2019 Final Report Summary Sheet

Grantee Information

Project Title: Evaluating slow-release P fertilizers to increase crop production and environmental quality

Institution: University of Illinois Urbana-Champaign

Primary Investigator: Margenot

NREC Project # 2018-4-360731-385

Is your project on target from an IMPLEMENTATION standpoint? ☒ **Yes** ☐ **No**
If you answered "no" please explain:

Is your project on target from a BUDGET standpoint? ☒ **Yes** ☐ **No**
If you answered "no" please explain:

Based on what you know today, will you meet the objectives of your project on-time and on-budget? ☒ **Yes** ☐ **No**

If you answered "no" please explain:

Have you encountered any issues related to this project? ☐ **Yes** ☒ **No**

If you answered "yes" please explain:

Have you reached any conclusions related to this project that you would like to highlight? ☒ **Yes** ☐ **No**

If you answered "yes" please explain:

- Though often proposed as a P fertilizer, struvite has not been sufficiently evaluated in the peer-reviewed scientific literature to enable its use by farmers. Current research on struvite as a P fertilizer is (1) is largely greenhouse-based (78% of observations), (2) does not record yield at the field-scale (<1%), (3) utilizes unrealistically high P application rates that bias findings in favor of struvite, (4) does not evaluate granule size, timing, or placement on crop response, and (5) does not evaluate blends of struvite with ammonium phosphates or super phosphates. Additionally, (6) no studies to-date comprehensively determine dual agricultural and environmental (P loss risk) outcomes of struvite. Each and every one of these deficits are being addressed in our ongoing NREC-supported research.
- In soils with deficient STP (<18 mg/kg Mehlich III colorimetric), 50-50% struvite-MAP blends appear optimum for maximizing vegetative corn and soybean growth while minimizing residual STP by up to -18%. This indicates lower DRP loss risk from surface soils via run-off without compromised crop growth.
- In soils with optimum to high STP, corn yields are unaffected by up to 75% struvite substitution and yields of double-cropped wheat and soybean are unaffected by up to 100% struvite substitution for MAP. This likely reflects 'banked' P from previous applications, but on the other hand is representative of STP in IL production agriculture (according to IPNI 2014 data). Future research should evaluate mechanisms and kinetics of crop uptake of struvite-derived vs native STP.
- Timing (fall vs spring) and placement (broadcast vs banding) did not influence corn yield response to struvite-MAP blends in 2019
- Residual struvite granules remaining in soils at the time of sampling may inflate apparent STP values, but these increases are sufficiently high (+600%) from a single granule being present in the relatively low soil mass being used for testing (2 g soil) that this potential artifact is easily identifiable.
- However, residual granules of struvite present at the end of the growing season are chemically and physically weathered, as revealed by state-of-the-art scanning electron microscopy and electron dispersion spectroscopy (SEM-EDS), suggesting that residual granules are more likely to dissolve than freshly applied struvite in the subsequent season
- Arbuscular mycorrhizal associations can increase solubilization of struvite by up to 40%, indicating that greater soil health promotes solubilization of struvite.

Have you completed any outreach activities related this project? Or do you have any activities planned? ☒ **Yes** ☐ **No**

If you answered "yes" please explain and provide details for any upcoming outreach:

Underlined names indicate undergraduate students, graduate students, or post-doctoral scholars supported by NREC.

Completed Presentations (oral unless otherwise indicated)

1. Hertzberger, A, **Margenot, AJ.** Utilizing struvite as a slow-release phosphorus fertilizer for Midwestern agriculture. Soil Science Society of America Meeting. Jan 9-12, 2019. San Diego, CA.
2. **Margenot, AJ**, Hertzberger, A, Cusick, R. Toward a regional phosphorus (re)cycle in the U.S. Midwest. Soil Science Society of America Meeting. Jan 9-12, 2019. San Diego, CA.
3. **Margenot, AJ**. Toward a phosphorus (re)cycle in Illinois production agriculture. Illinois Stakeholder Implementation of the Nutrient Loss Reduction Strategy. Universities Council on Water Resources (UCOWR) and National Institutes of Water Resources. 2019 Annual Water Resources Conference. June 11-13, 2019. Snowbird, Utah.

