NITROGEN MANAGEMENT

Estimating Ammonia Loss from Sprinkler-Applied Swine Effluent

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ABSTRACT

Volatilization of NH_3 from sprinkler-applied effluent is a major N loss pathway in the Great Plains region, but there is disagreement as to how much of the total NH_4–N applied in effluent is lost. The objectives of the study were to determine NH_3 loss during sprinkler application and from soil and to determine the amount of mineral N available to the crop over a series of swine effluent application rates, effluent sources, and field conditions. A 3-yr study was conducted on fields near swine (*Sus scrofa*) production operations. A mass balance method was used to estimate N loss during and after effluent application at rates of 1.3, 1.9, and 2.5 cm. Change in inorganic N concentration in effluent captured below the sprinkler was used to estimate volatilization during application, and the change in inorganic N concentration in soil (before and 72 h after application) was used to estimate N loss from soil. Ammonia loss during application ranged from 8 to 27% of the total NH_4–N in the effluent due to drift and volatilization. The range of estimated N loss from the soil varied from 24 to 56% of the NH_4–N in the applied effluent. The total N loss from both the sprinkler application and the soil ranged from 32 to 83%, with an average loss of approximately 58%. 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.

Confined swine feeding operations produce large amounts of effluent containing N and other nutrients that have significant value for crop production. The majority of the N in anaerobically digested swine effluent is in the ammonium (NH_4–N) form, which can convert to ammonia (NH_3) gas and volatilize during or after field application (Liu et al., 1997). Since such a large fraction of the total N is subject to volatilization, knowledge of the NH_4–N fraction available to crops after effluent application is essential for developing sound nutrient management plans for effluent utilization. It is recognized by nutrient management planners that several other N loss pathways influence N availability from applied fertilizers and manures. However, it is also known that immobilization and denitrification occur at a much slower rate than volatilization of NH_3 from surface-applied effluents (Mattila, 1998). These loss components, and other potential loss fractions such as NH_4 fixation and NO_x emissions, are generally accounted for in Colorado by assuming a net annual N gain of 30 kg ha^{-1} for each percent soil organic matter (OM) (Waskom and Davis, 2000). The amount of NH_4 lost due to fixation and processes other than volatilization is minimal over a period of 72 h on low cation exchange capacity (CEC) soils (Mattila, 1998; Sharpe and Harper, 1995, 1997).

Swine producers in the Great Plains depend on NH_3 volatilization losses to reduce the land requirements for effluent utilization. Recent regulations in Colorado require swine producers to implement nutrient management plans in accordance with published university recommendations. Current guidelines on NH_3 volatilization losses are not based on Colorado research. The use of inappropriate volatilization estimates can lead to either overestimation of N availability from effluent applications, which may result in crop yield losses and reduced economic returns, or underestimations of N availability, resulting in soil N buildup and leaching losses to ground water. It has been reported that volatilized NH_3 from agricultural land has increased dramatically since the 1950s, resulting in measurable consequences to sensitive ecosystems (Baron et al., 2000).

Many factors can affect the rate and amount of NH_3 volatilized from the soil. Air temperature, humidity, and wind speed are positively correlated with NH_3 loss. Estimates of the total percent of NH_4–N lost during animal waste storage, or after land application, vary from 10 to 100% of the NH_4–N fraction (Lauer et al., 1976; Lockyear et al., 1989; Dewes et al., 1990; Safley et al., 1992; Sommer and Hutchings, 1995; Eghball et al., 1997). This wide range in measured NH_3 losses results from differences in waste composition, climatic conditions, soils, application methods, and the techniques used for measuring NH_3 fluxes.

