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Annual Swine Manure Applications to Soybean Under Corn-Soybean Rotation

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Keywords

Agronomy, Corn and soybean yields, Manure, Subsurface drainage, Water quality

Disciplines

Agricultural Science | Agriculture | Agronomy and Crop Sciences | Bioresource and Agricultural Engineering

Comments

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A. Bakhsh, R. S. Kanwar, J. L. Baker, J. Sawyer, A. Malarino

Abstract. *The response of a corn-soybean rotation system receiving fall manure application to both corn and soybean is not well understood in terms of its impact on nitrate leaching to subsurface drainage water and crop yields. This field study was conducted from 2001 through 2005 with the key objective of determining the effects of manure application to both corn and soybean on NO_3-N concentrations in subsurface drainage water and corn-soybean yields. The study was conducted on 0.4 ha plots instrumented with state-of-the-art subsurface drainage monitoring systems at the Iowa State University research center, Nashua, Iowa. Nitrogen application rates from liquid swine manure averaged 174 and 219 kg N ha^{-1} to both years of the corn and soybean production system, respectively, compared with 177 kg N ha^{-1} to corn years only. Field data collected on subsurface drainage, NO_3-N concentrations, and leaching losses to subsurface drainage water and crop yields were analyzed as a randomized complete block design. The results indicated that the average flow-weighted NO_3-N concentrations and leaching losses increased by more than 50% when manure was applied to both corn and soybean in comparison with manure application to corn only, while yield differences were less than 4%. These results suggest that fall manure application to both corn and soybean is likely to increase NO_3-N leaching to shallow groundwater without resulting in significant yield benefits. The increased NO_3-N leaching was primarily due to larger total N application from manure to both corn and soybean under the corn-soybean production system studied at this site.*

Keywords*. Corn and soybean yields, Manure, Subsurface drainage, Water quality.*

Properly used manure can be an excellent source of nutrients for crop production. Agricultural crops have responded positively to manure nutrient applications, and manure (from dairy, cattle, swine, and poultry) has been successfully used in agricultural watersheds all over the world for many years, including the Midwestern states in the U.S. Improper use of manure for crop production, however, can potentially become a source of nitrogen and phosphorus pollution of soil and water resources. In Iowa, swine manure has been used as a fertilizer for corn production under corn-soybean rotation systems. Application of swine manure to soybeans is not a common practice in Iowa, but it does occur. Sometimes, manure application plans for producers include swine manure application for soybean production under corn-soybean rotation systems. The effects of excessive swine manure applications on the environment have already led to the development of new legislation that limits the use of animal manure or localization of swine production in some countries (Bakhsh et al., 2005; Kanwar et al., 2005; Karlen et al., 2004; Schmidt et al., 2001; Sawyer, 2001).

In Iowa, swine production facilities have concentrated over the years. In 2004, a large number of operations (43%) had 5000 or more head, while a small number of operations (0.3%) had less than 100 head (USDA-NASS, 2005). This trend shows that manure production, in a relatively small geographic area, may lead to overapplication of manure in the adjacent lands because of its difficult transportation and hauling cost (Daverede et al., 2004). The issue is compounded in a corn-soybean rotation system where half of the land area is under soybean each year, further reducing the acreage for manure application. In this context, application of manure to soybean provides an alternative to avoid overapplication of manure to corn fields, as soybean has been reported to be a scavenger crop for N. Varvel and Peterson (1992) reported that soybean is a net N sink and can reduce the residual soil N available for leaching. The amount of N removed by soybean in a Nebraska study ranged from 150 to 200 kg N ha^{-1} (Varvel and Peterson, 1992). Depending on site-specific conditions, about 40% to 75% of N for a mature soybean is delivered from the soil, and demand for high-yielding soybean can be as high as 385 kg N ha^{-1} (Shibles, 1998). This shows that soybean can be a good option to use N from manure to increase its yield.

Application of manure to soybean is not necessarily meant to increase yield but mainly to provide a means of manure disposal (Schmidt et al., 2000). The response of soybean to manure application is also not well understood, varying from

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place to place depending on the soil, climate, and management practices. Randall and Schmidt (1998) concluded that, for Minnesota soybean, yield may increase by addition of soil fertilizer but responses were inconsistent and varied with variety, rate, timing and source of fertilizer, and also other factors. Lamb et al. (1990) reported increase in soybean yield as a result of N application at two out of ten locations in Minnesota where soil had low organic matter and low N availability. Similarly, Oplinger and Bundy (1998) concluded that in Wisconsin there was very little increase in soybean yields in response to N application. They also cautioned about possible lodging and disease problems associated with N application to soybean.

