DENITRIFICATION IN SOIL TREATED WITH BEEF-FEEDLOT MANURE

KEY WORDS: Land disposal, animal waste, nitrogen loss, nitrate reduction.

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ABSTRACT

Effects of yearly applications of beef-feedlot manure on denitrification in an irrigated silty clay loam soil (pH 7.0) were studied in the field. Mass balance calculations could not account for large quantities of N. Plots that had received 85 cumulative t/ha (metric) of dry manure (1.0% N) had 2830 kg/ha of unaccountable N loss after two years. Plots that had received the highest manure treatment (1043 cumulative t/ha) had the least unaccountable N loss (700 kg/ha). Relative to control plots, one meter soil profile distributions showed increased total N and organic C at depths of 50 cm in plots that had received 522 and 687 t/ha/yr of manure, respectively, after two years. Indirect evidence in manured soil of reducing conditions necessary for denitrification.
was found in increased soil solution concentrations of Fe and Mn, and lowered $O_2$ and increased $CH_4$ concentrations in the soil atmosphere. Soil and soil solution samples taken in the summer were found to contain NO$_3$-N.

Profile distributions of relative gas concentrations in the soil atmosphere were successfully obtained using an access tube sampling technique. N$_2$O, an end product of denitrification, was detected at depths of 50 to 100 cm under two plots that had received 306 and 687 t/ha/yr of manure. Increased CO$_2$ also was recorded throughout the surface meter of soil in those two plots.

**INTRODUCTION**

The fate of the N fraction of animal wastes applied to land has both economic and environmental importance. When waste is substituted for chemical fertilizers, emphasis should be on maximum use of the added N by the crop being grown. When waste disposal is the objective, primary concern should be on potential contamination of groundwater by N, because the amount applied frequently exceeds that removed by the crop. Loss to the atmosphere of nitrogenous gases through denitrification reactions in soil lowers the amount of plant-available N and at the same time decreases the potential for groundwater contamination.

Broadbent and Clark (3) have reviewed the conditions necessary or conducive to denitrification in soil: reducing or anaerobic conditions; source of easily oxidizable C; basic pH;
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presence of nitrate-N (NO₃-N); relatively high temperature; and a
denitrifying microbial population. Applications of animal wastes
to soil help to promote several of these conditions. The waste
organic matter fraction provides a C source, stimulates microbial
respiration of this organic matter, and helps create anaerobic
conditions by removing O₂ from the soil atmosphere. Irrigation
can further reduce O₂ by restricting gas exchange with the above-
ground atmosphere. Organic N mineralized into NO₃-N provides the
denitrification substrate, and some wastes have been shown to
increase soil pH (6).

In the fall of 1969 we began yearly applications of beef-
feedlot manure on an irrigated silty clay loam soil. Suspecting
that denitrification could be significantly affecting the N
balance of this neutral to basic soil, we selected four plots to
study in detail in the summers of 1972 and 1973. In these plots
we measured soil-chemical and atmospheric conditions that affect
denitrification or suggest its presence.

METHODS AND MATERIALS

Yearly fall applications of beef-feedlot manure were begun
in 1969 on a silty clay loam soil (pH 7.0). The experimental
design and results of plant and other soil measurements have been
reported elsewhere (8).

Soil cores collected to a depth of 3 meters in the fall of
1969 before manure was applied and in the fall of 1971 after 2
years of treatments were analyzed in 10-cm increments for:
1) total N (not including NO$_3$-N) to 1 meter by microkjeldahl digestion with sulfuric acid and subsequent steam distillation (5); and 2) for NO$_3$-N to 3 meters by steam distillation. One-meter soil cores taken in the fall of 1972 after three manure applications were analyzed in 10-cm increments for organic C using a LECO 70-Second Analyzer (1) to obtain total C and subtracting the carbonate-C obtained by acid neutralization (2).

Four plots selected for detailed study in the summers of 1972 and 1973 had received 0, 58, 306, and 687 t/ha/yr of dry manure by the summer of 1973. Soil-atmosphere-access tubes were installed in mid-July of 1972 and 1973 at seven depths to one meter, each depth being replicated four times in each plot. The tubes were built and installed so that the gas within each tube would come to equilibrium with the gas in the soil depth being sampled (Fig. 1). In early September of 1972 and 1973, 10-ml gas samples were removed by syringe from the tubes and transferred to 15-ml glass bottles that had been evacuated by hand vacuum pump to 38.1 cm of mercury. The samples were analyzed for N$_2$, O$_2$, CO$_2$, CH$_4$, and N$_2$O using a Carle Model 8000 gas chromatograph with Porapak-Q (first) and molecular sieve (second) columns installed in series (25 ml/min flow rate and 55°C oven temperature). It was assumed that no gases other than the five named would be present in significant quantities. Area normalization, with correction factors for the relative sensitivity of the machine for each gas, was used to calculate percentage composition (6).
Soil-atmosphere-access tube design. A hole (2.38 cm diameter) is formed with a hand-operated soil sampler to a depth equal to the bottom of the soil depth being sampled. A ring, 0.5 cm thick, is cut from soft plastic tubing (I.D. = 1.59 cm, O.D. = 2.06 cm) and secured to rigid ABS plastic pipe (I.D. = 1.91 cm, O.D. = 2.22 cm) with slick, black electrical tape (width = 3.81 cm). The pipe is pushed into the hole until the ring is at the top of the soil depth to be sampled, and the rubber septa is inserted into the top of the pipe. Soil is used to seal around the pipe-soil surface junction.

