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Effect of phosphate fertilizer-coated Dicarboxylic Acid Polymer on rice yield and components under greenhouse conditions

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Abstract

A significant amount of phosphorus (P) becomes fixed by aluminium (Al) and iron (Fe) in acidic soils, leading to decreased efficiency in P utilization and subsequently lowering crop yield. Enhanced P fertilization offers a potential solution, as the dicarboxylic acid polymer (DCAP) coating on P fertilizer promotes increased plant productivity and more effective P utilization. The improvement achieved through enhanced P fertilization can contribute to higher rice yields in acidic soils, accompanied by an increase in P solubility. The study aimed to determine the impact of DCAP-mixed phosphate fertilizer on P uptake by plants, absorption efficiency, and rice yield. The results demonstrated a significant increase in available P (about 3.5 mg P/kg) when DCAP was used in a greenhouse setting, resulting in elevated yields and total P absorption (ranging from 0.03 to 0.05 grams/pot). However, the addition of 60 kg of phosphate mixed with DCAP has not yet demonstrated a significant increase in available phosphorus in the soil compared to adding just 60 kg of phosphate. The application of phosphate at a dose of 30 kg of P_2O_5 mixed with DCAP for growth and phosphorus absorption yield results equivalent to using 60 kg of P_2O_5 without DCAP. Furthermore, the use of DCAP in conjuction with 50% P fertilizer increased P availability by the same amount as that achieved with 100% P fertilizer. Consequently, DCAP reduced chemical P fertilizer in the soil by approximately 50%. However, it is essential to evaluate the effectiveness of mixed phosphate fertilizer (DCAP) under field conditions before recommending its widespread use.

Keywords

Dicarboxylic Acid Polymer (DCAP); available phosphorus; rice; phosphate fertilizer; phosphorus absorption

Introduction

One of the nutrients that globally influences agricultural output is phosphorus (P) (1–3). While tropical and subtropical soils can naturally contain high total P content, reaching values as high as 1800 mg kg^{-1}(4), the strong P adsorption of iron (Fe) and aluminium (Al) oxides, along with 1:1 clay minerals, means that only a minimal amount of this P is readily available for plants (5). In these soils, phosphate fertilizers becomes the primary means to meet the crop's P requirements (6). According to Pal and Adhikary (7), phosphorus is a secondary requirement that often poses the most significant limitation for crops and forage output after nitrogen.

The primary function of phosphorus in plants is to store and transport the energy generated by photosynthesis for use in growth and reproduction.

Phosphorus in the soil exists in forms such as phosphates (PO_4^{3-}), mono- and di-hydrogen phosphates (HPO_4^{2-}), and $H_2PO_4^-$. The predominance of these anions depends on the pH of the solution or soil, which controls their eager interconversion. Plants most readily absorb phosphorus when the pH is between 6.5 and 7.5. Due to its high mobility, phosphorus can move from older, actively growing plant tissue to younger, more actively growing parts when it is insufficient. Consequently, early vegetative responses to phosphorus deficiency are frequently observed.

In acid sulphate soil, the efficiency of phosphorus uptake by plants can be limited, with only about 5-25% of the applied fertilizer being utilized. This is due to the high iron and aluminium content in acid sulphate soil, where phosphorus becomes fixed into insoluble compounds that are not easily dissolved by plants, making absorption more challenging (8). Consequently, approximately 75% to 95% of the phosphorus applied to the soil remains unavailable for crops. Moreover, this unutilized phosphorus, located near or on the soil's surface, can significantly impact the environment through erosion and leaching into rivers and lakes (9). It's noteworthy that phosphorus is most available to the plant within a few days to two weeks after fertilizer addition, gradually decreasing over time (20). Therefore, enhancing the efficiency of phosphorus uptake by plants not only improves economic efficiency but also reduces environmental pollution. Recent research and development have explored the additive effect of "Dicarboxylic Acid Polymer" (DCAP) in phosphate fertilizer. DCAP aims to protect phosphorus particles from immobilization by iron and aluminium in low pH conditions and by calcium and magnesium in high soil pH conditions. Results indicate that DCAP combined with phosphorus application increases the efficiency of phosphorus uptake and the yield of some crops (10–12). However, findings from Curtis research (13) on phosphate fertilizer application at a dose of 67 kg P_2O_5/ha mixed with DCAP in five experimental potato growing sites revealed that four sites exhibited higher yields.

