N-management and crop rotation effects on yield and residual soil nitrate levels

A. Bakhsh  
Iowa State University

R. S. Kanwar  
Iowa State University, rskanwar@iastate.edu

D. L. Karlen  
United States Department of Agriculture, doug.karlen@ars.usda.gov

C. A. Cambardella  
United States Department of Agriculture, cindy.cambardella@ars.usda.gov

T. B. Bailey  
Iowa State University, tbbailey@iastate.edu

See next page for additional authors

Follow this and additional works at: http://lib.dr.iastate.edu/abe_eng_pubs

Part of the Agriculture Commons, and the Bioresource and Agricultural Engineering Commons

The complete bibliographic information for this item can be found at http://lib.dr.iastate.edu/abe_eng_pubs/794. For information on how to cite this item, please visit http://lib.dr.iastate.edu/howtocite.html.
N-management and crop rotation effects on yield and residual soil nitrate levels

Abstract
Swine production facilities are becoming more concentrated in Iowa, and public is concerned about the impact of using swine manure for crop production on soil and water quality. This field study was conducted from 1996 to 1998 to compare the effects of liquid swine manure and urea ammonium nitrate (UAN) application on crop yield and residual soil nitrate for continuous corn (Zea mays L.) and corn-soybean (Glycine max (L.) Merr.) rotation systems. Six N management treatments were replicated three times in a randomized complete block design at Iowa State University's northeastern research center in Nashua, Iowa. Injected UAN provided 135 kg N ha\(^{-1}\) to continuous corn and 110 kg N ha\(^{-1}\) to corn grown in rotation with soybean. The 3-year average amount of N from swine manure was 123 kg ha\(^{-1}\) for continuous corn and 97 kg ha\(^{-1}\) for rotated corn. The average grain yield for continuous corn for UAN and manure treatments (7.8 vs. 7.5 Mg ha\(^{-1}\), respectively) was not significantly (P = 0.05) different. Corn yields from plots rotated with soybean were significantly different, averaging 9.4 and 8.9 Mg ha\(^{-1}\) for UAN and manure plots, respectively. Similarly, rotation effects reduced the residual soil nitrate by 25% (18 vs. 24 kg-N ha\(^{-1}\)) and 33% (20 vs. 30 kg-N ha\(^{-1}\)) under UAN and manure N-management systems, respectively, compared with continuous corn plots. The plots fertilized with swine manure also showed greater average levels of residual soil nitrate over winter months (12 vs. 5 kg-N ha\(^{-1}\)) compared with UAN-fertilized plots. The results of this study suggest that using swine manure as a nitrogen supplement results in greater residual soil nitrate without increasing corn grain yield, compared with UAN-application, and can, therefore, build up excessive nitrate amounts in the root zone causing increased potential for NO\(_3\)-N leaching to groundwater.

Keywords
Swine manure, UAN, continuous corn, corn after soybean, soil nitrate

Disciplines
Agriculture | Bioresource and Agricultural Engineering

Comments
This article is from Soil Science 166 (2001): 530–538.

Rights
Works produced by employees of the U.S. Government as part of their official duties are not copyrighted within the U.S. The content of this document is not copyrighted.

Authors
A. Bakhsh, R. S. Kanwar, D. L. Karlen, C. A. Cambardella, T. B. Bailey, T. B. Moorman, and T. S. Colvin

This article is available at Iowa State University Digital Repository: http://lib.dr.iastate.edu/abe_eng_pubs/794
SUPPLEMENTAL  N from either inorganic chemical fertilizer or animal manure is essential to meet food and fiber needs of an increasing global population. In Iowa and in many other states, swine production facilities are becoming more concentrated and are generating large quantities of liquid swine manure. A fundamental farming system question is how these two agricultural situations (crop needs for N and abundant swine manure) can be resolved to provide win-win solutions for farmers, consumers, and the environment.