In 1972 one-meter soil cores were taken at four locations in each of the four plots in May, June, July, and September. The
May sampling was approximately 2 weeks after planting; the later samplings were from 7 to 14 days after 10-cm irrigations. The cores were divided into seven depth increments, stored in plastic bags and frozen in the field with dry ice. After the frozen soil samples were crushed to obtain a representative sample, they were analyzed for NO$_3^-$-N by steam distillation (5) and for gravimetric water. In 1973 soil solution samples were obtained by porous cups at six depths (15, 25, 35, 50, 70, and 90 cm) at four locations in each plot. Vacuum was applied to the cups on August 10 (one day after a 10-cm irrigation) and on August 24 (one day after an 8-cm rain). In each case vacuum was maintained until water samples were collected the next day; soil-solution samples were then refrigerated. The solution samples were analyzed within 1 week for NO$_3^-$-N by steam distillation (5) and (after filtering) for Fe and Mn by atomic absorption spectrophotometry.

RESULTS AND DISCUSSION

Total Nitrogen and Organic Carbon

Nitrogen-balance calculations based on total N and NO$_3^-$-N analyses of the fall 1970 and 1971 soil cores are given in Table 1. It can be seen that significant amounts of N were not accounted for by the measurements used. The plots receiving the lowest manure treatment lost more nitrogen from fall 1969 to fall 1971 than was added in the manure during that period, indicating that the manure had caused disappearance of native N. Of the plots receiving manure, the plots receiving the heaviest...
Nitrogen Balance Calculations in Plots That Had Received Applications of Dry Beef-Feedlot Manure (t/ha) for two years.

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>Accumulative Manure Applied</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>85</td>
</tr>
<tr>
<td></td>
<td></td>
<td>metric tons/hectare</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Fall 1969 Total N*- kg/ha</th>
<th>Fall 1971 Total N*- kg/ha</th>
<th>Total N Difference - kg/ha</th>
<th>N Added in Manure - kg/ha</th>
<th>N Removed by Corn - kg/ha</th>
<th>Unaccounted for Loss of N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>9250</td>
<td>8910</td>
<td>-340</td>
<td>0</td>
<td>204</td>
<td>136</td>
</tr>
<tr>
<td>85</td>
<td>13580</td>
<td>11250</td>
<td>-2330</td>
<td>850</td>
<td>353</td>
<td>2830</td>
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<tr>
<td>372</td>
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<td>10780</td>
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<td>358</td>
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<tr>
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<td>20240</td>
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<td>10740</td>
<td>20240</td>
<td>10740</td>
</tr>
</tbody>
</table>

* Kjeldahl N to one meter + NO3-N to three meters

Manure treatments had the least amount of unaccountable N loss. In work we reported earlier (8), soluble salt accumulations in the soil which increased the osmotic potential of the soil solution were thought to be responsible for the decreased growth of corn. Similarly, that negative growth factor could have affected the functioning of denitrifying organisms and lowered net N loss from plots receiving the large tonnages of manure.

Organic carbon increased relative to the control at the 10-cm depth in all three manured plots in 1972 (Fig. 2) and movement of C to the 50-cm depth was evident in the plot that had received 687 t/ha/yr. Some of the increased C would be available for oxidation in denitrification reactions.
Organic soil C (dry-weight basis) in soil cores as affected by depth and yearly beef-feedlot manure applications.

Soil Atmosphere

Analyses for N\textsubscript{2}, O\textsubscript{2}, CO\textsubscript{2}, CH\textsubscript{4}, and N\textsubscript{2}O in the atmosphere samples taken in late summer of 1972 and 1973 were averaged for the four replications at each depth. No trend due to treatment was evident in the 1972 N\textsubscript{2} data, but the 1973 data do show lower percentages of N\textsubscript{2} at all depths beneath the plot that received 687 t/ha/yr of manure (Fig. 3). This lower N\textsubscript{2} percent was probably due to higher levels of CO\textsubscript{2} and CH\textsubscript{4} found in those samples which would have displaced N\textsubscript{2} and lowered its relative concentration (Figs. 3 and 4). Increased N\textsubscript{2} would be expected if denitrification had been occurring, but production of N\textsubscript{2} by denitrifying organisms could have been overshadowed by increased production of CO\textsubscript{2} and CH\textsubscript{4}.
Percentage $N_2$, $O_2$, and $CO_2$ in soil atmosphere as affected by depth and yearly beef-feedlot manure applications.

