IMPROVING N AND P USE EFFICIENCY WITH POLYMER TECHNOLOGY

Dr. Larry Murphy, Murphy Agro, 2805 Claflin Road, Suite 200
Manhattan, KS 66502 phone: 785-776-6623 fax 85-776-8347
e-mail: murphyagro@cs.com
Dr. Larry Sanders, Specialty Fertilizer Products, 134 Cherry Hill
Drive, Belton, MO 64012, phone: 816-322-7200, fax: 816-322-7207
e-mail: jlarrysanders@specialtyfertilizer.com

Abstract

The microenvironment surrounding a P fertilizer granule or within a fluid P fertilizer band is subject to a series of primary and secondary reactions which substantially impact nutrient 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 5-25% 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 fixation. The reported polymer technology affects P use efficiency that is economical and profitable. Urea and urea containing N solutions (UAN) are subject to different efficiency-limiting factors. A polymer technology similar in structure to the P polymer has shown good effects in the field. In this case, soil N reactions are being affected, enhancing efficiency of applied N and again positively affecting yields and profitability.

Introduction

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

Phosphorus Fertilizers – The Problem

It has long been understood that even under the best conditions only 20-30% of applied fertilizer P is taken up by the crop during the first cropping season. It is also understood that at high soil pH levels, P is fixed 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 lack of availability.

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Residual P not taken up by the crop (70-80%) 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.

Phosphorus Fertilizers – 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 compounds are biodegradable and highly water-soluble. The technology (Avail) can be applied directly to granular P fertilizers as a coating or mixed into liquid fertilizers.

The theory of mode of action is that the high charge density of the polymer (approximately 1,500 meq/100 g of polymer) results in adsorption 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.

Table 1. Polymer effects on MAP solubility in various solutions.

MAP coating % polymer	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^oC. 24 hours. No stirring. Griffith, Kansas State University

In the soil, the dissolving polymer is theorized to adsorb or sequester 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.

An elegant study conducted at Washington State University by Dr. Rich Koenig emphasized the effects of the Avail polymer on the activity of trivalent Al ions in solution. A study of the sensitivity of wheat varieties to Al toxicity was conducted in the lab with three Al concentrations in the growth medium (Fig. 1A). Root length was measured as an indication of plant growth or Al sensitivity. When Avail polymer was introduced into the growth media, the effects of Al disappeared (Fig. 1B).

Fig. 1A. ALUMINUM EFFECTS ON WHEAT GROWTH
Koenig, Washington State Univ.

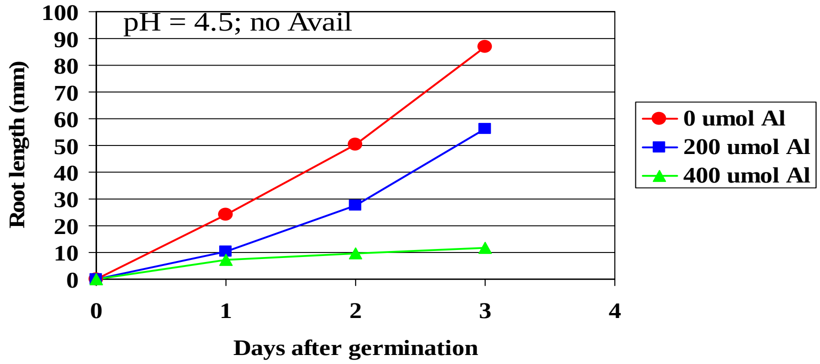
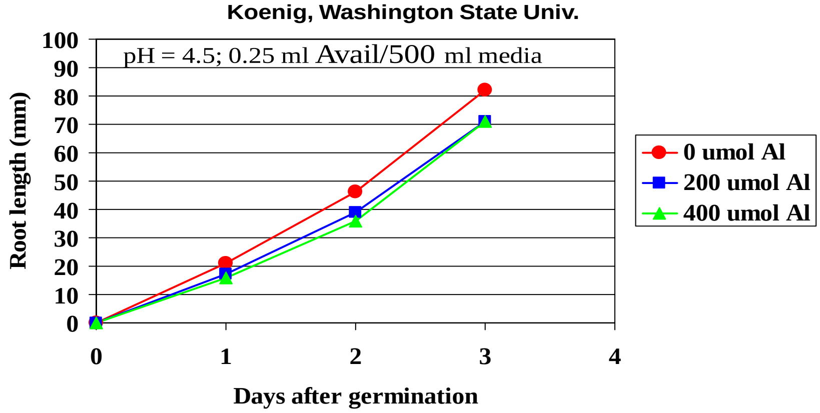