Typical swine manure production ranges from 1 to 10 kg d\(^{-1}\) hog\(^{-1}\), depending on the animal’s size, type, and ration. Currently in Iowa, 25.8 Tg (28.4 million tons) of liquid swine manure is gathered in pits each year (Midwest Plan
of NO₃-N leaching from the root zone are the
been reported. Similar studies with liquid swine manure have not
Porter et al., 1997; Anderson et al., 1997), but
crease NO₃-N concentrations in the soil profile
uous corn production has also been shown to in-
(1998) reported similar effects with regard to
yield by 11% when the crops were grown in ro-
tion (UAN), climate, and crop production sys-
tems (ridge-tillage, moldboard, chisel, and no-
till) and cropping systems consisting of either
continuous corn or a corn-soybean rotation. In
1993, the study was changed to include only two
tillage treatments (chisel or no-till) in order to ac-
commodate N-management treatments with
UAN or liquid swine manure. Following the
conversion, 18 plots were used to study six N-
management systems: (i) continuous corn fertil-
ized with UAN (CCF), (ii) continuous corn with
liquid swine manure (CCM), (iii) corn after soy-
bean with UAN (CSF), (iv) corn after soybean
with swine manure (CSM), (v) soybean after corn
with UAN applied to only the corn crop (SCF),
and (vi) soybean after corn with swine manure
applied only to the corn crop (SCM). Single pre-
plant spring application of UAN solution fertil-
izer was made using a spoke injector, which in-
jects at about 200-mm intervals and at 250 mm
from corn rows (Baker et al., 1989). Liquid swine
manure was injected in the fall and plots were
then chisel plowed within a week to mix manure
in the top 100 to 150 mm of soil. Corn, whether
fertilized with UAN or liquid swine manure, was
planted in 750-mm rows into a seedbed prepared
by fall chiseling and field cultivating in the
spring. Soybean was drilled in 200-mm rows di-
planted in 750-mm rows into a seedbed prepared
then chisel plowed within a week to mix manure
in the top 100 to 150 mm of soil. Corn, whether
fertilized with UAN or liquid swine manure, was
planted in 750-mm rows into a seedbed prepared
by fall chiseling and field cultivating in the
spring. Soybean was drilled in 200-mm rows di-
rectly into corn stover from the previous year.
The same varieties of corn (Golden Harvest
2343) and soybean (Sands of Iowa 237) were
grown during the 6-year experiment.

The detailed schedule of management ac-
tivities for this study is given in Table 1. This

The primary factors controlling the amount
of NO₃-N leaching from the root zone are the
availability of soil nitrate after accounting for
plant N-uptake and the amount of water perco-
lating through the soil profile, both of which de-
depend on climate and management practices
(Staver and Brinsfield, 1990; Serem et al., 1997;
Durieux et al., 1995). The interaction between
the different sources of nitrogen supply (liquid
swine manure or urea ammonium nitrate solu-
tion (UAN)), climate, and crop production sys-
tems (continuous corn or corn after soybean) and
their effects on the residual soil nitrate and crop
yields have been documented in only a few stud-
ies. Therefore, the objectives of this study were to
evaluate the effects of liquid swine manure and
UAN-fertilizer applications on the residual soil
NO₃-N mass accumulated in the root zone and
crop yields under continuous corn and corn after
soybean production systems.

METHODS AND MATERIALS

The experimental site is located at Iowa State
University’s northeastern research center near
Nashua, Iowa, on Floyd loam (fine-loamy, mixed,
mesic Aquic Hapludolls), Kenyon silty clay loam
(fine-loamy, mixed, mesic Typic Hapludolls), and
Readlyn loam (fine-loamy, mixed, mesic Aquic
Hapludolls) soils. These soils contain 30 to 40 g
kg⁻¹ (3 to 4%) organic matter, are moderately well
to poorly drained, have a seasonally high water table
(Voy, 1995), and benefit from subsurface drainage
systems. The site also has approximately 60 m of
pre-Illinoian till overlying a carbonate aquifer, al-
though in some areas bedrock is near the surface.

