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## *Meet the Student-Author*

**Jonathan Brye**

Jonathan Brye recording soil volumetric water content measurements within the furrow-irrigated-rice tubs in the greenhouse.

I went to Farmington High School in Farmington, Arkansas and lived in Fayetteville my whole life. I am a 3-year member of the University of Arkansas Soil Judging Team. I have been 2nd in individuals overall in three consecutive Region IV soil judging competitions, while the team has placed 1st. I have participated in two national soil judging competitions, highlighted by a 2nd-place team-judged pit finish in 2023 and 6th place overall finish. I have worked as a research assistant, resident assistant, and as student manager for the Arkansas men's basketball team. I am a Presidential Scholar, the recipient of the John W. White Outstanding Student Award, Crop, Soil and Environmental Sciences (CSES) Senior Award, and numerous departmental and collegiate scholarships. Through CSES, I have worked on multiple research projects, including a rainfall-runoff simulation experiment, a greenhouse gas emissions study in flood- and simulated-furrow-irrigated rice, an aggregate stability study, and my own Honors research, which has cultivated a love and appreciation for research. After graduation, I aspire to earn a Master's degree from the University of Arkansas and eventually earn a Ph.D. degree in some area related to environmental science/natural resources to allow me to pursue a career as a professor. I would like to thank Dr. Brye for his gracious, unwavering mentorship throughout my entire life, and I would also like to thank Diego Della Lunga, Chandler Arel, and Morgan Brye for their assistance in the greenhouse.

## *Research at a Glance*

- Recovering wastewater phosphorus to produce struvite could remediate ecosystems affected by excess nutrients.
- Struvite could decrease global dependence on unsustainable sources of rock-phosphate-derived fertilizer.
- Electrochemically precipitated struvite may be a viable substitute for rock-phosphate fertilizers.

# Rice Biomass Response to Various Phosphorus Fertilizers in a Phosphorus-Deficient Soil Under Simulated Furrow-Irrigation

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### Abstract

Wastewater-recovered phosphorus (P), in the form of the mineral struvite ($MgNH_4PO_4 \cdot 6H_2O$), may provide a sustainable alternative to decreasing rock-phosphate reserves. Struvite can be generated via precipitation methods, potentially reducing the amount of P runoff to aquatic ecosystems. The objective of this greenhouse tub study was to evaluate the effects of chemically and electrochemically precipitated struvite (CPST and ECST, respectively) on aboveground plant response in a hybrid rice cultivar grown using furrow-irrigation compared to other common fertilizer-P sources [i.e., triple super phosphate (TSP) and diammonium phosphate (DAP)] using three replications of fertilizer treatment in a P-deficient silt loam (Typic Glossaqualfs). Aboveground rice dry matter (DM), aboveground DM P uptake, grain yield, and grain P uptake from CPST and ECST did not differ from DAP or TSP. However, aboveground DM P concentration was numerically largest ($P < 0.05$) from TSP (0.05 %), which did not differ from DAP, and was at least 2.5 times larger than that from ECST, CPST, and the unamended control (UC). Similar rice responses among struvite and other common fertilizer-P sources suggest CPST and ECST are both possible alternative fertilizer-P sources that warrant further research into struvite's role in food production and water quality restoration and preservation.

* Jonathan Brye will be a May 2024 honors program graduate with a degree in Environmental, Soil, and Water Science.
† Kristofor Brye, the faculty mentor, is a University Professor in the Department of Crop, Soil and Environmental Sciences.
§ Diego Della Lunga is a Senior Graduate Assistant in the Department of Crop, Soil and Environmental Sciences.

## Introduction

In an agronomic setting, optimal P improves systematic functions of photosynthesis, leading to healthier and more productive plants, which ultimately correlates to greater crop yields. In contrast to N and K, in moist, upland soils, P is generally highly insoluble in the soil, which leads to limited plant-available P in the soil solution (Weil and Brady, 2016). Approximately 90% of the current global P supply is mined as phosphorite or rock phosphate (RP), which is then processed to create several fertilizer-P materials. However, RP production is expected to reach a peak in the next 50 years, when Earth's finite supply of RP will be nearly depleted (Cordell et al., 2009). One possible solution to the limited supply of mined RP is the mineral struvite ($MgNH_4PO_4 \cdot 6H_2O$) (Omidire et al., 2020). Under the right physiochemical conditions, struvite precipitates inside wastewater treatment plant (WWTP) pipes, which is a major problem for WWTP operation on account of clogged pipes. However, when struvite-producing conditions are controlled in specialized reactors through manipulated sludge digesting processes, WWTPs can intentionally produce an abundance of struvite and prevent struvite buildup in WWTP pipes (Talboys et al., 2015).

