It is assumed that the deeper root growth observed in the APSA-80™ plots would result in greater extraction of nutrients by the corn plant from a deeper soil depth. If this is the case then there should be a decrease in the requirement for supplemental nitrogen application as less nitrogen is being lost to the corn plant through percolation in the soil. In order to more fully ascertain the accuracy of this assumption soil samples for nitrogen analysis will be taken from the 24-33 in and 33-48 in. depths during the 2001 growing season.

REFERENCES
2. Soil compaction and Drainage, Ohio State Univ. Extension Bulletin AES-301.
4. Managing Soil Compaction, Petersen, M.L., Colorado State University Cooperative Extension #0.519.

THE USE OF A NON-IONIC SURFACTANT TO ALLEVIATE THE EFFECTS OF COMPACTED SOIL ON CORN (ZEA MAYS) YIELD AND ROOT GROWTH

Ernest H. Brumbaugh (correspondence), Michael Petersen

1Access Business Group International, 7575 Fulton Street East, Ada, Michigan, 49355, USA
2Natural Resources Conservation Service, United States Department of Agriculture, Greeley, Colorado, 80631, USA

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SUMMARY
The use of a non-ionic surfactant applied to soil has been shown to increase corn root growth and yield at statistically significant levels. The test site was an irrigated field in Eastern Colorado, USA, composed of a sandy loam surface layer with a sandy clay loam subsoil that forms a compacted zone 8-15 in. beneath the soil surface. In a four year, two site study, application of APSA-80™, a non-ionic surfactant, applied at rates of 15, 30 and 45 oz/acre resulted in significantly increased root depth and crop yield. Corn root depth measured at 90% root volume increased 25-56%, and corn yield increased 13-17% depending on APSA-80™ use rate. Inter-row ripping, used one year on half of each surfactant plot, did not result in increased yield or root depth either the year the plot was ripped or the following two years.

Key words: soil compaction, non-ionic surfactant, corn (Zea mays) root growth

INTRODUCTION
Soil compaction caused by mechanised farming has long been recognized as negatively affecting crop yield in corn and many other crops (1, 3, 4, 5, 6). Soil compaction increases soil bulk density resulting in soil with a lower pore volume (1, 3, 4). Lower pore volume results in lower water and air holding capacity of the soil (1). Compacted soil also has a lower hydraulic conductivity resulting in slower movement of water through the soil profile (1, 2, 4). A compacted soil layer can make the plow layer wetter resulting in later planting, increased moisture stress on the crop and greater soil denitrification (1). Compacted soil reduces root growth by increasing the pressure needed to penetrate the compacted layer beyond the capability of the crop root to penetrate the soil (1, 3, 4). A compacted soil can increase soil carbon loss to the atmosphere (7). Soil compaction in the subsoil layer is proportional to total axle load of machinery used in the field and is not removed by plowing or freeze-thaw cycles (1, 3, 4). Increased farm mechanisation, larger farm equipment, monoculture agriculture and increased cropping have all resulted in greater soil compaction (1, 3, 4, 6). In some states up to 95% of land used in corn production is compacted (5).

Surfactants both lower the surface tension of water and decrease the contact angle of water to the soil particles (8,9). Soil moisture tension, which is proportional to the amount of water required for a root to extract moisture from the soil, is proportional to the product of the surface tension and the cosine of the soil:water contact angle (11). The combined effect of a surfactant will lower the surface tension and the soil:water contact angle having a beneficial effect on soil moisture tension depending on soil type and soil:water contact angle (11).
Surfactants have been shown to increase water infiltration into the soil, seedling germination and establish-ment, and to decrease soil erosion on "hard to wet" soils (9, 10). Surfactant soil treatments have also been reported to increase crop yield in compacted soils (12). Soil treatments should, ideally, provide a beneficial effect but not accumulate in the soil. Biodegradable surfactants are readily consumed by bacteria in the soil and would not be expected to bioaccumulate. The product used in this paper has been shown to be such a surfactant (13).

MATERIALS AND METHODS
This study was conducted from 1997 to 2000 at the Irrigation Research Foundation (IRF), 40161 Highway 59, Yuma County, Colorado, USA, 80759. Soil at the IRF is a Haxtun sandy loam soil with two layers of sandy clay loam 6-10 inches and 10-18 inches beneath the sandy loam layer. Data on the soil series at the IRF is shown in Table 1.

Two irrigated fields at the IRF were used in this study. The first field used in 1997 had a compacted layer 8-15 in. beneath the soil surface. The second field, used in 1998-2000, had a compacted layer 10-15 in. beneath the soil surface. Corn was planted in the spring and soil treatments applied shortly after planting by broadcasting spraying diluted product on the soil surface. Test plots were 20 x 100 feet in 1997 and 20 x 150 feet in 1998-2000. Each plot was planted in eight rows, on 30 in. centers, of corn with target populations of 28,000 plants per acre. Herbicides were applied both pre- and post-emergence. The plots were a part of a 160 acre field with center pivot overhead irrigation. Irrigation water was applied to supplement natural rain as needed as determined by moisture sensors in the field. Fertilizer was applied as recommended by soil analysis. All treatments received the same fertilizer and irrigation levels. Agronomic practices used in each plot over the four years of this study are shown in Table 2.

