Corn Response to Starter Fertilizer With and Without AVAIL

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Abstract
Starter fertilizers containing phosphorus are often applied when planting corn (Zea mays L.) in the Delmarva Region. Recently, a new fertilizer additive called AVAIL (Specialty Fertilizer Products LLC, Leawood, KS) has been promoted in this region as a product that will increase the plant availability of P fertilizers by reducing P adsorption by iron and aluminum minerals. There have been, however, no reported studies in corn that demonstrate that AVAIL increases fertilizer P availability. The objective of this study was to evaluate the value of adding AVAIL to starter fertilizers containing P when growing corn. Early growth of corn was increased by starter fertilizer at all site years; however, AVAIL had no effect on early growth. Grain yields were increased by adding P in the starter fertilizer at only two of the eight site-years, but AVAIL had no effect on grain yields at any of the site-years. Overall, our results suggest that AVAIL had no effect on crop uptake or response to P.

Introduction
Fertilizer phosphorus is available for plant uptake when initially added to the soil and then slowly converted to unavailable forms (6,14,18). This process is generally referred to as P fixation (10). Recently, a fertilizer additive called AVAIL (Specialty Fertilizer Products LLC, Leawood, Kansas, USA) has been developed and is being widely marketed and sold as a product that will keep P fertilizer from being “fixed” or converted to unavailable forms. The Material Safety Data Sheet identifies AVAIL as a maleic-itaconic copolymer, ammonium salt. The manufacturer claims that this product will slow the process of P fixation by soils, thereby increasing the overall availability of P fertilizer. However, there is a lack of peer-reviewed studies evaluating this product; in fact, we found only one. Dunn and Stevens (5) evaluated rice yield response to P fertilizer with and without AVAIL added. They found that 25 lbs/acre P2O5 treated with AVAIL was as effective as 50 lbs/acre of untreated P2O5.

Multiple research studies have shown that P fertilizer efficiency is typically greater for banded applications than for broadcast applications(7,13). In fact, banding of P near the seed at planting (i.e., starter fertilizer) is common practice in many corn producing areas (1), including the Delmarva Region (2). Starter fertilizer refers to a small amount of fertilizer that is applied near the seed during the planting process. Numerous studies(8,9,12,16,18) have documented that starter fertilizers containing P will often result in early growth responses of corn, but these early growth responses seldom result in corresponding increases in grain yield if soil test P levels are optimal or above. Nonetheless, the use of starter fertilizers is still a common practice among corn growers, and AVAIL is being promoted and used as a fertilizer additive in these starter fertilizers. The objective of our study was to evaluate early growth response of corn, P uptake in young plants, and grain yield response to starter fertilizers containing AVAIL.
**Field Research**

This study was conducted at eight different sites in Delaware and Maryland over three growing seasons, resulting in eight site-year combinations. Table 1 presents details for each site-year, including crop management, soil P concentrations, and yields. Weather conditions varied across the three years of this study (Fig. 1). Rainfall amounts were below normal in 2007 and temperatures were slightly above normal; however, both locations in 2007 were irrigated. In 2008, grain yields were well below normal at all non-irrigated locations due to late-season drought stress that began shortly before tassel initiation and continued well into the grain-fill period (Table 1). The 2009 growing season was cooler than normal with above-average amounts of rainfall occurring at both locations.

The study included ten treatments replicated at each site year. These ten treatments included a control that received no fertilizer with the planter, an N-only treatment that received 28 kg N/ha with no P, and four rates of P (2.4, 4.8, 9.6, and 14.4 kg P/ha). All starter fertilizer treatments were formulated by mixing 30-0-0, 10-34-0, and water to achieve the desired rates of N and P. The four rates of P were applied with and without AVAIL mixed at a rate of 0.5% (v/v) as per label instructions. All the starter fertilizer treatments contained 28 kg N/ha. Nitrogen fertilizer was dribbled onto the control plots at 28 kg N/ha one week after planting so that the total rate of N was the same on all plots. With the exception of the highest rate of P and the N-only treatments, all starter treatments were applied at the same fertilizer rate of 98 liters/ha. Each treatment was applied in a band 5 cm to the side and 5 cm below the seed at planting. All other nutrients were managed by the cooperating farmer based on soil test recommendations. For all site-years except 5 and 8, additional N fertilizer was applied by each cooperating farmer in a dribble band on the soil surface at sidedressing when the corn was at about the V6 growth stage. At site-years 5 and 8, additional N was applied in the spring before planting as 82-o-o.

