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Original research article

Influence of MAP Recovered from Swine Wastewater as a Fertilizer Source on the Growth and Nutrition of Maize Plant

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ABSTRACT

Magnesium ammonium phosphate (MAP), also known as struvite, was recovered from swine wastewater and the feasibility of utilizing it as a slowly-releasing fertilizer was examined. Field trials were conducted to investigate the effects of MAP and NPK fertilizers on maize. A total of 5 treatments (Control: non-fertilizer, NPK: 140 kg N/ha - 80 kg P_2O_5/ha - 90 kg K_2O/ha, MAP 1:50 kg N/ha, MAP 2:100 kg N/ha, MAP 3: 150 kg N/ha) were carried out. Maize growth, leaves number, leaf area, morphology, and quality of the corn were assessed at growing stages. The results showed that maximum height of maize (228.1 cm) was observed in the MAP 3 treatment at 50 days (the time at which cob formation begins), and there was a significant difference ($\alpha < 0.01$) between MAP 3 and control treatment. Besides, the tassel stage was a significant difference ($\alpha < 0.01$) between MAP 3 (50.3 days) and other treatment. However, there was no significant difference ($\alpha > 0.01$) in the number of leaves for the different treatments. On the other hand, the maximum leaf area at 50 days in NPK treatment (343.3 cm^2 $plant^{-1}$), the estimated leaf area was significantly different ($\alpha < 0.01$) in MAP 1 (246.9 cm^2 $plant^{-1}$) and control treatments (264.7 cm^2 $plant^{-1}$). The morphology (length and diameter) and sweetness of the corn were not significantly different ($\alpha > 0.01$) between MAP and NPK treatment. It could be suggested from the results that MAP would be an eco-friendly sustainable fertilizer source for maize production.

Keywords: Fertilizer; MAP; Maize plant; Recovery; Swine wastewater

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1. Introduction

Vietnam is a rapid industry country located in the southeastern margin of the Indochinese Peninsula. The economic performance within the past decades has been remarkable: transforming the country from a food-insecure nation to one of the world's leading exporters in food commodities [1]. Agricultural land makes up over 40% of Vietnam's total land area. In Vietnam, maize (*Zea mays* L.) is considered the second vital food crop, after rice. Maize is used for food, feed, and in a variety of industries. Previous studies have shown that using fertilizer could increase the yield and improve the quality of maize crop production [2-4]. Normally, in order to sustain soil fertility so that sufficient amounts of nutrients can be delivered to growing plants in conventional cropping systems, mineral nutrients are added as inorganic or organic fertilizers [5]. However, excessive fertilization causes soil nutrient imbalances and environmental pollution [6]. Therefore, balanced use of fertilization is a vital step to produce high maize yield while avoiding environmental degradation.

Of all the nutrients required by maize growth, nitrogen is the one most often deficient in the soil [7]. Also, due to the highly soluble characteristic of nitrogen fertilizer, it has shown the greatest potential for losses. Phosphorus is also a vital constituent element of protoplasm and nucleus which can stimulate the growth of maize [8]. Only 10-20% of the fertilizer phosphate applied to soil is absorbed and utilized by crops [9]. Therefore, simultaneous improvement in the use efficiency of conventional fertilizers and in the decrease of environmental hazards by application of slow-release fertilizers has been considered a promising strategy. Noteworthy characteristics of the slow-release fertilizers include dropping the fertilizer loss rate, lessening the application frequency providing sustainable nutrients, and reducing the potential negative effects of the overdosage [10, 11].

Struvite, also known as MAP, is a slow-release fertilizer which is formed with equal molar concentrations of magnesium, ammonium, and phosphate combined with six water molecules ($MgNH_4PO_4.6H_2O$). Struvite could be recovered from different kinds of wastewaters such as swine wastewater [12-14], semiconductor wastewater [15], municipal wastewater [16], industrial wastewater [17] and poultry manure wastewater [18]. According to Latifian, Liu (19), the theoretical fertilizer value of MAP is 12.5% P, 5.7% N, and 9.9% Mg that varies depending on the source and recovery process. The MAP could be the alternative for complex fertilizers to reduce nutrient leaching and eutrophication as it can slow-release nutrients and provide fertilization for a longer period of time. The nutrient leaching rates of MAP in soil are very low [19-21]. On the other hand, MAP has 2–3 times lower heavy metals impurities than other fertilizers [22]. Lee, Rahman (23) reported MAP can help to decrease greenhouse gas emissions from agriculture because plants absorb most of the N after its application.

