Soils

Soil Nitrogen Mineralization in the Presence of Surface and Incorporated Crop Residues

S. J. Smith* and A. N. Sharpley

ABSTRACT

The increasing adoption of farming practices which maintain crop residues on the soil surface has created a need for more detailed information regarding associated soil N availability. This study examines the effects of crop residue placement and type on soil N availability for a range of soils. Representative field rates of alfalfa (Medicago sativa L.), corn (Zea mays L.), oat (Avena sativa L.), peanut (Arachis hypogaea L.), sorghum, (Sorghum sudanense (Piper) Stapf), soybean (Glycine max L.), and wheat (Triticum aestivum L.) crop residues were applied to eight Oklahoma surface soils. The experiment was conducted under aerobic laboratory conditions at 35 °C, and involved 2-mm soil particles and 0.25-mm crop residue materials. The N availability was measured on the basis of indigenous and fertilizer-derived soil N mineralized during short- (14 d) and long- (84 d) term incubation. Short-term, an initial depression (more than 80% with corn) in net mineralization occurred with non-legume residue additions. The depression was enhanced when the residues were incorporated rather than left on the soil surface. The relative depression was greater with the newly formed, fertilizer-derived soil N than the older, indigenous soil N. On the other hand, N mineralization was enhanced more than 50% with the alfalfa addition. Effects of crop residue type on N mineralization showed ranges up to threefold or more and generally proceeded in the order alfalfa > peanut > soybean > oat > sorghum > wheat > corn. Long-term, N mineralization for all systems was more comparable to that without residue additions.

Conservation of reduced-tillage continues to increase in usage as an alternative for practically all forms of crop production (Follett et al., 1987). Management systems which maintain crop residues at or near the soil surface have several attractive features, including reduced soil erosion, less on-farm energy use, and more available soil water (Unger and McCalla, 1980). The adoption of conservation tillage systems, however, has created a need for more detailed information regarding the behavior of indigenous and fertilizer-derived soil N in the presence of surface rather than incorporated crop residues. Such information has important implications from both an agronomic and environmental standpoint.

For the most part, studies to date comparing soil N availability under reduced-tillage management systems have involved either a single crop residue or soil (e.g., Douglas et al., 1980; Power et al., 1985). The relative soil N availability depends on both soil and crop residue factors. In general, however, less drastic effects on soil N availability may be expected when high C/N ratio crop residues (e.g., corn and small grain) are left on the soil surface, rather than incorporated. This is because a slower decomposition of the crop residue occurs with surface application. Parker (1962), for instance, reported that half the corn stalk residue placed on the soil surface had decomposed in 8 wk, compared to 5 wk for incorporated residue. On the other hand, a low C/N ratio crop residue (e.g., peanut) may pose a different case. The purpose of the present study was to examine the effects of crop residue placement and type on soil N availability for a range of soils. The N availability was measured on the basis of indigenous and fertilizer-derived N mineralized during aerobic, laboratory incubation.

MATERIALS AND METHODS

The eight surface soils (0–150-mm depth) used in the investigation comprised a broad range of chemical, physical, and biological properties (Table 1). They were available from a prior field lysimetry study (Smith et al., 1982) involving the disposition of 15N-tagged fertilizer associated with forage sorghum production. All the soil in each lysimeter was collected in the fall after harvest, spread into thin layers to air dry, and stubble and roots were removed by hand. Thereupon, each soil was crushed gently to pass a 2-mm sieve, mixed thoroughly, and stored in tightly sealed glass containers to await chemical and biological analysis. Subsequent procedures were conducted in duplicate.

Seven crop residues were collected locally, air dried, and ground to pass a 0.25-mm sieve (Table 2). Complete above-
Table 1. Characteristics of surface soils (0- to 150-mm depth) used in crop residue placement study.