In contrast, one site yielded less than the control group under an unmixed condition. This can be explained by the mixing of phosphorus with DCAP, which increases the available soil phosphorus content while reducing certain trace elements such as copper, zinc, and manganese in the soil, subsequently leading to a decrease in crop yield (14–17). Therefore, the effective use of DCAP depends on factors such as the amount of phosphate fertilizer applied, the response of each soil, and the specific types of crops being cultivated. The active ingredient "dicarboxylic acid polymer" is utilized to enhance the efficiency of phosphate fertilizer in various locations. However, the response to this active ingredient varies across different soil areas and crop types. In the Mekong Delta, acid sulfate soils cover approximately 1.6 million hectares, and while the phosphorus content in these soils is high, the efficiency of phosphorus use remains low. Hence, there is a pressing need to improve the efficiency of phosphate fertilizer use in acidic soils. DCAP, as an active ingredient, is known to increase the efficiency of phosphate fertilizer use and rice productivity. Consequently, this study aims to assess the response of mixed phosphate fertilizer (DCAP) in a greenhouse setting. This preliminary evaluation is crucial, providing a foundation for conducting extended trials in the acidic soil regions of the Mekong Delta before recommending its widespread use.

Materials and Methods

Material

Place and time of performance: The experiment took place from February 2020 to May 2021 in the net house located at the Soil Science Department, College of Agriculture, Can Tho University, Can Tho City, Vietnam. (Latitude: 10° 01'43.30"N, Longitude: 105°45'59.71"E)

Experimental soil was sourced from the 0–20 cm layer in Hoa An commune, Phung Hiep district, Hau Giang province. The collected soil underwent a thorough process, including drying, mixing to ensure homogeneity, and removal of any debris. Subsequently, the soil was subjected to comprehensive analysis, covering key criteria such as pH, electric conductivity (EC), available phosphorus (P), free iron (Fe), and exchangeable aluminium (Al).

Fertilizers: urea (46% N), DAP (18% N–46% P_2O_5), and KCl (60% K_2O).

Experimental pots: For the experiment, pots with a height of 35cm, width of 40cm, and a soil capacity of 15 kg soil were utilized. Each pot was planted with five germinating rice seeds.

Rice variety and its characteristics: The rice variety chosen for the experiment was OM2517. This variety typically has a growth cycle of approximately 90–95 days, reaching a height of about 90–100 cm and displaying robust tillering ability. The number of panicles or spikelets ranges from 9–12, while the grain length measures between 7.0–7.3 mm. A thousand seeds weigh around 26–28 g, with an amylase content of about 24-25%. The chalkiness of rice, denoting the silver belly of rice grain, falls within grades 1 to 5. For this variety, the expected yields are 5 tons/ha for the summer-autumn crop and 8 tons/ha for the winter-spring crop.

Method

Experimental layout

The experiment was arranged in a Completely Randomized Design (CRD), comprising 5 treatments, each with six replicates, where each replicate corresponds to an individual pot. The experimental treatments are shown in Table 1.

Soil and plant analysis

Soil analysis was conducted at the Soil Physics - Chemistry Analysis Laboratory, situated within the Soil Science Department, College of Agriculture, Can Tho University. The specific methods employed for soil analysis are mentioned in Table 2a, while the methods for crop analysis are in Table 2b.

Table 1. The treatments of the experiment

No	Experiment	Describe
1	0 P_2O_5	No phosphate fertilizer (control)
2	30 P_2O_5	Apply 100% phosphate as recommended with DAP
3	30 P_2O_5 + DCAP	Apply 100% phosphate as recommended with DAP fertilizer mixed with DCAP
4	60 P_2O_5	Apply 100% phosphate as recommended with DAP
5	60 P_2O_5 + DCAP	Apply 100% phosphate as recommended with DAP fertilizer mixed with DCAP

Note: Use 2 litres of mixed DCAP solution for one ton of DAP fertilizer to achieve a concentration of 2‰ (as recommended by the manufacturer); DCAP: Dicarboxylic Acid Polymer