Many studies have evaluated the growth and nutrition of maize plants using struvite as a potential fertilizer [24-26]. However, as far as we know, the previous studies on the fertilizer effect of MAP fertilizer on plant growth and nutrition were performed only in pots experiment. Therefore, an investigation of MAP fertilizer from a field experiment viewpoint should be carried out. In this research, the efficiency of MAP fertilizer recovered from swine wastewater as a sustainable fertilizer was tested by investigating the influence of MAP on the growth and nutrition of maize plants under the field test.

2. Materials and Methods

2.1 Site description

Field experiments were conducted during the maize growing season (November 2020 to February 2021) at the research field of the Faculty of Agronomy, Nong Lam University (10°52'21.0"N 106°47'20.4"E), located in Thu Duc City, HCMC, Vietnam (Fig. 1). Some physico-chemical soil properties in the layer (0 to 30 cm depth) at the experimental site were analyzed before sowing. The soil was acid in pH with low organic matter, total K, and total N, but sufficient in available potassium and phosphorus. Therefore, it is necessary to add more nutrients during the trial planting of maize. The summary can be found in Table 1. The research area has a tropical monsoon and sub-equatorial climate, with year-round high temperatures and two distinct rainy and dry seasons, which have a significant impact on the landscape environment.

Fig. 1. The research field of the Faculty of Agronomy, Nong Lam University HCMC, Vietnam.

Table 1. Initial soil characteristics of the field experimental.

Characteristics	Unit	Value
Sand	%	74.5
Silt	%	15.4
Clay	%	10.2
pH	-	5.63
Organic matter	%	0.73
Total nitrogen	%	0.079
Total potassium	%	0.084
Exchangeable phosphorus	Cmol/kg	32.14
Exchangeable potassium	Cmol/kg	15

2.2 Fertilizer preparation

The effluent from an anaerobic digester treating swine wastewater was used in the present study. The wastewater sample was collected from a pig farm located in a city in Tay Ninh province (Vietnam). The physicochemical properties of the swine wastewater are shown in Table 2. Generally, swine wastewater contains a high concentration of ammonium in comparison to phosphate and negligible magnesium. For effective struvite crystallization, an amount of phosphate and magnesium salts are required to be added. In this study, after previous exploration experiments, the molar ratio of Mg^{2+}: NH_4^+: PO_4^{3} was adjusted to 1.6:1:1.5 using $MgCl_2.6H_2O$ 1.5M and $K_2HPO_4.3H_2O$ 1.5M. The pH of the swine wastewater was set to a value of 9.0 using NaOH 5N to facilitate crystallization. The chemicals used in the experiments were purchased from Xilong Scientific Co. Ltd., China. The MAP crystal was then dried for 24 hours at 50°C to create a powder.

Table 2. Characteristics of swine wastewater.

Parameter	Unit	Mean ± SD (n=3)
pH	-	8.3 ± 0.1
Temperature	°C	29.0 ± 4.1
NH_4^+	mg/L	674.9 ± 73.0
PO_4^{3-}	mg/L	149.4 ± 17.7
Ca^{2+}	mg/L	29.1 ± 4.1
Mg^{2+}	mg/L	113.8 ± 9.2

After recovering MAP from swine wastewater, its effect on the growth of maize was investigated and compared with that of general chemical fertilizers such as super phosphate, urea, potassium, and NPK (Table 3).

Table 3. The summary of fertilizer source.