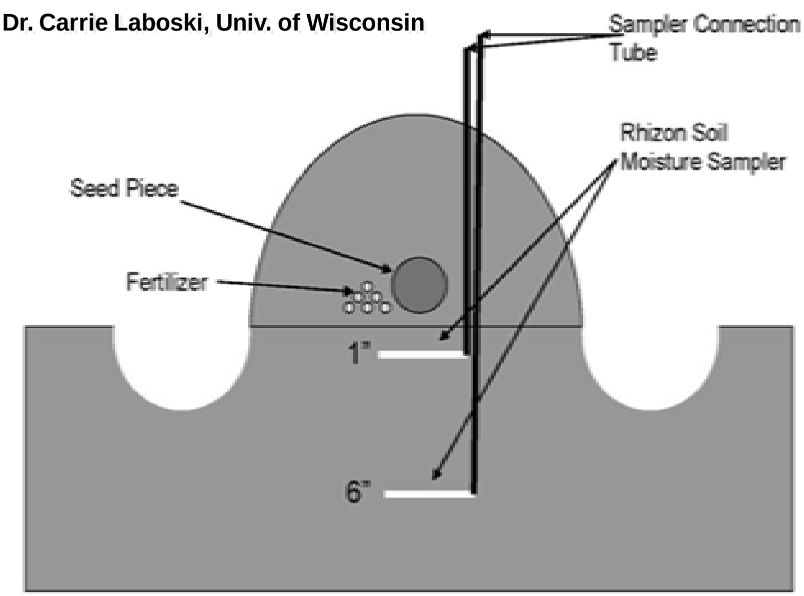
Fig. 1B ALUMINUM EFFECTS ON WHEAT IN PRESENCE OF AVAIL POLYMER
Koenig, Washington State Univ.



Vertical P Mobility. Enhanced P availability through reduced fixation has been demonstrated to enhance vertical P mobility. Recent studies in Iowa with fluid starter P applications for corn (Kovar) 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 polymer, are assumed to have interrupted normal P fixation reactions through the modification of the microenvironment of the P application zone. University of Wisconsin studies (Laboski, 2007) of P mobility in the presence of Avail coating (Fig. 2) have shown enhanced concentrations of P in the soil solution with Avail. Quoting the researchers, "At one inch 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." These results indicate a change in P soil reactions due to the presence of the Avail polymer.

Fig. 2. SAMPLING SOIL SOLUTION FOR P MOBILITY

Dr. Carrie Laboski, Univ. of Wisconsin



Polymer Effects on Plant Responses to Applied P

Phosphorus fertilization effects on plant growth and yields can be influenced by several factors including:

* Methods of P application
* Soil pH
* P application rates
* Type of crop
* Soil test P levels
* Polymer rates

Greenhouse and field investigations have evaluated polymer effects on crop responses to applied P with variables of the factors listed above. Initial greenhouse studies on high P, acidic, P-fixing soils provided the positive impetus (data not shown) for continuing the work in the field. As in any other series of investigations of this type, not all locations have been responsive to polymer coatings on P fertilizers. However, out of all P-responsive sites, polymer coatings have produced positive responses about 80% of the time.

Methods of P Application. University of Arkansas wheat data (Table 2) show that polymer-coated MAP was more effective than uncoated MAP. 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. The largest increase was with banded P applications but broadcast P applications, widely recognized as less efficient, were also consistently increased by Avail coating of MAP.

