Reprinted from SOIL SCIENCE SOCIETY OF AMERICA PROCEEDINGS
Vol. 31, No. 3, May–June 1967, pages 377–379
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Nitrogen Gradients and Nitrification Associated with Decomposing Corn Plants and Barley Straw in Soil[1]

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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.

THE DECOMPOSITION of crop residues in soil releases ions that can affect surrounding soil and plants. In cases where the crop residues are high in N, their decomposition may release large concentrations of ammonia. Smith and Burns observed high ammonia and K^+ concentrations near decomposing layers of alfalfa (*Medicago sativa* L.) in soil (7). High concentrations of ammonia can suppress nitrification (1, 2, 3, 6, 8). On the other hand, when crop residues are low in N, their decomposition may be retarded. Harmsen and Van Schreven (4) reported in a review paper that numerous investigators agree that plant materials must contain at least 1.5 to 2.0% N in the dry matter, which corresponds to a C/N ratio of 20 to 25, before N can be mineralized. Rubins and Bear (5) investigated the decomposition of organic ammoniates and waste organic materials and reported that factors other than C/N ratio influenced decomposition. High lignin content and some unknown factors decreased plant material decomposibility.

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 decomposibility. 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 NH_3 gas and both NH_3 and NH_4^+ in solution. Specific forms are designated as NH_3 for nonionized ammonia and NH_4^+ 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 27C 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 K_2SO_4 (6) and

[1] Contribution from the Snake River Conserv. Res. Center, Northwest Branch, SWCRD, ARS, USDA, Kimberly, Idaho; Idaho Agr. Exp. Sta. cooperating. Received Oct. 24, 1966. Approved Jan. 6, 1967.
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Table 1—Chemical composition of corn plants and barley straw by particle sizes

Particle size, mesh	N %	N	K	Ca	Mg	P
		meq/100 g				
Corn Plants						
35 – 60	1.27	90.7	35.1	13.5	30.8	7.8
100 – 150	1.78	127.1	35.6	13.7	30.9	8.7
thru – 150	2.05	146.4	34.4	12.5	32.1	9.4
Barley Straw						
20 – 32	1.00	71.4	40.8	4.1	3.6	2.2
32 – 60	1.27	90.7	30.5	7.2	6.0	2.8
60 – 115	1.78	127.1	30.5	9.8	7.2	3.0
thru – 115	2.10	150.0	25.8	14.5	9.6	3.5

analyses for ammonia, NO_2^-, NO_3^-, 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/100g of soil at 3.6 cm distance. The associated NO_3^- content was about 0.1 meq/100g of soil near the plant material layer and it increased to 0.2 meq/100g at approximately 1.3 cm distance. Although not shown in Fig. 1, there was a NO_2^- concentration of 0.05 meq/100 g of soil in the first 0.5-cm layer. No NO_2^- 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_2^- concentration of 0.04 meq/100 g of soil was found in the first 0.5-cm layer of soil. No NO_2^- 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

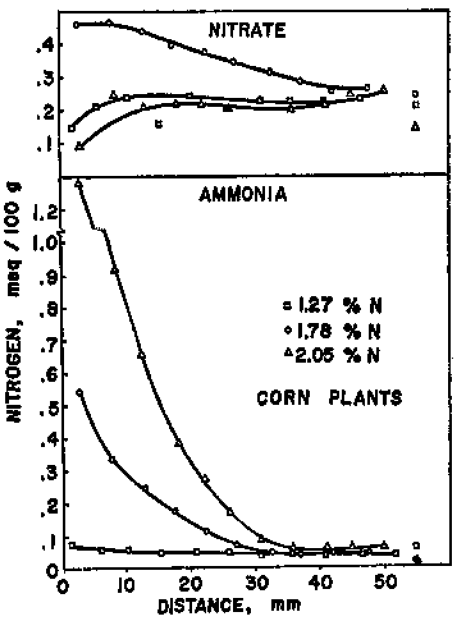

Fig. 1—Ammonia and nitrate gradients away from a layer of decomposing corn plants as influenced by nitrogen content. (The unconnected points beyond the ends of the curves are for control samples.)