Planting populations were 64,198 seeds/ha for three site-years (SY 1, SY 2, and SY 6) and 74,074 seeds/ha for the other five site site-years. Individual plots were 3.1 m wide (4 rows) and 45.7 m long. The plots were arranged in randomized complete blocks with either four or six replications at each site-year.

Early plant samples were taken at the V5 to V6 growth stage for all site-years except SY 3 (V4 stage) by harvesting a total of 20 plants from the two outside rows (10 per row) of each plot. These plants were cut at the soil surface, weighed, placed in paper bags, and immediately dried in an oven at 60°C. After drying for several days, each sample was weighed for dry matter determinations. To evaluate the impact of the treatments on crop growth rate, the number of plants showing silks at the tips of the ears was counted. These counts were taken when the plants with the greatest fertilizer P rates had about 90% of the plants showing silks. Grain yields were determined by harvesting the center two rows of each plot with a plot combine and a weigh wagon. In order to compare yield response to starter fertilizer across site-year, relative yield_{cont} (RY_{cont}) was calculated as the plot yield divided by the mean no-P control yield for that site-year. In addition, relative yield_{max} (RY_{max}) was calculated for each plot as the yield divided by the maximum yield for that site-year. The maximum yield was the highest mean yield from that site of the eight P starter fertilizer treatment combinations (P rate × AVAIL).
Fig. 1. Cumulative rainfall and growing degree units from April 1 through September 30 of each growing season recorded by the University of Delaware Research and Education Center weather station located near Georgetown, Sussex County, Delaware.
Table 1. Properties, cropping practices, grain yield, and grain yield relative to the no-phosphorus control treatment at each of the eight site-years.

<table>
<thead>
<tr>
<th>Site-year</th>
<th>Planting date</th>
<th>Soil texture</th>
<th>Soil organic matter (%)</th>
<th>Previous crop</th>
<th>Hybrid</th>
<th>Tillage</th>
<th>Irrigated</th>
<th>M3P^X (mg/kg)</th>
<th>Grain yield^Y (Mg/ha)</th>
<th>RY_cont^Z (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1-May-07</td>
<td>LS</td>
<td>1.4</td>
<td>Corn</td>
<td>P33B51</td>
<td>Convl.</td>
<td>Yes</td>
<td>181</td>
<td>11.78 b</td>
<td>101 ab</td>
</tr>
<tr>
<td>2</td>
<td>14-May-07</td>
<td>LS</td>
<td>2.0</td>
<td>Corn</td>
<td>DK63-39</td>
<td>No-till</td>
<td>Yes</td>
<td>259</td>
<td>14.72 a</td>
<td>101 ab</td>
</tr>
<tr>
<td>3</td>
<td>23-Apr-08</td>
<td>L</td>
<td>2.2</td>
<td>WW/S</td>
<td>P33B54</td>
<td>Convl.</td>
<td>No</td>
<td>40</td>
<td>6.53 e</td>
<td>103 ab</td>
</tr>
<tr>
<td>4</td>
<td>22-Apr-08</td>
<td>LS</td>
<td>1.4</td>
<td>Corn</td>
<td>P33T57</td>
<td>Convl.</td>
<td>Yes</td>
<td>197</td>
<td>10.55 d</td>
<td>95 b</td>
</tr>
<tr>
<td>5</td>
<td>24-Apr-08</td>
<td>SL</td>
<td>1.6</td>
<td>WW/S</td>
<td>DKC6169</td>
<td>Vert.-till</td>
<td>No</td>
<td>75</td>
<td>8.12 c</td>
<td>113 a</td>
</tr>
<tr>
<td>6</td>
<td>7-May-08</td>
<td>L</td>
<td>1.5</td>
<td>WW/S</td>
<td>P33T57</td>
<td>No-till</td>
<td>No</td>
<td>24</td>
<td>7.98 c</td>
<td>114 a</td>
</tr>
<tr>
<td>7</td>
<td>20-May-09</td>
<td>L</td>
<td>1.8</td>
<td>WW/S</td>
<td>P35K04</td>
<td>Convl.</td>
<td>No</td>
<td>25</td>
<td>12.48 b</td>
<td>109 a</td>
</tr>
<tr>
<td>8</td>
<td>21-May-09</td>
<td>SL</td>
<td>1.9</td>
<td>WW/S</td>
<td>DKC52-62</td>
<td>Convl.</td>
<td>No</td>
<td>50</td>
<td>14.40 a</td>
<td>103 ab</td>
</tr>
</tbody>
</table>

^y LS = loamy sand; L = loam; SL = silt loam.