4. **Margenot, AJ.** Peak Phosphorus: Myth vs Reality. Illinois Farm Bureau Webinar. Feb 21, 2019.
5. **Margenot, AJ**, Chatterjee, N. Slow-release phosphorus for Illinois production agriculture. Illinois Farm Bureau and LaSalle Co. Farm Bureau Field Day. June 17, 2019. Streator, IL. Di Tomassi, I, Chatterjee, N, Dady, E, **Margenot, AJ**. Effects of struvite and its placement on mycorrhizal colonization and phosphorus uptake in tomato. Illinois Student Research Symposium. July 17, 2019. Urbana, IL.
6. **Margenot, AJ**. Mycorrhizae for enhanced P use efficiency in low solubility P forms. 1st Workshop on Biological N fixation and bio-solubilization of P: Linking fundamental knowledge to applied research. Benguerir, Morocco. Oct 3-4, 2019. (**invited**)
7. **Margenot, AJ**. Managing the Goldilocks Nutrient by capitalizing on fertilizer chemistry. 5th International Symposium on Innovation and Technology in the Phosphate Industry [SYMPHOS 2019]. Benguerir, Morocco. Oct 8-11, 2019. (**invited**)
8. Chatterjee, N, **Margenot, AJ**. Assessing the phosphorus loss reduction potential of a slow release fertilizer struvite for the Midwest. Soil Science Society of America Meeting. Nov 10-13, 2019. San Antonio, TX.
9. Gu, C, **Margenot, AJ**. Adjusting agronomic soil P tests for renewable P inputs: struvite. Soil Science Society of America Meeting. Nov 10-13, 2019. San Antonio, TX.
10. **Margenot, AJ**. New developments in 4Rs for phosphorus: slow-release, P-only, and biostimulants. 52nd Annual Fertilizer and Pesticide Conference. Southern Illinois Fertilizer and Pesticide Board. Nov 26, 2019. Mt. Vernon, IL. (**invited**)
11. Hertzberger, A, Cusick, R, **Margenot, AJ**. Struvite: A slow release phosphorus source for Illinois corn and soybean. Illinois Nutrient Loss Reduction Symposium. Dec 3, 2019. Springfield, IL. (poster)
12. Chatterjee, N, Kleczewski, N, Ames, K, **Margenot, AJ**. Assessing the Phosphorus Loss Reduction Potential of a Slow Release Fertilizer Struvite for the Midwest. Illinois Nutrient Loss Reduction Symposium. Dec 3, 2019. Springfield, IL. (poster)
13. Hertzberger, A, Cusick, R, **Margenot, AJ**. Struvite: A slow release phosphorus source for Illinois corn and soybean. Illinois Nutrient Loss Reduction Symposium. Feb 13, 2020. Urbana, IL. (poster)
14. Chatterjee, N, Kleczewski, N, Ames, K, **Margenot, AJ**. Assessing the Phosphorus Loss Reduction Potential of a Slow Release Fertilizer Struvite for the Midwest. Illinois Nutrient Loss Reduction Symposium. Feb 13, 2020. Urbana, IL. (poster)

Upcoming Presentations

1. **Margenot, AJ**, Chatterjee, N, Hertzberger, A. Best practices for utilizing struvite as a slow-release P source: evidence from 2019 field trials. Illinois Farm Bureau and LaSalle Co. Farm Bureau Field Day. June 30, 2020. Streator, IL.
2. Chatterjee, N, Hertzberger, A, Berkshire, T, Gu, C, **Margenot, AJ**. Options for the 'Right Source' of P for Illinois production agriculture. University of Illinois Agronomy Day. August 2020. Urbana, IL.
3. **Margenot, AJ**. Updates to the Illinois Agronomy Handbook: Phosphorus. University of Illinois Agronomy Day. August 2020. Urbana, IL.
4. Chatterjee, N, **Margenot, AJ.** Field-evaluation of struvite as a phosphorus source for Illinois production agriculture. Soil Science Society of America Meeting. Nov 8-11, 2020. Phoenix, AZ.
5. **Margenot, AJ**, Chatterjee, N, Hertzberger, A. Evaluating struvite from molecular to field-scales to optimize its use as a P fertilizer. Soil Science Society of America Meeting. Nov 8-11, 2020. Phoenix, AZ.

Summary Report: 2019

Objective 1: Determine optimum formulations of slow-release P for testing agronomic and environmental
potential under field conditions
Status: Complete

This objective has been successfully completed according to schedule. The greenhouse experiments indicate that struvite can be used to meet vegetative growth P needs of corn (through V12) and soybean (through R1) at a rate of up to 50% of total applied P for corn and up to 25% of total applied P for soybean. At this proportion of total P derived from struvite (vs MAP), soil test P was 18% lower in surface soil (0-3 in depth) compared to MAP only. This indicates lower DRP loss risk from surface soils via run-off. This hypothesis is currently being tested in three field trials (please see Objective 2). The results of this experiment will be communicated in a peer-review publication by a PhD student with a target submission to a scientific journal in summer 2020, currently in preparation.

