ENHANCED EFFICIENCEY PHOSPHORUS FERTILIZERS

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ABSTRACT

Phosphorus (P) is essential for plants. However, first-year phosphorus fertilizer uptake by plants is low, resulting in economic and environmental impacts. Developments with P Enhanced Efficiency Fertilizer (EEF) sources show improved uptake efficiency and increased yield and/or crop quality, while reducing environmental risk. Research with EEFs (including organic acids, maleic itaconic copolymer, and struvite) all show these improvements, especially when: 1) soil test P concentrations are low, 2) rates are reduced (typically ~50%), and 3) applied to soil with extreme acidity or alkalinity/calcareous. On average, there is a 5% increase in yield/quality over the studies summarized herein. In all cases, if the cost of these materials is too high it may negate any economic advantage with increased yield/quality. Struvite has an added societal advantage in that it is created from recycled materials from wastewater streams, reducing resource consumption. The use of P EEF has potential if used properly and cost is not excessive.

INTRODUCTION

Phosphorus (P) is an essential plant nutrient, second only to nitrogen (N) as a fertilizer and a key to global food security (Hopkins, 2015, 2020; Hopkins and Hansen, 2019). The effective use of P fertilizer has been elucidated in a wide body of research for the "4 R's" of fertilizer stewardship to apply the Right source at the Right rate at the Right placement and Right timing. These efforts steadily improved yields and uptake efficiency (Bruulsema et al., 2012; Hopkins and Hansen, 2019). However, P fertilizer impacts the environment through resource consumption and pollution (Bruulsema et al., 2012; Hopkins, 2015, 2020; Sharpley et al., 2018).

Some claim the supply of raw phosphate ore will be exhausted in a few decades, although more informed sources estimate several centuries as new mines are located and technology for recovery improves (Hopkins, 2015). Either way, future generations may run out of easily accessible reserves of raw fertilizer materials making conservation a worthy effort.

Environmental impacts are a more immediate concern. The main fertilizer pollutants are N and P (Hopkins, 2015; Sharpley et al., 2018). Unlike N, P is not very mobile in soil and accumulates at the soil surface. As soil erodes and/or surface water flows over P-enriched soil, accumulation of this nutrient in surface waters often occurs. This causes eutrophication and hypoxia as it enriches the nutritional supply for algae, increasing its rate of growth (Sharpley et al., 2018). Enhanced Efficiency Fertilizers (EEF) result in a greater percentage of applied P to be taken up by plants with positive impacts on yields while reducing environmental impacts.

NEED FOR ENHANCED EFFICIENCY PHOSPHORUS FERTLIZER

The most commonly used P fertilizers in the USA are ammoniated phosphates (Hopkins, 2020). The most common dry versions are monoammonium phosphate (MAP) and diammonium phosphate (DAP), which are most commonly broadcast applied to soil. The most common liquid form is ammonium polyphosphate (APP), which is typically used in concentrated fertilizer bands and/or injection into irrigation water.

Most of the P in liquid P fertilizers precipitates as iron/aluminum phosphates in acid soils and calcium/magnesium phosphates in alkaline soils. The dry P fertilizers suffer the same fate after they quickly dissolve after being added to soil. As plants take up dissolved P from the soil solution, the solid-phase P re-dissolves to bring the solution back up to equilibrium. The rate mostly depends on pH and the minerals present. However, in many cases, this process is too slow to match plant requirements at peak demand. There is a wide body of research instructing how to best apply these P fertilizers in terms of correct rates, placement, and timing; relative to the unique root architecture and morphology of various species (Hopkins and Hansen, 2019).

However, first year recovery of applied P remains low. Uptake in the first year for a broadcast placement is 5-10%, although 90% of the P is taken up after a decade (Syers et al., 2008). First year uptake efficiency can increase to about 25-35% when placed in a concentrated band, but use of an EEF could increase efficiency by up to ~50% (Hopkins and Hansen, 2019). Thus, there is significant interest to develop EEF for P (Hopkins et al., 2008, Hopkins, 2020). Our research group evaluated three categories of EEF P fertilizers, namely: organic acids, polymers, and struvite.

ORGANIC ACIDS

One development in EEFs is blending P with various organic acids (humic, fulvic, etc.; Tan, 2003; Hill et al. 2015a and b; Hopkins, 2015; Hopkins and Hansen, 2019; Hopkins et al., 2014; Olk et al., 2018; Summerhays et al., 2017). Soils in arid and semi-arid regions have relatively low P solubility due to alkaline pH and calcareousness. This is especially problematic for crops with high demand for P, like potato (Hopkins et al., 2020). Research done using organic acids blended with ammoniated P fertilizers on a variety of crops shows consistent increases in P uptake, as well as associated increases in yield and crop quality when grown on calcareous soils (Fig. 1).

