Nitrogen Gradients and Nitrification Associated with Decomposing Corn Plants and Barley Straw in Soil

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ABSTRACT

Ammonia, nitrite, and nitrate concentrations and pH were measured in 5-mm increments of soil over a 50-mm distance from decomposing layers of corn plants (Zea mays L.) and barley straw (Hordeum vulgare L.) that contained from 1.00 to 2.10% N. During 16 days of incubation, corn plants containing 2.05% N produced an ammonia concentration of 1.3 meq/100 g of soil in the layer near the plant material and inhibited nitrification. At 1.78% N the maximum ammonia concentration was approximately 0.55 meq/100 g of soil and nitrification proceeded almost without inhibition. At 1.27% N, a nitrogen deficiency existed and nitrate moved from the soil into the plant material. Similar gradients of a lesser magnitude were found in soil near decomposing layers of barley straw. Plant materials with the higher N contents increased adjacent soil pH, whereas those with lower N contents had less influence.

Decomposition of alfalfa layers was studied and reported in a previous paper by Smith and Burns (7). High concentrations of ammonia near the decomposing alfalfa were observed to produce toxicity that limited nitrification. Alfalfa would be expected to decompose and release a large amount of nitrogen because of its high nitrogen content and ease of decomposability. Nonleguminous plant materials, on the other hand, would be expected to decompose less readily than alfalfa and in the process release less or perhaps no nitrogen to the surrounding soil. The objectives of this study were to determine the distribution of forms of N in soil associated with decomposing nonleguminous plant material layers of lower N content than was contained in the alfalfa used previously. The plant materials used contained from 1.00 to 2.10% N and the lower N plant materials were expected to deplete the soil N near them. In this paper ammonia is used as a general term to indicate NH₃ gas and both NH₄⁺ and NH₃⁺ in solution. Specific forms are designated as NH₄⁺ for nonionized ammonia and NH₃⁺ for ammonium ions.

MATERIALS AND METHODS

Red Bay sandy loam soil was diluted with glass beads and incubated with layers of barley straw (Hordeum vulgare L.) or corn plants (Zea mays L.) in plastic boxes. The soil, plastic boxes, and method of handling are described in a previous paper (7). The plant materials used in these experiments were barley straw and immature corn plants that were dried, ground, and screened for particle sizes. The plant materials are described in Table 1. Two grams of the plant materials were wetted with 2 ml of water and packed into the bottom of the plastic box. Soil containing approximately 10% water (approximately 0.2 bars tension) was then packed on top of the plant material layer until the box was full. The open end of the box was covered with aluminum foil and the box was incubated for 16 days at 27°C in a high-humidity chamber.

All treatments were set up one at a time to allow immediate chemical analyses of the soil after incubation. The soil was extruded from the box by a screw-driven plunger and sliced into layers approximately 0.5-cm thick parallel to the layer of plant material. The second layer was used for the determination of the final moisture content of the soil. All the other layers were mixed and divided into two parts. Ammonia was extracted from the first part of the soil layer with 20 ml of acidic H₂SO₄ (6) and
Table 1—Chemical composition of corn plants and barley straw by particle sizes

<table>
<thead>
<tr>
<th>Particle size, mesh</th>
<th>N %</th>
<th>K meq/100 g</th>
<th>Ca meq/100 g</th>
<th>Mg meq/100 g</th>
<th>P meq/100 g</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Corn Plants</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>35 - 60</td>
<td>1.27</td>
<td>90.7</td>
<td>35.1</td>
<td>13.5</td>
<td>30.8</td>
</tr>
<tr>
<td>100 - 150</td>
<td>1.78</td>
<td>127.1</td>
<td>36.6</td>
<td>13.7</td>
<td>30.9</td>
</tr>
<tr>
<td>thru - 150</td>
<td>2.06</td>
<td>146.4</td>
<td>36.4</td>
<td>12.0</td>
<td>32.1</td>
</tr>
<tr>
<td><strong>Barley Straw</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20 - 32</td>
<td>1.00</td>
<td>71.4</td>
<td>40.8</td>
<td>7.2</td>
<td>6.0</td>
</tr>
<tr>
<td>32 - 60</td>
<td>1.27</td>
<td>90.7</td>
<td>30.5</td>
<td>9.8</td>
<td>7.2</td>
</tr>
<tr>
<td>thru - 115</td>
<td>2.10</td>
<td>150.0</td>
<td>25.8</td>
<td>14.5</td>
<td>9.0</td>
</tr>
</tbody>
</table>