Objective 2: Measure P availability, loss and crop performance in the field for the promising slow-release P forms identified in column
Status: In progress

Year 1 of two years of field trials have been completed, with a total of three P timing and placement treatments of fall broadcast vs spring broadcast vs spring banding being evaluated for struvite-MAP blends and struvite granule sizes identified as feasible for production agriculture in the completed Objective 1 (please see above). Though originally proposed for one on-campus (Urbana, IL) field site, the field evaluation of agronomically optimum struvite treatments has expanded to a total of three sites, each for two growing seasons (2019-2020) for a total of 6 site years. This enabled additional evaluation of a third crop (wheat) and the potential 'stacking' of struvite with a BMPs for soil P management: cover crops (rye) and no-till. The crop rotations and locations being evaluated include: corn-soybean (originally proposed; Urbana, IL), wheat-soybean-corn (Urbana, IL), and cover cropped corn-soybean (Streator, IL). In field settings, including an on-farm location in LaSalle Co., wheat, soybean, and corn yields were not affected by substituting up to 75% of MAP for struvite. In the Urbana corn field trial, differences in grain yield were greater (and statistically significant) between no-till and conventional (chisel) tillage than among substitution gradient of struvite (0 to 75% MAP replaced by struvite). This is hypothesized to be due to adequate to high STP values already present in these fields, but on the other hand these are realistic STP values for agriculturally managed soils in Illinois according to a 2014 survey by IPNI. Thus, the favorable reduction in residual STP values post-harvest (i.e., soil P at risk of DRP loss during the winter and spring) observed in the greenhouse experiment achieved with 25-50% substitution of MAP for struvite appear to be feasible without negatively impacting yield of the three major crops of Illinois.

The results of the wheat-soybean double crop field experiment will be communicated in a peer-review publication by a PhD student with a target submission to a scientific journal in early 2021, as well as a publication on the two corn field sites in summer 2021. Additionally, in response to stakeholder input at a meeting with Illinois Farm Bureau and GrowMark, Inc. in early 2018, an evaluation of how residual struvite (i.e., remaining undissolved at the time of post-harvest fall soil sampling) may impact soil test P values, a study was completed using outside funding by a post-doc in the Margenot lab to support this NREC work. Residual struvite does dissolve in Mehlich-3 and Bray test extractants, but if this struvite is to be dissolved in the following growing season, it may be credited toward STP values. Additionally, a single granule of struvite markedly increases STP values to levels that are obvious contamination, making artifacts easy to spot. Finally, residual struvite is chemically and physically weathered than fresh struvite, suggesting it will more rapidly dissolve in the subsequent season. The manuscript communicating these results has been submitted to the journal *Geoderma* where it is currently under review.

Planned Activities:

A second year of field trials will be conducted in the 2020 growing season, at two sites in Urbana and Streator for soybean. This will complete two site years for each phase of a corn-soybean rotation. Soil and leachate data from 2019 and 2020 will be completed and acquired, respectively, to determine DRP loss risk from field trials. PI Margenot is pursuing potential field sites in southern Illinois (including Ewing Research and Demonstration Center) to extend field evaluations of struvite for the unglaciated region of our state, for which additional funding may be requested from corporate partners and NREC. This second year of field data will furnish data for economic analysis (Obj. 4). Buried mesh bags of struvite will enable quantification of potential residual struvite effects on STP values.

Objective 5: Conduct a literature review on the actual and potential roles of P fertilizer formulation, timing,

and placement to help meet agronomic and environmental P management goals
Status: Complete

This objective has been completed and has been used to identify key knowledge gaps on struvite, methodological recommendations on struvite research. It has also identified the value of the current NREC project, which evaluates – for the first time – soil texture effects, struvite granule size, struvite placement and timing, tillage effects, and yield responses. Conclusions from this quantitative literature view (i.e., meta-analysis) are that full substitution of water soluble P fertilizers (MAP, DAP, SSP, TSP) for struvite results in soil- and crop-variable outcomes for vegetable plant growth that range from poor (struvite vs soluble P fertilizer response ratio (RR) < 1) to similar (RR = 1) to excellent (RR > 1), though yield responses are currently uncharacterized in the current scientific literature. Importantly, this systematic literature review and meta-analysis identifies three major salient knowledge gaps, and many minor but collectively important gaps, that are being addressed by the in-progress experimental work: relatively fewer field-scale evaluations of struvite, extremely limited yield data and zero grain yield data response to struvite, and a lack of evaluating blends of struvite with conventional P fertilizers.