<table>
<thead>
<tr>
<th>Soil type</th>
<th>Classification</th>
<th>pH</th>
<th>Organic C</th>
<th>Indigenous</th>
<th>Fertilizer incorporated†</th>
<th>Total Kjeldahl nitrogen</th>
<th>Initial mineral N‡</th>
<th>Mineralized N (84 d)§</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bowie loam</td>
<td>Fragic Paleudults</td>
<td>5.7</td>
<td>7 600</td>
<td>529</td>
<td>5.6</td>
<td>5.1</td>
<td>0.05</td>
<td>59.5</td>
</tr>
<tr>
<td>Claremore clay</td>
<td>Lithic Argiudolls</td>
<td>6.6</td>
<td>17 000</td>
<td>1364</td>
<td>12.5</td>
<td>10.6</td>
<td>2.03</td>
<td>119</td>
</tr>
<tr>
<td>Muskegoe loam</td>
<td>Aquic Paleudalfs</td>
<td>7.2</td>
<td>13 000</td>
<td>830</td>
<td>10.5</td>
<td>9.4</td>
<td>1.11</td>
<td>78.4</td>
</tr>
<tr>
<td>Ruston sandy loam</td>
<td>Typic Paleudalfs</td>
<td>6.2</td>
<td>8 000</td>
<td>618</td>
<td>4.4</td>
<td>9.6</td>
<td>0.26</td>
<td>76.7</td>
</tr>
<tr>
<td>Ruston sandy clay</td>
<td>Typic Paleudalfs</td>
<td>6.2</td>
<td>9 400</td>
<td>653</td>
<td>8.4</td>
<td>5.0</td>
<td>0.07</td>
<td>75.0</td>
</tr>
<tr>
<td>San Saba clay</td>
<td>Udic Pellusterts</td>
<td>7.7</td>
<td>25 000</td>
<td>1902</td>
<td>13.6</td>
<td>12.8</td>
<td>2.35</td>
<td>55.7</td>
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<tr>
<td>Teller loam</td>
<td>Udic Argiustolls</td>
<td>7.4</td>
<td>6 800</td>
<td>666</td>
<td>5.5</td>
<td>5.6</td>
<td>0.02</td>
<td>55.7</td>
</tr>
<tr>
<td>Yahola silty clay</td>
<td>Typic Ustifluvents</td>
<td>7.8</td>
<td>18 000</td>
<td>1720</td>
<td>22.1</td>
<td>63.9</td>
<td>32.00</td>
<td>159</td>
</tr>
</tbody>
</table>

† Residual ¹⁵N-enriched fertilizer incorporation.
‡ Includes any residual ¹⁵N-enriched fertilizer N present in the original K¹⁵NO₃ form.
§ Mineralized N was predominantly in the NO₃⁻ form.

ground portions of the crop residues were used. The alfalfa residue was hay cut at the quarter-bloom stage, and the forage sorghum residue was hay cut at the soft dough stage. The other crop residues were collected shortly after combine harvest of the grain. In the case of the oat crop, some lodging had occurred, and, consequently, the residue contained more than a normal amount of grain.

Total soil organic and plant N was determined by a semimicro-Kjeldahl procedure (Bremner and Mulvaney, 1982), soil organic C by wet oxidation (Mebius, 1960), and pH by the glass electrode (soil weight/water volume, 1:2).

The aerobic N mineralization procedure was conducted at -80 kPa water potential and 35 °C using a successive incubation procedure (Stanford and Smith, 1972). The study here utilized 20 g of soil and 2 g of exfoliated vermiculite mixtures in 50-mL glass filter tubes. Each leaching involved 50 mL of 0.01 M CaCl₂ followed by 25 mL of N nutrient solution. The vermiculite, added to facilitate recovery of mineralized N, was ground to pass a 0.85-mm sieve. This makes for a uniform, dry mix with soil that does not tend to segregate upon transfer to the filter tube. Prior testing of the vermiculite used indicated it would pose no NH₃ fixation problems. The crop residues were placed on the surface of the soil in the filter tube or incorporated throughout the soil in the tube. Residue rates added to the soils were selected to reflect typical field crop situations (Table 2). Therefore, the rates varied depending upon the particular crop residue applied. Mineralized N in the soil-crop residue systems was extracted periodically by leaching with 0.01 M CaCl₂, 14, 28, 56, and 84 d. Mineralized N (NO₃⁻, NO₂⁻, and NH₄⁺) in the extracts was determined by microdiffusion (Stanford et al., 1973).

Isotope ratio analysis was carried out by the method of Smith et al. (1963), using a Perkin Elmer RMS4 single-beam (Perkin Elmer Corp., Norwalk, CT) or Nuclide RMS 3-60 isotope ratio mass spectrometer (Isotope Services, Inc., Los Alamos, NM). Precision of the determinations was ± 0.003 atom% ¹⁵N, or better.

Total soluble organic N in the mineralization extract was determined using a semiautomated Kjeldahl procedure developed for determining biologically-derived N in waters and wastes (U.S. Environmental Protection Agency, 1979). Soil organic N was fractionated by hydrolyzing samples with HCl according to procedures described by Porter et al. (1964).

Statistical analysis was conducted with the SAS program (Barr et al., 1979) which contains both multiple analysis of variance and Duncan's multiple range routines. Therefore, the program allows determination of among and within treatment class statistical differences. In other cases, the t-test for paired data has been employed. The particular test used is indicated at the pertinent place in the text. Comparisons among the assorted crop residues should be interpreted with the stricture that the crop residues involved varied rates and N contents (Table 2).