Soybean is a legume crop and is assumed to fix N from the atmosphere for its needs. The response of soybean to N application in terms of symbiotic processes is not yet clear. Some researchers have reported that there is a direct effect of reduced symbiotic N_2 fixation when soil N is available (McAuliffe et al., 1958; Deibert et al., 1979). Other researchers reported that N_2 fixation is not completely inhibited in the presence of soil N (Allos and Bartholomew, 1955; Weber, 1966). Schmidt et al. (2000) reported that N fixation compensated for N and did not risk decreasing yield when N application was less than plant uptake. They also mentioned that applying more N than required did not affect the seed yield but represented an increased potential for nitrate loss to the environment. They recommended that applying N at a rate equivalent to the N accumulated in the soybean crop appears to be a sound N management practice for livestock producers in the upper Midwest. The same authors, in 2001, reported an average increase in soybean yield of 1.4 kg kg^{-1} N applied from manure at three of seven locations in southern Minnesota despite lodging. At three other locations, the seed yield increase was essentially innocuous, although a few cultivars at each location responded favorably to increasing manure rate. At the seventh location, seed yield was adversely affected due to disease.

Sawyer (2001) reported that N application to soybean seldom produces yield enough to cover the cost associated with its application. He concluded that N application to soybean is not a recommended practice for Iowa. He mentioned that liquid swine manure application sometimes improves yields, but this response is not consistent. In situations, when soil P and K test are deficient, manure application may increase yields.

All the above-mentioned studies have reported inconsistent results on the effects of manure application to soybean. In addition, no study has reported the effects of liquid swine manure application to the lands each year under a corn-soybean rotation system and underlain by subsurface drainage tile system. The subsurface drainage systems in the Midwestern part of the U.S. have already been linked to the elevated NO_3-N concentrations in the Mississippi river, which contributes about one-third of the N delivered to the Gulf of Mexico (Baker et al., 2005; Kanwar et al., 1997; Alexander et al., 1995; Dinnes et al., 2002).

Bakhsh et al. (2005) reported in their long-term study at Nashua, Iowa, that liquid swine manure resulted in significantly greater NO_3-N losses and showed no difference in corn grain yields in comparison with UAN fertilizer application under a continuous corn production system. Under these conditions, it is interesting to study the impact of liquid swine manure applications on NO_3-N concentrations in subsurface drainage water and on corn-soybean yields when manure is applied to both years of a corn-soybean production system. This study was designed to compare and evaluate the effects of fall liquid swine manure applications to both corn and soybean compared with manure application to corn only under a rotation system on NO_3-N concentrations in subsurface drainage water, NO_3-N leaching losses via subsurface drainage flows, and corn-soybean grain yields.

Materials and Methods

Site Description

This study was conducted at the Iowa State University's northeastern research center near Nashua, Iowa. The soils at the site include Floyd loam (fine-loamy, mixed, mesic Aquic Hapludolls), Kenyon loam (fine-loamy, mixed, mesic Typic Hapludolls), and Readlyn loam (fine-loamy, mixed, mesic Aquic Hapludolls) (Kanwar et al., 1997). These soils have seasonally high water table conditions and benefit from subsurface drainage.

In 1979, subsurface drains were installed at a depth of 1.2 m and a spacing between drains of 28.5 m. The site has thirty-six 0.4 ha plots (58.5 × 67 m) with fully documented tillage and cropping records for the past 28 years. Each plot has an independent drainage sump with flowmeter for measuring subsurface drain flows and collecting composite water samples for chemical analysis. Further details on this subsurface drainage system can be found in Kanwar et al. (1999). Drainage water sampling frequency averaged three times a week if subsurface drains were flowing. There is usually no drainage during the months of December through February due to cold weather and snow conditions. Subsurface drain water samples were collected and refrigerated until chemical analyses of NO_3-N concentrations were determined with a Lachat Model AE ion analyzer (Lachat Instruments, Milwaukee, Wisc.). Further detail on this analysis can be found in Karlen et al. (2004) and Bakhsh et al. (2005). No supplemental irrigation was applied, and no runoff was observed during the experiment.

