A NEW METHOD FOR INFLUENCING PHOSPHATE AVAILABILITY TO PLANTS

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Abstract

Nutrient availability is largely affected by soil chemical characteristics immediately surrounding the point of nutrient application. Availability and uptake of P from commercial P fertilizers is dramatically affected by soil reactions with various cations including Ca, Mg, Al and Fe. Recent product development research has demonstrated that modification of soil chemical characteristics in the immediate vicinity of a granule of commercial P fertilizer such as monoammonium phosphate or diammonium phosphate or in a band of fluid ammonium polyphosphate can have significant effects on P availability to plants. Modification of the microenvironment at the surface of granular P products by an economical coating of this new type of chemistry has had consistent effects on P uptake and crop yields, improved P use efficiency, improved crop profitability and lessened potential environmental impact. This paper presents the results of lab and field studies of P fertilizer microenvironmental modifications and the application of this technology to fertilizer manufacturing, fertilizer use and crop production.

Introduction

The microenvironment surrounding a fertilizer granule is subject to a series of primary and secondary reactions which substantially impact nutrient availability to plants. Influencing or controlling these reactions is of primary importance due to their influence on fixation and the subsequent plant availability of the nutrients involved.

Phosphorus Fertilizers – The Problem

It is well known that even under the best conditions only 20-30% of fertilizer phosphorus (P) is taken up by the crop during the first cropping season. It is also recognized that at high pH, levels P is fixed by calcium (Ca) and magnesium (Mg) and at low pH levels by predominately iron (Fe) and aluminum (Al). Thus, the historical problem with the soil chemistry of P fertilizers has been lack of availability.

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The residual P that is not taken up by the crop (70-80%) becomes a possible environmental concern. Recently a number of studies have suggested that soil erosion carrying increased loads of fertilizer P may contribute to eutraphication of lakes, streams, and the Gulf of Mexico. This focuses on the need to develop a product that is more efficient, that produces greater crop responses and leaves less of an environmental footprint.

Phosphorus Fertilizers – The Solution

Specialty Fertilizer Products has developed and patented a family of compounds that affect the availability and utilization of P fertilizers. These compounds are biodegradable and highly water-soluble. The technology can be applied directly to granular P fertilizers as a coating or mixed into liquid fertilizers.

The mode of action appears to be simple, but effective. Table 1 shows the effect of varying concentrations of the technology coated onto granular MAP which was placed in 100 ppm solutions of Ca, Fe and Al. The resulting P concentrations in solution show that the compound sequesters the antagonistic ions out of solution leaving the P available and unfixed.

Table 1. Experimental material effects on MAP solubility in various solutions.

Treatment Applied % Experimental Material	Cation ppm	Mgm P/Gram MAP	% of Total P in Solution
0.00	Al 100	236.9	45.5
0.25	Al 100	298.4	57.4
0.50	Al 100	284.5	54.7
0.75	Al 100	326.0	62.7
1.00	Al 100	309.4	58.9
0.00	Ca 100	251.5	48.4
0.25	Ca 100	295.8	56.9
0.50	Ca 100	314.1	60.4
0.75	Ca 100	310.4	59.7
1.00	Ca 100	308.2	59.3
0.00	Fe 100	289.9	55.8
0.25	Fe 100	316.7	60.9
0.50	Fe 100	303.5	58.4
0.75	Fe 100	329.2	63.3
1.00	Fe 100	305.2	58.8

20^{o}C. 24 hours. No stirring. Kansas State University

The coating dissolves rapidly in the soil. It then sequesters the antagonistic ions that tie up P in the area surrounding the fertilizer granule. Since P is immobile, once the chemistry of the dissolution area has been modified, the un-fixed P can be taken up by the plant without interference.

Further laboratory investigations of the effects of the experimental material on metals contained in commercial DAP have shown that the compound extracts (and adsorbs) much larger amounts of Fe and Mg than is the case with water, acetic acid or acetic-citric acid combinations (Table 2). The high cation exchange capacity of the experimental compound which can be as high as 1.8 equivalents per 100 grams of solid material is related to this effect. That adsorption of metals underscores the effects of the experimental material on P solubility as shown in Table 1.

