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Improving Phosphorus use Efficiency with Polymer Technology

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Abstract

The soil microenvironment surrounding a P fertilizer granule or within a fluid P fertilizer band is subject to a series of primary and secondary solution reactions which substantially impact P availability to plants. Influencing or slowing these reactions is a means of improving applied P use efficiency, improving yields and profitability with positive implications for environmental concerns. It is well recognized that even under the best conditions, only 5 to 25% of fertilizer P is taken up by the crop during the first growing season. Thus, the historical problem with the soil chemistry of P fertilizers has been the lack of availability due to soil fixation reactions. The patented Avail ® polymer technology positively affects P use efficiency by limiting soil solution reactions which fix P thus extending availability of applied fertilizer P and ultimately providing economical and profitable benefits for growers, manufacturers and distributors. The functionality of the polymer is predicated on the polymer's high effective charge density. Extensive studies with Avail® have been conducted since 1999 with investigations in the United States, Canada, United Kingdom, Argentina, The Philippines and many other countries. A wide number of crop species and soil conditions have been involved in these investigations with both solid and fluid P sources. Results of many of these investigations are reported in this paper.

1. Introduction

The microenvironment surrounding a phosphorus (P) fertilizer granule or within a fluid P fertilizer band is subject to primary and secondary reactions which substantially impact P availability to plants. Influencing or controlling these reactions is highly desirable because of their influence on P fixation and the subsequent plant availability of the nutrients involved.

1.1. The Problem

Even under the best conditions only about 25% of applied fertilizer P is taken up by the crop during the first cropping season. It is generally understood that at high soil pH levels, P is precipitated by calcium (Ca) and magnesium (Mg) and at low soil pH levels predominately by iron (Fe) and aluminum (Al). Thus, the historical problem with the soil chemistry of P fertilizers has been rapid fixation reactions which limit P availability.

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Residual P not taken up by the crop and remaining on or near the soil surface has a possible environmental impact through the combined effects of soil erosion and higher P concentrations in run-off water. A P fertilizer product that is more efficient, that produces greater crop responses, has a positive impact on returns to crop producers and leaves less of an environmental footprint is highly desirable.

1.2. The Solution

Specialty Fertilizer Products has developed and patented a family of high charge density dicarboxylic copolymers that affect the availability and plant utilization of applied P fertilizers. These polymers are biodegradable and highly water-soluble. The technology marketed as Avail® can be applied directly to granular P fertilizers as a coating or mixed into liquid fertilizers.

The mode of action is that the high charge density of the polymer (approximately 1800 milliequivalents [meq]/100 grams of polymer) results in sequestration of polyvalent metal cations in soil solution, disrupting and delaying normal P fixation reactions resulting in extended availability of highly water soluble ammonium and calcium phosphates. Results of a laboratory study (Table 1) show the effects of varying concentrations of Avail polymer coated on granular monoammonium phosphate (MAP) which was placed in 100 ppm solutions of Ca, Fe and Al. The resulting P concentrations in solution suggest that the polymer affected the reactions of the three cations with the dissolving MAP allowing more P into solution and ultimately available for plant uptake.

In the soil, the dissolving polymer sequesters the antagonistic cations that react with P in the soil solution of the microenvironment surrounding the fertilizer granule or in the fluid P band. 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.

1.3. AVAIL Effects on Aluminum Toxicity

A study at Washington State University by Dr. Rich Koenig emphasized the effects of the Avail® polymer on the activity of trivalent Al ions in solution. The sensitivity of wheat varieties to Al toxicity was investigated in the lab with three Al concentrations in the growth medium pH 4.5 (Fig. 1A). Root length was measured as an indication of plant growth or Al sensitivity. When the Avail® polymer was introduced into the growth media at 0.5%, the effects of Al disappeared (Fig. 1B). Similar results were reported at pH 5.0.

Table 1. Avail effects on map solubility in various solutions.

