Title
Distribution of Phosphorus and Potassium Following Surface Banding of Fertilizer in Conservation Tillage Systems

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Introduction
Band application of fertilizers is a common practice in maize (Zea mays L.) production systems in some areas of the USA (Bordoli and Mallarino, 1998; Wolkowski, 2000). Granulated or liquid blends with varying amounts of nitrogen (N), phosphorus (P), and potassium (K), as well as other nutrients, are applied before or at planting to the side, below, or in the seed furrow. The effectiveness of these applications depends on both the ability of the added material to increase the soil supply of nutrients, especially immobile nutrients such as P and K, and the ability of the maize seedling to respond to this increase (Kovar and Barber, 1987). Hence, the spatial distribution of fertilized soil relative to actively growing roots is important (Qin et al., 2005). Previous research with P applied as a subsurface band demonstrated that residual P can be measured in soil up to 18 months after application (Stecker et al., 2001). Our objective was to determine the relative distribution of P and K applied as a N-P-K liquid fertilizer in surface bands during the early part of the growing season.

Materials and Methods
Research was conducted during six growing seasons (2001-2006). Phosphorus availability was addressed during the first three years, while K availability was the focus during the final three years. Field plots (under disk tillage for P trials and under no-till for K trials) were established at two Iowa State University research farms in central Iowa. Soils were classified as Canisteo silty clay loam (fine-loamy, mixed, superactive, calcareous, mesic Typic Endoaquolls), Clarion silt loam (fine-loamy, mixed, superactive, mesic Typic Haplaquolls), or Webster silty clay loam (fine-loamy, mixed, superactive, mesic Typic Endoaquolls). Phosphorus movement was characterized after 15 kg P ha$^{-1}$ were dribbled on the soil surface 5 cm to the side of the maize row at the time of planting. The material was a blended combination of 7-9-6 (N-P-K) liquid and 32-0-0 urea ammonium nitrate solution. Potassium movement was characterized after 28 kg K ha$^{-1}$ were applied as a broadcast application using 0-0-50 (N-P-K) granular fertilizer, as a subsurface band 5 cm to the side of the maize row using 0-0-50 granular fertilizer, or as a liquid (0-0-8) surface band 5 cm to the side of the maize row. With the exception of 2001, a control plot was included each year. Phosphorus treatments were replicated three times, and K treatments were replicated four times. To maintain uniform application, water was added to the liquid fertilizer, and the material was applied at 280 L ha$^{-1}$. Each year, soil samples (0-15 cm) were collected with a hand probe before planting, and analyzed for pH, organic matter content, Bray-1 extractable P, and exchangeable K, Ca, and Mg (Table 1).

The distribution of available P and K from the application band into the soil profile was evaluated during the early part of the growing season in each year. At 43 days after planting (DAP) in 2001, a 15 cm x 15 cm sheet of bicarbonate-saturated anion exchange membrane was inserted vertically into the soil profile within and perpendicular to the row of two plot replicates. The membranes were centered on the plant row. At the end of a 24-h extraction period, the membranes were removed from the plots, and brought into the lab for analysis. Each membrane sheet was then cut into 2.5 cm$^2$ strips, and P desorbed by shaking each strip in 50 mL of 1.0M sodium chloride (NaCl) solution. The P concentration in the NaCl solution was determined colorimetrically. The same procedure was used to evaluate downward P movement from surface application of liquid fertilizer in 2002 and 2003. Measurements were made 43 and 68 DAP in 2002 and 42 and 63 DAP in 2003. To ensure adequate soil moisture for measurements, membranes were placed in plots only after a rainfall event. In 2002, membrane sheets were inserted into the soil profile of two reps of three fertilizer treatments, including a control, a liquid
blend application of 17 kg N ha\(^{-1}\), 15 kg P ha\(^{-1}\), and 9 kg K ha\(^{-1}\), and a liquid blend application of 67 kg N ha\(^{-1}\), 15 kg P ha\(^{-1}\), and 9 kg K ha\(^{-1}\). The higher N material was used in 2001, and the lower N material was added to the study in 2002 to reflect the types of fertilizers producers are currently using. In 2003, measurements were made in all three reps of the same three treatments evaluated in 2002. Available K in the soil profile was measured by inserting a 15 cm x 15 cm sheet of sodium-saturated cation exchange membrane vertically into the soil profile perpendicular to the maize rows approximately four to six weeks after application of the liquid or dry materials at the time of planting. Available soil K was measured again eight to ten weeks after application. Resin sheets remained in the soil for 24 hours. The sheets were then removed, cut into 2.5 cm\(^2\) strips, extracted, and analyzed for K (via ICP spectroscopy) to determine the spatial distribution of available K within the soil.