Table 2a. Method of soil analysis at the beginning of the crop

Parameters	Unit	Method
pH $_{H2O}$		Extraction with distilled water, ratio 1:2.5 (soil/water), measured by pH meter.
EC	mS/cm	Extraction with distilled water, ratio 1:2.5 (soil/water), measured by EC meter.
Avai P	mg P/kg	Bray II method: soil extraction with HCl 0.1N + NH_4F0.03N, ratio 1:7 (soil: extract solution),
Fe^{3+}	%Fe_2O_3	extraction with oxalate - oxalic acid, Fe determination on atomic absorber
Al^{3+}	meq/100g	Extract with 1N KCl, titrate with 0.01N NaOH, complex with NaF and titrate with 0.01N H_2SO_4

Table 2a. Method of soil analysis at the beginning of the crop

Parameters	Unit	Destruction of samples	Method*
P total	%P	6g salicylic acid + 18ml demineralized water + 100ml H_2SO_4 96%, H_2O_2 used for oxidation	Colorimeter on a spectrophotometer

Notes: Walsh and Beaton (1973)

Time and dose of fertilizer

The fertilizer formula for rice consists of 100 N–30 K_2O (kg/ha). The application schedule and corresponding fertilizer doses are planned at 10, 20, and 40 days after seeding (DAS) (Table 3).

Table 3. Period and dose of fertilizer for the experiment

Fertilization period	Amount of fertilizers (%)		
	N	P_2O_5	K_2O
1st application (10 DAS)	30	50	50
2nd application (20 DAS)	40	50	0
3rd application (40 DAS)	30	0	50

DAS: days after sowing

Data collection and analysis

Soil samples were collected for available P analysis at both the beginning and ending of the cropping season.

The data on height and the number of rice shoots were collected at specific intervals: 20, 45, 65, and 90 days after sowing (DAS).

Data collection included yield components such as the number of flowers per pot, the percentage of firm seeds (%), the weight of a thousand seeds (at 14% moisture content), and the number of seeds per panicle. The grain yield/pot at 14% moisture was determined by harvesting the entire rice plant from each pots. The yield was then calculated in grams.

For the straw and seed sampling method, 5 plants were randomly chosen from each treatment. The biomass of straw and grains was measured by weighing them in the pots at the harvest stage and subsequently drying them at 70 °C for 72 hours.

Absorbance = biomass (straw and seeds) x the content of each part.

The analysis of variance (ANOVA) was done using SPSS software version 16.0 to compare the mean differences, using the Duncan test.

Results

Initial soil properties of the experiment

The initial soil characteristics at a depth of 0–20cm are presented in Table 4. The soil was initially in a state of perennial rice cultivation. The impact of soil chemical parameters on plant growth was assessed using the rating scale developed by Có dấu giữa 2 tác giả (19). The soil selected for the experiment was identified as acid sulfate soil (Epi-Orthi Thionic Fluvisols), characterized by a low pH (3.8) and high levels of exchangeable aluminium (Table 4). The prevalence of high iron and aluminium content in the soil led to phosphorus fixation, resulting in low soil phosphorus content (20).

Table 4. Initial experimental soil properties

Targets	Value	Evaluation for plant
pH $_{H2O}$	3.82 ± 0.05	Low, slightly acid
$EC_{1:2.5}$ (mS/cm)	4.52 ± 0.08	High
Available P (mg/kg)	9.63 ± 0.14	Relatively low
Exchange Al (meqAl^{3+}/100g)	13.3 ± 0.11	Pretty high
Free Fe (%Fe_2O_3)	0.95 ± 0.01	Medium

The concentration of available soil phosphorus after mixing phosphorus with DCAP

The addition of 30 kg of P_2O_5 mixed with DCAP to the soil resulted in an increase in available phosphorus compared to the control (Figure 1). The peak available phosphorus content was observed four days after application. Interestingly, when 60 kg of P_2O_5 mixed with DCAP was introduced to the soil, there was no additional increase in available phosphorus, similar to the case with 30 kg of P_2O_5 mixed with DCAP.