In addition to chemical precipitation, other P-extracting technologies from wastewater are available. For example, more recently, electrochemical precipitation of struvite from synthetic wastewater has been developed and studied. Electrochemical precipitation can synthesize struvite using an electrical current applied to a solution of known N and P concentration, while magnesium (Mg) is supplied to the solution through a Mg anode that partially decays in the process to release Mg ions (Kékedy-Nagy et al., 2020). Since struvite is a P-containing mineral and there is an abundance of wastewater, struvite could be an alternative fertilizer-P source for agricultural use (Omidire et al., 2020). In addition to struvite, furrow irrigation was also utilized in the study. Furrow-irrigation is conducted by the establishment of raised beds separated by furrows that extend the length of the field between the raised beds, and furrow-irrigation has been shown to use 41% to 48% less water than conventional irrigation methods (i.e., flooding in rice cultivation) (He, 2010).

The objective of this study was to evaluate the effects of struvite (i.e., ECST and CPST) compared to several other commercially available fertilizer-P sources (i.e., DAP and TSP) on aboveground plant response to rice grown under furrow-irrigation in a P-deficient, silt loam soil. It was hypothesized that both struvite-P sources (ECST and CPST), TSP, and DAP would have similar aboveground rice dry matter but that tissue-P concentrations would differ between the two struvite-P sources themselves (ECST and CPST) due to differences in source materials, where ECST was prepared from a synthetic solution containing N and P, and CPST was generated from municipal wastewater.

## Materials and Methods

The soil used in this study was a Calloway silt loam (fine-silty, mixed, active, thermic Aquic Fraglossudalfs) collected on 19 April 2021 with a shovel from the upper 10 to 15 cm from a tilled field at the University of Arkansas System Division of Agriculture's Pine Tree Research Station near Colt in St. Francis County, Arkansas. Subsamples of air-dried soil were oven-dried at 70 °C for 48 hours, crushed, and sieved through a 2-mm mesh screen for determination of sand, silt, and clay, soil pH, and electrical conductivity (EC), soil organic matter (SOM) and total C and N, and Mehlich-3 extractable nutrients (i.e., K, P, Ca, Mg, Fe, Na, Mn, Cu, S, and Zn) (Table 1).

This study was designed to evaluate rice response to five fertilizer-P treatments: ECST, CPST, TSP, DAP, and an unamended control (UC). Treatments were arranged in a randomized complete block design on a single greenhouse bench and replicated three times for a total of 15 tubs.

Approximately 26.4 kg of sieved and air-dried soil was placed into 15 plastic tubs (51 cm wide by 67 cm long by 15 cm deep) on the same greenhouse bench and separated into three blocks, with each block containing five tubs. Tubs were seeded manually with a hybrid cultivar (Gemini 214, RiceTec) on 15 May 2021.

The first of four fertilizer applications occurred approximately 10 days after seeding (DAS), where 1 g of zinc sulfate was surface-applied to the soil surface of each tub and was watered into the soil by lightly irrigating with tap water to prevent zinc deficiency, creating a more ideal rice-growing condition. At 16 DAS, at approximately the 2 to 3 leaf stage, fertilizer-P treatments were applied manually to the soil surface of each respective tub. Each tub received 0.76 g of total P, which was equivalent to the recommended fertilizer-P rate of 29.4 kg P/ha based on the initial soil-test P concentration (Table 1; Hardke, 2021), from each fertilizer-P source (i.e., DAP, TSP, ECST, and CPST). In addition to the P, each tub received 2 g N initially, either from the fertilizer-P source, urea, or a combination of both. At 27 DAS, a second N application of 3.78 g N per tub, which was equivalent to 145.7 kg N/ha, as coated urea was surface-applied to each tub and watered into the soil by lightly irrigating with tap water. At 46 DAS, a second and final split application of 0.58 g N per tub, which was equivalent to a rate of 22.4 kg N/ha, was manually surface-applied to each tub and watered into the soil by lightly irrigating with tap water. From 11

June 2021 to 17 September 2021, all tubs were manually watered using distilled water approximately every other day.

Biomass collection took place on 25 September 2021, when the rice plants were at harvest maturity. Aboveground biomass was dried for approximately 7 days at 55 °C and weighed to determine dry matter. Rice seeds were manually stripped from the aboveground dry matter and collected to determine grain yield per tub. Subsamples of rice aboveground plant tissue were mechanically ground and sieved to < 1 mm for subsequent laboratory analyses for total N, P, and Mg. Only grain P concentration was measured. Plant nutrient uptake was determined by multiplying the vegetative dry mass and measured elemental concentrations on a plot-by-plot basis. For reporting purposes, rice yield was adjusted to 12% moisture.

Based on the randomized complete block design with three replications, a one-factor analysis of variance was conducted using PROC GLIMMIX in SAS v. 9.4 (SAS Institute, Inc., Cary, N.C.) to evaluate the effect of fertilizer-P source (i.e., DAP, TSP, CPST, ECST, and UC) on aboveground plant properties in furrow-irrigated rice. Significance was judged at $P < 0.05$. When appropriate, means were separated by least significant difference at the 0.05 level.