Results were analyzed according to a split-plot design. Main effects included soil profile depth and fertilizer type (P) or placement (K) in a randomized block design. Time of sampling was considered the split plot. Analyses of treatment effects were conducted by ANOVA, using the MIXED procedure of SAS (SAS Institute, 2003). Multiple comparisons for values with significant treatment effects were tested with the Bonferroni method at the 0.05 level of significance. Least square means are reported in tables. Contour plots of the data were developed to assess relative differences in soil P and K availability within the profile.

Table 1. Initial properties of soils used in the field trials.

<table>
<thead>
<tr>
<th>Year</th>
<th>Soil</th>
<th>pH</th>
<th>OM†</th>
<th>Bray-1 P</th>
<th>Exch. K</th>
<th>Exch. Ca</th>
<th>Exch. Mg</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>Canisteo sicl</td>
<td>6.5</td>
<td>54</td>
<td>70</td>
<td>208</td>
<td>4165</td>
<td>539</td>
</tr>
<tr>
<td>2002</td>
<td>Canisteo sicl</td>
<td>7.9</td>
<td>90</td>
<td>31</td>
<td>199</td>
<td>6765</td>
<td>338</td>
</tr>
<tr>
<td>2003</td>
<td>Clarion sil</td>
<td>6.6</td>
<td>51</td>
<td>46</td>
<td>86</td>
<td>2530</td>
<td>322</td>
</tr>
<tr>
<td>2004</td>
<td>Webster sicl</td>
<td>6.5</td>
<td>43</td>
<td>31</td>
<td>139</td>
<td>3673</td>
<td>459</td>
</tr>
<tr>
<td>2005</td>
<td>Webster sicl</td>
<td>6.2</td>
<td>40</td>
<td>34</td>
<td>133</td>
<td>3477</td>
<td>436</td>
</tr>
<tr>
<td>2006</td>
<td>Webster sicl</td>
<td>6.6</td>
<td>36</td>
<td>29</td>
<td>115</td>
<td>2642</td>
<td>385</td>
</tr>
</tbody>
</table>

†Loss on Ignition method.

**Results and Discussion**

**Soil Phosphorus**

Movement of available fertilizer P into the profile was clearly evident in 2001 (Fig. 1). Although the material was applied on the soil surface, the highest concentration of available P was found at a depth of more than 7 cm below the surface 43 DAP. Movement of P from fertilizer bands has been observed in other studies (Stecker et al., 2001), but the extent of the movement in this study was greater than expected. Because P diffusion in soil is a relatively slow process, the volume of material applied (280 L ha\(^{-1}\)) and the porosity of the soil may have played a role. Regardless, increased levels of available P would potentially benefit the plant throughout the early part of the growing season.

In 2002, the characterization of P movement from the surface band into the soil profile included two fertilizer blends, as well as measurements at both 43 and 68 DAP. Some movement of fertilizer P from the surface (0-2.5 cm) soil layer into the profile was evident 43 DAP of both low N (N1P, 17 kg N ha\(^{-1}\)) and high N (N2P, 67 kg N ha\(^{-1}\)) materials (Table 2). The highest concentration of available P was found at a depth of more than 10 cm below the surface for the low N treatment. In contrast to the 2001 results, however, application of the high N material
(used in 2001) had little measurable effect on available P concentrations 43 DAP. Because the 2002 data in Table 2 represent only two replications, movement of available P may have occurred, but was not measured.

Fig. 1. Profile distribution of available P 43 days after dribble application of liquid fertilizer on the soil surface approximately five cm to the side of the maize row in 2001. Phosphorus concentrations are µg P cm\(^{-2}\) and were determined by extraction with bicarbonate-saturated exchange resin membranes.

At 68 DAP, the highest concentration of available P was measured at a depth of less than five cm below the surface for the low N treatment (Table 2). For the high N treatment, no differences in available P could be detected.

