# Phosphorus Use Efficiency in Crop Production

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**ABSTRACT**

The limited availability of phosphorus (P) in calcareous and acidic soils can be a major factor that limits crop production. The objectives of this study were to investigate the mobility and availability of P from monoammonium phosphate (MAP), diammonium phosphate (DAP) and ammonium polyphosphate (APP) fertilizers alone and with AVAIL, a fertilizer enhancement product. Two different soil types were used to examine the relationship between P reaction products and available P. Soils were incubated in petri dishes containing of each fertilizer treatment (Rep = 5) five weeks at 25° C. At the end of the incubation period, four concentric sections of soil surrounding the P fertilizer placement point were removed and individually analyzed. Measurements included soil pH, total P, scanning electron microscopy-energy dispersive x-ray analysis of granules and P reaction products using synchrotron based x-ray absorption near-edge structure spectroscopy. The liquid P fertilizer was more mobile and available for plant uptake in highly calcareous soils than granular P fertilizer containing the same rate of P. The data also indicates enhanced diffusion and/or solubility of some P reaction products in select soils and increased P availability when AVAIL was applied by examining certain P reaction products which are more soluble and plant available which is related to improved P use efficiency.

## INTRODUCTION

Nutrient management issues including phosphorus associated with production agriculture are becoming more of a concern and a point of discussion. Management considerations are no longer focused on just meeting yield goals or improved crop performance, but now include questions on how their use on agriculture lands impacts surface water, watersheds, soil quality, long-term health benefits and economic viability for the producer.

It is estimated that 30 to 40 % of production inputs are associated with purchasing and applying commercial fertilizers. Inputs of commercial fertilizer are essential to meeting food requirements of our nation and the global community whose population continues to increase at an alarming rate. Few people would also argue that every individual should have access to safe, nutritious foods in feeding the people who inhabit the world now and in the foreseeable future. Without the availability of this precious resource of fertilizers the demand for raising the needed amount of food simply cannot happen. Many involved in global markets also recognize the relationship between global food security and the availability of inorganic fertilizer related to a countries food production goals and that countries sustainability.

However, the question has been asked and continues: Can we as a responsible community involved in production agriculture and specifically soil fertility do a better job at developing fertilizers products that improve the efficiency of those nutrients needed for sustainability of our population as well as address concerns for the environment and the far reaching impacts of our soil fertility recommendations.

Healthy productive soils have biological and chemical processes occurring simultaneously that may impact the efficiency of P fertilizers. This paper makes an attempt to address some of these issues and makes a case for the need to improve fertilizer applications by considering the use of AVAIL, an enhanced efficiency product for improving P efficiency manufactured by Specialty Fertilizer Products.

Phosphorus is essential and plays a critical role in all crops. Phosphorus influences photosynthesis, respiration, energy storage and transfer, cell division, cell enlargement, and other plant processes including the hastening of maturity that may very well improve water use efficiency. Plants must have adequate P applied at the right time and the right form in order to complete production cycles without compromising yield potential. Finally and maybe the most critical, is that higher fertilizer phosphorus (P) prices are likely to continue, which is one reason why improved P efficiency is critical in obtaining higher crop yields, sustained profitability and improved environmental stewardship. If we are able to move more P into a plant with less being tied up by antagonistic cations then we can improve P utilization and efficiency.

Phosphorus is present in the soil in both the organic and inorganic forms and is absorbed by the plant from P within the soil solution. The most common form of plant available P is inorganic (ortho-phosphate). Organic matter will also mineralize P similar to N and provide available P from background levels of organic matter as well as from the breakdown of manure and compost. It should be noted that many of our western soils with high P concentrations are a direct result of copious amounts of manure being applied. Immobilization or precipitation of fertilizer P also occurs reducing the concentration of inorganic P into soil solution. Phosphorus can be lost from the soil through erosion as well as crop removal. Phosphorus is also lost from some fields through soil solution and subsequent losses from a field in runoff. Reducing these losses or management of P fertilizer is a part of stewardship that each crop advisor, researcher and grower should both recognize and manage for improvements.

With all of these losses of P as factors to consider, the greatest loss in P efficiency is the fixation of P by antagonistic cations. Rapid reaction of applied P fertilizers with antagonistic soil cations of calcium (Ca), magnesium (Mg) in alkaline soils to form Ca and Mg phosphates and aluminum (Al), iron (Fe), oxides in acid environments to form Al and Fe phosphates. It has been estimated that there are over thirty phosphate combinations that are involved in this process known as P-fixation. This phenomenon is a worldwide concern that keeps efficiency of applied P fertilizers at relatively low levels and increases production costs. The efficiency of applied P fertilizer and initial year's recovery has been estimated at between 5 to 25 percent of the applied

P the year of application. Increased crop production inputs and an environmental awareness of the fate of applied P fertilizers have increased the need for improved P efficiency.