The experimental site has 36 plots (58.5 by
67 m) with fully documented tillage and cropping
records for the past 20 years. From 1978
through 1992, these plots were in a randomized
complete block design with four tillage treat-
ments (ridge-tillage, moldboard, chisel, and no-
till) and cropping systems consisting of either
continuous corn or a corn-soybean rotation. In
1993, the study was changed to include only two
tillage treatments (chisel or no-till) in order to ac-
commodate N-management treatments with
UAN or liquid swine manure. Following the
conversion, 18 plots were used to study six N-
management systems: (i) continuous corn fertil-
ized with UAN (CCF), (ii) continuous corn with
liquid swine manure (CCM), (iii) corn after soy-
bean with UAN (CSF), (iv) corn after soybean
with swine manure (CSM), (v) soybean after corn
with UAN applied to only the corn crop (SCF),
and (vi) soybean after corn with swine manure
applied only to the corn crop (SCM). Single pre-
plant spring application of UAN solution fertil-
izer was made using a spoke injector, which in-
jects at about 200-mm intervals and at 250 mm
from corn rows (Baker et al., 1989). Liquid swine
manure was injected in the fall and plots were
then chisel plowed within a week to mix manure
in the top 100 to 150 mm of soil. Corn, whether
fertilized with UAN or liquid swine manure, was
planted in 750-mm rows into a seedbed prepared
by fall chiseling and field cultivating in the
spring. Soybean was drilled in 200-mm rows di-
rectly into corn stover from the previous year.
The same varieties of corn (Golden Harvest
2343) and soybean (Sands of Iowa 237) were
grown during the 6-year experiment.

The detailed schedule of management ac-
tivities for this study is given in Table 1. This
experimental field study was started in 1993 to evaluate the impact of liquid swine manure and UAN-fertilizer applications on NO$_3$-N concentrations in the soil profile under continuous-corn (CC) and corn-soybean rotations (CS). Liquid swine manure was obtained from a manure pit under a growing/finishing building. The actual rates of N-application from UAN and swine manure under continuous corn and corn-soybean production systems are given in Tables 1 and 2. The application rates of actual-N from liquid swine manure were not consistent from year to year because of the variability in the quality of swine manure in terms of solid concentrations and the available form of ammonia and NO$_3$-N levels in the manure at the time of application. For summarizing the experiment over years, however, data for the final 3-year period (1996 to 1998) were used for analysis because this period of study received more uniform applications of N from swine manure (Table 2).

Profile soil NO$_3$-N concentrations were measured for the top 1.2 m, at three locations spaced at least 15 m apart in the central 25% of each plot (58.5 by 67 m). Soil samples were collected about 1 to 2 weeks before planting and about 2 weeks after harvest (Table 1) using zero contamination tubes (plastic liner inside) that were 1220 mm long and 22.2 mm in diameter. Soil compaction in each core was measured at 300-mm increments by comparing the depth to the soil surface inside and outside of the core. The samples were frozen immediately after collection. They were subsequently thawed, fractionated into four to seven depth increments, compensated for soil compaction, and composited for the three sampling locations within each plot. The composite samples were sieved, subsampled to determine gravimetric water content and for extraction with 2 M KCl, and were analyzed spectrophotometrically using a Lachat Model AE ion analyzer to determine NO$_3$-N concentrations (Bjorneberg et al., 1998). The data were reported as mg kg$^{-1}$ (ppm) NO$_3$-N in the soil. The NO$_3$-N concentrations per unit mass of soil (ppm) were multiplied by the corresponding depth of soil (cm) and bulk density (g cm$^{-3}$) and were divided by 10 (conversion factor) to calculate the NO$_3$-N mass (kg N ha$^{-1}$) for that soil horizon. The calculated NO$_3$-N mass for each depth increment was summed to determine the total NO$_3$-N mass for the entire 1.2-m-deep soil profile. Corn and soybean yield data were collected from each plot, tested for