In a comparison of broadcasting vs. band spreading pig slurry, Ferm et al. (1999) found that an average of 50% of NH_4–N applied by either method was lost by volatilization during warm and dry conditions, while only 10% was lost during cold and wet conditions. They reported that most of the loss occurred within the first 24 h after application. Under controlled conditions in a laboratory, Subair et al. (1999) found that NH_3 volatilization from liquid hog manure ranged from 28 to 53% of the initial N content of the manure and the N loss was reduced by additions of materials with high C/N ratio to the manure. Fenn and Kissel (1974) demonstrated that increasing temperature affected the rate of NH_3 volatilization, but the total amount of N loss over time was only slightly affected by temperature. Wind

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Abbreviations: ET, evapotranspiration; GLM, general linear model; OM, organic matter; RCB, randomized complete block design.

speed has also been positively correlated with gas flux from stored and applied wastes (Harper et al., 2000). Volatilization of organic compounds from swine waste lagoons was positively correlated with wind velocities between 0.2 and 9.4 m s^{-1}, and maximized at a wind velocity of 3.6 m s^{-1} (Zahn et al., 1997). In a study where swine effluent was applied through a sprinkler system, Sharpe and Harper (1997) found that up to 69% of the NH_4–N was volatilized within 24 h after application. They reported that the rate of NH_3 flux was dependent on air temperature and wind speed and about 13% of the NH_4–N in the effluent was lost during the irrigation process. Safley et al. (1992) reported that wind drift NH_3 loss during center pivot application of swine effluent averaged 20% of the total NH_4–N applied, while a traveling gun system averaged about 26% loss.

A number of methods have been proposed and used to estimate or directly measure NH_3 flux from the soil surface. Micro-meteorological mass balance methods and other methods that use chamber techniques placed over the soil surface to capture NH_3 in acid traps have been used to estimate NH_3 flux from both soils and lagoons (Denmead et al., 1977; Ryden and McNeill, 1984; Svensson, 1994; Sommer et al., 1996). There are pros and cons for these systems. For example, NH_3 volatilization estimated by the chamber method can be influenced by microclimatic conditions within the chamber (McInnes et al., 1986). Other field measurement methods such as wind tunnels, gradient techniques, and mass balance methods with various kinds of traps have known limitations, including labor and instrumentation requirements, potential modification of transport processes, as well as problems with interference from other sources of NH_3, such as nearby animal houses.

The purpose of this study was to refine our understanding of N availability from swine effluents by improving estimates of NH_3 loss during and after application by sprinkler irrigation systems on field scale conditions. To accomplish this task at production swine facilities, an alternative to gas sampling methods was needed. Our initial work with a passive chamber method resulted in NH_3 recovery rates consistently exceeding 100% of applied NH_4–N. Therefore, a mass balance approach was used to directly measure NH_3 loss from the sprinkler system and to estimate soil N availability over a period of 72 h after effluent application. The specific objectives of this study were to (i) determine NH_3 loss during sprinkler application and from soil and (ii) determine the amount of mineral N available to the crop over a series of swine effluent application rates, effluent sources, and field conditions. A goal of the study was to establish guidelines for estimating N availability that can be used by swine producers in the arid, windy Great Plains to develop sound nutrient management plans.

MATERIALS AND METHODS

Field Experiment Description

The field experiment was conducted from 1997 to 1999 at a swine production facility with a two-stage lagoon located 9 km south of Yuma, CO. In 1999, the field experiment was also conducted at two other facilities, both having one-stage lagoons. *One-stage* is a single anaerobic cell lagoon connected directly to the animal housing units waste collection system via underground pipe. *Two-stage* consists of two connected anaerobic cells where effluent is pumped from the second cell to the field or recycled for flushing the waste collection system. One-stage lagoon effluent typically contains a greater N concentration than two-stage lagoons, and there was interest in seeing if this influenced N availability. Field experiments at the one-stage lagoon sites were conducted at a 2-yr-old operation 15 km south of Burlington, CO, and at a 6-yr-old operation facility 30 km north of Wray, CO. Soil of both Yuma and Wray sites was Valent sand (mixed, mesic Ustic Torripsamments) with average pH of 7.2 and OM of 0.5 to 1.0%. Soil at the Burlington site was Satanta loam (fine-loamy, mixed, superactive, mesic Aridic Argiustolls), with an average pH of 6.9 and OM of 1.0 to 2.0%.