Planned Activities:

Literature review findings have been prepared in a second manuscript submitted to the *Soil Science Society of America Journal* and currently in revision (acceptance with revisions).

Major Accomplishments and Findings:

- We have performed the first comprehensive meta-analysis of struvite as a P fertilizer, currently in revision for peer-review publication. The potential of struvite as a P source has been evaluated, but few studies have evaluated (i) field-scale conditions, (ii) details of struvite usage that must be decided on by farmers (e.g., granule size, application method and timing), (iii) realistic P application rates, (iv) grain crops that dominate Illinois and the US Midwest, (v) soil types that reflect Illinois and the US Midwest, (vi) P loss risk concurrent with crop production metrics. No studies have evaluated blends of struvite with ammonium phosphates or super phosphates. Our study identifies next steps needed to fully evaluate the potential of struvite as a slow-release P fertilizer.
- Partial substitution of MAP with struvite does not compromise crop growth (greenhouse) and yield (field trials) while decreasing post-harvest soil test P, which is a pool of soil P prone to run-off loss as DRP during the subsequent winter and spring months.
- Greater STP (optimum to high class) enable higher struvite ratios in struvite-MAP blends to be used without detrimental effects of yield (corn, soybean, wheat).
- At the field-scale with typical (optimum) STP values, timing (fall vs spring) and placement (banded vs broadcast) of struvite-MAP blends do not influence corn, soybean or wheat yields (2019 season).

Peer-reviewed publications

Published:

1. **Margenot, AJ**, Kitt, D Graming, BM, Berkshire, T, Chatterjee, N, Hertzberger, A, Aguiar, S, Furneaux, A, Sharma, N, Cusick, R. Toward a regional phosphorus (re)cycle in the U.S. Midwest. *Journal of Environmental Quality*. 48(5):1397-1413.

In review or revision

2. Hertzberger, A, Cusick, R, **Margenot, AJ**. Agricultural potential of struvite as a phosphorus fertilizer: a review. *Soil Science Society of America Journal*. In revision. Resubmission Feb 17, 2020.

   Gu, C, **Margenot, AJ**. Adjusting agronomic soil P tests for renewable P inputs: struvite. *Geoderma*. In review. Submitted Feb 7, 2020

Manuscripts in active preparation:

1. Di Tomassi, I, Chatterjee, N, **Margenot, AJ**. Arbuscular mycorrhizae increase dissolution of struvite and enhance crop uptake of phosphorus.

   Hertzberger, A, Cusick, R, Margenot, AJ. Crop growth and soil test phosphorus trade-offs in the substitution of monoammonium phosphate with struvite.

Figure 1. Conceptual diagram of optimizing crop production and environmental benefits of struvite through blends of struvite and ammonium phosphates

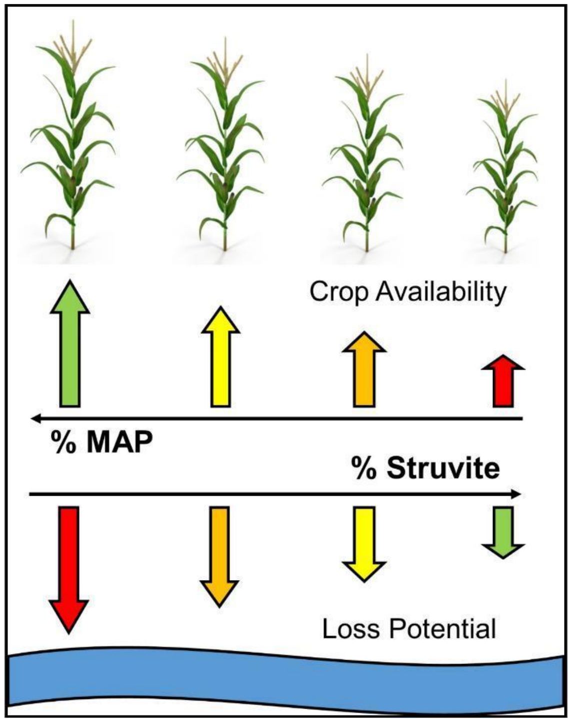

Figure 2. Comparison of struvite with monoammonium phosphate (MAP) and the benefits of struvite for meeting crop production and P loss mitigation goals