### Table 1

<table>
<thead>
<tr>
<th>Field operations</th>
<th>1996</th>
<th>1997</th>
<th>1998</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring soil sampling</td>
<td>Apr 26</td>
<td>Apr 29</td>
<td>Apr 28</td>
</tr>
<tr>
<td>Spring fertilizer application†</td>
<td>May 3</td>
<td>May 12</td>
<td>May 1</td>
</tr>
<tr>
<td>Corn planting</td>
<td>May 21</td>
<td>May 12</td>
<td>May 5</td>
</tr>
<tr>
<td>Soybean planting</td>
<td>May 30</td>
<td>May 16</td>
<td>May 18</td>
</tr>
<tr>
<td>Cultivation (corn plots)</td>
<td>Jun 24</td>
<td>Jun 19</td>
<td>Jun 4</td>
</tr>
<tr>
<td>Approximate corn maturity</td>
<td>Oct 5</td>
<td>Sep 30</td>
<td>Sep 10</td>
</tr>
<tr>
<td>Corn harvesting</td>
<td>Oct 21</td>
<td>Oct 10</td>
<td>Sep 22</td>
</tr>
<tr>
<td>Soybean harvesting</td>
<td>Oct 8</td>
<td>Oct 2</td>
<td>Oct 1</td>
</tr>
<tr>
<td>Fall soil sampling‡</td>
<td>Oct 17</td>
<td>Oct 20</td>
<td>Nov 7</td>
</tr>
<tr>
<td>Fall application of manure</td>
<td>Nov 15</td>
<td>Nov 10</td>
<td>Nov 15</td>
</tr>
<tr>
<td>Primary tillage (chisel plow)</td>
<td>Nov 17</td>
<td>Nov 12</td>
<td>Nov 17</td>
</tr>
</tbody>
</table>

†110 kg N ha$^{-1}$ for corn after soybean in rotation plots (CS) and 135 kg N ha$^{-1}$ for continuous corn (CC) plots.‡Fall soil sampling in 1995 was on Oct. 25 and manure application was on Nov. 17; earlier fall soil sampling in 1996 was due to labor management problems.

### Table 2

<table>
<thead>
<tr>
<th>Application rates</th>
<th>N</th>
<th>P$_2$O$_5$</th>
<th>K$_2$O</th>
</tr>
</thead>
<tbody>
<tr>
<td>(kg ha$^{-1}$)</td>
<td>CCS</td>
<td>CC</td>
<td>CCS</td>
</tr>
<tr>
<td>N</td>
<td>82</td>
<td>101</td>
<td>85</td>
</tr>
<tr>
<td>P$_2$O$_5$</td>
<td>25</td>
<td>37</td>
<td>28</td>
</tr>
<tr>
<td>K$_2$O</td>
<td>36</td>
<td>53</td>
<td>45</td>
</tr>
</tbody>
</table>

‡CS = corn after soybean; ‡CC = continuous corn.
moisture content, and adjusted to a constant water content of 155 g kg\(^{-1}\) (15.5%) for corn and 130 g kg\(^{-1}\) (13%) for soybean. Grain yield for each plot was measured using a modified commercial combine with all stover left in the field (Bjorneberg et al., 1998).

Crop yield and residual soil NO\(_3\)-N data for the six treatments were analyzed using a randomized complete block design. Analysis of variance (ANOVA) tables were developed using SAS Version 6.1 (SAS, 1989), and least significant difference (LSD\(_{0.05}\)) method was used to compare treatment mean values. Cropping system effects on crop yields were evaluated on a yearly basis, as well as on average values for 3 years, with data from corn and soybean analyzed separately. The changes in residual soil nitrate over winter months, after crop harvest in the preceding year to before planting in the following year (Table 1), were compared using LSD\(_{0.05}\) to see treatment effects on the storage of soil nitrates levels in the soil profile when crops were not growing.