The field experiment layout was a randomized complete block design (RCB) with four replications containing three treatments of swine effluent at application rates of 1.3, 1.9, and 2.5 cm. These application rates were achieved by using a sprinkler (center pivot) system equipped with a computerized management system to control the effluent application rate. Ten rain gauges were used in each plot to monitor each application rate. An average of 10 readings was used to determine the actual application rate. The CVs of measured application rates were consistently <10% of the designed application rate. The plots were established on fallow corn (*Zea mays* L.) fields with approximately 30% surface residue cover. Small plots measuring 7.6 by 4.6 m were located on flat area where no runoff occurred. Plots were separated by 3.3 m between individual plots and 6.6 m between replications. Immediately before applying the swine effluent, 7 to 10 soil samples to a 30-cm depth were collected from each plot. Samples were subdivided into depth increments of 0 to 2.5, 2.5 to 5.0, 5.0 to 7.5, 7.5 to 15.0, and 15.0 to 30.0 cm to determine gravimetric water content. After they were air-dried, samples were weighed, ground, and analyzed for NH_4–N and NO_3–N using Colorado State University Soil Testing Lab standard procedures (Workman et al., 1988; Mulvaney, 1996).

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 (Table 1). At the same time, four effluent samples were taken from the pipe (at the pump) that transports effluent to the field, mixed, subsampled, and placed in clean acidified sealed plastic bottles and placed in a cooler. Effluent analyses reported in Table 1 are averages with CVs of 10 to 15%. However, the actual values of effluent analyses for NH_4–N and NO_3–N for each time of application were used in the calculation of NH_4–N loss.

After the pivot passed over each plot where effluent was applied, soil samples 0 to 2.5, 2.5 to 5.0, 5.0 to 7.5, 7.5 to 15.0, and 15.0 to 30.0 cm deep were taken in a predesignated subplot of 0.8 by 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, 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 Zn reduction (Workman et al., 1988) and automated phenate method (Mulvaney, 1996) at the Colorado State University Soil Test-

Table 1. Averages of effluent chemical analysis derived from one-stage and two-stage lagoons.†

		Two-stage lagoon			One-stage lagoon§	
Constituent	Unit	1997	1998‡	1999	1999 A	1999 B
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}	1025	–	1060	1720	1117
pH	–	7.6	–	7.8	7.5	8.0
Solids	mg kg^{-1}	1200	–	1000	2500	6100

† Two-stage lagoon effluent is from breeding units and one-stage effluent is from finishing units.
‡ In 1998, only the analysis of N is available.
§ Lagoon A is 1 yr old and Lagoon B is 6 yr old.

ing Lab. Air temperature, soil temperature, and humidity were measured onsite during each application and sampling time using portable digital humidity and temperature devices. Weather data such as wind speed, air temperature, soil temperature, and humidity were measured using local weather and evapotranspiration (ET) stations (Campbell Scientific Weather Station).

Our initial work with a passive chamber method at the Yuma and Burlington sites resulted in NH_3 recovery rates consistently exceeding 100% of applied NH_4–N, likely due to high background NH_3 from the nearby swine operations, coupled with limitations of the chamber method in field situations (data not published). Gas capture methods are generally not feasible for producers faced with developing nutrient management plans for regulatory compliance. Earlier published work showed the potential for field scale methodologies to estimate NH_3 loss under sprinkler irrigation systems (Safley et al., 1992; Sharpe and Harper, 1997). Therefore, we used a mass balance approach to directly measure NH_3 loss from the sprinkler system, and a soil sampling approach to estimate soil N availability on a field scale during a period of several days after effluent application.

Data generated by this study and results presented were statistically analyzed using the statistical analysis system (SAS Inst., 1988). The general linear model (GLM) procedure was used to perform the analyses of variance, and LSD was used for mean separation within a given effluent application rate.

Mass Balance Approach

Ammonia loss during application was 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 sprinkler:

$$E_{sp} = (L_c - J_c) \times K \times R \quad [1]$$

where

E_{sp} = ammonia loss during sprinkler application (kg ha^{-1})
L_c = NH_4–N concentration of lagoon effluent before application (mg L^{-1})
J_c = NH_4–N concentration of effluent after application as it reaches soil surface (mg L^{-1})
K = mass conversion coefficient of liquid effluent (kg ha-cm^{-1} per mg L^{-1})
R = effluent application rate (cm)

K value used in Eq. [1] (0.10 kg ha-cm^{-1} per mg L^{-1}) was used to convert NH_4–N concentration (mg L^{-1}) of swine effluent liquid to kg ha-cm^{-1}. The R values were 1.3, 1.9, and 2.5 cm.