### RESULTS AND DISCUSSION

#### Crop Residue Additions and N Mineralization

At first, all the N mineralization data were processed through the SAS multiple analysis of variance program to determine treatment class effects. The treatment classes were soil N type (two levels), crop residue placement (two levels), crop residue type (seven levels), soil type (eight levels), and mineralization time (four levels), with two replications. All treatments and interactions were significant at the = 0.01 level except the soil N type X placement X soil type X time interaction, which was significant at the P = 0.05 level. Obviously, then, soil N mineralization was strongly influenced by the type of soil N, crop residue, placement, soil, and mineralization time.

To obtain a synoptic view of indigenous and fertilizer-derived soil N mineralization in the presence of the individual crop residues, a pictograph was constructed and, to aid interpretation, the data were expressed as a percent of the control (i.e., no crop residue added). Therefore, values in the pictograph > 100 indicate the crop residue enhanced soil N mineralization, whereas values < 100 indicate immobilization.
Results, averaged for each eight soil-specific crop residue treatment, are presented for the short- (14-d) and long- (84-d) term incubation in Fig. 1. Values inside the bar graphs indicate that, for a specific crop residue, placement generally had little influence on variability of mineralization in the respective incubation systems.

For the short-term incubation and a specific crop residue, differences were not always statistically significant \( (P = 0.05) \) with regard to placement and control. Even so, every nonlegume residue-incorporated result was lower than its surface counterpart. Also, the fertilizer-derived soil N mineralization result tended to be lower than its indigenous soil N counterpart. The largest decrease, relative to the control, was with corn residue (>80%), whereas the largest increase was with alfalfa (>50%).

For the long-term incubation, no major decreases were evident in indigenous soil N mineralization, except for the corn residue. However, decreases due to some nonlegume additions, both incorporated and surface applied, were still evident with fertilizer-derived soil N mineralization.

Overall, the results in Fig. 1 indicate that crop residues and their placement had a larger and longer effect on depressing net mineralization of fertilizer-derived N than on indigenous soil N. The depression is enhanced with incorporated residues and is attributed to a larger portion of more labile fertilizer-derived soil N (Smith and Power, 1985) being appropriated by soil microbes during residue decomposition. Consequently, fertilizer-derived soil N was not as mineralizable, relative to indigenous soil N, upon residue addition. Such results are considered to support evidence of a priming effect (Hauck and Bremner, 1976) on mineralization of indigenous soil N by comparatively small amounts of fertilizer-derived soil N. This assumes, however, no major mineral N contributions from the residues per se, an assumption based on the preliminary experimental observation that when eight comparable soil types not enriched in \(^{15}\)N were incubated with \(^{15}\)N-enriched sorghum residue, relatively little \(^{15}\)N was found in the mineralization extracts (S.J. Smith and A.N. Sharpkey, 1988, data not shown).

Eventually, crop residue additions can be expected to increase net soil N mineralization (Black, 1968). In the case of the legume residues, with their generally low C/N ratios (Table 2), some increases occurred even during the initial 14-d incubations (Fig. 1). Moreover, residue placement was not an important factor with the legumes. Further SAS examination of the time effect on mineralization showed that, on the average, immobilization due to crop residue addition was evident only during the first 14 d. Thereafter, immobilization decreased and by 56 d net mineralization was evident. For the 0- to 14-, 14- to 28-, 28- to 56-, and 56- to 84-d incubation periods and indigenous soil N, the respective values relative to the control, were 0.70a, 1.01b, 1.32c, and 1.38d, with statistically similar values \( (P = 0.05) \) followed by the same letter. Corresponding values for fertilizer-derived soil N were 0.62a, 0.95b, 1.36c, 1.29c. Consequently, for both soil N forms, the immobilization/mineralization patterns followed general expectations.

To avoid appreciable suppression of soil N miner-
alization and concurrently supply the needs of soil microbes during most crop residues' decomposition. Minimum N residue contents of 1.5 to 1.7% (C/N ratios of 30:25) have been suggested (Allison, 1973). Even higher N residue contents tend to enhance net soil N mineralization. Additional SAS examination of crop residue type effects on soil N mineralization showed ranges up to threefold or more and that, on the average, mineralization proceeded in the order alfalfa > peanut > soybean > oat > sorghum > wheat > corn. This was true for both indigenous and fertilizer-derived soil N, and for either the short- (14 d) or long- (84 d) term incubation. Therefore, the results generally followed the expected case (compare sequence order to that for N values and C/N ratios in Table 2), even though different residue rates and N contents were involved. The soybean data, however, may be somewhat of an exception. Despite a fairly high C/N ratio of 54, our soybean residue did not greatly influence soil N mineralization. It bears noting, though, that the soybean residue application rate (Table 2) was the lowest among residues. Consequently, the rate may have been insufficient to have had appreciable effect. Also, along these lines, the individual nature of organic components in different crop residues should not be discounted.