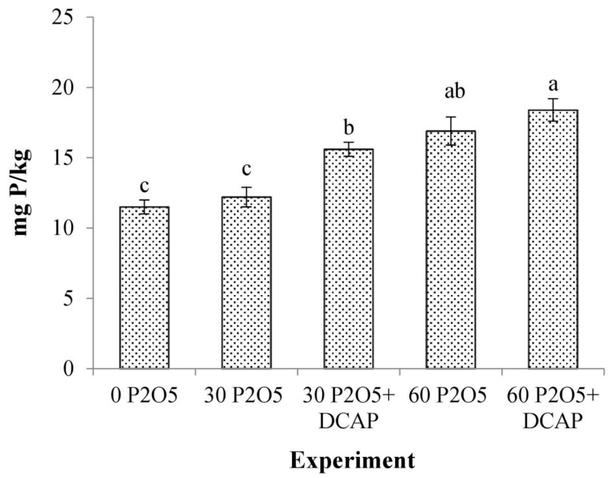

Fig 1. The content of available phosphorus doses

The absence of added phosphorus in fertilizers leads to a decrease in soil phosphorus content due to the uptake by plants during their growth and development. Application of mixed phosphate fertilizer DCAP plays a crucial role in reducing the fixation of Fe^{2+}, Fe^{3+}, and Al^{3+} ions with $HPO_4^{2-}$and $H_2PO_4^-$, consequently elevating the available phosphorus content in the soil. This observation aligns with findings from Noble's study (21), where the application of mixed phosphate fertilizer DCAP was associated with an increase in the soil's available phosphorus content.

Effects of mixed phosphate fertilizer DCAP on growth parameters of rice growing under Greenhouse Conditions

Height of rice plants: The height of rice plants in treatments without any phosphate application was significantly shorter at 45, 65 and 90 DAS compared to those receiving 30 P_2O_5 + DCAP, 60 P_2O_5, and 60 P_2O_5 + DCAP. This difference was found to be statistically significant at a 5% level of significance. Specifically, the application of 30 kg of P_2O_5 mixed with DCAP resulted in a precise height of rice, while 60 kg of P_2O_5 was applied without DCAP at the 45 and 90 DAS stages (Table 5).

Given that phosphorus plays a crucial role in photosynthesis, respiration, energy storage and transfer, cell division, and various other plant processes, including growth promotion and enhancement of water use efficiency (22), the absence of phosphorus application led to a reduction in the height of rice plants compared to those receiving other treatments. Notably, the soil treatment involving 30 kg P_2O_5/ha for rice cultivation showed reduces height at stages 45 and 90 DAS. This reduction might be attributed to the fixation of the applied phosphorus applied (13), preventing the rice plants from utilizing it fully or partially.

The number of rice shoots: Table 6 indicates no significant difference in the number of rice shoots among treatments at the 20 and 45 DAS stages. However, variations emerged at the 65 DAS stage. Specifically, treatments without phosphate and 30 kg of P_2O_5 without DCAP exhibited the lowest number of rice shoots compared to the other treatments at the 65 DAS stage. Notably, the number of rice shoots in the treatment without phosphate significantly decreased from 45 to 65 DAS. This decline could be attributed to the plant's need for sufficient phosphorus to maintain the number of flowers at this stage. These findings align with the results of Khuong (23), which demonstrated an increase in rice shoots in soils mixed with DCAP.

Table 6. Effect of DCAP mixed phosphate fertilizer on the rice shoot numbers

Experiment	Rice shoot's number per pot		
	20 DAS	45 DAS	65 DAS
0 P_2O_5	10.0	25.7	20.8 b
30 P_2O_5	11.8	24.3	22.1 b
30 P_2O_5 + DCAP	11.0	27.0	26.2 a
60 P_2O_5	11.5	25.9	26.4 a
60 P_2O_5 + DCAP	10.1	26.8	26.6 a
F	Ns	ns	*
CV(%)	4.12	8.17	5.89

Note: In the same column, numbers followed by different letters have statistical significance at 5% (*); ns: no statistically significant difference

Effect of mixed phosphate fertilizer DCAP on rice yield components and yield under greenhouse conditions

The application of phosphate at a dosage of 30 kg P_2O_5 mixed with DCAP showed that the number of panicles per pot, the ratio of firm seeds, and yield (grams/pot) were comparable to the treatment of 60 kg P_2O_5 and 60 kg P_2O_5 mixed with DCAP. However, a significantly higher value was observed in the treatment without any additional phosphate and in the treatment with 30 kg of P_2O_5 without DCAP (Table 7).