MAP coating % Avail	ppm	mg 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. Unpublished data, Griffith, Kansas State University

P in Soil Solution

University of Wisconsin studies (Laboski, C. and Repking, M. 2007. Hancock & Antigo Potato Field Days, Dept.. of Soil Science, Univ. of Wisconsin-Madison, July 18-19, 2007 personal communication) of the concentration of available P in the soil solution as affected by Avail® coated on monoammonium phosphate (MAP) for potatoes showed that Avail® enhanced concentrations of P in the soil solution throughout the growing season. Quoting Dr. Laboski, "At one inch (2.5 cm) below the seed piece on June 18th (1st flower), July 2nd, and July 16th at Hancock, solution concentrations from MAP+Avail® were significantly greater than MAP and control. No difference between treatments at six inches (15 cm)".

These results indicate a modification of soil P reactions due to the presence of the Avail® polymer.

1.4. Initial Greenhouse Study

The initial study with the polymer that became Avail® was conducted at Kansas State University by Dr. Ray Lamond (deceased). An acid (pH 4.7) soil, high in soil test P, was selected for the study because of the acidity of the site (no liming) and the high P soil test produced by continued P application for wheat and poor plant utilization. Maize was planted in rows and MAP with or without the polymer was banded 2.5 cm to the side and 2.5 cm below the seed with a target application rate equivalent to 45 kg P2O5/ha. Growth effects of the polymer were striking (Table 2). After 30 days, plants were harvested, dried, weighed, ground and analyzed. Results reported in Table 2 showed a highly significant effect of polymer on plant dry weights, P concentration and P uptake and encouraged expansion to field studies.

Table 2. Initial avail polymer evaluation on maize under greenhouse

Material	Dry Wt	P Conc	P Uptake
g	%	mg	
Control	5.18	0.827	43.2
P1X*	8.90	0.996	88.7
P2X*	9.55	1.043	99.6
LSD.05	2.47	0.177	31.8

Lamond, Kansas State Univ.
** initial Avail formulations.*
Soil pH=4.7; Soil test P=74 ppm (Bray-1.)

1.5 In the Field

Wheat. A large number of field trials with various crops have demonstrated that the benefits of improved P availability from Avail polymer occur under a wide array of soil conditions and methods of P application. The question of polymer effects on P response on higher pH soils was addressed in an early wheat study in Arkansas in the USA on a soil pH of 7.6. Under those conditions, polymer coated MAP was more effective than uncoated MAP (Table 3). Yields produced by P banded with the seed (starter), P broadcast, and broadcast mixtures of seed and MAP were all significantly increased with Avail® coating of MAP.

University of Maryland data have shown similar Avail effects on wheat yields on acidic soils in the eastern USA with yield increases averaging near 0.5 t/ha. Wheat yield increases due to Avail on soils low to medium in available P, pH 6.2, 1.8% organic matter in Kansas in the USA have been of that same general magnitude (data not shown).

Maize. Maize data (Table 4) indicate an example of Avail performance with an acid soil (pH 5.9) with a low P soil test and both broadcast preplant and banded P (starter) applications at seeding. The data indicated no maize response to untreated MAP, but a significant response to polymer-coated MAP.

Table 3. polymer and p application method

Effects on wheat yields

Treatment	Yield t/ha
Control	3.14
MAP banded	3.68
MAP + polymer, banded	5.17
MAP broadcast	3.91
MAP + polymer, broadcast	4.41
MAP + seed, broadcast	3.70
MAP + polymer + seed, broadcast	4.59
LSD (0.05	0.44

33 kg P_2O_5/ha. Soil P Mehlich 3: low. Soil pH=7.6

Palmer, Univ. of Arkansas, USA

Table 4. Maize response to enhanced p availability from avail

Missouri, USA

Treatment	Yield t/ha
Control, No P	8.46
MAP broadcast	8.28
MAP + Polymer broadcast	9.47
MAP banded	8.28
MAP + Polymer banded	9.85
LSD 0.05	1.00

22 kg P_2O_5/ha. Soil test Bray P-1: 7 ppm
Soil pH: 5.9 Blevins, University of Missouri

MAP coated with Avail also performed well on medium to high P testing, near neutral soils in Kansas (Gordon, 2007). Irrigated maize yields were increased from 0.5-1.25 t/ha over the uncoated MAP by polymer coated MAP applied as a starter banded 5 cm to the side and 5 cm below the seed (Table 5). Early season plant dry weights, plant P concentrations and P uptake were also increased by the enhanced P availability in this 3-year study. Apparently there is still opportunity for improved P management on soils with good P soil tests and moderate pH levels.