RESULTS AND DISCUSSION

The average N-application rates from liquid swine manure for both rotated (97 kg-N ha\(^{-1}\)) and continuous corn (123 kg-N ha\(^{-1}\)) plots were much closer to the target levels of 110 and 135 kg N ha\(^{-1}\) for the period 1996 through 1998 (Table 2) than during the first 3 years (1993 through 1995) when N application rates averaged 175 and 197 kg ha\(^{-1}\), respectively. Therefore results and conclusions were derived using data for the last 3 years. An analysis of variance for that 3-year period (1996–1998) showed that the cropping system effect on soybean yield was not significant (\(P = 0.05\)) because no N-fertilizer was applied. The season (year) effect was highly significant (\(P = 0.01\)) for both residual soil nitrate and crop yield, possibly because of weather differences. The monthly growing season rainfall data for this 3-year period (Fig. 1), available from the on-site weather station, showed that 1998 was wet with a growing season rainfall of about 980 mm. This compares with the normal amount, which is about 840 mm (Voy, 1995). During 1996 (680 mm) and 1997 (750 mm), seasonal rainfall was below normal.

Post harvest residual soil NO\(_3\)-N varied from year to year, from the lowest average value of 15 kg-N ha\(^{-1}\) in 1996 to the highest average value of 39 kg-N ha\(^{-1}\) in 1997, because of weather differences over the years (Table 4). In 1996, rotated plots under soybean fertilized with either UAN or swine manure to corn phase of production showed significantly (\(P = 0.05\)) higher residual soil NO\(_3\)-N (24 to 28 kg-N ha\(^{-1}\)) than all other treatments (Table 4). However, no such significant difference among treatment means was observed in 1997, which may have been the result of low rainfall for this year as well as low rainfall and low corn grain yields in the preceding year of 1996 (Fig. 2). Such weather effects on soil NO\(_3\)-N have also been reported by Randall, (1998). In 1998, the rotated plots under soybean showed significantly (\(P = 0.05\)) higher residual soil NO\(_3\)-N than rotated plots under corn, by 71% (24 vs. 14 kg-N ha\(^{-1}\)), when fertilized with UAN and showed a nonsignificant difference of 21% (23 vs. 19 kg-N ha\(^{-1}\)) with swine manure application.

When averaged across 3 years from 1996 through 1998, residual soil NO\(_3\)-N to a depth of 1.2 m was variable, ranging from 18 to 32 kg N ha\(^{-1}\) after harvest (Table 4). The lowest residual NO\(_3\)-N amounts (18 to 20 kg N ha\(^{-1}\)) were measured in plots where corn was grown in rotation with soybean. This reflected a higher N-uptake rate because of higher grain yields associated with rotated corn. The highest amount of residual soil NO\(_3\)-N (32 kg-N ha\(^{-1}\)) was measured in plots under soybean after corn and also in continuous

<table>
<thead>
<tr>
<th>TABLE 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analysis of variance on residual soil nitrate (after harvest) and crop yields (1996–98)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sources of variability</th>
<th>Residual soil NO(_3)-N (kg-N ha(^{-1}))</th>
<th>Yield (Mg ha(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>df</td>
<td>MSE</td>
</tr>
<tr>
<td>Blocks (blk)</td>
<td>2</td>
<td>20</td>
</tr>
<tr>
<td>Cropping systems (trt)</td>
<td>5</td>
<td>289</td>
</tr>
<tr>
<td>Error, (blk (\times) trt)</td>
<td>10</td>
<td>76</td>
</tr>
<tr>
<td>Year</td>
<td>2</td>
<td>2660</td>
</tr>
<tr>
<td>Year (\times) trt</td>
<td>10</td>
<td>72</td>
</tr>
<tr>
<td>Error, (blk (\times) trt (\times) year)</td>
<td>24</td>
<td>67</td>
</tr>
</tbody>
</table>

\(df = \) degree of freedom; \(\text{MSE} = \) mean square error; \(P > F = \) probability values
corn plots (30 kg-N ha⁻¹) fertilized with swine manure. The manured plots, when averaged across all treatments, showed 17% (27 vs. 23 kg-N ha⁻¹) higher residual soil NO₃-N than UAN-fertilized plots. This occurred because estimates of manure N concentration were not as intended during the first 3-year period (1993 to 1995) and also because of the slow release of N from manure in the years following application (Andraski et al., 2000; Bandel and Fox, 1984; Beauchamp, 1983).