Management Practices and Experimental Treatments

These plots had been managed in a randomized complete block design with four tillage systems (chisel, ridge, moldboard, and no-till) since 1979 (Bjorneberg et al., 1996). In 1993, new farming systems were initiated at this site with three options of N management treatments (preplant single N application, late spring soil test based N application, and manure application) and two tillage systems (chisel and no-till) under continuous corn and corn-soybean production systems. In fall 1998, new experiments were designed to study the nutrient leaching losses with major focus on swine manure management as well as removing the existing continuous corn treatments.

Of these 36 plots, 12 plots were used to compare the effects of liquid swine manure applications to both corn and soybean with the liquid swine manure application to corn only under a corn-soybean production system. Liquid swine manure was obtained from a growing-finishing building. The application of manure to achieve the required N application rate was difficult because of the non-uniform quality of the manure, variable volatilization rates occurring over the

Table 1. Management activities schedule at the northeast research center, Nashua, Iowa.[a]

Field Operations	2001	2002	2003	2004	2005
Corn planting	19 May	7 May	26 April	24 April	28 April
Soybean planting	18 May	15 May	20 May	7 May	5 May
Cultivation for corn plants	22 June	--	17 June	15 June	5 May
Corn harvest	12 Oct.	7 Oct.	23 Sept.	15 Oct.	6 Oct.
Soybean harvest	5 Oct.	10 Oct.	25 Sept.	23 Sept.	20 Sept.
Fall manure injected	1 Nov.	7 Nov.	4 Nov.	21 Oct.	10 Nov.
Primary tillage with chisel plow	4 Dec.	12 Nov.	13 Nov.	7 Nov.	17 Nov.
Corn variety	NK45-T5	NK45-T5	NK45-T5	NK45-T5	NK45-T5
Soybean variety	Kruger 2525	Asgrow 2103	Asgrow 2105	Asgrow 2105	Asgrow 2106

[a] Fall manure and primary tillage with chisel plow were performed in the preceding year. Corn and soybean varieties were grown based on seed availability in the market, and average planting rate was 79,000 and 494,000 seeds per ha-1, respectively.

Table 2. Nitrogen application rates (kg ha^{-1}) from liquid swine manure treatments.

Treatment[a]		2001	2002	2003	2004	2005	Average
CSMA	PAN	171	220	141	173	182	177
	P_2O_5	169	162	71	100	75	115
	K_2O	180	175	111	129	118	143
CSME	PAN	173	212	148	154	183	174
	P_2O_5	402	161	66	72	67	154
	K_2O	178	173	114	128	119	142
SCMA	P_2O_5	--	--	--	--	--	--
	K_2O	--	109	--	--	--	--
SCME	PAN	223	260	176	227	211	219
	P_2O_5	233	187	80	130	83	143
	K_2O	238	214	154	161	138	181

[a] PAN = potentially available N.
CSMA = corn after soybean - fall manure to corn only.
CSME = corn after soybean - fall manure to both corn and soybean.
SCMA = soybean after corn - no manure to soybean.
SCME = soybean after corn - fall manure to soybean.

years, and associated problems, as discussed by Karlen et al. (2004) and Sommer and Hutchings (2001). The detail schedule of management activities and actual N application rates from swine manure are given in tables 1 and 2. Manure samples were collected from several loads, and analysis was done by the Iowa Testing Lab (Eagle Grove, Iowa). Liquid swine manure was injected to the field at a depth of 150 to 200 mm in fall prior to the growing season. Potentially available N from manure during the first cropping season was assumed to be all of the ammonia and 50% of the organic N, i.e., 0.5[TKN – NH_3–N] + NH_3–N (Karlen et al., 2004).

The study consisted of four treatments, each replicated three times in a randomized complete block design: (1) CSMA: corn after soybean receiving fall liquid swine manure application to corn only; (2) SCMA: soybean after corn with no N application to soybean; (3) CSME: corn after soybean with fall liquid swine manure application to both corn and soybean each year; and (4) SCME: soybean after corn with fall liquid swine manure application to soybean. The average N applications rates to corn under the CSMA and CSME treatments were 177 and 174 kg N ha^{-1}, respectively, with average N application of 219 kg N ha^{-1} to soybean for the SCME treatment (table 2).