Table 5. enhancing p availability for irrigated maize with avail

Kansas, USA

Treatments kg P_2O_5/ha banded	Year 1	Year 2 t/ha	Year 3
Control	10.78 b	7.46 e	10.60 d
22 MAP	12.04 a	8.91 d	12.04 c
22 MAP + Avail	12.48 a	10.85 bc	13.17 a
45 MAP	12.10 a	10.53 c	11.79 bc
45 MAP + Avail	12.10 a	11.92 ab	13.17 a
67 MAP	12.10 a	10.85 bc	12.23 b
67 MAP + Avail	12.61 a	12.16 a	13.17 a

Duncan's multiple range test, 5% level
Gordon, Kansas State Univ.
P banded at planting.
Soil pH: 6.8.
Soil P = 25-38 ppm Bray-1.

A two-year study on the same soils as reported in Table 5 and including 3 rates of P showed that Avail polymer applied with P in the autumn was as effective as that applied in the spring immediately prior to maize seeding (data not shown). Those studies indicated that the polymer remained effective in temperate soils for a period of 9-12 months.

Studies in Argentina showed significant Avail effects on maize when Avail was coated at 0.25% on MAP. In those studies, largest responses were recorded on acidic, low P testing soils with 2.3-3.4% organic matter when both Avail and the N management polymer NutriSphere-N were used (Table 6). Similar benefits from use of both polymers have been reported in the USA with maize, cool season forage grasses and cotton.

Broadcast preplant DAP with Avail on higher organic matter (5-6%) soils in the northern Corn Belt of the USA also increased maize response to applied P. Initially, there was some concern that higher organic acid concentrations in soil (from organic matter) might mask the effects of the Avail polymer. Both the University of Minnesota study in Table 7 and grower field experiences have demonstrated that the polymer technology also has merit under these kinds of conditions. Note that the soil pH associated with the trial was slightly above neutral emphasizing that P use efficiency can be modified even when soil conditions are considered to be near optimal for P availability.

Potato. University potato studies in the western USA on high pH soils also show positive effects of Avail coated MAP compared to untreated MAP (Hopkins et al. 2008; Hopkins, 2011). Stark at the University of Idaho reported yields were increased at two P rates by the polymer coating as were petiole P concentrations. The coated MAP increased US No. 1 yields by 14% and gross returns by as much as $494/ha. Approximately half of the increased return was related to quality.

Table 6. Maize responses to avail and nutrisphere-n polymers

Argentina

N Requirement	Avail	NutriSphere	Exp.St	Acevedo	Ocampo Kg/ha	Mercedes
100%	*No*	*No*	6.369	7.746	4.777	6.292
		Yes	6.112	7.731	4.572	7.077
	Yes	*No*	6.385	7.906	4.788	7.679
		Yes	6.253	8.265	4.926	7.536
80%	*No*	*No*	6.109	7.726	4.685	6.580
		Yes	6.728	8.043	4.841	7.210
	Yes	*No*	6.690	7.856	4.374	6.083
		Yes	6.319	8.166	4.413	7.083
Overall rates	Without Avail		6.388	7.809	4.656	6.659
	With Avail		6.353	8.051	4.688	7.227
	Without NutriSphere		6.330	7.811	4.719	6.790
	With NutriSphere		6.412	8.048	4.625	7.096
pr > F_{Treat}			0,3	0,99	0,91	0,64
$LSD_{5\%}$			638	1840	2809	690
CV %			4,61	19,6	27,6	10,0

Table 7. Enhancing p availability and maize response to avail coated on dap

Minnesota, USA

P Source kg P_2O_5/ha	P Uptake V-6 g/12 plants	Yield t/ha
0	1.85	8.53
28 DAP	1.77	9.47
28 DAP + Avail	2.72	10.79
56 DAP	2.17	9.72
56 DAP + Avail	2.47	10.98
LSD (0.05)	0,79	1.38

P broadcast preplant. Soil pH: 7.3, 7 ppm Olsen P
Randall, Univ. of Minnesota

Extensive potato trials in the United Kingdom (UK) have shown similar responses to Avail coated on MAP. Yields, quality and storage characteristics (Fig. 1) have benefitted from the enhanced P availability and uptake.