![Fig. 1. Monthly rainfall for the growing season (March through November) from 1996 through 1998.](image)

### TABLE 4
Effects of cropping systems on post-harvest residual soil NO₃-N (RSN) and crop yields

<table>
<thead>
<tr>
<th>Cropping systems</th>
<th>Residual Soil NO₃-N (RSN)</th>
<th>Average (1996–98)</th>
<th>RSN (kg-N ha⁻¹)</th>
<th>Corn yield (Mg ha⁻¹)</th>
<th>Soybean yield (Mg ha⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuous-corn-UAN (CCF)†</td>
<td>11b</td>
<td>37a</td>
<td>23ab</td>
<td>24abc</td>
<td>7.8c</td>
</tr>
<tr>
<td>Continuous-corn-manure (CCM)‡</td>
<td>14b</td>
<td>47a</td>
<td>28a</td>
<td>30a</td>
<td>7.5c</td>
</tr>
<tr>
<td>Corn-soybean-UAN (CSF)§</td>
<td>7b</td>
<td>32a</td>
<td>14b</td>
<td>18c</td>
<td>9.4a</td>
</tr>
<tr>
<td>Corn-soybean-manure (CSM)¶</td>
<td>6b</td>
<td>36a</td>
<td>19ab</td>
<td>20bc</td>
<td>8.9b</td>
</tr>
<tr>
<td>Soybean-corn, UAN for corn (SCF)#</td>
<td>24a</td>
<td>34a</td>
<td>24a</td>
<td>28ab</td>
<td>3.9a</td>
</tr>
<tr>
<td>Soybean-corn, manure for corn (SCM)&quot;</td>
<td>28a</td>
<td>47a</td>
<td>23ab</td>
<td>32a</td>
<td>3.8a</td>
</tr>
<tr>
<td>Average</td>
<td>15</td>
<td>39</td>
<td>22</td>
<td>25</td>
<td>8.4</td>
</tr>
<tr>
<td>Coefficient of variation (%)</td>
<td>36</td>
<td>32</td>
<td>25</td>
<td>33</td>
<td>4.4</td>
</tr>
<tr>
<td>Least Significant Difference (LSD₀.₀₅)</td>
<td>9</td>
<td>23</td>
<td>9</td>
<td>9</td>
<td>0.4</td>
</tr>
</tbody>
</table>

†CCF=continuous corn fertilized with urea ammonium nitrate solution fertilizer (UAN); ‡CCM=continuous corn fertilized with liquid swine manure; §CSF=corn after soybean fertilized with UAN; ¶CSM=corn after soybean fertilized with liquid swine manure; #SCF=soybean after corn with UAN applied to only corn; "SCM=soybean after corn with liquid swine manure applied to only corn.
study, post-harvest residual soil NO₃-N was often found to be the same or higher after soybean than after corn even though no additional N was applied before planting soybean (Table 4). This suggests that annual fertilizer or manure application rate is not the controlling factor for residual soil NO₃-N, but rather it is the inorganic/organic soil N pool and its mineralization processes and the effect of changing rainfall patterns from year to year (Gentry et al., 1998; Cambardella et al., 1999; Randall, 1998).