Type of fertilizer	Compounds	Sources of fertilizer
MAP	9.2% N, 16.8% P, 5.8% K	This research
Phu My Urea	46.3% N	PVFCCo, Vietnam
Phu My potassium MOP	61% K_2O	PVFCCo, Vietnam
Phu My NPK	15% N, 15% P_2O_5, 15% K_2O	PVFCCo, Vietnam
Lam Thao super phosphate	16% P_2O_5	LAFCHEMCO, Vietnam

2.3 Maize crop growth experiment

To compare the efficiency of MAP, five treatments were conducted in the field. The treatments comprised:

(1) The control: non-fertilizer used at planting.
(2) The NPK: 140 kg N/ha - 80 kg P_2O_5/ha - 90 kg K_2O/ha
(3) The MAP 1:50 kg N/ha
(4) The MAP 2:100 kg N/ha
(5) The MAP 3:150 kg N/ha

The maize hybrid cultivar R111/K60 (Faculty of Agronomy, Nong Lam University) was selected for this research. It has excellent yields, great quality, disease resistance, early maturity, and a wide range of adaptability. Totally, 17.5 m^2 area were used in the field experiment with 5 lines. The spacing between lines was kept at 70 cm. Seeds were sown after a 3 cm deep trench was made with a hand hoe for proper seed placement with spacing between adjacent plants kept at 25 cm (Fig. 2).

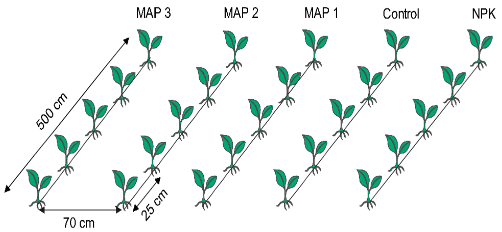

Fig. 2. Diagram of the field experiment.

2.4 Crop sampling and measurements

To identify the stage of crop development, the standardized maize developmental staging system was used according to technical regulations Country on trial value of cultivation and use of maize varieties (QCVN 01-56:2011/BNNPTNT). All treatments were monitored for the following criteria: growth time through stages; the height of plants; number of leaves and leaf area; morphological characteristics and quality of corn.

Leaf area (LA) was determined according to Zhou, Zhou (27). The LA was calculated by Eq. (1), where 0.75 is the factor [28].

$$LA\left(cm^2\right) = Length\left(cm\right) \times Width\left(cm\right) \times 0.75, \quad (2.1)$$

The quality of corn and the sweetness of the seeds were determined as follows: Selecting 5 seeds at different points on the corn and then pressing for water to measure with the Brix at harvest on 10 plants of each treatment.

2.5 Analysis methods

The percentage of organic matter was determined using the Walkley–Black method (TCVN 4050:1985), total N was determined using the Kjeldahl method (ISO 11251-95). The total K content was determined after extraction with H_2SO_4 and $HClO_4$ using a Flame photometer (TCVN 4053:1985). The pH was measured in a soil/water suspension (ISO 10390-2005). The exchangeable phosphorus was determined using the Olsen method (TCVN 8661:2011). The exchangeable potassium was measured using the emission spectroscopy method (TCVN 8662:2011). The morphology and chemical composition of the precipitates were obtained on a Scanning Electron Microscopy–Energy Dispersive X-ray Spectroscopy (Prisma E SEM, Thermo Fisher Scientific Co. US). Data of experiments were collected and calculated on computers according to ANOVA statistical analysis method and Duncan's multiple range test by using SAS 9.1 software.

3. Results and Discussion

3.1 Characterization of MAP

At optimal conditions such as pH 9.0, molar ratio of 1.6 Mg^{2+}:1 NH_4^+:1.5 PO_4^{3-}, and reaction time determined as 30 min in the batch tests, the MAP precipitation removed about 98.1±0.5% ammonium and 98.9±0.4% phosphate in swine wastewater. In addition, precipitate mass obtained the highest value up to 14.6±0.6 g/L. The SEM-EDS analysis of the dry struvite precipitate showed that struvite crystals developed (Fig 3). The EDS analysis on the surface of precipitates detected the presence of O, Mg, P, and small amounts of Na, K, and Cl. The EDS reported main components in the precipitates were ordinarily the highest weight percentage of O (49.63%), P (18.48%), and Mg (12.77%) which imply that the major crystal formed could be struvite. The SEM image of the precipitates demonstrated regulated crystals with an average length of around 100 µm. Furthermore, in this research, the crystals are formed as white powder and their average diameter is about 0.7 ± 1.3 mm.