## Results and Discussion

Several aboveground rice tissue properties were affected ($P < 0.05$) by fertilizer-P source (Table 2). Contrary to expectation, aboveground rice dry matter was unaffected ($P = 0.24$) by fertilizer-P source. Aboveground rice dry matter ranged from 1.31 kg/m$^2$ from ECST to 2.16 kg/m$^2$ from TSP and averaged 1.70 kg/m$^2$ overall among all fertilizer-P sources. The four fertilizer treatments behaved similarly as expected, but the fertilized treatments did not differ from the UC, which was likely because of a decrease in soil pH that caused previously immobilized P to release into the soil solution and become plant available to overcome initial soil-P deficiency (Hardke, 2021).

In contrast to aboveground dry matter, aboveground rice dry matter P concentrations differed ($P < 0.05$) among fertilizer-P sources (Table 2). Aboveground P concentration was numerically largest from TSP, which did not differ from DAP, and was at least 2.5 times greater than from the other two fertilizer-P sources, which did not differ among themselves. In addition, aboveground P concentration from the UC was similar to DAP. It is possible that solubility and in-plant translocation differences among fertilizer-P sources could have resulted in more plant-available P being released from fertilizer-P sources with larger solubilities (i.e., TSP or DAP), thus causing the aboveground dry matter P concentration to be greater from TSP and DAP than from struvite.

Similar to aboveground rice dry matter, aboveground N and Mg concentrations were unaffected ($P > 0.15$) by fertilizer-P source (Table 2). Aboveground rice dry matter N concentration ranged from 0.53% from CPST to 0.65% from TSP and averaged 0.57%, while aboveground rice dry matter Mg concentration ranged from 0.55% from the UC to 0.72% from ECST and averaged 0.65% overall among all fertilizer-P sources.

Aboveground rice dry matter N uptake ranged from 7.1 g/m$^2$ from ECST to 14.1 g/m$^2$ from TSP and averaged 9.9 g/m$^2$, while aboveground rice dry matter Mg uptake ranged from 8.5 g/m$^2$ from the UC to 13.8 g/m$^2$ from TSP and averaged 10.8 g/m$^2$ overall among all fertilizer-P sources (Table 2). Uniform N application and sufficient soil Mg concentration likely explain the similar N and Mg uptakes among fertilizer-P sources. However, contrary to expectations and in contrast to their aboveground concentrations that differed among treatments, aboveground dry matter P uptake was unaffected ($P > 0.10$) by fertilizer-P source (Table 2). Aboveground rice dry matter P uptake ranged from 0.24 g/m$^2$ from ECST to 0.90 g/m$^2$ from TSP and averaged 0.47 g/m$^2$ overall among all fertilizer-P sources (Table 2).

Similar to the results of the current study, Della Lunga et al. (2021) reported that aboveground rice N uptake from conventional tillage was 7.76 g/m$^2$ in 2018 and 7.44 g/m$^2$ in 2019, and rice P uptake was 0.79 g/m$^2$ in 2018 and 0.97 g/m$^2$ in 2019, which were similar to the N and K uptakes measured in the current study (Table 2).

Similar to aboveground rice tissue properties, certain rice grain properties were unaffected ($P > 0.05$) by fertilizer-P source, while grain P and Mg concentrations differed ($P < 0.04$) among fertilizer-P sources (Table 2). A rice yield response to fertilizer-P additions was expected due to the initial low soil-test P (Table 1); however, grain yield was unaffected ($P = 0.44$) by fertilizer-P source, which ranged from 1.11 kg/m$^2$ from DAP to 1.47 kg/m$^2$ from TSP and averaged 1.26 kg/m$^2$ overall among all fertilizer-P sources (Table 2). Similar to aboveground dry matter, the four fertilizer treatments behaved similarly as expected, but grain yield from the fertilized treatments was not greater than from the UC, which, similar to aboveground dry matter, was likely because of a decreased soil pH that released additional P over the course of the growing season.

In contrast to grain yield, grain P and Mg concentrations from TSP, DAP, ECST, and CPST, which did not differ, were at least 1.2 times greater than the UC (Table 2). It is unclear why Mg concentration differed between the fertilized treatments and the UC considering there was likely adequate initial soil Mg among all treatments, but it is possible that there was a differential interaction between the soil Mg and the fertilizer-P sources during plant Mg uptake. Contrary to the current study, Omidire et al. (2022a) reported that grain P and Mg concentrations in a flood-irrigated, pure-line cultivar were unaffected by fertilizer-P source (i.e., TSP, DAP, ECST, CPST, and UC). In contrast to the current study, a 2-year field study evaluating P fertilizers (i.e., ECST, CPST, monoammonium phosphate, DAP, TSP, and rock phosphate) in corn on a silt loam (Aquic Fraglossudalfs) in eastern Arkansas reported that kernel P and Mg concentrations were unaffected (Omidire et al., 2022b).