Corn yield for the various N-management treatments showed statistically significant \( P = 0.05 \) differences for 3 years (Fig. 2). Soybean, which was grown in rotation but without additional manure or UAN fertilizer, showed no significant yield differences (Fig. 3). Grain yields for the continuous corn treatments were always numerically and usually statistically lower than when corn was rotated with soybean. For example, grain yield for UAN and manure treatments averaged 7.8 versus 7.5 Mg ha⁻¹, for continuous corn and 9.4 and 8.9 Mg ha⁻¹ for rotated corn (Table 4). When averaged for 3-year period, continuous corn yield was about 17% (7.8 vs. 9.4 Mg ha⁻¹) lower than the yields measured for rotated corn fertilized with UAN. This response was consistent for manure treatments, which showed 16% (7.5 vs. 8.9 Mg ha⁻¹) less yield for continuous corn than rotated corn. This very significant reduction in grain yield for continuous corn agrees with numerous other studies (Karlen et al., 1994; Kanwar et al., 1997; and Karlen et al., 1998). The lower yields for continuous corn plots can be associated with lower plant N-uptake because these plots also showed 33% (24 vs. 18 kg-N ha⁻¹) and 50% (30 vs. 20 kg-N ha⁻¹) higher residual soil NO₃-N than plots under rotated corn for both UAN and swine manure management systems, respectively (Table 4). This demonstrates clearly that continuous corn production is simply not as efficient as growing corn with soybean because of significant differences in yield and post-harvest residual soil NO₃-N levels.

In addition to the effects of climate on crop yield, the amount of rainfall has a major effect on the fate of the residual soil NO₃-N. This is especially true for the rainfall after harvest, which has been reported to be a major factor responsible for flushing of NO₃-N from the root zone (Cambardella et al., 1999; Staver and Brinsfield, 1990). The changes in residual soil NO₃-N during the winter months varied from year to year because of confounding factors of climate and different N application rates from swine manure, particularly during the early 3-year period (1993 to 1995) of...
study. The net changes in residual soil NO$_3$-N over winter reflect the net effect of mineralization, immobilization, denitrification, and leaching during that period (Durieux et al., 1995). The average maximum gain of 25 kg-N ha$^{-1}$ in residual soil NO$_3$-N was observed after the 1996/1997 winter, and a maximum loss of -8 kg-N ha$^{-1}$ occurred during the winter of 1997/1998 (Table 5). The reason for these variations may be less rainfall for 1996 (19% less than normal) and more rainfall for 1998 (17% more than normal), particularly during the early spring period (Fig. 1) when crops were not growing. The rotation effect also resulted in significant ($P = 0.05$) gains (39 vs. 13 kg-N ha$^{-1}$) and nonsignificant greater levels (37 vs. 18 kg-N ha$^{-1}$) of residual soil NO$_3$-N than in continuous corn plots over the 1996/1997 winter for both UAN- and manure-applied corn plots, respectively (Table 5). However, this rotation effect was not significant for the other two winter seasons (1995/1996 and 1997/1998) because of weather differences.

For the treatments receiving swine manure (CCM or CSM) or presumably drawing soil NO$_3$-N from a residual organic N pool contributed to by previous manure applications (SCM) or that were the result of higher N-application rates to corn during the early 3 years (1993 to 1995) of the study, the average greater levels of profile NO$_3$-N for the last 3 years, to a depth of 1.2 m, were 14, 23, and 0 kg-N ha$^{-1}$, respectively (Table 5). Rotation plots that received UAN for the corn crop showed an average greater level of residual soil NO$_3$-N of 10 kg-N ha$^{-1}$ in plots where soybean was grown the previous year and 8 kg-N ha$^{-1}$ in plots where corn had been grown. Average values for the continuous corn plots fertilized with UAN showed a slight lower level ($\sim 3$ kg ha$^{-1}$). On average, the plots fertilized with swine manure resulted in greater levels of residual soil NO$_3$-N, 12 versus 5 kg-N ha$^{-1}$, over the winter months compared with plots fertilized with UAN. The relatively greater level of residual soil NO$_3$-N in plots fertilized with liquid swine manure reflects the net mineralization effect that occurred between those two sampling dates (fall of preceding year and spring of the following year). The average slight greater level of soil NO$_3$-N in CSF than in SCF plots (10 vs. 8 kg N ha$^{-1}$) reflects mineralization of soybean roots and residue rather than corn residues. These greater levels of residual soil NO$_3$-N between late fall and early summer are one of the most potentially damaging environmental aspects of fall manure or anhydrous ammonia (Kidwaro and Kephart, 1998) applications. Although the NO$_3$-N could be taken up by a subsequent corn crop, relatively high rainfall (Fig. 1) during May, June, or early July before the corn root system was fully developed could easily result in substantial NO$_3$-N leaching out of the root zone. To prevent these potentially adverse environmental effects and increase corn yields, manure and fertilizer management strategies that synchronize N mineralization and plant need for NO$_3$-N must be developed.