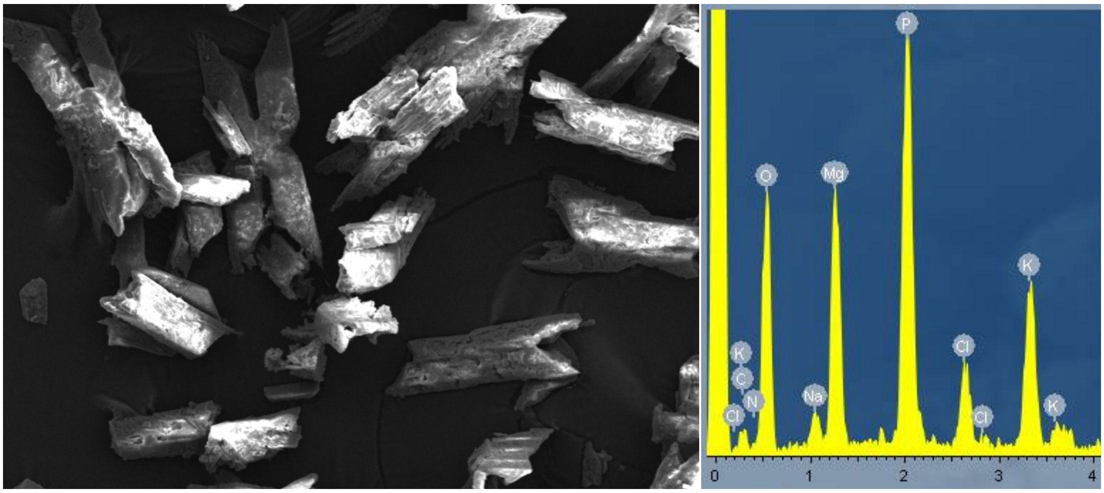

Fig 3. Morphology and chemical composition of recovered struvite crystals from swine wastewater as analyzed via SEM-EDS.

3.2 Fertilizer test

3.2.1 Maize growth (height and tassel)

The maize growth for different treatments is shown in Table 4 and 5. A significant difference ($\alpha < 0.01$) was found in plant height and tassel stage between control and treated groups during the whole growth period. Plant height is one of the important criteria in assessing the growth of maize. Overall, the maize that received NPK fertilizer and MAP was more vigorous in growth than those in the control. As seen in Table 4, the result shows that at different monitoring times, the plant height of the treatments continuously increased.

However, at 20 days, the results of the statistical analyses revealed that there were no significant differences ($\alpha > 0.01$) in the height between maize plants with different fertilizers. The maximum height of maize (228.1 cm) was observed in the MAP 3 treatment at 50 days (the time at which cob formation begins); there was a significant difference ($\alpha < 0.01$) between MAP 3 and the control treatment. The height was lowest in the control treatment (147.2 cm) at the final stage of growth (at 50 days). These results might indicate that the MAP fertilizers had significantly different effects on maize growth. Besides, this result showed that N promotes the vegetative growth of maize. Pandey, Ved (29) also observed that the plant height of maize increased greatly when the seeds were planted sparsely, and a sufficient amount of N was applied. On the other hand, the maize height depends on other factors such as genetic constituency, soil fertility, climatic conditions, day length, light intensity, and season [2].

Table 4. The height of maize plants.