RESULTS AND DISCUSSION
Four years of corn yield data is shown in Table 3. The use of APSA-80™, at all rates tested, resulted in significantly increased yield when compared to the untreated control plot. The average yields were 169.2, 192.1, 190.2 and 197.6 bushels/acre (bu/a) for the untreated control and 15, 30 and 45 oz/acre APSA-80™ treatments respectively. All rates of APSA-80™ increased yield over the untreated control at a 90% confidence level. The 15 and 45 oz/acre rates of APSA-80™ increased yield compared to the control at a 95% confidence level. The 45 oz/acre APSA-80™ rate was only run in 1998 and 1999.

CONCLUSIONS
The data shows that the use of a non-ionic surfactant, APSA-80™, applied to the soil significantly increased the depth and volume of corn root growth. Increased corn root growth should supply the corn plant with more water and nutrients from the soil, which should improve crop yield. The data also shows that the use of APSA-80™ increased corn yield significantly. Inter-row ripping did not affect corn yield when used on soil already treated with APSA-80™.

The use of APSA-80™ is a cost-effective method of dealing with effects of soil compaction. At suggested retail, the APSA-80™ treatments cost from $2.70 - $8.10 US per acre. Yield increases in this paper show a net return from use of APSA-80™ of $45.80, $42.00 and $56.80 for the 15 oz/a, 30 oz/a and 45 oz/a rates of APSA-80™ respectively based on the currently depressed corn prices of $2.00/bushel. Net pay back less product cost was 6.8 and 6.0:1 for the three APSA-80™ rates respectively.
Two irrigated fields at the IRF were used in this study. The first field used in 1997 had a compacted layer 8-15 in. beneath the soil surface. The second field, used in 1998-2000, had a compacted layer 6-10 inches and 10-18 inches beneath the sandy loam layer. Data on the soil series at the IRF is shown in Table 1.

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<table>
<thead>
<tr>
<th>Depth (in)</th>
<th>Texturea</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-6</td>
<td>sandy loam</td>
<td>6.8</td>
</tr>
<tr>
<td>6-10</td>
<td>sandy clay loam</td>
<td>7.3</td>
</tr>
<tr>
<td>10-18</td>
<td>sandy clay loam</td>
<td>7.3</td>
</tr>
<tr>
<td>18-24</td>
<td>sandy clay loam</td>
<td>7.2</td>
</tr>
<tr>
<td>24-40</td>
<td>clay loam</td>
<td>7.0</td>
</tr>
<tr>
<td>40-60</td>
<td>clay loam</td>
<td>6.4</td>
</tr>
</tbody>
</table>

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The use of APSA-80™ has been shown to increase the depth of the roots to drive deeper into the soil when compared to the untreated control. Inter-row ripping used on one half of each APSA-80™ test plot in 1998. The effect of inter-row ripping on crop yield was measured in 1998 and each subsequent year, although the plots were not ripped in 1999 or 2000. The data is shown in Table 5. Inter-row ripping did not increase crop yields on plots treated with APSA-80™.

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It is assumed that the deeper root growth observed in the APSA-80™ plots would result in greater extraction of nutrients by the corn plant from a deeper soil depth. If this is the case then there should be a decrease in the requirement for supplemental nitrogen application as less nitrogen is being lost to the corn plant through percolation in the soil. In order to more fully ascertain the accuracy of this assumption soil samples for nitrogen analysis will be taken from the 24-33 in and 33-48 in depths during the 2001 growing season.

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Once compacted, cultivated soil will remain compacted for many years (3, 6).

Farmers have used various methods of alleviating soil compaction below the plow layer. These include reducing field traffic, limiting traffic to certain rows (controlled traffic), staying out of the field when it is wet and the use of subsoiling techniques such as inter-row ripping and subsoiling (deep ripping up to 30-36 in.) (1, 4). Sub-soiling can improve crop yield by breaking up the compacted layers but it must be done under the proper conditions and does result in loss of soil moisture (1, 4). Too much soil moisture during the subsoiling procedure can increase soil compaction (1, 4).

Surfactants both lower the surface tension of water and decrease the contact angle of water to the soil particles (8,9). Soil moisture tension, which is proportional to the amount of work required for a root to extract moisture from the soil, is proportional to the product of the surface tension and the cosine of the soil:water contact angle (11). The combined effect of a surfactant will lower the surface tension and the soil:water contact angle having a beneficial effect on soil moisture tension depending on soil type and soil:water contact angle (11).