Table 2. Experimental material effects on metal concentration in DAP solution

Extraction Solution	DAP Coatings	Fe	Mg
		in solution	
		-------------ppm-------------	
1st extraction	None	20	9
H_2O, 25°C	Oil	18	7
	0.25% SFP	38	38
	0.50% SFP	34	28
2nd extraction	None	24	12
0.2 % acetic acid	Oil	29	13
60° C	0.25% SFP	43	19
	0.50% SFP	98	42
3rd extraction	None	132	56
0.2 % acetic acid	Oil	169	63
0.2 % citric acid	0.25% SFP	239	89
60°C	0.50% SFP	280	108

30 g DAP, 300 ml solution. Hall, IMC

Phosphorus fertilization and its effect on plant growth and yields can be influenced by many factors. Some of these are:

(a) Methods of application
(b) Type of crop
(c) Soil pH
(d) Soil test P
(e) P application rates

The following research has attempted to encompass all of these factors under field conditions. Initial greenhouse studies on high P, acidic, P-fixing soils provided the positive impetus for continuing the work in the field.

Methods of Application

University of Arkansas wheat data (Table 3) show that MAP coated by the experimental compound out yielded ordinary MAP. Yields on banded, broadcast, and broadcast seeded treatments were all significantly increased with a 1% coating. The largest increase was with banded applications where yields were increased 22 bu/A.

Arkansas Wheat

Table 3. Enhanced P availability and placement effects on wheat yields.

Treatment	Yield bu/A
Control	46.7
MAP Banded	54.7
MAP Broadcast	58.2
MAP + Exp. Product, Banded	76.9
MAP + Exp. Product, Broadcast	65.6
Broadcast Seeded, MAP	55.1
Broadcast Seeded, MAP + Exp.	68.3
LSD (0.05)	7.5

University of Arkansas

30 lb P_2O_5/A. Soil P test low. Soil pH=7.6.

Georgia corn data (Table 4) provide additional evidence that the experimental compound coated on MAP improved P response to both banded (starter) P and broadcast preplant applications under low soil test P and P-fixing conditions (soil pH 5.9). Analyses of the corn grain for cadmium (Cd) indicated another interesting effect of the experimental material. Cadmium concentrations were consistently lower, although not statistically significant in the presence of the experimental material. This is consistent with the theory that the high CEC of the experimental material may be adsorbing divalent and trivalent ions and in this case, affecting Cd uptake by plants. More remains to be learned in this area but the results are interesting.

Crops

Phosphate fertilizers coated at rates from 0.5% to 1.0% of experimental product have produced increased P uptake and increased yields on a wide range of crops. Experiments with collards, grass, corn, wheat and potatoes have produced positive responses to the coated P fertilizer over regular material. Table 5 presents Auburn University data with collards. Both banded and broadcast applications of experimental MAP increased yields over uncoated, commercial MAP by 6 and 21 percent, respectively.

Table 4. Experimental material effects on corn grain

Treatments 30 lb P_2O_5/A	Grain Cd ppb		Yield bu/A
P Band	22.8		134.5
P Band + Exp.	18.2	(-20%)	154.0
P Broadcast	15.8		122.2
P Broadcast + Exp.	13.2	(-16%)	144.1
Level of significance	46%		11%

Univ. of Georgia

Alabama Collards

Table 5. Enhanced P availability effects on collards.

Treatment Applied	Fresh Wt. lb/plot
Control	1.4
MAP Banded	5.2
MAP Broadcast	3.9
MAP + Exp. Product, Banded	5.5
MAP + Exp. Product, Broadcast	4.7

Auburn University

30 lb P_2O_5/A. Soil P tests low. Soil pH=6.3

Missouri-Kansas Forage Grasses

Coating MAP with experimental material also was effective on acidic, P-fixing soils for cool season grass forages in Kansas and Missouri. Data in Table 6 indicate how broadcast P applications with the experimental material coating during the dormant period enhanced P uptake and yields. Enhanced P availability through reduced fixation is speculated to possibly enhance P mobility on these surface applications although that has not been examined. Recent studies in Iowa with fluid starter P applications for corn have demonstrated that P mobility vertically in the soil can be considerably increased (10 cm) by the presence of high concentrations of ammonium ions (2:1 N to P_2O_5 ratios) in the same soil retention zone. Those ammonium ions, like the experimental material, are assumed to have interrupted normal P fixation reactions through the modification of the microenvironment of the P application zone.