Additional SAS examination indicated the impact of soil type on N mineralization was much less than that of crop residue type. No consistent ranking across soil type was evident, and the range among soils for a given crop residue was often <20 percent, compared to the much higher variations observed among crop residues. One soil type, however, Teller loam, usually exhibited the lowest N mineralization.

### Crop Residue Additions and Leaching of Soluble Organic N

The potential extent and importance of soluble organic N leaching in soils have received considerable attention (Beauchamp et al., 1986; Bremner, 1965; Broadbent and Nakashima, 1971; Legg et al., 1971; Smith et al., 1980). A recent N mineralization study involving the eight soils used here and no crop residue additions (Smith, 1987) indicated leaching of soluble organic N components during recovery of mineralized N comprised, on average, only about 5% or less of the inorganic N produced during incubation. This subject was expanded in the present study to include the possible role of crop residue additions. As is evident from Table 3, soluble organic N recovered in the mineralization extracts was affected little by residue addition and this was the case irrespective of incubation time, and whether the residue was incorporated or placed on the soils' surface. Therefore, with the field rates of residue used here, no particular enhancement of soluble organic N leaching losses was observed due to crop type.

### Crop Residue Additions and Soil Organic N Fractions

The role of crop residue type and placement on soil organic N chemistry was examined by comparing the distributions of organic N forms in the mineralization systems at the end of the incubation. This was done by separating soil organic matter into three broad N fractions. Fraction 1 includes amide N and amino sugar N. Fraction 2 includes amino acid N, and Fraction 3 includes acid-insoluble N.

The N distributions for the eight soils receiving no crop residues were, on average, 22, 46, and 32% for Fraction 1, 2, and 3, respectively, at the end of the 84-d incubations (S.J. Smith and A.N. Sharpley, 1988, data not shown). Such values compare favorably to those observed earlier for a Northern Plains grassland soil at the end of a 168-d incubation (Smith and Power, 1985). More importantly, neither crop residue type nor placement were observed in the present study, to have significant effect \((P = 0.05, t\)-test for paired data) on distribution of the organic N forms. Therefore, no unique impacts of the crop residues on gross soil organic N fractionation were discernible after prolonged mineralization.

### GENERAL DISCUSSION

While no pretense is made that this laboratory study, conducted at near optimum conditions with finely ground crop residues, directly reflects a field situation, several observation seem warranted. An initial depression in net N mineralization of both indigenous and fertilizer-derived soil organic N may occur with nonlegume residue additions, and the depression is enhanced when the residues are incorporated rather than left on the soil surface. Moreover, the relative depression is greater with the newly formed, fertilizer-derived soil N than the older, indigenous soil N. This is because the newer soil N, being more labile (Smith and Power, 1985), is preferentially appropriated by the soil microbes in decomposing the crop residues.

Irrespective of residue placement or soil N age, (i.e., indigenous or fertilizer-derived N) an initial enhancement of soil N mineralization may occur with legume additions.

Over a long period (i.e., 84-d incubation), the net N mineralization of both indigenous and fertilizer-derived soil N in the presence of either surface or incorporated crop residues is more comparable to that without residue addition. In fact, after the 14-d incubation, immobilization tended to decrease and by 56 d some net mineralization was evident. Even so, certain high C/N ratio crop residues (e.g., corn) may...
continue to exhibit an overall decrease after 84 d. Effects of residue type on soil N mineralization showed ranges up to threefold or more, and generally proceeded in the order alfalfa > peanut > soybean > oat > sorghum > wheat > corn. Unlike residue type, no particular trends of soil type on mineralization were evident.

None of the crop residue additions, applied at a representative single-season field rate, resulted in appreciable enhancement of soluble organic N leaching losses during recovery of mineralized N. Neither did the residues have a noticeable impact on the relative distribution of the soil organic N components. This was the case, despite the fact that total soil N mineralized in the study was about 10%, compared to 3% or less annually that would be expected under actual field conditions (Bremner, 1965). Consequently, over the short term, perhaps a 2- to 3-yr field situation, any changes in soil organic N chemistry due to crop residue type and placement are expected to be gradual rather than drastic. The latter, however, may develop with higher rates and successive years of crop residue additions.

REFERENCES