^w WW/S = winter wheat followed by double-crop soybean.

^x M3P = Mehlich 3 soil phosphorus concentration.

^y Means followed by different letters were significantly different (P < 0.05).

^z RY_cont = Relative Yield_cont calculated by dividing the mean yield for each site-year by the mean yield for the no-phosphorus control for that site-year.

Soil samples were taken from each site and analyzed for soil organic matter by loss on ignition (19) and Mehlich-3P (11,19) by the University of Delaware Soil Testing Laboratory. Total P concentrations in the plant samples were determined using a potassium persulfate acid digestion method (15). Dried plant samples were ground to pass a 1-mm sieve and then 0.1 g was weighed into a digestion vessel with 1 g K$_2$S$_2$O$_8$, 35 mL of deionized H$_2$O, and 2 mL of 5M H$_2$SO$_4$. The mixture was allowed to digest in an autoclave for 1 h at 121°C and 0.12 MPa. Phosphorus concentrations in the extracts were determined colorimetrically using the phosphomolybdate-ascorbic acid method (4) and a QuickChem 8500 Flow Injection Analysis System (Hach Co., Loveland, CO). Phosphorus uptake was calculated based on the total P concentration per plant, the dry matter weights per plant, and the average plant population at each site-year.

The experimental design was a randomized complete block design as a two by four factorial, with two levels of AVAIL (no AVAIL and 0.05% v/v) and four levels of P fertilizer (2.4, 4.8, 9.6, and 14.4 kg P/ha). Control treatments receiving no P fertilizer were withheld from statistical analysis since the objective of the study was to evaluate the response to inclusion of AVAIL with the P fertilizer. Statistical analysis was performed using the MIXED PROCEDURE in SAS version 9.1 (17). Site-year and location within the field were used as blocking factors and included in the RANDOM statement in the MIXED procedure. Differences between treatment means were determined to be significant for P ≤ 0.05 using the Tukey adjustment of least square means.

**Corn Response to Fertilizer Treatments**

There were no significant interactions between P rate and AVAIL. In addition, AVAIL was not found to be a significant factor for any response variables. The following discussion will therefore focus on the main effects averaged across site years.

As stated previously, the treatments without starter P or N were not included in the statistical analysis. However, their means are presented in Table 2 for comparison. The addition of starter P fertilizer resulted in 35 to 71% more biomass at the V4 to V6 stage, while the addition of 28 kg N/ha alone resulted in 25% more biomass at this stage. The degree of responsiveness between site-years was largely related to soil test P concentration. However, since soil test P was confounded with site-year, and hence climate, the site-year factor was
treated as a blocking factor and not evaluated statistically. Nonetheless, when averaged across site-year there was a clear response to starter P rate (Table 2). Application of 14.4 kg P/ha resulted in significantly more biomass at V4 to V6 than any of the other treatments and the application of 9.6 kg P/ha produced significantly more biomass than the lowest two rates, which were not significantly different. Although there was a clear response of plant biomass at the V4 to V6 stage to P rate, AVAIL was not found to have any significant effect. When averaged across all P rates, the amount of biomass on plots receiving AVAIL was 344 kg/ha, while plots not receiving AVAIL averaged 336 kg/ha.

Table 2. Response in tissue phosphorus concentration, phosphorus uptake and biomass (V4 - V6), percent plants silked, and grain moisture content and yield at harvest to starter fertilizer treatments.

