Utilizing Swine Effluent on Sprinkler-Irrigated Corn

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ABSTRACT

The expansion of large swine production facilities in Colorado prompted a need to evaluate the impact of swine effluent applied on irrigated corn grown on sandy soil. The objectives of this study were to: evaluate the use of swine effluent as a nutrient source for irrigated corn production, evaluate irrigated corn response grown on sandy soils to different application rates, determine NH_3 loss during sprinkler application and the 72 hour period following application, and evaluate N movement through the soil profile under swine effluent and commercial-N fertilizer for irrigated conditions. The 5-year study was initiated in 1995 on a 14.5-ha sprinkler-irrigated field planted to grain corn. In 1999, the field experiment was expanded to two other facilities, both having one-stage lagoons to evaluate ammonia volatilization from single stage lagoon effluent. Both swine effluent and commercial-N fertilizer treatments were applied at four N rates labeled, control, low, agronomic, and high. All treatments were replicated three times in a randomized complete block design. Approximately 90% of the total nitrogen from the 2-stage lagoon effluent was in ammoniacal form, and the total dry matter content of the effluent was only 0.1-0.2% by volume. Corn yields increased with the increase of both swine effluent and commercial-N fertilizer rates. In contrast to the swine effluent treatments, significant soil-N buildup was observed at the 1.5 to 3.0 m depths for the commercial-N fertilizer treatments. Higher total N and P plant removal for the swine effluent treatments resulted in little N accumulation below the root zone. As the swine effluent application rate increased, the plant N and P removal and recovery rate increased. Ammonia loss during application ranged from 8 to 27% of the total NH_4-N in the effluent due to drift and volatilization, with an average loss of 17%. The range of estimated N loss from the soil within 72 hours of application varied from 24 to 56%, with an average loss of 42% of the NH_4-N in the applied effluent. The total N loss from both the sprinkler application and the soil ranged from 33 to 73% of the applied NH_4-N, with an average loss of approximately 60%. Effluent N concentration did not significantly impact the percent of N lost, while air temperature and wind speed were significant variables in the percent of N lost.

INTRODUCTION

Animal wastes produced by confined swine feeding operations can be a valuable source of nutrients for crop production. However, when manure is used under irrigated conditions, an increased potential for nutrient runoff or leaching occurs, especially on sandy soils. Recent expansion of concentrated swine production facilities in eastern Colorado has increased concerns about potential nitrate (NO_3-N) contamination of the Ogallala Aquifer, the sole source of water for drinking and irrigation in the area.

Concentrated swine production facilities in the area commonly utilize one- or two-stage lagoon systems where effluent must be removed from the lagoon periodically to prevent overflow. Effluent from second-stage lagoon is typically utilized for flush water. Sprinkler application of swine effluent to crop fields is the most common way to utilize these materials. Over-application of lagoon effluent, combined with irrigation or precipitation in excess of crop evapotranspiration, has been implicated in NO_3-N leaching below the root zone.

A five-year study was conducted to evaluate the potential impacts of swine effluent application on irrigated, sandy soils in eastern Colorado. The objectives of this study were to: 1) evaluate the use of swine effluent as a nutrient source for irrigated corn production, 2) evaluate corn yield response to different application rates, 3) determine the amount of mineral N available to the crop over a series of swine effluent application rates, effluent sources, and field conditions and 4) evaluate N movement though the soil profile under swine effluent and commercial-N fertilizer for irrigated conditions.

MATERIALS AND METHODS

The study started in the spring of 1995 on a swine production facility and grain farm in Yuma County, Colorado, and continued through the 1999 growing season. The primary study field was on a 14.5 ha center pivot irrigated field located near a swine production facility with a 4,000-head annual capacity. In 1995 and 1996, the facility was a swine finishing unit, and in 1997 switched to breeding sows. The waste generated from the animals was stored in a two-stage anaerobic lagoon system. A 50-gallon per minute commercial well was used to supply water mainly for animal use and limited flushing of the animal waste to the first lagoon. However, effluent from the second lagoon recycled every 8 hours to flush the animal waste to the first lagoon. Field experiments at the one-stage lagoon sites were conducted at a 2-year old operation 15 km south of Burlington, CO and at a 6-year old operation facility 30 km north of Wray, CO. Soil of both Yuma and Wray sites was Valent sand, while the Burlington site was on a Satanta loam.