Arkansas Wheat

Table 2. Avail and P application method effects on wheat yields

Treatment	Yield bu/A
Control	46.7
MAP banded	54.7
MAP + Avail, banded	76.9
MAP broadcast	58.2
MAP + Avail, broadcast	65.6
MAP + seed, broadcast	55.1
MAP + Avail + seed, broadcast	68.3
LSD (0.05)	7.5

30 lb P_2O_5/A. Low soil P, pH 7 Palmer, University of Arkansas

Wheat data from South Australia (Holloway) show that polymer-coated MAP out performed MAP at three different P rates on highly calcareous soils. Although limited by moisture, yields were increased as much as 10% on these high pH (8.3) soils containing approximately 70% free calcium carbonate (data not shown).

Kansas wheat studies on high P testing soil (75 ppm Bray-1) acidic soil also showed a significant yield response of wheat to polymer-coated MAP. Although these soils test high for P, they also have a high P fixation capacity due to their very low pH (4.7).

University of Missouri corn data (Table 3) indicate an example of Avail performance with an acid soil pH (5.9), low P soil test combination and with both broadcast and banded P applications. The data indicated no response to untreated MAP, but a significant response to polymer-coated MAP (20 bu/A).

Missouri Corn

Table 3. Corn response to enhanced P availability.

Treatment	Grain Yield bu/A
Control, No P	135
MAP broadcast	132
MAP + Polymer broadcast	151
MAP banded	132
MAP + Polymer banded	157
LSD (0.05)	16

20 lb P_2O_5/A. Soil test Bray P-1: 7 ppm pH: 5.9
Blevins, Univ. of Missouri

Very interestingly, MAP coated with polymer also performed well on medium to high P testing, near neutral soils in Kansas. Irrigated corn yields were increased from 8-20 bu/A over the uncoated MAP by polymer-coated MAP applied as a starter (Table 4). Early season plant dry weights, plant P concentrations and P uptake were increased by the enhanced P availability in this 3-year study (data not shown). Soybeans also responded well to banded (starter) polymer-coated MAP with yield increases up to 16 bu/A over uncoated MAP (Table 5) at this same location. Apparently there is still opportunity for P management on soils with good P soil tests and moderate pH levels.

Kansas Corn

Table 4. Enhancing P availability for irrigated corn.

Treatments	Year 1	Year 2	Year 3
lb P_2O_5/A	------------------------	bu/A	---------------------
Control	172b	119e	169d
20 MAP	192a	142d	192c
20 MAP + Avail	199a	173bc	210a
40 MAP	193a	168c	188bc
40 MAP + Avail	193a	190ab	210a
60 MAP	193a	173bc	195b
60 MAP + Avail	201a	194a	210a

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.

Kansas Soybeans

Table 5. Enhancing P availability for irrigated soybeans.

Treatments lb P_2O_5/A	Year 1	Year 2 bu/A	Year 3
Control	52d	32d	60
30 MAP	62c	41c	70
30 MAP + Avail	70b	57a	78
60 MAP	62c	47b	74
60 MAP + Avail	73a	58a	78

Duncan's multiple range test, 5%. P banded beside row. Gordon, Kansas State Univ.
Soil test P: 38 ppm Bray 1. Soil pH: 6.8.

Studies at soil pH values above 7.0 were conducted at the University of Arkansas (wheat shown earlier, Table 2) and at the University of Minnesota with corn (Table 6). All of these studies showed positive responses to MAP and DAP coated with the Avail polymer compared to untreated P materials.

Crops. Phosphate fertilizers coated with Avail polymer have produced increased P uptake and increased yields on a wide range of crops. Experiments with collards, grass, corn, wheat, onions, rice, tomatoes, sweet corn, canola, and potatoes have produced positive responses to coated P fertilizer over uncoated P indicating that this is a soil chemistry phenomenon, not associated with species.