**CONCLUSIONS**

A field study was conducted for 6 years (1993 to 1998) to determine the impact of liquid swine manure application on crop yields and accumulation of residual soil nitrate in the root zone compared with UAN application under continuous corn and corn after soybean production systems.

### TABLE 5

<table>
<thead>
<tr>
<th>Cropping systems</th>
<th>Changes in residual soil NO$_3$-N (kg-N ha$^{-1}$) over winter$^6$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuous-corn-UAN (CCF)</td>
<td>6a</td>
</tr>
<tr>
<td>Continuous-corn-manure (CCM)</td>
<td>-3a</td>
</tr>
<tr>
<td>Corn-soybean-UAN (CSF)</td>
<td>3a</td>
</tr>
<tr>
<td>Corn-soybean-manure (CSM)</td>
<td>14a</td>
</tr>
<tr>
<td>Soybean-corn, UAN for corn (SCF)</td>
<td>22a</td>
</tr>
<tr>
<td>Soybean-corn, manure for corn (SCM)</td>
<td>15a</td>
</tr>
<tr>
<td>Average</td>
<td>10</td>
</tr>
<tr>
<td>Coefficient of variation (%)</td>
<td>245</td>
</tr>
<tr>
<td>Least Significant Difference (LSD$_{0.05}$)</td>
<td>43</td>
</tr>
</tbody>
</table>

$^6$Change = RSN in spring of the next year - RSN in fall of the preceding year.
However, the data were analyzed for the last 3 years (1996 to 1998) because of more uniform N-application rates from swine manure for these years than during the early 3-year period (1993 to 1995). The following conclusions, based on the last 3 years data analyses, were derived:

(i) The effect of swine manure application resulted in 25% (30 vs. 24 kg-N ha\(^{-1}\)) higher residual soil NO\(_3\)-N in the root zone with 4% less corn grain yield by (7.5 vs. 7.8 Mg ha\(^{-1}\)) compared with UAN fertilized plots under continuous corn production system.

(ii) The rotated corn grain yield was significantly (\(P = 0.05\)) higher than continuous corn under the N-management systems of both UAN (9.4 vs. 7.8 Mg ha\(^{-1}\)) and swine manure (8.9 vs. 7.5 Mg ha\(^{-1}\)). The rotation effect also reduced the residual soil NO\(_3\)-N by 25% (18 vs. 24 kg-N ha\(^{-1}\)), and 33% (20 vs. 30 kg-N ha\(^{-1}\)) under UAN and manure management systems, respectively.

(iii) On average, plots fertilized with swine manure resulted in greater levels of profile NO\(_3\)-N (12 vs. 5 kg-N ha\(^{-1}\)) than UAN-applied plots, showing the net effect of mineralization over winter months (from post-harvest in the preceding year to pre-plant the following year).

**Abbreviations:** UAN urea ammonium nitrate solution fertilizer; NO\(_3\)-N nitrate-nitrogen; CCF continuous corn fertilized with UAN; CCM continuous corn fertilized with liquid swine manure; CSF corn after soybean fertilized with UAN; CSM corn after soybean fertilized with liquid swine manure; SCM soybean after corn with UAN applied to only corn; RSN post-harvest residual soil NO\(_3\)-N mass in the top 1.2 m soil; SAS statistical analysis system; LSD 0.05 least significant difference at \(P = 0.05\);

**REFERENCES**


Kanwar, R. S., T. S. Colvin, and D. L. Karlen. 1997. Ridge, moldboard, chisel, and no-till effects on tile


Voy, K. D. 1995. Soil survey of Floyd County, Iowa. USDA-SCS in cooperation with Iowa Agric. and Home Econ. Exp. Stn., Coop. Ext. Serv., Iowa State University, Ames, IA.