The primary study site was under continuous corn production prior to 1995, and was fertilized with commercial-N fertilizer only. The site was a circular field under sprinkler irrigation (center pivot) divided into 3 pie-shaped replications. Each replication contained 4 treatments, including 3 swine effluent rates plus a control. Swine effluent treatments and the control were assigned to each replication randomly using a randomized complete block design. Swine effluent was applied on the field using a sprinkler (center pivot) system by pumping effluent from the second cell of the two-stage lagoon through an underground pipe to the center pivot. Effluent from the first cell flowed into the second cell via gravity through a PVC pipe with an inlet at 1.5 m below the water surface (lagoon depth was 6 m). The solid content of the effluent from the second cell was 0.1-0.2% by volume. The effluent application rates were estimated based on the agronomic N requirements for irrigated corn, according to Colorado State University recommendations for irrigated grain corn production. The low (L) and high (H) rates were 56 kg N ha^{-1} below and above estimated agronomic N. The control (C) received only 28 kg N ha^{-1} of commercial-N fertilizer, as a starter, was applied at planting time.

Glass jars containing 10 ml (8%) H_2SO_4 were used to collect swine effluent samples for each plot by placing them on a metal post 1.6 m above the ground. Four jars were used per plot. After the pivot passed over each plot, effluent samples were transferred to clean plastic bottles, capped, and immediately stored in a cooler until analysis. At the same time, four effluent samples were taken from the pipe (at the pump) that transports effluent to the field, mixed, sub-sampled, and placed in clean acidified sealed plastic bottles and placed in a cooler.

After the pivot passed over each plot where effluent was applied, soil samples 0-2.5, 2.5-5.0, 5.0-7.5, 7.5-15.0, and 15.0-30.0 cm deep were taken in a pre-designated sub-plot of 0.8 x 0.8 m within the main plot where the initial soil samples were taken. Seven to 10 soil cores per depth increment were taken with a stainless steel hand probe, combined, placed into clear plastic bags, and transferred immediately to a cooler. The first soil-sampling period immediately after effluent application was designated 0-h (hours after application), and sampling was repeated 24, 48, and 72-h after effluent application. All soil and effluent samples were analyzed for NH_4-N and NO_3-N using zinc reduction and automated phenate method at the Colorado State University Soil Testing Lab. Ammonia loss during application was calculated as the difference between NH_4-N concentration of the swine effluent pumped from the lagoon and NH_4-N concentration collected in an acidified solution in a glass jar under the pivot. The ammonia loss from the soil was estimated as the difference between soil NH_4-N content at a given time after effluent application and the initial soil NH_4-N mass prior to applying swine effluent. Air temperature, soil temperature, and humidity were measured on site during each application and sampling time using portable digital humidity and temperature devices.

RESULTS

Swine effluent nutrient analysis

Ammonium-N represented on average approximately 90% of the total nitrogen for the two-stage lagoon, where total dry matter was only 0.1-0.2% by volume. Effluent analysis from a two-stage lagoon containing waste from swine finishing units in 1995 and 1996, and swine breeding units in 1997, revealed large differences, especially for NH_4-N and P concentrations (Table 1). Another difference observed was that the concentration of micronutrients from the finishing units was greater than the concentration of the breeding units' effluent.

Table 1. Average of effluent analyses from one-stage and two-stage lagoons†.

		-------- Two-Stage Lagoon --------			One-Stage Lagoon§	
Constituent	Unit	1997	1998 ‡	1999	1999A	1999B
NH_4-N	mg L^{-1}	218	334	209	351	610
NO_3-N	mg L^{-1}	0.24	0.24	0.68	0.87	1.6
Total N	mg L^{-1}	223	340	215	368	639
Total C	mg kg^{-1}	1,025	---	1,060	1,720	1,117
pH	-----	7.6	---	7.8	7.5	8.0
Solids	mg kg^{-1}	1,200	---	1,000	2,500	6,100

† Two-stage lagoon effluent is from breeding units and one-stage effluent is from finishing units.
‡ In 1998, only the analysis of nitrogen is available.
§ Lagoon A is one year old and Lagoon B is 6 years old.