The ammonia loss from the soil (E_s) was the difference between soil NH_4–N content after effluent application (S_c) and the initial soil NH_4–N mass (S_i) before applying swine effluent. Ammonia loss from soil was calculated as follows:

$$E_{s(z,t)} = (S_c - S_i) \times D \quad [2]$$

where

$E_{s(z,t)}$ = ammonia loss from soil at any given time and soil depth (kg ha^{-1})
S_c = soil NH_4–N + NO_3–N (mineral N) content after effluent application at a given time (mg kg^{-1})
S_i = soil NH_4–N + NO_3–N (mineral N) content before effluent application (mg kg^{-1})
D = mass conversion coefficient of soil inorganic N content to mass for a given soil depth and sampling period (kg ha^{-1} per mg kg^{-1})

The soil NH_3 loss calculation included NO_3–N for each depth and time period before and after swine effluent application to account for the possibility of concentration changes due to N transformation (i.e., nitrification, denitrification, mineralization, etc.) at the different depth increments of soil during the 72-h period.

For the Yuma and Wray sites (Valent sand: mixed, mesic Ustic Torripsamments), D values for depths 2.5, 7.5, 15, and 30 cm were 0.34, 1.02, 2.04, and 4.04, respectively. For the Burlington site (Satanta loam: fine-loamy, mixed, superactive, mesic Aridic Argiustolls), D values for depths 2.5, 7.5, 15, and 30 cm were 0.31, 0.93, 1.86, and 3.72, respectively. The total NH_3 loss was estimated as a percentage of the total applied NH_4–N:

$$\text{E-NH}_3\% = [(E_{sp} + E_s)/(L_c \times K \times R)] \times 100 \quad [3]$$

Determination of Soil Wetting Front

The soil depths used in the estimation of NH_3 loss were determined by using the advance of the wetting front. The wetting front was determined from soil moisture data that was collected for each depth increment for each time of measurement (0, 24, 48, and 72 h). Increases in soil moisture in the root zone following effluent application were used to indicate the appropriate depth of soil used to estimate NH_3 loss. Soil moisture relationships from the sand and loam soils over three

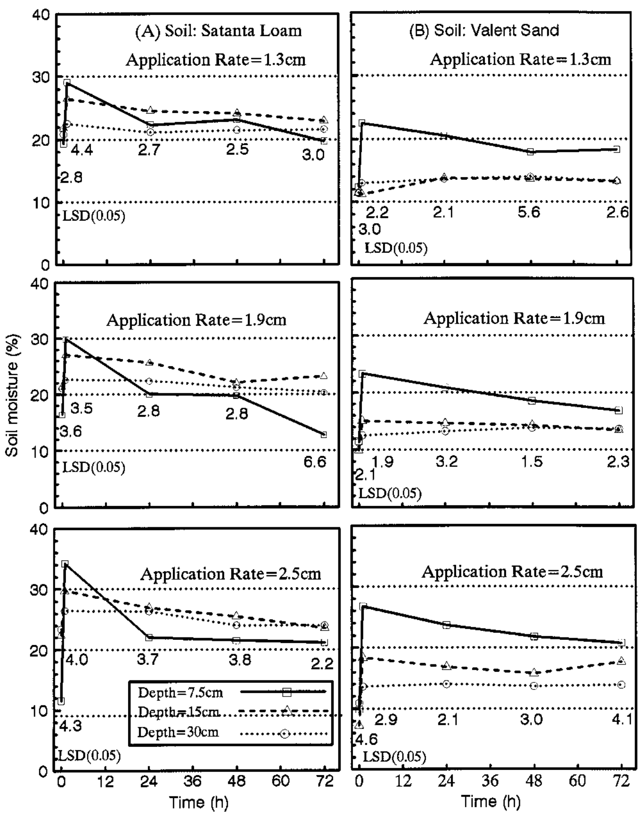

Fig. 1. Soil moisture content and wetting depth at different sampling periods and effluent application rates.