Corn was planted in rows spaced 750 mm apart after preparing the seedbed with a field cultivator. Soybean was drilled in 200 mm rows directly into corn stover from the previous year when no manure was applied to soybean. Commercially available corn hybrids and soybean varieties were grown each year with the predominant ones being NK45-T5 corn and Asgrow 2105 soybean during the five-year experiment from 2001 to 2005 (table 1). Primary tillage was performed using chisel plow in fall after manure application. Secondary tillage was field cultivation before planting and during plant growth to control weeds. Weeds were controlled satisfactorily with herbicides and row cultivation. Grain yield for each plot was measured using a commercial combine with all stover left in the field.

Statistical Analysis

Crop yield data for corn and soybean were analyzed separately as a randomized complete block design using the PROC GLM procedure in SAS version 9.1 for Windows (SAS, 2003). Analysis of variance (ANOVA) tables were developed for subsurface drainage volume, flow-weighted average NO_3–N concentrations, and NO_3–N leaching losses in subsurface drainage water. Comparison among treatments within the years and over the years were tested at 5% significance level using the least significant difference (LSD) method (P = 0.05).

Results and Discussion

Precipitation and Subsurface Drainage

The five-year average rainfall (745 mm) was below normal (771 mm) because three of the five years had below-average amounts (table 3). This shows that in general the study period experienced less precipitation than normal. The years 2004 and 2005 were wetter than average, with precipitation of 885 and 839 mm, respectively. The other years, 2001, 2002, and 2003, had precipitation of 674, 719, and 604 mm, respectively. These variable rainfall patterns from year to year showed highly significant (P = 0.01) effects on tile flow, NO_3–N concentrations in subsurface drainage water, and NO_3–N leaching losses to subsurface drainage water (table 4) when averaged across years (2001-2005). Within-season precipitation has less effect on subsurface drainage than early spring or late autumn events because of crop water use. These data suggest that not only the amount of rainfall but its distribution during the growing season is important. On the average, block effects on tile flow volumes were found to be significant (P = 0.5), which showed the impact of spatial variability effects on tile flow rates.

The analysis of variance showed that treatment effects on tile flow volumes were not significant across years or annually, which was expected. The minimum tile flow volume of 8 mm was observed in 2002 for soybean plots receiving swine manure each year (table 4). Soybean plots receiving no

Table 3. Growing seasonal monthly precipitation (mm) data from 2001 to 2005.

Month	2001	2002	2003	2004	2005	Avg.[a]	Normal[b]
March	41	14	31	110	12	42	54
April	63	109	98	44	59	75	87
May	148	75	99	285	110	143	109
June	64	75	155	74	202	114	121
July	70	179	76	155	98	116	104
Aug.	73	155	12	74	152	93	103
Sept.	149	51	49	57	168	95	90
Oct.	40	54	16	50	7	33	62
Nov.	26	7	68	36	31	34	41
Total	674	719	604	885	839	745	771
SD	42	55	44	75	67	37	26

[a] Average of years 2001 to 2005.
[b] Recorded from 1951 to 1984 at Charles City, Iowa.

Table 4. Treatment means for annual subsurface drainage flow (mm).

Treatment[a]	2001	2002	2003	2004	2005	Average
CSMA	76 a	46 a	55 a	143 a	40 a	72 ab
CSME	84 a	12 a	61 a	91 a	51 a	60 b
SCMA	191 a	11 a	141 a	99 a	99 a	108 a
SCME	132 a	8 a	91 a	119 a	47 a	79 ab
Average	121	19	87	113	59	80
$LSD_{(0.05)}$	143	48	96	67	68	41

[a] CSMA = corn after soybean - fall manure to corn only.
CSME = corn after soybean - fall manure to both corn and soybean.
SCMA = soybean after corn - no manure to soybean.
SCME = soybean after corn - fall manure to soybean.