Contrary to expectations and in contrast to their grain concentrations that differed among treatments, grain P uptake was unaffected ($P > 0.09$) by fertilizer-P source (Table 2). Grain P uptake ranged from 2.4 g/m$^2$ from the UC to 3.9 g/m$^2$ from TSP and averaged 3.2 g/m$^2$ among fertilizer-P sources.

## Conclusions

This study evaluated the effects of two struvite materials, ECST and CPST, on the aboveground plant response of a hybrid rice cultivar grown in the greenhouse in a P-deficient, silt-loam soil under simulated furrow-irrigation compared to other common fertilizer-P sources. As hypothesized, both ECST and CPST treatments produced a similar rice response amongst the struvite treatments and the RP-derived fertilizers, but contrary to the hypothesis, tissue-P concentration was similar among struvite treatments. Based on the results of this greenhouse study, it can be concluded that struvite, namely ECST, is a viable fertilizer-P source that could be used as an alternative to RP-derived fertilizers for simulated furrow-irrigated rice production in a P-deficient, silt-loam soil.

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**Table 1. Summary of initial physical and chemical property means (n = 5) and standard errors (SE) for the soil used in the greenhouse experiment.**

| Soil Property | Mean ( ± SE) |
|---|---|
| Sand (g/g) | 0.09 (<0.01) |
| Silt (g/g) | 0.79 (<0.01) |
| Clay (g/g) | 0.12 (<0.01) |
| Electrical conductivity (dS/m) | 0.167 (<0.01) |
| pH | 7.5 (0.01) |
| Extractable soil nutrients (mg/kg) | |
| P | 11.4 (0.1) |
| K | 46.1 (0.9) |
| Ca | 2005 (4.2) |
| Mg | 276.3 (2.3) |
| S | 11.9 (0.4) |
| Na | 29.8 (0.6) |
| Mn | 244.3 (5.1) |
| Fe | 303.8 (7.8) |
| Cu | 1.6 (<0.1) |
| Zn | 2.5 (0.1) |
| Soil organic matter (g/kg) | 25.7 (0.2) |
| Total C (g/kg) | 11.4 (0.2) |
| Total N (g/kg) | 1.1 (<0.1) |
| C:N ratio | 10.0 (0.1) |

**Table 2. Analysis of variance summary of the effect of fertilizer-phosphorus treatment [i.e., electrochemically precipitated struvite (ECST), chemically precipitated struvite (CPST), diammonium phosphate (DAP), triple superphosphate (TSP), and unamended control (UC)] on aboveground dry matter, aboveground dry matter elemental concentrations and uptake, grain yield, and grain P uptake for rice grown in the greenhouse under simulated furrow-irrigated conditions.**

| Plant Property | *P*-value | ECST | CPST | DAP | TSP | UC | Overall Mean |
|---|---|---|---|---|---|---|---|
| Dry matter (kg/m$^2$) | 0.24 | 1.31 | 1.90 | 1.57 | 2.16 | 1.54 | 1.70 |
| Dry matter concentration | | | | | | | |
| N (%) | 0.38 | 0.54 | 0.53 | 0.60 | 0.65 | 0.55 | 0.57 |
| P (%) | 0.03 | 0.017 c[†] | 0.016 c | 0.036 ab | 0.047 a | 0.020 bc | -- |
| Mg (%) | 0.15 | 0.72 | 0.65 | 0.68 | 0.64 | 0.55 | 0.65 |
| Dry matter uptake | | | | | | | |
| N (g/m$^2$) | 0.24 | 7.08 | 10.02 | 9.68 | 14.06 | 8.58 | 9.88 |
| P (g/m$^2$) | 0.10 | 0.24 | 0.34 | 0.58 | 0.90 | 0.27 | 0.47 |
| Mg (g/m$^2$) | 0.10 | 9.25 | 11.95 | 10.59 | 13.83 | 8.53 | 10.8 |
| Grain yield (kg/m$^2$) | 0.44 | 1.13 | 1.42 | 1.11 | 1.47 | 1.19 | 1.26 |
| Grain P concentration (%) | 0.02 | 0.26 a | 0.26 a | 0.27 a | 0.27 a | 0.20 b | -- |
| Grain Mg concentration (%) | 0.04 | 0.11 a | 0.11 a | 0.12 a | 0.12 a | 0.09 b | -- |
| Grain P uptake (g/m$^2$) | 0.10 | 2.98 | 3.72 | 3.05 | 3.87 | 2.39 | 3.20 |

[†] Means in a row with different letters are different at $P < 0.05$.