application rates are summarized in Fig. 1. The application rate of 2.5 cm of swine effluent resulted in the advance of the wetting to 15 cm deep in the Valent sand only. Soil moisture content did not change significantly at the 15- to 30-cm depth for either soil. The soil depth used to estimate NH_3 loss for the Valent sand was 0 to 7.5 cm for effluent application rates of 1.3 and 1.9 cm, while a 0- to 15-cm soil depth was used for NH_3 loss calculations at the 2.5 cm effluent application rate. Soil moisture content for the Satanta loam soil showed no significant change below the 7.5-cm soil depth at all application rates. Therefore, the top 7.5 cm of soil was used to estimate soil NH_3 loss for all treatments on the Satanta loam (Fig. 1).

RESULTS AND DISCUSSION

Ammonia Loss from Sprinkler and Soil

Ammonia loss during sprinkler application accounted for 8 to 27% of the total NH_4–N applied, while NH_4–N loss from the soil system accounted for an additional 24 to 56% (Table 2). Ammonium-N concentration was greater in the one-stage lagoons compared with 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 as shown for Yuma and Burlington on 3 and 6 May 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. In addition, analysis of variance of the results shows no significant difference in N loss during sprinkler application or from soil due to different application rates except for soil loss at Yuma site (Table 3). 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. However, the study was not designed to separate the effect of different climate variables on N loss. Effluent source (one- vs. two-stage lagoon) has no influence on the percentage of N loss during sprinkler application or from soil surface (Table 3). This indicates that the percentage of N loss due to volatilization was source independent, but weather condition and time of application were the major factors in N loss.

High temperatures and wind speeds increased NH_4–N loss during effluent application and from the soil. It is not possible to separate the combined effect of both parameters on NH_4–N loss from sprinkler and soil. However, it was evident that higher air temperatures increased NH_4–N loss during May and November of 1999, and high wind speeds increased NH_4–N loss during 3 and 6 May 1999 (Table 2). These results show the percentage of NH_4–N loss was affected by both temperature and wind speed changes. For example, cool temperatures (-6.7 to -2.6°C) and low wind speed (2.6–2.9 m s^{-1}) in November 1999 at Wray site resulted in a smaller percentage NH_4–N loss during sprinkler application (9–10%). Then 20% loss was observed when temperatures and wind speeds were greater in June of 1998 (Table 2). This comparison was significant across all effluent application rates.

Effluent application rate did not affect the percentage of N lost during sprinkler application (Table 4). Table 4 shows the averages of N sprinkler's loss was 13.8% from the 1.3 cm h^{-1} application rate, whereas 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 percentage of soil N loss compared with 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

Table 2. Ammonium-N loss during effluent sprinkler application and from the soil 72 h after application at different air temperature and wind speed.