Day	Height (cm)					CV (%)	F_{value}
	NPK	Control	MAP 1	MAP 2	MAP 3		
10	25.1^{a}	21.6^{b}	24.5^{a}	23.7^{a}	23.3^{ab}	4.4	5.0^{*}
20	62.8	53	59	61.9	61	7.9	2.1^{ns}
30	114.4^{a}	96.7^{c}	100.6^{bc}	106.5^{abc}	110.1^{ab}	5.2	4.9^{*}
40	161.9^{ab}	143.5^{c}	151^{bc}	162.7^{ab}	175^{a}	5.8	5.2^{*}
50	216.3^{a}	147.2^{c}	177.7^{bc}	196.9^{ab}	228.1^{a}	7.0	17.0^{**}

Note: In the same row, numbers with the same letter do not have a statistically significant difference; ns: no significance; ∗: significant difference at the level of $\alpha = 0.05$; ∗∗: very significant difference at the level of $\alpha = 0.01$.

Likewise, Table 5 shows a significant difference ($\alpha < 0.01$) in tassel stage between MAP 3 and other treatments. This result indicated that MAP fertilizer with high nitrogen content will shorten the tassel stage of maize. Alternatively, the MAP composition also contains phosphorus and magnesium, which are essential nutrients for the tassel stage of maize.

Table 5. The tassel stage of maize plants.

Tassel stage (day)					CV (%)	F_{value}
NPK	Control	MAP 1	MAP 2	MAP 3		
53.7^{a}	54^{a}	53.7^{a}	53.7^{a}	50.3^{b}	1.1	19.3^{**}

Note: In the same raw, numbers with the same letter do not have a statistically significant difference; ∗∗: very significant difference at the level of $\alpha = 0.01$.

3.2.2 Leaves number and leaf area

The variation in the leaves number and leaf area of the maize for the different treatments are shown in Table 6 and 7, respectively. As seen in Table 6, the number of leaves increased with time for all treatments. However, there was no significant difference ($\alpha > 0.01$) in the number of leaves for the different treatments. This result indicates that the fertilizer did not affect the number of leaves on the maize. On the contrary, Liu, Rahman (2) commented that the leaf number is dependent on several environmental factors including nutrient levels in the soil. The low number of leaves might be due to senescence, which is also caused by the low nutrient status of the soil [30].

Table 6. The leaves number of maize plants.

Day	Leaves number (leaf/plant)					CV (%)	F_{value}
	NPK	Control	MAP 1	MAP 2	MAP 3		
10	3	2.8	2.8	3	3	4	2.7^{ns}
20	3	2.8	3.3	3.2	3	6.5	3.2^{ns}
30	4.3	4.6	5.2	5.1	4.6	8.9	2.5^{ns}
40	7.7	7.6	8.6	8.7	8.3	11.2	0.9^{ns}
50	14.6	10	11.1	10.7	10.3	27	1.1^{ns}

Note: ns: no significance

Similarly, the leaf area also increased during the growth period for all treatments (Table 7). Overall, among the fertilizers, NPK showed a higher leaf area relative to the other treatments. At 20 and 30 days, the leaf area was significantly different ($\alpha < 0.01$) between NPK and other fertilizers. The results in Table 7 also showed that the maximum leaf area at 50 days in NPK treatment (343.3 cm^2 $plant^{-1}$), the estimated leaf area was significantly different ($\alpha < 0.01$) in MAP 1 (246.9 cm^2 $plant^{-1}$) and control (264.7 cm^2 $plant^{-1}$). Likewise, the estimated leaf area in MAP 2 and MAP 3 was 278 and 290.5 (cm^2 $plant^{-1}$), respectively, but no significant differences were found among the treatments.

Table 7 shows that the more MAP is added from 50 - 150 kg N ha^{-1}, the larger the leaf area is. Some researches suggest that nitrogen levels in the soil are responsible for the green coloration and chlorophyll content of leaves, and nitrogen deficiency greatly affects the yield [31, 32]. According to previous studies, the larger leaf area ensures good photosynthetic activity, which in turn increases the biomass yield [33-35]. Feng, Raza (36) also demonstrated that the leaf area development of maize plants was directly associated with the growing conditions under different planting patterns.

Table 7. The leaf area of maize plants.