Research has demonstrated management tools such as banding or direct seed applications as well as enhanced P availability in many cropping systems improve yields and nutrient use efficiency. Most of these techniques have been understood and demonstrated for many years and may also increase the efficiency of applied P fertilizer. Although P availability is considered to be near its maximum level at a near neutral pH (pH range 6.8 to 7.2) soils, there continues to be appreciable amounts of P fixation taking place. These efforts will continue, but there appears to be an improved chemistry that impacts the reactions of precipitates at a reactionary scale. This is surrounding the Phosphate granule or within the band itself. AVAIL polymer applied with P fertilizer has demonstrated increased P efficiency and increased yields in several crops (Dunn and Stevens, 2008; Mooso et.al, 2012, Stark and Hopkins, 2013 and Tindall and Mooso, 2011).

AVAIL is a complex organic acid of maleic-itaconic acid copolymers and a patented family of dicarboxylic acid products. It is designed to sequester antagonistic metals (Al, Fe, Ca, Mg etc) in the soil around the fertilizer granule to reduce the "tie-up" of P and keep it in a plant-available form through most of the growing season of many annual crops. AVAIL is distributed world-wide by Specialty Fertilizer Products. Third party research trials including many western based University, Governmental and grower demonstrations have indicated wide consistency in improving P use efficiency that would be measured as either: improved yield, quality, tissue P concentration or improved soil P availability within the growing season. The polymer is impregnated on to a wide array of dry granule P fertilizer or also formulated to be included in liquid formulations like ammonium polyphosphates or ortho-based liquid formulations that can be used in starter formulations. Data sets also include the applicability of applying AVAIL through drip or under some fertigation systems.

## METHODS

A calcareous soil (Idaho) and a Oxisol (Brazil) were used in the initial phase of this study. The soil characteristics for the two soils are presented in Table 1. Petri dishes where filled with each soil type (Replication = 5) to prepare for receiving the P treatments. Monoammonium phosphate (MAP 42 mg/dish), diammonium phosphate (DAP 43 mg/dish) and ammonium polyphosphate (APP 40 uL/dish) were placed in the center of each dish. Another set of dishes were prepared with each P source treated with the AVAIL polymer applied at the recommended rate (2 quarts/ton for MAP and DAP or 2 quarts / 100 gal for APP). Untreated controls samples of each soil type were also prepared. All samples were incubated at 77 degrees F for 35 days. At the end of the incubation period, the petri dishes were analyzed based on the distance from the point of application (0 to 7.5 mm, 7 to 13.75 mm, 13.75 to 25mm and 25 to 53.5 mm). The pH of each sample was measured to determine the effect of P source and AVAIL on soil pH. Samples were also transported to the Argonne Lab near Chicago, IL to perform X-ray Absorption Near Edge Structure Spectroscopy (XANES) using the synchrotron to determine

P reaction products (Pierzynski et. al., 2012). Dr. Ganga Hettiarachchi is one of only a few scientists in the world that has developed this methodology to use the synchrotron to be able to identify the P reaction products in the soil.

Table 1. Soil Characteristics of two soils evaluated with X-ray Absorption Near Edge Structure Spectroscopy (XANES) Analysis

| Sample | pH | Ca ppm | CEC meq /100g | OM % | Fe ppm | Mn ppm | Al ppm | N ppm | P ppm |
|---|---|---|---|---|---|---|---|---|---|
| Calcareous ID | 8.0 | 3376 | 19.6 | 0.6 | 2.4 | 3.6 | ND | 403 | 468 |
| Oxisol BZ | 4.3 | 49 | 12.4 | 3.7 | 52.9 | 2.2 | 79.5 | 1243 | 237 |

## RESULTS AND DISCUSSION

The P fertilizer source had a greater effect on soil pH on the calcareous soil than on the acid soil; from Brazil. Effect of P fertilizer source decreased as the distance from the point of application increased. On the calcareous soil, all of the P sources decreased soil pH APP with AVAIL had the greatest overall effect on soil pH compared to the control (Fig. 1). On the Oxisol soil, all P sources increased pH near the point of application.