Table 6. Enhancing P availability for bromegrass and tall fescue.

Treatments	Bromegrass Miami Co., KS	Bromegrass Miami Co., KS	Fescue Lawrence Co., MO
	lb/A		
No P	5100	3210	3096
MAP	5290	4160	4392
MAP + Exp.	6010	4710	4724

Low P soils. 20 lb P_2O_5/A. Acidic pH. Kansas State Univ.
Brome – 90 lb N/A, Fescue – 100 lb N/A. Univ. of Missouri

Soil Effects

Soil pH is a major factor affecting P availability. At pH levels below 5.5, Fe and Al readily react to fix P. At pH values above 7.0, Ca and Mg influence P availability. This experimental chemistry apparently interrupts reactions of fertilizer P availability and improving P uptake by the crop.

Soil pH Less Than 5.5. Kansas winter wheat data (Table 7) showed enhanced yield response with the experimental P. Although soil (pH 4.7) at this site had a high P test, it also has a high fixation capacity because of high reactivity of Fe and Al at this pH level.

Kansas Wheat

Table 7. Wheat response to enhanced P availability.

Treatment Applied	Grain Yield bu/A
Control	31.6
MAP	34.2
MAP + Experimental Product	39.5
LSD (0.10)	7.2

Murphy Agro – Kansas State Univ.
20 lb P_2O_5/A banded at planting.

Soil pH Between 5.5-7.0. University of Missouri corn data (Table 8) indicate an example of experimental product performance at a moderate soil pH (6.3) and low P soil test combination which should be very responsive to P fertilizer. The data indicated no response to untreated MAP, but a significant response to experimental MAP (20 bu/A).

Soil pH Above 7.0. Studies at soil pH values above 7.0 were conducted at the University of Arkansas (Table 3) and at the South Australia Research and Development Institute (SARDI) at Minnipa, SA on wheat, and at the University of Minnesota on corn. All of these studies showed positive responses to MAP coating with the experimental material compared to untreated MAP.

Missouri Corn

Table 8. Corn response to enhanced P availability.

Treatment	Grain Yield bu/A
Control, No P	135
MAP broadcast	132
MAP + Exp. broadcast	151
MAP banded	132
MAP + Exp. banded	157
$LSD_{.10}$	13

Univ. of Missouri

20 lb P_2O_5/A
Soil test Bray P-1:10
Soil pH: 5.9

Minnesota Corn

Table 9. Corn responses to enhanced P availability on high pH soil.

Treatments	Dry weight g/6 plants	P %	P Uptake mgm/6 plants	Grain Yield bu/A
Control, No P	14.5	0.306	44	108
MAP banded	18.8	0.309	58	116
MAP + Exp. banded	19.3	0.328	64	122
$LSD_{.10}$	2.7	0.016	10	5

Univ. of Minnesota - Lamberton

20 lb P_2O_5/A Soil pH = 7.8 Soil test P = Low

Table 10. Enhancing P availability for corn

P Source lb P_2O_5/A	Application Method	Yield bu/A
0	--	136
50 DAP	Broadcast	155
50 DAP + Exp.	Broadcast	175
$LSD_{.10}$		18

Exp. 0.25% coating. Univ. of Minnesota, Waseca
Soil pH: 7.3 Soil test P: 7 ppm Olsen

Soil Test P. Although low P soils are very responsive, soils with a medium to high P soil test may not produce a yield response to applied P. A study from central Texas (Table 11) shows that wheat yields were not increased over the control with the application of untreated MAP, but the experimental P did increase yields on this medium P test soil.