Day	Leaf area (cm^2/plant)					CV (%)	F_{value}
	NPK	Control	MAP 1	MAP 2	MAP 3		
20	114.9^{a}	62.7^{b}	68.2^{b}	62.6^{b}	71.4^{b}	12.9	15.2^{**}
30	161.8^{a}	102.2^{b}	96^{b}	112.7^{b}	118.5^{b}	11.3	11.4^{**}
40	279.8^{a}	191.9^{b}	195.7^{b}	240.5^{ab}	267.4^{b}	13.5	4.8^{*}
50	343.3^{a}	264.7^{b}	246.9^{b}	278^{ab}	290.5^{ab}	8.5	6.8^{**}

Note: In the same raw, numbers with the same letter do not have a statistically significant difference; ∗: significant difference at the level of $\alpha = 0.05$; ∗∗: very significant difference at the level of $\alpha = 0.01$.

3.2.3 Morphological characteristics and quality of corn

Table 8 shows the results of measurements on the morphology and quality of the corn after harvest. Overall, the length and diameter of the corn were significant different ($\alpha < 0.01$) between MAP 2 and control treatment. This result indicated that MAP and NPK fertilization increased the size of the corn more than the control treatment (no fertilization). Besides the morphology of the corn, the quality of sweet corn varieties was an indicator that consumers always care about. Therefore, the

Brix degree was an important indicator in the evaluation of corn quality. As seen in Table 8, the Brix of the MAP treatment were over 13%, ranging from 13.9 – 14.5%. There was a significant difference ($\alpha < 0.01$) in Brix between the fertilizing treatment (MAP and NPK) and the control treatment. However, the Brix of corn in the MAP and NPK fertilization was not significantly different ($\alpha > 0.01$). Potassium in fertilizers affects the sweetness of the corn. Although MAP contains a small amount of potassium, it still ensures the same sweetness as that of the treatment using NPK fertilizers.

Table 8. The morphological and quality of corn.

Parameter	Treatments					CV (%)	F_{value}
	NPK	Control	MAP 1	MAP 2	MAP 3		
Corn length (cm)	17.9^{ab}	16.5^{b}	17.7^{ab}	18.9^{a}	18.1^{b}	7.4	3.8^{**}
Corn diameter (cm)	51.5^{abc}	49.8^{c}	51.1^{bc}	56^{a}	55.4^{ab}	3	9.2^{**}
Brix (%)	14.3^{a}	12.6^{b}	13.9^{a}	14.5^{a}	14.3^{a}	3	11.1^{**}

Note: In the same raw, numbers with the same letter do not hve a statistically significant difference; ∗∗: very significant difference at the level of $\alpha = 0.01$.

3.3 Economic efficiency

In this research, the socio-economic and technical viability of using MAP recovered from swine wastewater to plant maize has been considered. We made an initial assessment of the financial efficiency of MAP manufacturing based on the data obtained in this study. Accordingly, MAP obtained approximately 14 kg/m^3 of swine wastewater. The commercial price of MAP from Jiangxi Rutom Industrial Co., Ltd. (China) is \$0.3-\$0.35/kg. As a result, the profits can range from \$4.2 to \$4.9 for the total amount of MAP recovered per cubic meter. On the other hand, we have estimated the chemical and energy (electricity) costs of the MAP recovery technology. The entire cost of treating swine wastewater in the direction of MAP recovery can be determined between \$5 - \$6 per cubic meter. We realized the values of the recovered product are a little less than the cost of treating the swine wastewater. However, it should be noted that we do not manufacture MAP alone, but utilize the added value of swine wastewater treatment technology. Thus, the MAP as fertilizer slow-release can be applied to crops. Besides, controlled MAP crystallization is a key for protecting engineered systems from undesirable pipe blockage and reducing the cost of cleaning significantly [37].

4. Conclusion

In this study, the MAP was recovered from swine wastewater and its efficiency as a sustainable fertilizer was investigated. The results indicated MAP could be successfully applied in field maize cultivation. In the case of height, leaves number, leaf area, corn length, corn diameter, and sweetness, it was equally effective as NPK fertilizers. However, the tassel stage was significantly higher in MAP 3 treatment than in NPK treatment. Hence, our results show that MAP was recovered from swine wastewater could be an effective alternative to general chemical fertilizers.

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