Date	Site†	Application rate	Sprinkler appl. N loss	Weather condition during application		Soil N loss after 72 h	Weather condition 72 h after application		Total N loss (sprinkler + soil)
				Air temp.	Wind speed		Air temp.	Wind speed	
		cm h^{-1}	%	C°	m s^{-1}	%	C°	m s^{-1}	%
12 June 1997	Yuma	1.3	26.9	17.3	2.9	46.2	18.9	3.5	73.1
2 July 1997		1.3	16.7	16.7	3.0	53.1	17.2	3.3	69.8
18 Apr. 1997		1.3	13.3	5.6	3.6	55.8	7.2	3.7	69.1
LSD (0.05)			11.3			8.1			10.6
12 June 1997	Yuma	1.9	25.2	17.3	2.9	44.7	18.9	3.5	69.9
2 July 1997		1.9	16.7	16.7	3.0	43.0	17.2	3.3	59.7
18 Apr. 1997		1.9	8.1	5.6	3.6	50.1	7.2	3.7	58.2
LSD (0.05)			12.0			6.6			9.3
11 June 1998	Yuma	1.3	19.8	21.1	4.6	44.9	12.6	4.6	64.7
3 May 1999	Yuma	1.3	15.8	13.3	4.2	43.4	10.4	8.2	59.2
6 May 1999	Burlington	1.3	25.0	8.2	10.0	41.8	13.0	5.5	66.8
23 Nov. 1999	Wray	1.3	10.2	−6.7	2.6	31.8	−2.6	2.8	42.0
LSD (0.05)			8.1			7.4			14.0
11 June 1998	Yuma	1.9	19.2	21.1	4.6	53.1	12.6	4.6	72.3
3 May 1999	Yuma	1.9	16.1	13.3	4.2	43.4	10.4	8.2	59.5
6 May 1999	Burlington	1.9	23.0	8.2	10.0	40.4	13.0	5.5	63.4
23 Nov. 1999	Wray	1.9	10.6	−6.7	2.6	23.6	−2.6	2.8	34.2
LSD (0.05)			7.8			11.5			19.2
11 June 1998	Yuma	2.5	20.9	21.1	4.6	43.0	12.6	4.6	63.9
3 May 1999	Yuma	2.5	21.8	13.3	4.2	38.2	10.4	8.2	60.0
6 May 1999	Burlington	2.5	20.7	8.2	10.0	42.5	13.0	5.5	63.2
23 Nov. 1999	Wray	2.5	9.4	−6.7	2.6	24.0	−2.6	2.8	33.4
LSD (0.05)			8.0			13.2			17.5

† Yuma is a two-stage lagoon, Burlington is a one-stage lagoon (1 yr old), and Wray is a one-stage lagoon (6 yr old).

equipment. By this time, roughly 50% of the applied N may be lost.

Nitrogen Availability following Effluent Application

The amount of N available in the soil after effluent application is highly variable and is dependent on several factors. Effluent application rate, the source of the effluent, and the weather conditions during the effluent application were observed to have a significant impact on the amount of available N in the soil 72 h after effluent application (Table 5). Effluent source, whether from a one or two-stage lagoon, contributed significantly to the amount of N available after effluent application. For example, the average NH_4–N concentration from one-stage lagoons is 481 mg L^{-1}, compared with the average NH_4–N concentration from two-stage lagoons of 271 mg L^{-1} (Table 1). The greater initial N content of the one-stage lagoon resulted in a greater soil N availability on a mass basis 72 h after application compared with the two-stage lagoon.

The net gain of soil mineral N was significantly different across application rates. In general, the greater the application rate, the greater the amount of net N that was received at the soil surface. Effluent application during cool and calm weather increased the amount of N received at the soil surface, as shown in April, May, and November applications, where the percentage of NH_4–N loss was the smallest compared with applications during June and July. The greatest N availability was observed during November, where 58 to 66% of applied NH_4–N was available 72 h after application. High application rates resulted in greater N availability compared with 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. Thus, farm managers need to use the appropriate N availability estimates for each time of application to determine the

Table 3. Analysis of variance of NH_4–N loss from each site by application rate, lagoon type, and time of application.

Location†	Source	df	Mean square	*F*	*P* < 0.05
Yuma	Appl. rate × Sprinkler N loss	2	76.3	2.0	0.16
	Appl. rate × Soil N loss	2	78.9	5.8	0.03
	Appl. time × Total N loss	4	364.1	3.8	0.01
Burlington‡	Appl. rate × Sprinkler N loss	2	69.7	1.1	0.46
	Appl. rate × Soil N loss	2	85.7	1.0	0.14
Wray‡	Appl. rate × Sprinkler N loss	2	65.8	0.43	0.66
	Appl. rate × Soil N loss	2	43.3	0.44	0.81
One-stage vs. two-stage lagoon	Lagoon × Sprinkler N loss	1	152.0	1.6	0.22
	Appl. rate × Soil N loss	2	78.9	3.6	0.06

† Effluent used in Yuma location is from a two-stage lagoon, whereas effluent used in Burlington and Wray was from one-stage lagoon.
‡ Both Burlington and Wray sites' studies were conducted during 1 mo only (May and November 1999, respectively).