In 1972 lower percentages of $O_2$ were found at several depths beneath the plots receiving 687 t/ha/yr of manure; in 1973 they were lower beneath plots receiving 306 and 687 t/ha/yr (Fig. 3). Lower $O_2$ percentages could have been because $O_2$ was removed for organic matter oxidation or because of increased concentrations of $CO_2$ and $CH_4$. 
The 1972 samplings revealed higher CO$_2$ percentages in the surface 40 cm under plots receiving 687 t/ha/yr than under the control plots; 1973 samplings revealed higher CO$_2$ percentages at all sampling depths beneath plots receiving 306 and 687 t/ha/yr (Fig. 3). Higher CO$_2$ concentrations reflected greater respiration of soil organisms resulting from added organic matter in the manure.

No CH$_4$ or N$_2$O was found in the 1972 gas samples. Analysis of samples taken in 1973 beneath the plot receiving 687 t/ha/yr of manure showed significant concentrations of CH$_4$ at all depths except the one closest to the soil surface (Fig. 4). No CH$_4$ was found in samples from the other three plots. A reduced form of C, methane, indicated that anaerobic conditions existed beneath
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the plot receiving the heaviest manure treatment. In the 1973 samples nitrous oxide was found in the lower portions of the surface meter under plots receiving the two heaviest manure treatments; it was not found under the control plot or that plot with the least manure (Fig. 4). Because \( \text{N}_2\text{O} \) is an end product of denitrification its presence indicates that denitrification did occur.

The technique for sampling soil atmosphere was shown to be adequate for monitoring the appearance or disappearance of the gases measured. The large, variable volume of the access tube made quantification difficult, but profile distributions of relative concentrations were successfully measured.

Soil and Soil-Solution Analyses For 1972 and 1973, Respectively

Relative to the control plot, soil cores taken in 1972 from the three manured plots had greater \( \text{NO}_3\)-N concentrations throughout the entire surface meter. In 1973, increased \( \text{NO}_3\)-N concentrations were found generally at depths of 50 to 100 cm in soil-solution samples taken from the manured plots (Fig. 5). The magnitude of \( \text{NO}_3\)-N concentrations was much greater in the two plots receiving the heaviest treatment, indicating that large amounts of N were being nitrified into \( \text{NO}_3\)-N and leached downward.

In 1972 soil samples were collected at least one week after irrigations; in 1973 soil-solution samples were taken when the soil was still wet from an irrigation and a rain. Late sampling dates in 1972 (relative to wet soil conditions) would have allowed re-aeration of the soil and nitrification reactions to
NO$_3$-N (dry-weight basis) in soil cores as affected by depth and yearly beef-feedlot manure applications.

resume, thereby explaining why NO$_3$-N concentrations were found uniformly higher throughout the surface meter in 1972 than in 1973. The 1973 soil-solution samples were collected when the soil was still wet and probably oxygen deficient, conditions conducive to denitrification. Entrance of NO$_3$-N into denitrification reactions could explain why concentrations of NO$_3$-N were generally lower in the surface 50 cm than between 50 and 100 cm in 1973.

Iron in the soil-solution samples was higher under the three manured plots than under the control plots. The magnitude of Fe concentrations was greater in plots with heavy than with light manure applications. In the two most heavily manured treatments, manganese concentrations in soil solution were greater than those of Fe (Fig. 6). The 687 t/ha/yr treatment increased Mn throughout
Fe and Mn in soil solution as affected by depth and yearly applications of beef-feedlot manure.

Meek et al. (7) found that Mn and, to a lesser extent, Fe solution concentrations were increased when an organic matter-amended soil was flooded. They attributed the enhanced solubility of Mn and Fe to chemical reduction in the anaerobic conditions they measured in the soil. Assuming that the neutral pH of the soil prevented Fe and Mn solution concentrations from being significantly increased by inorganic equilibria, our Fe and Mn data can be seen as indirect evidence for the presence of anaerobic conditions necessary for denitrification.

SUMMARY AND CONCLUSIONS

In plots that had received yearly applications of beef-feedlot manure, N balance calculations showed that large amounts of N were not accounted for by soil, plant and manure analyses. Atmospheric
and other soil analyses suggested that N loss could have occurred
from denitrification reactions. The presence of reducing condi-
tions necessary for denitrification was suggested indirectly by
increased Fe and Mn in the soil solution and by lowered O2 and
elevated CH4 contents of the soil atmosphere. Detection of N2O
(an end product of denitrification) in the soil atmosphere was
further evidence that denitrification had occurred.

It was shown that in land disposal of manure the potential
for NO3-N contamination of groundwater can be lowered by denitri-
fication. When determining disposal rates based on N balance cal-
culations, one should recognize and consider that N loss.

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