The analysis of swine effluent also showed considerable temporal variability in nutrient concentration at different times during the crop growing season. The analysis showed that the N content decreased late in the growing season. This decrease was due to the high use of fresh water in the flushing system late in the growing season, as compared with early in the season. Also, during the first year of the study, the rate of application was designed to be 1.25, 2.5, and 5.0 cm of effluent due to high initial residual soil-N. In 1996 and 1997 the rates were increased to meet the designed N rates to 2.5, 5.0, and 8.0 cm of effluent based on the residual soil-N and effluent nitrogen content. Interestingly, no foliar burn was observed at any rate or application time over the 4-years of this study.

Corn yield response to swine effluent

Yield performance of irrigated corn increased with the increase of effluent application rates across all three years. The highest rate of swine effluent did not significantly increase grain yield over the recommended agronomic rate (Table 2). However, poor weather conditions, such as cool temperatures and hail damage, affected plant growth and grain yields in 1995 and 1996, as compared to the 1997 growing season, where growing conditions were more optimal. The total amount of rainfall received between May and August during 1995, 1996, and 1997 was 46, 48, and 37 cm, respectively. Cooler than normal temperatures and 3-4 events of high rainfall (>4.0 cm) occurred between early May and mid-August in 1995 and 1996, while only one high rainfall event occurred in early August of 1997. These conditions contributed to relatively low yield performance in 1995 and 1996.

Table 2. Grain yield of irrigated corn under swine effluent treatments.

Effluent Rates	Total N Available†	Yield 1995	Yield 1996	Yield 1997
	kg ha^{-1}			
Control	84	2195	2634	2759
Low	151	5707	4264	8215
Agronomic	207	7212	7400	11288
High	263	7713	8529	12229
$LSD_{(0.05)}$		3382	2695	2875
P>F(0.05)		0.0256	0.0059	0.0580

† Total amount N available for effluent includes credits from soil-N, organic matter, starter-N, and irrigation water-N. Differences between treatments greater than LSD value are significant at alpha= 0.05.

Corn grain yields increased with the addition of commercial-N fertilizer up to the agronomic rate. The increase in N rate by 56 kg N ha^{-1} above the agronomic rate did not produce a significant increase in grain yields. Yield difference between years was primarily a function of weather conditions. The trend of yield response to commercial-N fertilizer rates was similar to those of swine effluent.

Swine effluent can alter soil properties, such as AB-DTPA extractable soil-P, pH, and EC. The AB-DTPA extractable P increased in the top 15 cm as the swine effluent application rate increased. However, during the first year of swine effluent application no significant increase in extractable P value at the top 15 cm for all rates was observed, as compared to the initial level prior to swine effluent application. The increase in P value was significant after 3 consecutive years of swine effluent application, especially under the high application rate. Soil pH did not change in the top 15 cm during the 3 years of swine effluent application. On the other hand, soil EC increased slightly in the top 15 cm after the second and third year of swine effluent application. The average EC value was 0.3 dS m^{-1}, which is not considered high according to soil salinity standards.

Soil N profile after 3 years of swine effluent application

Residual soil-N distribution in the soil profile after 3 years of swine effluent application at different rates showed no significant differences in residual soil-N at all depths. The residual soil-N after harvest was significantly lower for all swine effluent treatments, as compared to the initial residual soil-N prior to the first effluent application in 1995. The decrease in residual soil-N content after 3 consecutive years of swine effluent application was due to soil-N removal by the crop (Fig. 1). This was evident where continued increase in plant-N removal under swine effluent treatments was observed from 1995 to 1997. Soil-N buildup was greater for the high rate of effluent application in the top of the soil profile. The cumulative residual soil-N in the 1.5-3.0 m zone for all swine effluent application rates was greater than in the root zone (0-1.2 m). Approximately 20 kg N ha^{-1} accumulated below the root zone. This accumulation may suggest a potential for N leaching below the root zone, where N is beyond the typical plant rooting depth.