Analyses for ammonia, NO$_3^-$, NO$_2^-$, and pH were made on the remaining part of the soil layer. Analyses were made on moist samples and converted to dry soil equivalent values.

**RESULTS**

Concentration gradients of ammonia and NO$_3^-$ resulting from the decomposition of layers of corn plants with N contents of 1.27 to 2.05% are illustrated in Fig. 1. At 2.05% N in the corn plants, almost 1.3 meq of ammonia/100 g of soil was found in the first 0.5-cm layer of soil. For this presentation, the “first” layer of soil is adjacent to the plant material layer. The ammonia content decreased to about 0.06 meq/100 g of soil at 3.6 cm distance. The associated NO$_3^-$ content was about 0.1 meq/100 g of soil near the plant material layer and it increased to 0.2 meq/100 g at approximately 1.3 cm distance. Although not shown in Fig. 1, there was a NO$_2^-$ content of 0.05 meq/100 g of soil in the first 0.5-cm layer. No NO$_3^-$ was found in the other layers of soil.

Where corn plants contained 1.78% N there was an ammonia concentration of 0.55 meq/100 g of soil in the first 0.5-cm layer. This decreased to about 0.05 meq/100 g of soil at 3-cm from the plant material layer. In this case, there was an accumulation of NO$_3^-$ of about 0.45 meq/100 g of soil in the first layer that decreased to the level found in the control at about 4 cm distance. Where corn plants contained 1.27% N no ammonia was released in the decomposition and the ammonia content remained at the same level found in the control soil. In this case there was insufficient N for release of N into the soil during decomposition of the corn plant layer and NO$_3^-$ diffused from the soil into the corn plant layer.

Concentration gradients for ammonia and NO$_3^-$ resulting from the decomposition of layers of barley straw with N contents of 1.00 to 2.10% are illustrated in Fig. 2. Where barley straw contained 2.10% N, 0.62 meq of ammonia/100 g of soil was found in the first 0.5-cm layer of soil. This decreased at 3.5 cm to about 0.03 meq/100 g of soil. The associated nitrate content approached 0.4 meq/100 g in the first 0.5-cm layer of soil. This decreased to the N content of the control, about 0.2 meq/100 g soil, at about 4 cm from the barley straw layer. A NO$_3^-$ concentration of 0.04 meq/100 g of soil was found in the first 0.5-cm layer of soil. No NO$_3^-$ was found in the other soil layers. This is not shown in Fig. 2. At 1.00, 1.27, and 1.76% N in the barley straw, N deficiency prevented the release of ammonia and a low concentration was found throughout the 5-cm sampling distance equal to the ammonia concentration of the control soil. In each case there was a NO$_3^-$ content of about 0.05 to 0.07 meq/100 g of soil in the first 0.5-cm layer of soil indicating diffusion of nitrogen into the plant material layer. In the third and subsequent layers of soil the NO$_3^-$ content was between about 0.1 and 0.2 meq/100 g of soil which was about the level found in the control samples.

The seven control samples shown in Fig. 1 and 2 were all incubated under the same conditions. Five samples had NO$_3^-$ contents of approximately 0.2 meq/100 g of soil. The other two samples, for some unknown reason, contained lower NO$_3^-$ contents. The five higher values were, therefore, accepted as normal for this system and the discussion was based on them.