Texas Wheat

Table 11. Wheat responses to enhanced P availability on medium P soil. Texas

Treatment Applied	Yield lb/A
Control	30.1
MAP 25 lb P_2O_5/A	29.5
MAP 50 lb P_2O_5/A	32.4
MAP + Exp. 25 lb P_2O_5/A	37.6
MAP + Exp. 50 lb P_2O_5/A	37.8
$LSD_{.10}$	7.6

Soil pH = 7.3. Soil test P = medium. Texas A&M

Kansas wheat studies on high P test soils also showed enhanced yield response on wheat with the experimental P (Table 7). Although these soils test high for P, they also have a high fixation capacity due to their very low pH (4.7).

MAP coated with experimental material also performed well on medium testing, near neutral soil in Kansas. Irrigated corn yields were increased from 8-20 bu/A over the untreated MAP by experimental MAP applied as a starter (Table 12). Early season plant dry weights, plant P concentrations and P uptake were increased by the enhanced P availability. Soybeans also responded well to the experimental material on broadcast P with yield increases up to 11 bu/A (Table 13).

Table 12. Enhancing P availability for irrigated corn.

Treatments lb P_2O_5/A	2001	2002	2003
	-----------------------	bu/A	--------------------
Control	172b	119c	169c
60 MAP	193a	173b	195b
60 MAP _ Exp.	201a	194a	210a

P banding at planting. Kansas State Univ.
Soil pH: 6.8. Soil P = 25-38 ppm Bray-1.

Table 13. Enhancing P availability for irrigated soybeans.

Treatments lb P_2O_5/A	2002 Grain Yield bu/A	2003 Grain Yield bu/A
Control	51.8c	32.3c
60 MAP	62.2b	46.7b
60 MAP + SFP experimental	72.8a	57.5a

P broadcast preplant Kansas State Univ.
Soil test P: 38 ppm Bray 1. Soil pH: 6.8.

P Application Rates. Wheat data from South Australia show that experimental MAP out performed MAP at three different P rates. Although limited by moisture, yields were increased as much as 10% on these high pH (8.3) soils containing very high amounts of free calcium carbonate (Table 14).

Improved Economics

University of Idaho potato data (Table 15) also show the effects of the experimental MAP at varying rates over MAP compared to untreated MAP on a high pH soil (7.9). Yields were increased at both the 60 and 120 pound P_2O_5 rates by the experimental material. When experimental MAP was applied at both rates, significant increases in yields and dollar returns resulted. The higher experimental MAP rate (120 lb/A) gave the best yields and profits. The coated MAP increased US No. 1 yields by 14% and gross returns by $200/A at the higher P rate.

Australia Wheat

Table 14. Enhancing P availability for wheat
Australia

Treatments kg P/ha	Grain Yield kg/ha	Total Dry Matter kg/ha	Heads/meter^2
MAP 4	1689	5913	254
Exp. MAP 4	1879	7140	299
MAP 10	1944	7024	274
Exp. MAP 10	1955	8184	312
MAP 20	2081	7681	290
Exp. MAP 20	2241	7894	309
$LSD_{.10}$	132	1186	49

P banded at seeding. SARDI
Soil 70% $CaCO_3$.

Idaho Potatoes

Table 15. Potato yield and return responses to enhanced P availability.

Treatment Applied	Yield Cwt/A	Petiole P %	Gross Return $/A
Control	311 a	0.225 d	1456
MAP Untreated 60 P_2O_5 lb/A	330 ab	0.253 cd	1546
MAP Untreated 120 P_2O_5 lb/A	344 bc	0.275 bc	1591
MAP Treated 60 P_2O_5 lb/A	339 ab	0.288 ab	1575
MAP Treated 120 P_2O_5 lb/A	369 c	0.308 a	1791

Univ. of Idaho

Conclusions

Influencing or controlling reactions in the microenvironment around fertilizer granules has been proven to have significant benefits to the fate and availability of applied nutrients and subsequent plant response to applied P. The objective of agricultural producers has always been to provide the quantity of available nutrients to achieve the maximum economic yield for crops' genetic potential. With the technology introduced research shows that modification of the microenvironment around fertilizer P particles affects P absorption and utilization by a wide spectrum of crops at normal fertilization rates. This technology not only has the potential to improve crop yields and farmer profits but also has positive implications on possible environmental footprint of fertilizer use.