Minnesota Corn

Table 6. Enhancing P availability for corn

P Source lb P_2O_5/A	P Uptake V-6 g/12 plants	Yield bu/A
0	1.85	136
25 DAP	1.77	151
25 DAP + Avail	2.72	172
50 DAP	2.17	155
50 DAP + Avail	2.47	175
LSD (0.05)	0,79	22

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

Coating MAP with polymer has also been effective on acidic, P-fixing soils for cool-season grass forages in Kansas and Missouri. Data in Table 7 indicate how broadcast P applications with Avail coating during the dormant period enhanced P uptake and yields. These effects also were apparent visually. However, early growth differences in Kentucky on fescue did not result in yield increases.

Kansas and Missouri Cool Season Grasses

Table 7. 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 + Polymer	6010	4710	4724
LSD (0.10)	570	810	782

Low P, pH soils. 20 P_2O_5/A. MO 90 N, KS 100 N/A Lamond, Kansas State Univ. Massie, U of Missouri

University of Idaho potato data (Table 8) also show the effects of the polymer-coated 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 polymer coating. When polymer-coated MAP was applied at both rates, significant increases in yields and dollar returns resulted. The higher coated 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.

Idaho Potatoes

Table 8. Potato yield and return responses to enhanced P availability.

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

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

Polymer Rate Effects. Initial studies of polymer rates with solid P fertilizers involved coatings of up to 1 percent polymer formulation. However, subsequent greenhouse and field studies indicated that much lower rates could be utilized. Data in Table 9 indicated that rates could be reduced to 0.25 percent without loss of efficacy. That rate is currently recommended for all solid P fertilizers (MAP, DAP, TSP).

Table 9. Avail polymer rate effects on corn.
Kansas

Treatments	V-6 Dry Wt lb/A	V-6 P uptake lb/A	Yield bu/.A
No P control	380	0.91	103
MAP	501	1.34	121
MAP + 1% AVAIL	592	1.61	138
MAP + 0.75% AVAIL	585	1.58	136
MAP + 0.5% AVAIL	620	1.73	140
MAP + 0.25% AVAIL	601	1.65	137
$LSD_{.10}$	32	0.21	13

P banded 30 lb P205/a. Bray P-1 9 ppm, pH 7.4 Lamond, Kansas State Univ.

Polymer in Fluid Fertilizers

Polymer effects in P-containing fluid fertilizer formulations have also been evaluated but in fewer trials than with solid P fertilizers. Recognizing that fluid bands would have a much less defined geometry than the coating of polymer on a solid particle, polymer rates were increased beginning at 1% polymer by weight, the initial concentration of polymer coated on solids. Rates of 1% and 2% polymer were initially evaluated in field strip trials with a complete mixed fluid starter for corn in Indiana. These trials were replicated over years were harvested with a yield monitor. Initial results were encouraging (Table 10) but indicated that higher rates needed to be evaluated.

Indiana Corn
Table 10. Enhancing fluid starter responses with polymer

Treatments	Corn yields, bu/A		
	Year 1	Year 2	Year 3
Starter only	171	185	189
Starter + 1% polymer	171	190	202
Starter + 2% polymer	179	194	209

7-22-5 starter, 150 lb/A Anderson Fertilizer, Romney, IN

Replicated evaluations of polymer rates in fluid starter for irrigated corn were conducted in Kansas on high P testing, neutral pH (6.8) soil with high N:P ratio formulations which had been shown to enhance P responses under such soil conditions in reduced tillage production systems. Several polymer rates were evaluated in a 15+15+5 starter application placed 2 inches to the side and 2 inches below the seed (Table 11).

Further work with polymer in fluid starter with corn using various rates and a modified formulation established the current recommendation for 0.5% concentration (volume/volume) of Avail SD in side banded fluid starter and 1.5% Avail OS in pop-up starters.

Table 11. Enhancing P Availability in Fluid Starter
2002 - Kansas

Treatments N	P_2O_5	K_2O		Corn Yield bu/A
------------------lb/A-------------				
No starter				133 d*
15	15	5	No polymer	152 c
15	15	5	1% polymer	167 b
15	15	5	2% polymer	186 a

Soil pH = 6.8. Soil test P – 35 ppm Bray P-1. Kansas State Univ.
Means separated by Duncan's multiple range test, 5% level.