The pH values for each of the soil layers and the control

![Fig. 1](image1.png)  
Fig. 1—Ammonia and nitrate gradients away from a layer of decomposing corn plants as influenced by nitrogen content. (The unconnected points beyond the ends of the curves are for control samples.)

![Fig. 2](image2.png)  
Fig. 2—Ammonia and nitrate gradients away from a layer of decomposing barley straw as influenced by nitrogen content. (The unconnected points beyond the ends of the curves are for control samples.)
tion. The oxidation of NO₂⁻ to NO₃⁻ is specifically limited by
position
controlled and associated with cation exchange capacity in soil
by NIL and that the NH₃ -
strong evidence that ammonia toxicity is specifically caused
NH₃ that apparently limited both oxidation steps in nitrifica-
ceeds rapidly without buildup of ammonia or NO₂-, was
concentration of ammonia. Nitrification, which generally pro-
out inhibition and the amrnonifying organisms released a high
contained 2.05% N, decomposition appeared to proceed with-
particle size but the total
constituents vary somewhat between samples of different
Other factors than N may influence the decomposition of these
materials and contributed to the increased pH in the first
two or three layers of soil.

**DISCUSSION**

The concentration gradients of ammonia and NO₃⁻ shown in
Fig. 1 and 2 are related to the N contents of the different
particle size fractions of the corn plants and the barley straw. Other factors than N may influence the decomposition of these
plant materials but N seems to be the major factor. Other
constituents vary somewhat between samples of different
particle size but the total of the cations is surprisingly uniform
with corn plants or barley straw. When the corn plant materials
contained 2.05% N, decomposition appeared to proceed without
inhibition and the ammonifying organisms released a high
concentration of ammonia. Nitrification, which generally proceeds rapidly without buildup of ammonia or NO₃⁻, was
limited near the plant material layer by the concentration of
NH₃ that apparently limited both oxidation steps in nitrification.
The oxidation of NO₃⁻ to NO₂⁻ is specifically limited by
NH₄, which inhibits *Nitrobacter*. The oxidation of ammonia
may be limited by NH₄ if the concentration is high. There is
strong evidence that ammonia toxicity is specifically caused
by NH₄ and that the NH₄ — NH₄⁺ equilibrium is pH controlled and associated with cation exchange capacity in soil (6, 7).

When the corn plant material contained 1.78% N, decom-
position and nitrification proceeded with the formation of ammonia and NO₃⁻ gradients, which indicate that the plant
material contained adequate N for decomposition and had
some excess. At the 1.37% N content, a N deficiency existed
and nitrification was limited by lack of substrate. The plant
material had a low N content and NO₃⁻ diffused from the soil
into the plant material layer.

This same general situation was found in the decomposition
and nitrification of barley straw. The main difference between
the two materials was that the barley straw appeared to decompose more slowly, as reflected in lower ammonia concentra-
tions with similar N contents, than the corn plants. The N deficiency that was found at lower N contents in the
corn plant decomposition was also found with barley straw.
The N deficiency with barley straw was found at a higher N
concentration than with the corn plants. These differences in ion gradients and apparent decomposibility appear to result
from differences in plant species and maturity.

The low N plant materials did not mineralize N in the 16-
day incubation period and, therefore, no N accumulation was
seen in the adjacent soil. The ion gradients that were observed in the decomposition of the high N plant materials would probably not be observed at any time with low N plant
materials. Nitrogen deficiency in the low N plant materials
would require N supplementation from the soil until the C/N
ratio narrowed to about 25. Microbial utilization of any re-
leased N after that time would prevent ion gradient buildup
during even the latter stages of decomposition.

These observations point out the extreme heterogeneity of
the soil system in relation to decomposing plant residues. The
concentrations of decomposition products produced because of this heterogeneity, although they may exist only in limited
areas, can be expected to influence soil microorganisms, trace
element availability, pathogenic responses, and plant growth.

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