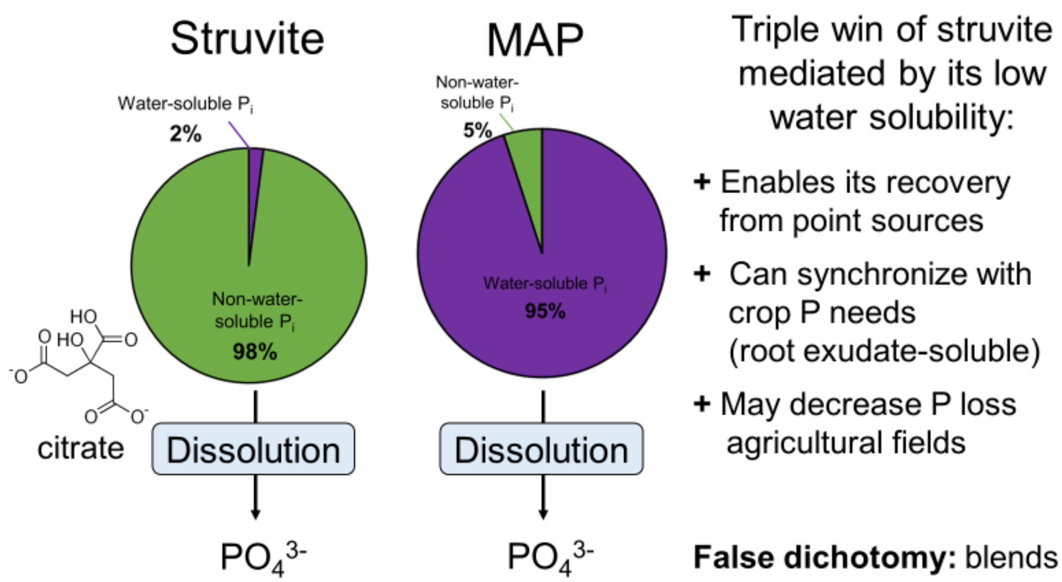

Figure 3. Vegetative corn and soybean growth (greenhouse experiment) across a gradient of struvite-MAP blends, compared to a zero P check treatment. Corn above-ground is less sensitive to struvite substitution for MAP whereas soybean below-ground growth is less sensitive.

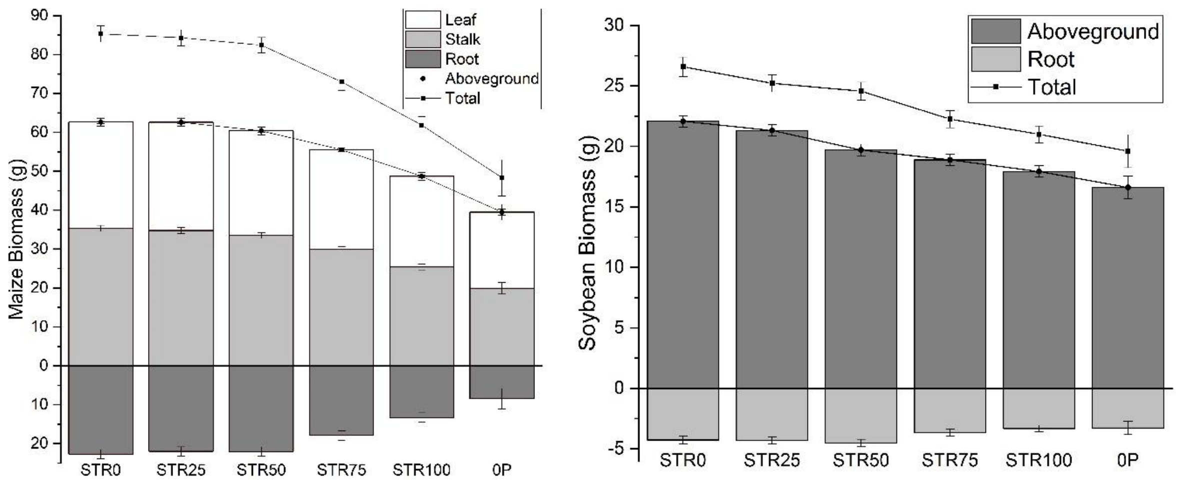

Figure 4. Field trial of struvite-MAP blends (0 to 75% struvite) for corn at Urbana, IL in 2019. No significant difference across struvite-MAP blends, nor placement or timing, but a significant effect of tillage. In other words, choice of tillage in 2019 had a larger effect on corn yield than using struvite for up to 75% of the P source.