<table>
<thead>
<tr>
<th>Starter treatment</th>
<th>Measured between V4 and V6</th>
<th>Relative yield Max x</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tissue phosphorus (mg/kg)</td>
<td>Biomass (kg/ha)</td>
<td></td>
</tr>
<tr>
<td>Control treatments receiving no starter P fertilizer y</td>
<td>3834</td>
<td>225</td>
<td>0.89</td>
</tr>
<tr>
<td>None</td>
<td>3834</td>
<td>225</td>
<td>0.89</td>
</tr>
<tr>
<td>N only</td>
<td>3522</td>
<td>281</td>
<td>1.02</td>
</tr>
<tr>
<td>Mean of starter fertilizer treatments with and without AVAIL (avg. across all starter P rates) y</td>
<td>3773</td>
<td>336</td>
<td>1.29</td>
</tr>
<tr>
<td>No AVAIL</td>
<td>3773</td>
<td>336</td>
<td>1.29</td>
</tr>
<tr>
<td>AVAL</td>
<td>3728</td>
<td>344</td>
<td>1.31</td>
</tr>
<tr>
<td>Mean of starter fertilizer treatments averaged across AVAIL treatments z</td>
<td>3661 b</td>
<td>304 c</td>
<td>1.15 c</td>
</tr>
<tr>
<td>2.4</td>
<td>3661 b</td>
<td>304 c</td>
<td>1.15 c</td>
</tr>
<tr>
<td>4.8</td>
<td>3741 ab</td>
<td>317 c</td>
<td>1.22 c</td>
</tr>
<tr>
<td>9.6</td>
<td>3712 ab</td>
<td>354 b</td>
<td>1.34 b</td>
</tr>
<tr>
<td>14.4</td>
<td>3886 a</td>
<td>385 a</td>
<td>1.50 a</td>
</tr>
</tbody>
</table>

w Yield Max was calculated by normalizing the yield over the maximum mean treatment yield for each site.

x Control treatments were not included in the statistical analysis and are only presented as a point of reference.

y The main effect of AVAIL was not significant at P < 0.05 for any of the response variables.

z Means followed by different letters were significantly different at P < 0.05. No significant differences were detected (P < 0.05) between treatments for Yield Max.

The mean concentration of total P in young corn plants ranged from 2,270 to 5,465 mg P/kg across all site-years and treatments. As with biomass, total P concentrations increased with increasing rate of P in the starter fertilizer. Plots that received no starter P had greater tissue P concentrations (3834 mg P/kg) than all other treatments except for the highest P rate (3886 mg P/kg). This was likely due to lower biomass production at the time of sample collection, which would have had a concentrating effect on tissue P. Although rate of P applied significantly affected tissue P concentrations, AVAIL had no significant effects. There were no statistical differences between the P rates 2.4, 4.8, and 9.6 kg P/ha, but the highest rate 14.4 kg P/ha resulted in significantly higher tissue P concentrations than the lowest P rate. In order to normalize the results for the concentrating effect produced by poor growth experienced when soil P was not adequate, as seen with the no P control, we calculated total P uptake on an area basis by multiplying biomass production by the tissue P concentration. The effect of P rate on biomass was mirrored in the total P uptake. Average P uptake for the five starter P rates (including the no P control) ranged from 0.89 to 1.50 kg P/ha (Table 2). The addition of N to starter increased P uptake 15% compared to the no P, no N control treatment, while the addition of N and P increased P uptake 30 to 68%. The highest P rate (14.4 kg P/ha) resulted in significantly higher P uptake than all of the other three rates and the second
highest rate (9.6 kg P/ha) was significantly higher than the lower two (2.4 and 4.8 kg P/ha), which were not statistically different.

Adding P fertilizer in starter is often promoted as a means to increase growth rates of corn. To evaluate this potential effect, the percentage of silked plants was measured at seven of the eight site-years. These results showed that P fertilizer in the starter did increase the growth rate of corn because there was a greater percentage of silked plants in the treatments that received P compared to the control or N-only treatments when averaged across the seven site-years where silk counts were taken (Table 2). At the first silk count, significantly more plants had silked in the highest P rate (23%) than the other three rates (13 to 17%). At the second counting, there was no significant difference between the percentage of silked plants in the 14.4 and 9.6 kg P/ha treatments (58% and 52%), but they still had significantly more silked plants than the 2.4 or 4.8 kg P/ha treatments (38 and 43%, respectively). By the last counting time, the 9.6 and 4.8 kg P/ha treatments were not significantly different (88 and 79%, respectively) and the 2.4 kg P/ha (75%) treatment was still significantly lower than the 9.6 and 14.4 kg P/ha (89%) treatments. While statistical differences were found between the P rates, no differences were found with or without AVAIL additions. Apparently, AVAIL, as with crop biomass, tissue P, and P uptake, had no effect on crop response.