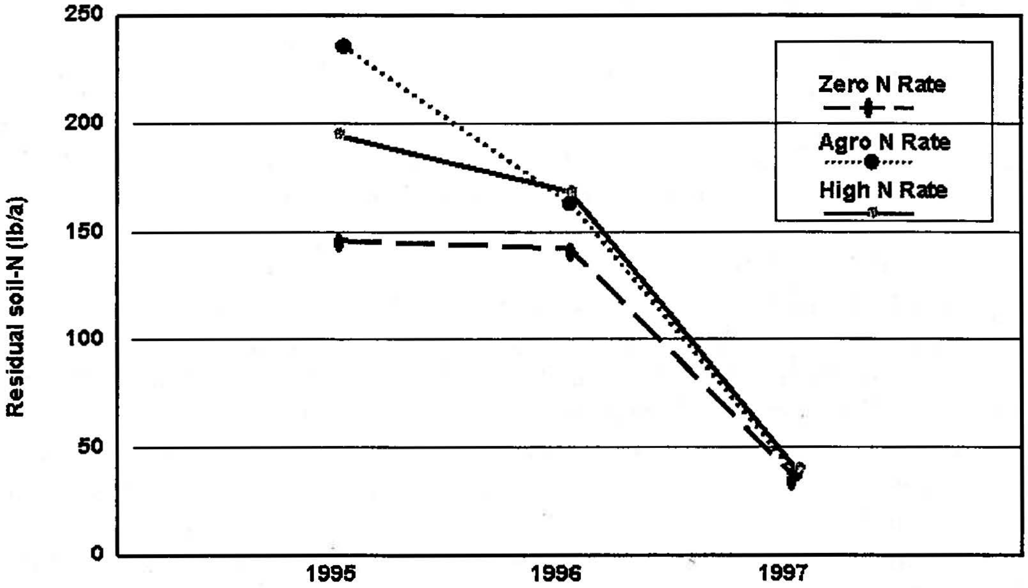

Figure 1. Residual soil-N in the 0-10 ft. soil profile under different effluent application rates.

Ammonia loss from sprinkler and soil

Ammonia loss during sprinkler application accounted for 8-27% of the total NH_4-N applied, while NH_4-N loss from the soil system accounted for an additional 24-56% (Table 3). Ammonium-N concentration was greater in the one-stage lagoons compared to the two-stage lagoon. However, NH_4-N loss on a percentage basis from effluent pumped from both types of lagoon systems (one and two-stage) was not significantly different for Yuma and Burlington on May 3 and 6, 1999. At the 2.5 cm application rate, sprinkler N losses from the two-stage lagoon at Yuma and the one-stage lagoon at Burlington were 21.8 and 20.7%, respectively. Soil N losses at these same sites and time were also not significantly different (38.2 and 42.5%), in spite of the differences in soil texture (sand vs. loam). This indicates that similar weather conditions resulted in similar total percentage of N losses, regardless of effluent source or concentration. However, N loss during different application times of effluent was significantly different. This can be attributed to great differences in weather conditions (i.e., air temperature, wind speed, soil temperature, humidity, etc.) during the times of applications of different months. Effluent source (one- vs. two-stage lagoon) had no influence on the percent of N loss during sprinkler application or from soil surface. This indicates that the percent of N loss due to volatilization was source independent, but weather condition and time of application were the major factors in N loss.