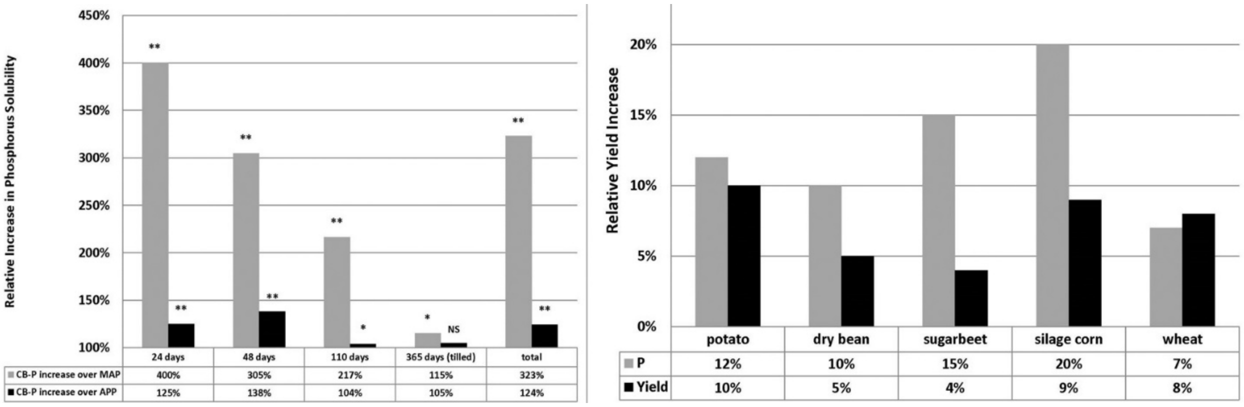

Fig. 1. An organic acid based Enhanced Efficiency Fertilizer, Carbond P (CB-P), has increased solubility relative to monoammonium phosphate (MAP) and ammonium polyphosphate (APP) [graph on left; * = significance at P = 0.05 and ** = 0.01 with NS = not significant], resulting in increased P uptake and yields in several species [graph on right; all bars are highly significant].

However, research in non-calcareous soils with higher amounts of soil organic matter often shows fewer promising results. Soil organic matter contains high concentrations of organic acids, and it has been hypothesized that organic acids blended with P fertilizer are more likely to be effective when organic matter levels are low (Tan, 2003; Summerhays et al., 2015; Olk et al., 2018). Yet positive responses have also been reported in high organic matter soils (Summerhays et al., 2015), with researchers suggesting some type of bio stimulation mechanism rather than a P response (Olk et al., 2018).

POLYMERS

Various polymer coatings have been developed to delay the release of fertilizer into the soil. Although these polymer coatings are more widely studied and used for N fertilizers (Hopkins et al., 2008), they have been evaluated for use with P fertilizers (Sharma, 1979; Nyborg et al., 1995; Yaseen et al., 2017). These coatings avoid the flush of a high concentration of P into the soil solution followed by rapid precipitation. Instead, P is released slowly—replenishing the soil solution P depleted by plant uptake.

Another use of polymers is a maleic itaconic copolymer (AVAIL) sprayed on the surface of dry phosphate fertilizers or blended with liquid phosphates (Stark and Hopkins, 2015; Hopkins et al., 2018). This is not a coating that physically protects the fertilizer, such as with polymer coated urea or blends with P. Rather, it impacts fertilizer chemistry. The mode-of-action is not agreed upon, but studies show it can be effective in soils with low levels of P, achieving yield increases of 5% when compared to traditional fertilizers (Fig. 2; Hopkins et al., 2018).