manure produced the greatest tile flow volume of 191 mm in 2001. These plots were under corn-soybean rotation, and spatial variability effects can also be observed by looking at the plots that were under soybean with no manure in 2001 and gave maximum tile flow volume of 191 mm. These plots also produced maximum tile flow volume of 46 mm for 2002, 141 mm for 2003, 143 mm for 2004, and 99 mm for 2005 irrespective of the crop for those years (table 4). This analysis shows the spatio-temporal variability effects on tile flow volumes because of terrain properties and rainfall patterns (Bakhsh and Kanwar, 2004). On the average, soybean plots receiving no manure produced significantly (P = 0.05) greater tile flow volume (108 vs. 60 mm) compared with corn plots receiving manure each year. Similarly, soybean plots with no manure produced greater tile flow volume than soybean plots receiving manure each year (108 vs. 79 mm), although the difference was not significant. Overall, soybean plots resulted in 42% greater tile flow volume (94 vs. 66 mm) in comparison to corn plots because of less evapotranspiration requirements for soybean (Schwab et al., 1995, p. 389).

NO_3-N Leaching Losses to Subsurface Drainage

When averaged across years, treatment effects on NO_3-N leaching losses to subsurface drainage water were found to be significant (P = 0.05) (fig. 1). Treatment effects for soybean were also significant for year 2004 because that year had above-normal rainfall of 885 mm. Treatment effects on NO_3-N leaching losses were non-significant for all other years because of spatio-temporal variability effects (Bakhsh et al., 2005) (fig. 1). In 2001, soybean plots with manure application produced greater NO_3-N leaching loss (42 vs. 28 kg N ha^{-1}) compared with soybean plots with no manure application (fig. 1). This trend was found to be consistent for almost all the years. In 2002, corn plots with manure application in alternate years produced the maximum NO_3-N leaching loss of 6 kg N ha^{-1} because of greater tile flow volume for that year. In three of the five years, soybean plots receiving manure each year produced the greatest NO_3-N leaching losses to subsurface drainage water. On the average, rotated soybean plots with manure application each year resulted in greater NO_3-N leaching loss (33 vs. 17 kg N ha^{-1}) than soybean plots receiving manure for corn years only. Similarly, corn plots in rotation with soybean receiving manure each year also resulted in greater NO_3-N leaching losses (26 vs. 21 kg N ha^{-1}) in comparison to corn plots receiving manure for corn years only (fig. 1). Overall, the corn-soybean rotation system receiving manure each year resulted in significantly greater NO_3-N leaching loss by 55% (59 vs. 38 kg N ha^{-1}) compared with the system receiving manure for corn years only because of larger total N application from liquid swine manure.

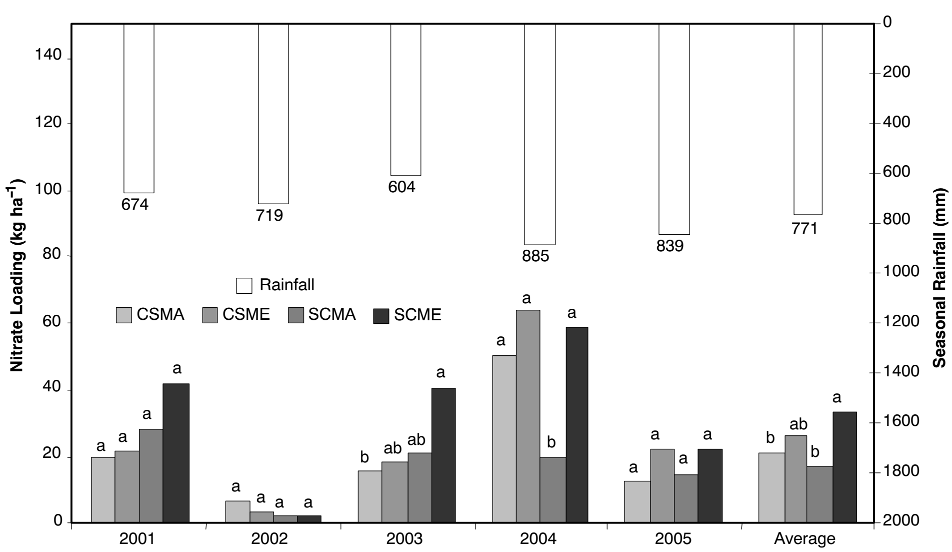

Figure 1. Treatmentwise nitrate leaching (kg ha^{-1}) via subsurface drainage water and the growing season rainfall over the years.