Effluent application rate did not affect the percent of N lost during sprinkler application. The average of N loss during sprinkler application from 1.3 cm h^{-1} application rate was 13.8%, while it was 12.8% from the 1.9 and 2.5 cm h^{-1} application rates. In contrast, N loss from the soil during the first 2-h after effluent application was significantly affected by effluent application rate. The 1.3 cm application rate resulted in a significantly greater percent of soil N loss compared to 2.5 cm application rate, 2-h after application. On the other hand, the rate of NH_4-N loss declined sharply after the 24-h sampling period for all application rates. A comparison of the three application rates (1.3, 1.9, and 2.5 cm) reveals no significant differences in additional NH_4-N loss at 24, 48 and 72-h after application. The total cumulative N loss from both sprinkler and soil was significantly different, however. These results have practical implications for producers as they attempt to manage NH_4 emissions from swine operations. Soil incorporation is currently the recommended best management practice following effluent application, yet producers typically must wait at least 24-h on sandy soils and up to 72-h on fine textured soils before soil moisture conditions are optimal for operating field equipment. By this time, roughly 50% of the applied N may be lost.

Effluent application during cool and calm weather increased the amount of N received at the soil surface, where the percent of NH_4-N loss was the smallest compared to applications during June and July. The greatest N availability was observed during November, where 58-66% of applied NH_4-N was available 72-h after application. High application rates resulted in greater N availability compared to low application rates, for the majority of sites and times of applications. Therefore, cool season applications at high rates can result in excess soil N and a greater potential for N leaching. Conversely, effluent application during warm, windy weather can lead to greater NH_3 volatilization and reduced N availability, resulting in potential crop N deficiencies. These differences in measured N losses and N availability can result in N excesses or deficiencies if not properly accounted for. Thus, farm managers need to use the appropriate N availability estimates for each time of application in order to determine the correct effluent application rate in their nutrient management planning.

Table 3. NH_4-N lost during application and from the soil (% of total applied) as a function of application rate at different sampling periods averaged across all sites and years.

Application Rate	NH_4-N Lost During Sprinkler Application	Soil Inorganic-N Loss at Different Hours After Effluent Application				Total Inorganic-N Loss
		2-h	24-h	48-h	72-h	
(cm h^{-1})	%					
1.3	13.9	27.3	7.8	6.4	5.3	60.7
1.9	12.8	22.6	10.3	6.6	5.4	57.7
2.5	12.8	13.4	8.4	8.0	5.7	48.3
LSD(0.05)	5.3	6.5	4.3	3.9	3.6	7.1

CONCLUSIONS

Several important aspects of utilizing swine effluent became apparent from this study. The N in swine effluent from two-stage lagoons was almost entirely (90%) in the ammoniacal form (NH_4-N). This is important because ammonium-nitrogen is immediately available to the crop, unlike organic forms of N found in many other waste products. Therefore, managing swine effluent-N becomes very similar to managing commercial-N fertilizer under irrigated conditions. The main difficulty in constructing a nutrient management plan is in determining the appropriate rate of ammonia volatilization.

We found that producers can expect to loose up to 25% of the NH_4-N in effluent just during sprinkler application in the summer months. Another 45% of the total NH_4-N in the effluent may subsequently be lost from the soil surface within 72-h after application during the hot months of the year. During cold weather, we observed sprinkler application losses of approximately 10% and soil losses of an additional 25% of the total NH_4-N applied. From this, producers can infer that approximately 30% of the NH_4-N in swine effluent applied during the summer is available for crop utilization, while up to 65% of the NH_4-N in effluent applied in the winter months is available. These N loss rates are consistent with previously published results (Sharpe and Harper, 1997; Safley, et al., 1992).

Increased N application by 56 kg N ha^{-1} above the recommended agronomic rate did not produce a significant yield increase under swine effluent or the commercial-N fertilizer. Total plant N and P removal increased as the swine effluent application rate increased. The increase in total N and P removal with the increase of the effluent application rate contributed to the increase of grain yields. This increase in N removal resulted in lower residual soil-N after three years of effluent application and less potential of N movement below the root zone. The N and P concentrations in the swine effluent were highly variable over time as a function of the waste flushing system, especially with the two-stage lagoon system. Therefore, the rate of N and P loading was highly variable.

Applications of swine effluent at different times during the growing season appears to be an effective way of managing swine effluent under irrigated conditions when it is applied through a sprinkler system, as no plant leaf burn was observed, even at high application rates. Sprinkler-applied swine effluent at the recommended agronomic rate resulted in higher yields and minimal N accumulation below the crop root zone.

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