Table 5. Effect of DCAP phosphate fertilizer on rice plant height

Experiment	Rice plant height (cm)			
	20 DAS	45 DAS	65 DAS	90 DAS
0 P_2O_5	34.9	53.1 b	76.8 b	80.7 b
30 P_2O_5	34.8	55.3 b	82.4 a	85.1 b
30 P_2O_5 + DCAP	35.8	60.2 a	82.0 a	94.6 a
60 P_2O_5	33.7	59.7 a	82.3 a	92.2 a
60 P_2O_5 + DCAP	34.1	61.5 a	81.9 a	94.4 a
F	Ns	*	*	*
CV(%)	5.04	6.75	7.10	5.24

Note: In the same column, numbers followed by different letters have statistical significance at 5% (*); ns: no statistically significant difference

Table 7. Effect of DCAP phosphate fertilizer on rice yield components and yield

Experiment	Number of panicles/pot	Number of seeds per panicle	Percentage of firm seeds (%)	Weight 1,000 seeds (grams)	Yield (gram/pot)
0 P_2O_5	19.5 b	91.0	75.7 b	26.6	38.1 b
30 P_2O_5	20.8 b	95.5	79.9 b	27.0	40.6 b
30 P_2O_5 + DCAP	25.1 a	93.5	84.4 a	26.9	56.6 a
60 P_2O_5	26.1 a	95.7	84.5 a	26.8	55.7 a
60 P_2O_5 + DCAP	24.3 a	97.9	83.5 a	26.9	54.4 a
F	**	Ns	*	ns	**
CV(%)	5.12	5.27	4.06	3.24	6.22

Note: In the same column, numbers followed by different letters have statistical significance at 1% (**) and 5% (*); ns: no statistically significant difference

Interestingly, the application of 60kg of P_2O_5 mixed with DCAP showed no difference in yield and yield components (grams/pot) compared to the treatment with 60kg of P_2O_5 alone. This suggests that rice plants may only require approximately 60kg of P_2O_5/ha for optimal growth and development, and the addition of DCAP at this dose does not increase phosphorus uptake efficiency.

Contrary to this research, research indicates that while high doses of phosphate application combined with DCAP did not result in a difference in rice yield compared to treatments without DCAP (11), the combination of low doses of phosphate with DCAP increased the phosphorus uptake efficiency and boosted yields in certain crops (12). According to the research results of Dang (24), phosphate fertilizer application at a dose of 30 kg P_2O_5/ha mixed with DCAP produced the yield of sweet potato and cassava tubers equivalent to those obtained with 60kg P_2O_5/ha without DCAP, a notable finding considering the potential reduction in yield when applying only 30kg P_2O_5/ha to the soil.

Effect of mixed phosphate fertilizer DCAP on phosphorus content and absorption by rice

No statistically significant differences were observed between phosphorus fertilization treatments in straw and seed phosphorus content. However, the total phosphorus absorption among the treatments was statistically different at the 5% significance level, potentially attributed to variations in the biomass of straw and grain (Table 8). The absence of phosphate application resulted in the lowest phosphorus absorption. The phosphorus absorption in treatments involving 30kg P_2O_5/ha mixed with DCAP was equivalent to that in the treatment with 60 kg of P_2O_5/ha without DCAP. These findings align with Wiatrak (25), where the application of phosphate at a dose of 45 kg P_2O_5/ha mixed with DCAP increased phosphorus uptake and wheat yield, comparable to the treatment with 90 kg P2O5/ha, which also enhanced phosphorus uptake and grain yield. The phosphorus content in seeds ranged from 0.20-0.24%, while in straw, it ranged from 0.10- 0.12%. These findings are consistent with Fairhurst (26), which stated that the average P content in seeds was around 0.20%, and in straw, it was 0.10%.

Effect of phosphate fertilizer mixed with DCAP on the content of available soil phosphorus at the end of the crop.