Moisture content of the grain from the no-P-no-N and N-only controls (18.79 and 18.87%, respectively) were similar to those receiving P fertilizer (18.63 to 18.98, Table 2). AVAIL, once again, had no significant effect on grain moisture content with plots receiving AVAIL averaging 18.76% and those without 18.80%. The plots receiving 14.4 and 9.6 kg P/ha in the starter fertilizer had significantly lower grain moisture content at harvest (18.63 and 18.72%, respectively) than the lowest rate of 2.4 kg P/ha (18.98%).

Although these results indicate significant early growth and P uptake response to inclusion of P in the starter fertilizer, ultimately grain yield is the most important factor when considering the economics of using starter fertilizer or any fertilizer enhancer such as AVAIL. Site-year was determined to have a significant effect on yield ($P < 0.0001$). This was likely due to the overriding effect of the different growing conditions for each site-year. Therefore, comparing the effect of starter fertilizer treatments on yield across site-years was not possible. Table 1 shows the effect of site-year on grain yield. No other factors were determined to be significant; therefore, only the main effect of site-year is presented. Yields ranged from 14.4 Mg/ha (site-year 8) to 6.53 (site-year 3).

Climate appeared to be one of the largest factors in separating the yield potential of site-years. However, the sites also differed in their response to starter fertilizer. Yield relative to the control was calculated and evaluated in order to determine responsiveness. Site-year was determined to be the only significant effect ($P < 0.0001$) for $R_{cont}$; therefore, only the main effect of site-year is presented (Table 1). Site-year 4 had significantly lower $R_{cont}$ than site-years 5, 6, and 7 (Table 1). In fact, $R_{cont}$ for site-year 4 was only 95% indicating that the no-P control on average yielded higher than the starter fertilizer treatments including P for that site-year. While not significant, there was a trend towards the site-years with lower soil Mehlich-3 P concentrations being more responsive to P fertilizer. For reference, the Universities of Delaware and Maryland consider soil P concentrations in the range of 51 to 100 mg/kg Mehlich 3 P to be optimum, with a low probability of economic response to P application (3,20). Site-years 5, 6, and 7 had Mehlich-3 P concentrations of 75, 24, and 25, respectively, and the three highest $R_{cont}$ values, ranging from 109 to 114% (Table 1), indicating that they were somewhat responsive to P inclusion in the starter fertilizer. Nonetheless, these differences were only deemed significant relative to site-year 4. Site-years 3 and 8 had similar soil test P concentrations to the P-responsive sites (site-years 5 to 7), but their $R_{cont}$ were more similar to the sites with high soil test P (Mehlich-3 P > 100). These results indicate that many other factors, beyond soil test P, over the course of a growing season and at a particular site can influence yield.
The yield relative to the site maximum yield, RY\textsubscript{max}, was evaluated to compare treatments across site-years. Dividing the yield by the maximum possible yield for each site-year normalized yield response across site-years, removing the effect of site-year and allowing evaluation of the main effects of AVAIL treatment and P rate. When evaluated across site-years the inclusion of P in the starter fertilizer seemed to provide some yield benefit with a mean RY\textsubscript{max} of 95% compared to no-P-no-N and N-only controls, which had similar RY\textsubscript{max} of 91 and 92%, respectively (Table 2); however, this relationship was not evaluated statistically. Relative yield\textsubscript{max} for the P rate treatments ranged from 94 to 96% with no significant differences found. Both the plots receiving AVAIL and without AVAIL had a RY\textsubscript{max} of 95%.

Summary
The results of this study indicate that with increasing P rate in starter fertilizer early growth increases, as measured by biomass and silking. In addition, increased P rate in starter fertilizer resulted in increased tissue P concentrations and therefore increased P uptake. However, the addition of AVAIL to the P fertilizer had no effect on any of these response variables. Therefore, this work suggests that AVAIL does not increase P availability, as measured by crop uptake, in Delaware or Maryland soils.

Literature Cited