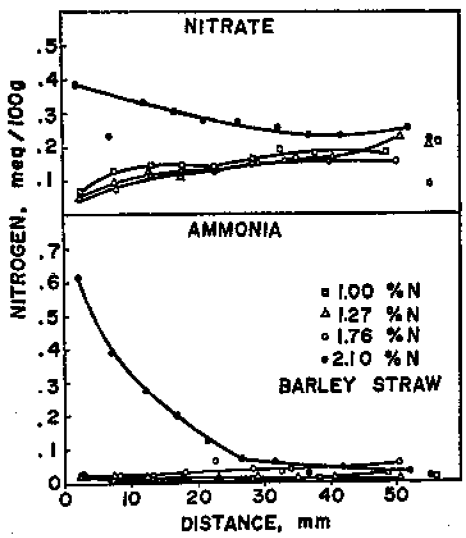

Fig. 2—Ammonia and nitrate gradients away from a layer of decomposing barley straw as influenced by nitrogen content. (The unconnected points beyond the ends of the curves are for control samples.)

Table 2—Soil pH as influenced by layers of decomposing plant material

Distance from layers, mm	Corn plants			Barley straw			
	N in Plant Material, %						
	2.05	1.78	1.27	2.10	1.76	1.27	1.00
	pH						
0	8.3	8.1	7.6	8.1	7.8	8.0	7.8
5	8.2	7.6	7.4	8.0	7.4	7.3	6.9
10	7.9	6.5	7.2	6.8	6.8	6.6	6.3
15	7.0	6.0	6.6	6.1	6.2	6.2	6.0
20	6.0	6.0	6.2	5.8	6.0	6.0	5.9
25	6.0	5.8	6.2	5.7	5.9	5.8	5.8
30	5.9	5.9	6.2	5.6	5.7	5.8	5.8
35	6.0	5.9	6.0	5.6	5.8	5.7	5.7
40	6.1	6.0	6.0	5.7	5.8	5.7	5.7
45	6.2	6.0	6.0	5.7	—	—	—
50	6.2	6.0	6.0	—	5.7	5.7	5.7
55	5.9	—	6.0	5.7			
60	→	5.9	→				
65	5.9		6.1				
Control	6.1	6.2	6.4	6.0	6.0	6.0	5.9

samples are given in Table 2. The pH values are highest in the decomposing plant material layers and decrease with distance from the layers with the decrease in ammonia concentration. Some cations probably moved a short distance from the plant materials and contributed to the increased pH in the first two or three layers of soil.

DISCUSSION

The concentration gradients of ammonia and NO_3^- 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 barleystraw. 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 NO_2^-, was limited near the plant material layer by the concentration of NH_3 that apparently limited both oxidation steps in nitrification. The oxidation of NO_2^- to NO_3^- is specifically limited by NH_3, which inhibits *Nitrobacter*. The oxidation of ammonia may be limited by NH_3 if the ocncenrtation is high. There is strong evidence that ammonia toxicity is specifically caused by NH_3 and that the $NH_3 - NH_4^+$ equilibrium is pH controlled and associated with cation exchange capacity in soil (6, 7).

When the corn plant material contained 1.78% N, decomposition and nitrification proceeded with the formation of ammonia and NO_3^- gradients, which indicate that the plant material contained adequate N for decomposition and had some excess. At the 1.27% N content, a N deficiency existed and nitrification was limited by lack of substrate. The plant material had a low N content and NO_3^- 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 concentrations 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 released N after that time would prevent ion gradient buildup during even the latter stages of decomposition.

These observations point out the extreme heterogeniety of the soil system in relation to decomposing plant residues. The concentrations of decomposition products produced because of this heterogeniety, 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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