The application of phosphorus mixed with DCAP at 30kg P2O5/ha resulted in soil available phosphorus content equivalent to that achieved by applying 60kg P2O5/ha by the end of the season, as illustrated in Figure 2. Treatments without phosphate and with phosphate applied at a dose of 30kg P2O5/ha exhibited low soil phosphate content at the end of the crop, significantly differing at the 5% significance level compared to other treatments. Phosphate application at the dose of 60kg P_2O_5/ha mixed with DCAP did not demonstrate a difference in available phosphorus content in the soil compared to the application of 60kg P_2O_5/ha alone. Despite the increase in available phosphorus content resulting from the application of DCAP mixed phosphate fertilizer, the levels remained low, measuring less than 20mg P/kg (18).

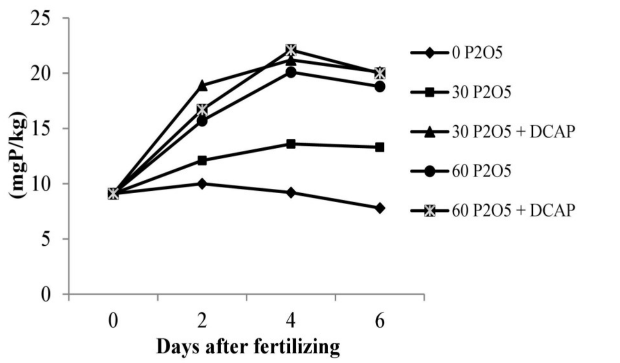

Fig 2. Effect of mixed phosphate fertilizer DCAP on the content of available soil phosphorus at the end of the crop

Table 8. Effect of mixed phosphate fertilizer DCAP on phosphorus content and phosphorus absorption of rice

Experiment	Biomass (gram/pot)		Phosphate content (%P)		Total P absorption (grams/pot)
	Seed	Straw	Seed	Straw	
0 P_2O_5	27.2 b	24.1 b	0.20	0.11	0.08 c
30 P_2O_5	29.0 b	28.5 b	0.22	0.12	0.10 bc
30 P_2O_5 + DCAP	40.4 a	39.9 a	0.22	0.11	0.13 ab
60 P_2O_5	39.7 a	42.0 a	0.24	0.12	0.15 a
60 P_2O_5 + DCAP	39.8 a	40.3 a	0.23	0.10	0.13 ab
F	*	*	ns	ns	*
CV(%)	5.11	4.32	8.19	7.10	4.15

Note: In the same column, numbers followed by different letters have statistical significance at 1% (**) and 5% (*); ns: no statistically significant difference

Conclusion

In summary, the experiments demonstrated that the utilization of DCAP-coated P fertilizer significantly increased the concentration of available phosphorus (~22%) in the soil, total phosphorus absorption (~23%), and yield (~28%) compared to the use of uncoated P fertilizer. Nevertheless, the addition of 60 kg of phosphate mixed with DCAP did not show a notable increase in phosphorus availability compared to the application of 60 kg of phosphate alone.

Furthermore, the study highlights the adverse effects of not using phosphate fertilizer, leading to reduced plant height, the number of shoots, and the percentage of firm seeds, ultimately lowering overall yield. The application of phosphate at a dose of 30 kg of P2O5 mixed with DCAP demonstrated an equivalent phosphorus absorption yield to that of 60 kg of P2O5 without DCAP.

The incorporation of DCAP in phosphate fertilizer proved effective in protecting phosphate particles from fixation by iron and aluminium toxins in low pH conditions and calcium and magnesium in high pH conditions. This not only enhances economic efficiency but also contributes to environmental sustainability by reducing pollution.

The study establishes that adding DCAP to phosphate fertilizer has the potential to improve phosphorus uptake and growth parameters, particularly in rice cultivation in acidic soils with limited phosphorus availability. These findings suggest the promising application of DCAP in agricultural practices, especially in regions with similar soil conditions, such as acid sulfate soils. However, further research and field trials are imperative to fully comprehend the extent of DCAP's effectiveness in real-world agricultural settings.

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Authors' contributions

Tran Van Hung: Field experiment data collection, processing, and drafting the manuscript.

Ngo Ngoc Hung: Topic development, field experiment design, final approval of the manuscript.

Vo Quang Minh*: Correct, revise the manuscript, and corresponding.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: "None".

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