In 2003, P movement from surface fertilizer bands was less evident (Table 2). At 42 DAP, the highest concentrations of available P were found in the upper 7.5 cm of soil for the high N treatment, whereas available P was not effected by application of the low N material. At 63 DAP, the highest concentration of available P was measured in the 7.5-10 cm layer of the low N treatment (Table 2). In contrast, no measurable differences in available P concentrations were found in the high N treatment 63 DAP. The reason for the difference between the two treatments at 42 and 63 DAP is unclear. As pointed out by Stecker et al. (2001), there often is significant variation in measurable soil P in the direction of band application. To better characterize the effect of increasing the amount of N relative to P in the fertilizer on P movement into the profile, more intensive sampling, better control of antecedent soil water content, or a broad range of N to P ratios would be needed.
Table 2. Plant available phosphorus determined via anion exchange resin membranes in six soil layers following surface band application of liquid fertilizer. The first sampling was 43 days after planting (DAP) in 2002 and 42 DAP in 2003. The second sampling was 68 DAP in 2002 and 63 DAP in 2003.

<table>
<thead>
<tr>
<th>Depth</th>
<th>CHK†</th>
<th>N1P</th>
<th>N2P</th>
<th>CHK</th>
<th>N1P</th>
<th>N2P</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-2.5</td>
<td>3.12aA‡</td>
<td>2.97bA</td>
<td>1.38bB</td>
<td>0.33aA</td>
<td>0.12bA</td>
<td>0.37aA</td>
</tr>
<tr>
<td>2.5-5</td>
<td>3.16aA</td>
<td>3.38abA</td>
<td>2.22aB</td>
<td>0.28aA</td>
<td>1.31aA</td>
<td>0.30aA</td>
</tr>
<tr>
<td>5-7.5</td>
<td>3.02aA</td>
<td>3.37abA</td>
<td>2.27aA</td>
<td>0.06aA</td>
<td>0.45abA</td>
<td>0.41aA</td>
</tr>
<tr>
<td>7.5-10</td>
<td>3.11aA</td>
<td>3.52abA</td>
<td>2.39aA</td>
<td>0.21aA</td>
<td>0.17abA</td>
<td>0.31aA</td>
</tr>
<tr>
<td>10-12.5</td>
<td>3.12aA</td>
<td>4.00aA</td>
<td>2.28aA</td>
<td>0.23aA</td>
<td>0.16abA</td>
<td>0.29aA</td>
</tr>
<tr>
<td>12.5-15</td>
<td>3.36aA</td>
<td>3.51abA</td>
<td>2.36aA</td>
<td>1.01aA</td>
<td>0.11bA</td>
<td>0.18aA</td>
</tr>
</tbody>
</table>

Fertilizer treatments include a control (CHK), a liquid blend application of 17 kg N ha$^{-1}$, 15 kg P ha$^{-1}$, and 9 kg K ha$^{-1}$ (N1P), and a liquid blend application of 67 kg N ha$^{-1}$, 15 kg P ha$^{-1}$, and 9 kg K ha$^{-1}$ (N2P).

§ Within each sampling period and fertilizer treatment, values in a column with the same lowercase letter are not significantly different at the 0.05 level. Within each sampling period and depth increment, values in a row with the same uppercase letter are not significantly different at the 0.05 level.

Soil Potassium

Higher concentrations of K were measured near the soil surface for all three of the K placements 28 DAP in 2004 (Fig. 2). Results were similar 41 DAP in 2005 and 2006 (data not shown). The highest concentrations of available K were found at a depth of 2.5-5 cm below the surface for both the liquid treatment and the broadcast treatment; however, only small increases in available K concentrations were measured in plots in which dry material was applied in a subsurface band in 2004. The reason for this is unclear. Perhaps, there was significant variation in measurable soil K in the direction of the application band, so that even with four replications, additional measurements may be necessary to identify areas with more available K. In 2005 and 2006, we were able to measure significantly higher concentrations of K throughout the 0-5 cm soil layer after K application, regardless of K source or placement (data not shown).

In contrast to the results of the first sampling, K concentrations in treated plots were similar to those in control plots at the time of the second sampling in all three years. Potassium concentrations were also uniform throughout the top 15 cm of soil, and were generally lower than those measured at the time of the first sampling.
Fig. 2. Profile distribution of available K 28 days after broadcasting dry material (top right), subsurface banding dry material (bottom left), or surface dribble application of liquid material (bottom right) approximately 5 cm to the side of the maize row in 2004. For comparison, the distribution of available K in the control plots also is shown (top left). Potassium concentrations are µg K cm\(^{-2}\) and were determined by extraction with sodium-saturated exchange resin membranes.

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**References**