Table 8. Potato yield and return to enhanced p availability

Idaho, USA

Treatment kg P_2O_5/ha	Yield t/ha	Petiole P %	Gross Return$/ha
Control	34.82 a	0.225 d	3596
67 MAP	36.96 ab	0.253 cd	3818
67 MAP + Avail	37.97 ab	0.288 ab	3890
134 MAP	38.53 bc	0.275 bc	3930
134 MAP + Avail	41.33 c	0.308 a	4424

Declo sandy loam, pH 7.9; Olsen P 23 ppm *Stark, Univ. of Idaho*
Duncan's multiple range test, 5%.

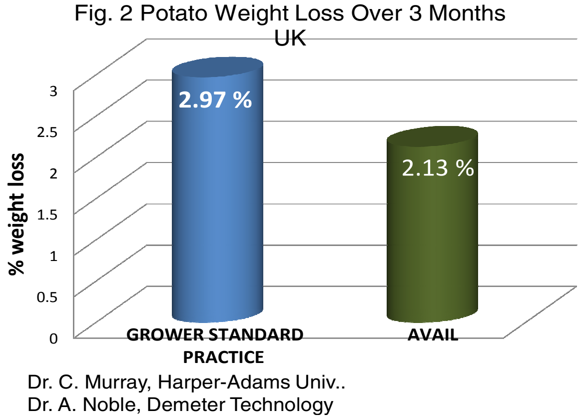

Figure 1. Potato Weight Loss Over 3 Months - U.K.

1.6 Avail and Forms of Phosphorus

MAP, DAP, TSP. Form of commercial fertilizer P has not been a factor in Avail effects on P responses. Examples of responses of MAP and DAP were mentioned earlier in this paper. Dunn et al. (2008) utilized triple superphosphate (TSP) in Avail studies with rice with good results. However, early evaluations with granulated rock phosphate in other studies indicated that there was essentially no effect of Avail on that product. Further, Avail does not release P that has already been fixed in soil reactions and applying the polymer alone will not enhance P availability. Carry-over trials have not shown an Avail effect on crops the following year.

Fluid P Fertilizers. Polymer effects in P-containing fluid fertilizer formulations have also been extensively evaluated. Recognizing that fluid bands would have a much less defined geometry than the coating of polymer on a solid particle, polymer rates were evaluated beginning at 1% volume to volume. Polymer formulation rates were eventually lowered to the present 0.5% or 0.5 liters per 100 liters of P fertilizer. An example of an Avail response in fluid starter placed in direct seed contact for maize is shown in Table 9. No difference in response has been noted between all orthophosphate fluids and polyphosphate-containing formulations.

Table 9. Avail in fluid starters for maize

Kansas, USA

Treatment	Grain Yield, t/h
No starter	9.78
Seed row, 75 L/ha 10-34-0	10.54
Seed row + Avail 0.5%	11.04
LSD.05	0.38

Soil pH: 6.8, 14 ppm Bray 1-P
Gordon, Kansas State Univ.

Conclusions

Influencing or modifying reactions in the soil solution microenvironment around fertilizer granules or in a fluid band or droplet has been shown to have significant benefits to the availability of and subsequent plant response to applied P. Research and extensive field experiences with the Avail polymer have shown beneficial effects on the availability and uptake of fertilizer P over a wide range of soil conditions and crops. Better P availability has led to higher yields and better crop quality by allowing crops to more nearly achieve their genetic potential. This technology not only has the potential to improve crop yields and farmer profits but also has positive implications on the possible environmental footprint of fertilizer use because of higher use efficiency and reduced carry over.

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