < 0.01$ ). The highest biomass yield was obtained in  $T_3$  ( $32.48 \text{ MT ha}^{-1}$ ). Moreover, the group treated with lower MAP ( $T_1$ ) also produced higher biomass yield ( $29.54 \text{ MT ha}^{-1}$ ) than  $T_2$  ( $26.22 \text{ MT ha}^{-1}$ ) and  $T_4$  ( $27.99 \text{ MT ha}^{-1}$ ). The extremely low biomass yield in  $T_0$  ( $9.02 \text{ MT ha}^{-1}$ ) could be due to the absence of N and P fertilizers. N is an integral part of chlorophyll, which is the primary absorber of the light energy needed for photosynthesis. The higher biomass yield in MAP-treated groups might be due to the longer-lasting availability of nutrients influencing cell elongation, cell division, nucleotide/coenzyme formation, and higher metabolic activities. Magnesium may also have had an effect on higher biomass yield in the MAP-treated groups.

The higher growth performance by MAP application was also reported by Li and Zhao (2003).

#### Nutritional state of the potted maize fodder

MAP- and FSP-urea-treated maize showed significantly higher dry matter (DM) and ash than maize in the control group ( $p < 0.05$ ). This is likely due to the effects of applying N and P. Yetilmmezsoy and Zengin (2009) reported that a higher DM was obtained in MAP-treated than in P fertilizer-treated garden grass due to the positive effects of MAP on DM content. In the present study, while DM and ash were slightly higher in the MAP-treated group ( $T_1$  and  $T_3$ ) than in the FSP-urea-treated groups ( $T_2$  and  $T_4$ ), the differences were not significant.

Crude protein (CP) content, one of the most important qualities of forage, was significantly higher in  $T_3$  (6.26%) compared to control ( $p < 0.05$ ). When comparing  $T_1$  with  $T_2$ , and  $T_3$  with  $T_4$ , average CP contents were higher in the MAP-treated groups than in the FSP-treated groups, although this difference was not statistically significant. Due to N deficiency at a later stage in the FSP-urea-treated groups ( $T_2$  and  $T_4$ ), the combined actions of NPK on enzyme activity and biosynthesis might be affected, and could result in lower CP contents relative to MAP-treated groups ( $T_1$  and  $T_3$ ). The presence of Mg might also have an effect on higher CP synthesis in MAP-treated maize since Mg is a component of chlorophyll that acts as an activating agent of enzyme production and P transfer.

Significantly lower levels of crude fiber (CF) and neutral detergent fiber (NDF) were found in MAP- and FSP-urea-treated groups compared to control ( $p < 0.05$ ), but there was no significant difference among the treated groups. The levels of acid detergent fiber (ADF) were similar in all treatments including control.

#### $\text{N}_2\text{O}$ emission

The amount of  $\text{N}_2\text{O}$  emitted from different treatments was evaluated according to the N leaching loss. Table 7 shows that the emission rates of  $\text{N}_2\text{O}$  were significantly higher in FSP-urea treated groups compared to MAP treated groups ( $p < 0.01$ ). Total amounts of emitted  $\text{N}_2\text{O}$  during the 6

**Table 7.** Amount of  $\text{N}_2\text{O}$  emitted ( $\text{g ha}^{-1}$ ) at different treatments

Treatments	Amount of N leached ( $\text{kg ha}^{-1}$ )	$\text{N}_2\text{O}$ Emission factor (Nevison, 2000)	Amount of $\text{N}_2\text{O}$ ( $\text{g ha}^{-1}$ )
$T_0$	0.2385 <sup>a</sup>	0.001	0.2385 <sup>a</sup>
$T_1$	0.2423 <sup>a</sup>	0.001	0.2423 <sup>a</sup>
$T_2$	1.0915 <sup>b</sup>	0.001	1.0915 <sup>b</sup>
$T_3$	0.4381 <sup>c</sup>	0.001	0.4381 <sup>c</sup>
$T_4$	1.4515 <sup>d</sup>	0.001	1.4515 <sup>d</sup>

$T_0$  = Control,  $T_1$  = MAP based on  $30 \text{ kg P ha}^{-1}$ ,  $T_2$  = FSP based on  $30 \text{ kg P ha}^{-1}$ +Urea equivalent to nitrogen of MAP applied in  $T_1$ ,  $T_3$  = MAP based on  $40 \text{ kg P ha}^{-1}$ ,  $T_4$  = FSP based on  $40 \text{ kg P ha}^{-1}$ +Urea equivalent to nitrogen of MAP applied in  $T_3$ ; MAP = Magnesium ammonium phosphate.

<sup>a-d</sup> Same column bearing different superscripts differ significantly ( $p < 0.01$ ).

weeks trial were 0.2385, 0.2423, 1.0915, 0.4381 and 1.4515 g ha<sup>-1</sup> for T<sub>0</sub>, T<sub>1</sub>, T<sub>2</sub>, T<sub>3</sub> and T<sub>4</sub>, respectively. N<sub>2</sub>O emissions were more than threefold in FSP-urea treated groups than that of MAP treated groups, indicating that urea fertilization enhances the N<sub>2</sub>O emission from soil. Several studies have reported that N fertilization (urea) could increase the emissions of N<sub>2</sub>O and NO from soils (Matson et al., 1998; Hall and Matson, 1999; Chu et al., 2004). However, using controlled release N fertilizers could decrease N<sub>2</sub>O (Minami, 1994) and NO (Hou et al., 2000; Yan et al., 2001; Chu et al., 2004) emissions. The controlled release N fertilizer has many advantages over conventional fertilizers, including a reduction of labor with a single basal application, a more efficient N uptake by the crops (Shoji and Gandeza, 1992), and is eco-friendly in terms of reducing N losses caused by leaching (Ueno and Yamamuro, 1996). Based on our results, MAP that was recovered from swine wastewater might be an effective fertilizer regarding N<sub>2</sub>O emission due to its slow releasing characteristics.

### CONCLUSIONS

MAP was recovered from swine wastewater and its efficiency as an alternative fertilizer was examined. The conclusions drawn from the results of this study can be summarized as follows.

MAP could be successfully applied in potted maize cultivation. In case of height and circumference it was equally effective with FSP-urea fertilizers.

Comparing MAP-treated and commercial FSP-urea-treated maize, no significant differences were found in nutritional components such as CP, CF, ash, ADF, and NDF. In addition, growth was statistically similar. However, leaf area and biomass yield were significantly higher in MAP-treated than in FSP-urea-treated groups ( $p < 0.01$ ).

The rate of N<sub>2</sub>O emission was near about one third in MAP treated soil than that from FSP-urea treated soil. So, MAP could be helpful to reduce greenhouse gas from crop cultivation. Thus, our results indicate that MAP recovered from swine wastewater could be an effective alternative to general chemical fertilizers.

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