Flow-Weighted NO_3-N Concentrations in Subsurface Drainage Water

Flow-weighted (FW) NO_3–N concentrations have been reported to be a good indicator to assess NO_3–N loadings, especially when subsurface drain water may join a drinking water body (Jaynes et al., 1999). The analysis of variance showed that treatment effects on FW NO_3–N concentrations in subsurface drainage water were found to be highly significant (P = 0.01) when averaged across years (table 5). Season effects and its interaction with the treatments were also highly significant. These effects were also significant on a yearly basis because of different rainfall patterns and variable manure application rates. The seasonal average FW NO_3–N concentrations ranged from a minimum value of 22.2 mg L^{-1} in 2002 to a maximum value of 44.2 mg L^{-1} in 2004 (table 5). This concentration variation is the outcome of many factors of soil, climate, and management practices, including N application rates from manure and its slow release of N (Schmidt et al., 2001). In 2001, soybean plots receiving manure each year produced significantly greater FW NO_3–N concentrations (31.5 vs. 15.8 mg L^{-1}) in comparison to soybean plots with manure application to corn only (table 5). In 2002, corn plots receiving manure application each year resulted in significantly greater FW NO_3–N concentrations (31.8 vs. 16.9 mg L^{-1}) in comparison to corn plots with manure application in alternate years to corn only. In 2003, soybean plots with manure application each year produced significantly greater FW NO_3–N concentrations (44.6 vs. 16 mg L^{-1}) when compared with soybean plots with manure applied to corn only. In 2004, all treatment means showed significantly different results, and maximum FW NO_3–N concentrations (70.4 mg L^{-1}) were found for corn plots receiving manure each year. This greatest concentration of 70.4 mg L^{-1} can be associated with the combined effects of N application rate from manure, slow release of organic N from manure applied during the previous growing season, as well as variable rainfall patterns from year to year and during the growing season (Bakhsh et al., 2005; Schmidt et al., 2001). In 2005, corn and soybean plots receiving manure each year produced similar FW NO_3–N concentrations of 46 and 48 mg L^{-1}, respectively, significantly different from treatments with manure application in alternate years to corn only (table 5).

Overall, corn plots with manure application each year gave the highest FW NO_3–N concentrations of 40.7 mg L^{-1}, which were significantly different (27 mg L^{-1}) from treatments with manure application in alternate years (table 5). Similarly, soybean plots in rotation with corn receiving manure each year produced significantly greater FW NO_3–N concentrations (38.9 vs. 17.2 mg L^{-1}) in comparison to soybean plots receiving no manure or manure application to corn only. Corn-soybean rotation treatments with manure application each year resulted in significantly greater average FW NO_3–N concentrations (39.8 vs. 22.1 mg L^{-1}) compared with the treatment receiving manure in alternate years for corn only. Both treatments produced FW NO_3–N concentrations well above 10 mg L^{-1}, a standard set by the U.S. EPA. This shows that the crops were not able to use the N applied through manure, and a significant amount of unused N was available for leaching to subsurface drainage water. On the average, the corn and soybean rotation with manure application each year received N application rates of 174 and 219 kg N ha^{-1}, respectively, compared with 177 kg N ha^{-1} for corn only. Nitrogen application rates were greater, which resulted in greater FW NO_3–N concentrations in subsurface drainage water.

Table 5. Treatment means for flow-weighted average NO_3–N concentrations (mg L^{-1}) in subsurface drainage water.

Treatment[a]	2001	2002	2003	2004	2005	Average
CSMA	24.9 b	16.9 b	26.8 b	36.5 c	30.1 b	27.0 b
CSME	25.9 b	31.8 a	29.4 b	70.4 a	46.2 a	40.7 a
SCMA	15.8 c	19.3 b	16.0 c	19.9 d	15.0 c	17.2 c
SCME	31.5 a	20.7 ab	44.6 a	50.1 b	48.0 a	38.9 a
Average	24.5	22.2	29.2	44.2	34.8	31.0
$LSD_{(0.05)}$	4.9	12.1	5.0	8.1	10.2	6.1

[a] CSMA = corn after soybean - fall manure to corn only.
CSME = corn after soybean - fall manure to both corn and soybean.
SCMA = soybean after corn - no manure to soybean.
SCME = soybean after corn - fall manure to soybean.