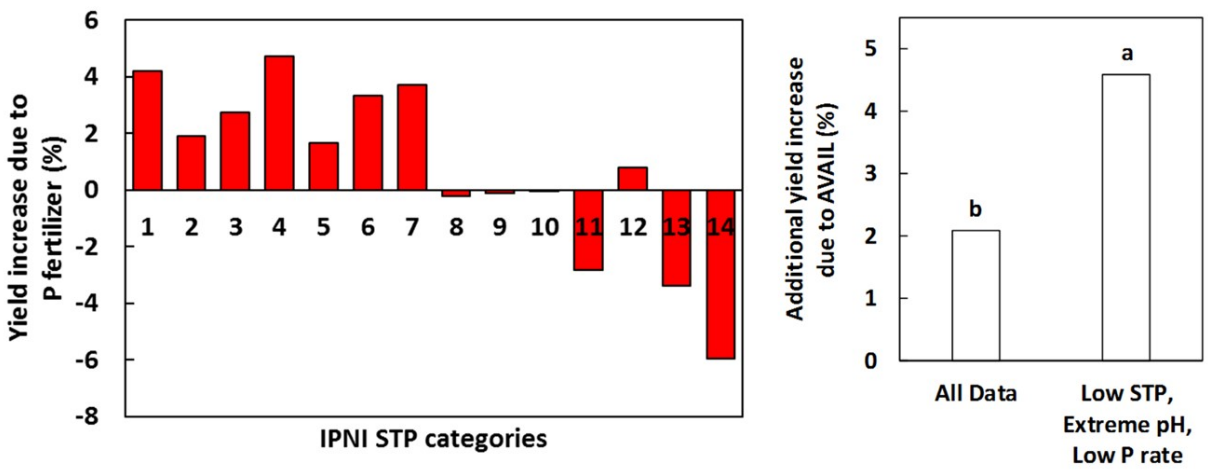

Fig. 2. Yield increase across 503 field sites for P treated with a maleic itaconic copolymer relative to untreated fertilizer for soil test categories ranging from extremely low (1) to extremely high (14) [graph on left] and combined for all data and parsed for just sites with a high probability of response with low soil test P (STP), extreme pH, and with low P rates [graph on right; bars with different letters indicate significant difference].

STRUVITE

Struvite is another example of a P EEF (Hopkins, 2015; Hopkins and Hansen, 2019; Rech et al., 2019). Struvite is a precipitated P material derived from sewage treatment waste streams.

Struvite is not water soluble, with its possible mode-of-action being that it stays protected until roots grow in proximity to the fertilizer. Crop roots exude various organic acids, possibly dissolving struvite and enhancing uptake. Struvite's acid solubility makes it more effective when applied as a concentrated band rather than broadcast. Trials show positive responses in various cropping systems. A recent study on struvite (Crystal Green) in sugar beet found it increased both sugar production and total yield when compared to MAP fertilizer (Fisher et al., 2019). Results have been largely positive in potato as well (Fig. 3). Struvite is appealing because it recycles waste P, reducing the amount of mined P needed for crop production. Struvite is also a slow-release fertilizer reducing leaching. This makes it a more environmentally friendly option (Fisher et al., 2019).

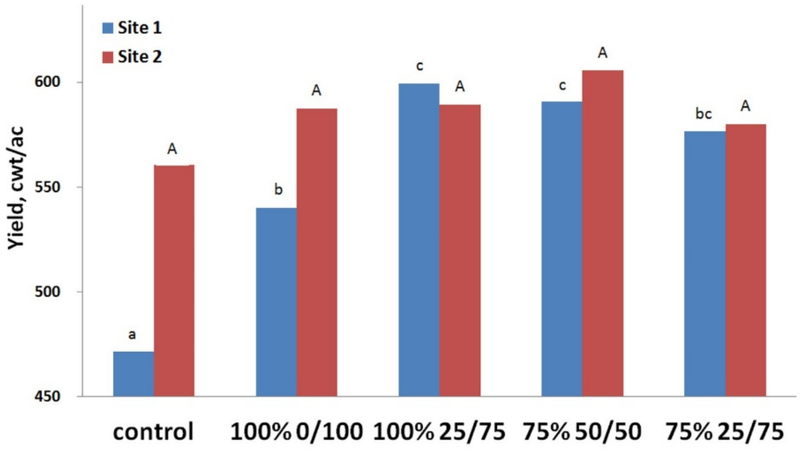

Fig. 3. Potato yield results for two sites with three P rates [0 (control), 75, and 100% of full recommended rate] applied with various blends of struvite/monoammonium phosphate (MAP) [eg. 100% 0/100 = 100% P rate with 0% struvite and 100% MAP]. Bars of each type sharing at least one of the same letter over the top of the bar are not statistically different from one another.

CONCLUSION

Using EEF P fertilizers could solve economic and environmental problems relating to P fertilizer. Three examples of P EEF show positive increases in yield (average of 5% across all types and sites). Studies have had promising results, showing increased yield and P uptake efficiency when applied correctly. These products can be effective if costs are not exorbitant.

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