Nitrogen

The problems associated with the use of urea or urea-containing solutions prompted examination of potential effects of another dicarboxylic polymer on N use efficiency. This polymer has a similar charge density to Avail but with significantly different formulation characteristics. Initial trials with the material showed some depression of ammonia volatilization, later was shown to have the ability to slow urea hydrolysis through effects on urease and shows effects on nitrification. This multi-functional material has a very high charge density, around 1800 meq/!00 grams of polymer. That characteristic is believed to have effects on metalloenzymes such as urease and soil N oxidation enzymes of *Nitrosomonas* and *Nitrobacter*. Each of these enzymes depends upon a specific multi-valent metallic cofactor, respectively Ni, Cu and Fe. The polymer labeled Nutrisphere-N is theorized to sequester or compromise the activities of these metals with resulting slowing of the respective reactions.

Field research begun in 2004 continues to produce positive results with polymer concentrations of 0.25% coated on urea and 0.5% concentrations in UAN. Field conditions of high amounts of surface residues where urea has traditionally experienced problems with N use efficiency were chosen for evaluation of Nutrisphere-N.

Data in Tables 12-15 indicated consistent Nutrisphere-N effects both in urea and in UAN applied to no-till corn. Table 16 shows how Nutrisphere-N performed on tall fescue. Those data plus similar results from N fertilization trials with bermudagrass in TX and AR and rice in MO indicate that this is a technology which allows urea to perform at a level equal to ammonium nitrate.

Table 12. NUTRISPHERE-N EFFECTS ON UREA
No-till Corn—Kansas 2004

Treatment lb N/A	% N	Corn Yield bu/A
0	1.77	154
80 Urea	2.00	176
80 + NSN	2.20	198
160 Urea	2.08	192
160 + NSN	2.32	210
240 Urea	2.22	230
240 + NSN	2.46	254
LSD .05		9

Broadcast N, no-till corn — Gordon, KSU
NSN = Nutrisphere-N

Table 13. NUTRISPHERE-N EFFECTS ON UREA
No-Till Corn—Kansas 2005

N Rate lb/A	Ear Leaf N %	Corn Yield bu/A
0	1.78	139
80 Urea	2.79	167
80 Urea + NSN	2.90	184
160 Urea	2.90	183
160 Urea + NSN	3.07	216
240 Urea	2.95	192
240 Urea + NSN	3.09	215
LSD.05		6

Soil pH = 7.0 — Gordon, Kansas State Univ.
NSN = Nutrisphere-N

Table 14. NUTRISPHERE-N POLYMER EFFECTS

No-Till Corn, Kansas--2006

N Rates lb/A	Urea Polymer	Urea None	UAN Polymer	UAN None
0		138 bu/A		
80	166	152	170	157
160	188	169	192	167
240	197	188	196	181
$LSD_{.05}$		6		

All N broadcast, Crete silt loam Gordon, KSU
Soil pH: 7.0

Table 15. IMPROVING N USE EFFICIENCY WITH *NUTRISPHERE-N*

***Ohio*--2006**

Treatment lb N/A Broadcast	Corn Yield bu/A
0	94
100 Urea	165
100 Urea + Nutrisphere-N	178
100 UAN	159
100 UAN + Nutrisphere-N	169
$LSD_{.10}$	23

No-till corn Mullen, Ohio State Univ.

Table 16. NUTRISPHERE-N FOR FESCUE

Missouri – Spring 2007

N Source Spring	Bradford Yield, lb/A	Mt. Vernon Yield, lb/A
No N	2167	1666
Urea	4717	3140
Urea + NSN	5254	3788
Am. nitrate	4827	3648
$LSD_{.05}$	550	416

75 lb N/A Kallenbach, Univ. of Missouri

Conclusions

Influencing or controlling reactions in the microenvironment around fertilizer granules or in a fluid band or droplet has been shown to have significant benefits to the fate and availability of applied nutrients and subsequent plant response to applied P and N. 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 this polymer technology, research shows that modification of the microenvironment around fertilizer N and P particles affects nutrient 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.