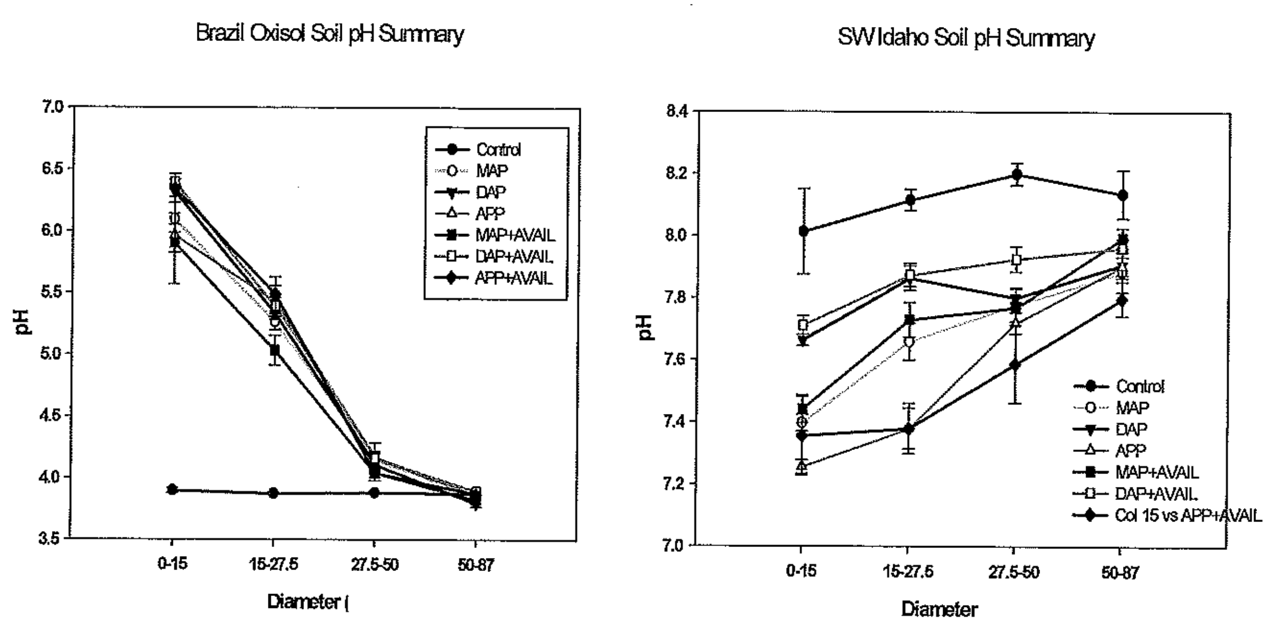

Figure 1. The effect of P fertilizer source without and with AVAIL on soil pH as affected by distance (mm) from the point of application.

The P reaction products for the untreated controls and the three P fertilizer sources without and with AVAIL for the calcareous and acid soils are presented in Tables 2 and 3, respectively. The P reaction products are sometimes referred to as P speciation which is the actual mineral compounds which were formed during the 35 day incubation period. For the calcareous soil the Apatite and Hydroxy Apatite are relatively insoluble forms of p and would not be plant available. Aluminum Phosphate, Ferrihydrite Adsorbed P and Vivianite would be relative soluble forms of P. It is interesting that when APP was applied to the soil it had the lowest percentage of insoluble P reaction products and the greatest percentage of soluble P reaction products. For each P source, AVAIL increased the percentage of soluble P reaction products across both Oxisol and Calcareous soils..

Table 2. Effect of three phosphorus sources without and with AVAIL copolymer on P reaction products obtained from XANES (inner-most section, 0-7.5 mm radius from the point of application) on a calcareous soil (Idaho).

| **Treatment** | **Apatite** | **Hydroxy Apatite** | **Aluminum Phosphate** | **Ferrihydrite Adsorbed P** | **Vivianite** | **Red. Chi Square** |
|---|---|---|---|---|---|---|
| Control | 20.4 | 48.2 | - | 31.4 | - | 0.06 |
| MAP | 59.2 | - | - | 31.0 | 9.8 | 0.02 |
| DAP | 64.1 | - | - | 35.9 | - | 0.04 |
| APP | 27.8 | - | - | 48.2 | 24.0 | 0.04 |
| MAP + AVAIL | 37.7 | 5.5 | - | 36.6 | 20.2 | 0.06 |
| DAP + AVAIL | 57.1 | - | - | 42.9 | - | 0.06 |
| APP + AVAIL | 32.0 | - | 7.1 | 61.0 | - | 0.16 |

For the acid soil, aluminum phosphate, alumina adsorbed P and ferrihydrite adsorbed P would be relative insoluble P reaction products and not plant available. Strengite and vivianite would be relatively soluble P reaction products and available for plant growth. Both DAP and APP produced highest percentages of relatively available P. The AVAIL polymer increased the relatively soluble P reaction products for MAP, DAP and APP on this strongly acid soil.

Table 3. Effect of three phosphorus sources without and with AVAIL copolymer on P reaction products from XANES (inner-most section, 0-7.5 mm radius from the point of application) on an Oxisol soil (Brazil)

| Treatment | Aluminum Phosphate | Alumina Adsorbed P | Ferrihydrite Adsorbed P | Strengite | Vivianite | Red. Chi Square |
|---|---|---|---|---|---|---|
| Control | 13.9 | - | 64.1 | - | 21.9 | 0.27 |
| MAP | - | - | 72.1 | - | 27.9 | 0.32 |
| DAP | - | 47.3 | - | - | 52.7 | 0.04 |
| APP | - | 43.6 | - | - | 56.4 | 0.02 |
| MAP + AVAIL | - | | 24.1 | - | 75.9 | 0.02 |
| DAP + AVAIL | - | 33.7 | - | - | 66.3 | 0.01 |
| APP + AVAIL | - | 21.4 | - | 78.6 | - | 0.00 |

**SUMMARY**

The efficiency of P fertilizers is significantly impacted by the source of the P fertilizer and the soil characteristics. P reaction products are different for P fertilizer sources applied to acid soils than the same P fertilizers applied to calcareous soils. AVAIL a polymer developed to improve the efficiency of P fertilizers increased the soluble P reaction products in both the acid and the calcareous soil. The increase in soluble P reaction products corresponds with improved crop production that has been observed in a number of studies.

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