Corn-Soybean Yields

The analysis of variance showed that season and treatment effects on corn and soybean grain yields were significant (P = 0.05). Season and treatment interaction effects were significant for soybean, and block effects were also found to be significant for corn yields. The yearly analysis showed that treatments effects on corn grain yield were significant for 2001 only (table 6). In 2001, corn plots receiving manure each year produced significantly greater corn grain yield (11.33 vs. 11.08 Mg ha^{-1}) compared with corn plots with manure applications in alternate years (table 6). In all other years, corn grain yields were not statistically different for both treatments (P = 0.05). Overall, corn plots with manure application to both corn and soybean resulted in significantly greater corn grain yield (11.83 vs. 11.54 Mg ha^{-1}) compared with corn plots receiving manure for corn only.

The yearly analysis of variance showed that treatment effects on soybean grain yields were significant for 2001, 2002, and 2005. Soybean plots receiving manure each year produced significantly greater soybean grain yields in comparison to soybean plots with no manure application: 3.78 vs. 3.45 Mg ha^{-1} in 2001, 3.99 vs. 3.75 Mg ha^{-1} in 2002, and 4.96 vs. 4.62 Mg ha^{-1} in 2005, respectively. On the average, soybean plots with manure application each year produced significantly greater soybean grain yields (3.68 vs. 3.55 Mg ha^{-1}) compared with no manure application to soybean. The average N application rate to soybean plots was 219 kg N ha^{-1} in addition to 174 kg N ha^{-1} to the corn years of production.

Table 6. Treatment means for corn-soybean yields (Mg ha^{-1}).

Treatment[a]	2001	2002	2003	2004	2005	Average
Corn						
CSMA	11.08 b	12.19 a	10.20 a	12.27 a	11.98 a	11.54 b
CSME	11.33 a	12.16 a	10.50 a	12.73 a	12.43 a	11.83 a
Average	11.21	12.17	10.35	12.50	12.20	11.69
$LSD_{(0.05)}$	0.21	0.47	1.61	1.37	0.67	0.12
Soybean						
SCMA	3.45 b	3.75 b	1.92 a	3.99 a	4.62 b	3.55 b
SCME	3.78 a	3.99 a	1.90 a	3.75 a	4.96 a	3.68 a
Average	3.62	3.87	1.91	3.87	4.79	3.61
$LSD_{(0.05)}$	0.17	0.06	0.44	0.53	0.27	0.12

[a] CSMA = corn after soybean - fall manure to corn only.
CSME = corn after soybean - fall manure to both corn and soybean.
SCMA = soybean after corn - no manure to soybean.
SCME = soybean after corn - fall manure to soybean.

Average N application rates to systems receiving manure each year was more than twice that applied to corn years only (393 vs. 177 kg N ha^{-1}). These N application rates from fall liquid swine manure resulted in greater FW NO_3-N concentrations and NO_3-N leaching losses via subsurface drainage water.

Summary and Conclusions

Field experiments were conducted at Iowa State University's northeastern research center near Nashua, Iowa, from 2001 through 2005 to evaluate the effects of liquid swine manure application to both corn and soybean years of production for soils underlain by subsurface drainage systems. Manure was applied in fall prior to the growing season followed by primary tillage with chisel plow. Nitrogen application rates from manure averaged 174 and 219 kg N ha^{-1} to both corn and soybean, respectively, compared with 177 kg N ha^{-1} to corn only. Data on subsurface drainage flow rates, NO_3-N concentrations in subsurface drainage water, and corn-soybean grain yields were measured for each plot and analyzed as a randomized complete block design. The following conclusions were drawn:

- On the average, corn-soybean rotations receiving manure each year to both corn and soybean resulted in significantly greater flow-weighted NO_3-N concentrations by 80% (39.8 vs. 22.1 mg L^{-1}) and NO_3-N loading by 58% (30 vs. 19 kg ha^{-1}) compared with treatments of manure application to corn years only because of larger total N application from liquid swine manure. Importantly, the grain yield differences were lesser than 3% for corn and 4% for soybean.
- The flow-weighted NO_3-N concentrations in subsurface drainage water were above the EPA safe drinking water levels due to larger N application rates from manure to both the treatments receiving manure each year.
- These results suggest that a corn-soybean rotation system receiving manure each year to both corn and soybean is likely to increase NO_3-N leaching to shallow groundwater without resulting in significant yield benefits. The increased NO_3-N leaching is primarily due to larger total N application from liquid swine manure under the corn-soybean production system studied at this site.

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