Table 4. Percent of NH_4–N lost during application and from the soil 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

correct effluent application rate in their nutrient management planning.

CONCLUSIONS

Producers need an applicable and attainable method for estimating N availability following swine effluent application on production fields to comply with nutrient management regulations. A mass balance method for estimating N availability following swine effluent application was examined over 3 yr in northeastern Colorado. In this region, most swine operations use center pivot irrigation systems for effluent application and need to know how much N is assumed lost due to drift and volatilization during and following effluent application. We found producers can expect to lose 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, whereas 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).

This method of estimating N availability is based on the assumption that most of the NH_4–N lost in the period immediately following effluent application is due to volatilization rather than other potential N transformations, such as immobilization or fixation (Sharpe and Harper, 1995; Mattila, 1998). This assumption is consistent with our finding that approximately 50% of total N loss occurred in the first 24 h following application on both sandy and loam soils. Producers attempting to manage NH_4 emissions from swine operations are currently advised to incorporate effluent within 72 h, yet much of the applied ammonia is already lost by this time.

A soil sampling approach to determining N availability from swine effluent is valid with certain restrictions and overcomes the problems associated with interferences from atmospheric background NH_3 from nearby swine facilities. Initial work with a passive chamber method at the Yuma and Burlington sites resulted in NH_3 recovery rates consistently exceeding 100% of applied NH_4–N, likely due to high background NH_3, coupled with limitations of the chamber method in field situations. Additionally, these methods are generally not feasible for producers faced with developing nutrient management plans for regulatory compliance. Soil sampling for determining N application rate is the standard approach in the Great Plains and the western USA, and crop advisors are generally well equipped to provide this service. This approach requires an intensive and

Table 5. Soil mineral N content 72 h after applying effluent.†

Date	Site‡	Initial soil N	Application rate	Applied effluent N	Soil N after 72 h	Net soil N gain after 72 h
		kg ha^{-1}	cm	kg ha^{-1}		
12 June 1997	Yuma	3.5	1.3	50.2	17.1	13.6
2 July 1997		2.8	1.3	24.0	10.1	7.3
18 Apr. 1997		4.4	1.3	56.0	21.7	17.3
LSD (0.05)		2.1		16.9	6.5	6.2
12 June 1997	Yuma	4.0	1.9	41.9	16.6	12.6
2 July 1997		3.8	1.9	32.4	17.4	13.6
18 Apr. 1997		3.8	1.9	75.8	35.4	31.6
LSD (0.05)		1.9		19.8	7.2	6.9
11 June 1998	Yuma	3.9	1.3	39.5	17.8	13.9
3 May 1999	Yuma	4.1	1.3	31.4	16.9	12.8
6 May 1999	Burlington	3.7	1.3	25.0	12.0	8.3
23 Nov. 1999	Wray	6.2	1.3	84.8	55.4	49.2
LSD (0.05)		2.0		25.9	23.0	19.9
11 June 1998	Yuma	3.8	1.9	52.8	18.4	14.6
3 May 1999	Yuma	2.6	1.9	41.4	19.4	16.8
6 May 1999	Burlington	4.0	1.9	34.0	16.4	12.4
23 Nov. 1999	Wray	7.7	1.9	126.7	91.1	83.4
LSD (0.05)		3.1		36.1	41.8	38.3
11 June 1998	Yuma	4.9	2.5	66.3	28.9	24.0
3 May 1999	Yuma	2.9	2.5	50.4	23.1	20.2
6 May 1999	Burlington	4.3	2.5	53.5	24.0	19.7
23 Nov. 1999	Wray	7.7	2.5	158.5	113.2	105.5
LSD (0.05)		3.0		45.3	39.7	33.4

† Soil mineral N content = NH_4–N + NO_3–N.
‡ Yuma is a two-stage lagoon, Burlington is a one-stage lagoon (1 yr old), and Wray is a one-stage lagoon (6 yr old).

consistent soil sampling methodology to reduce the inherent variability associated with commercial scale production conditions. It is also necessary to consistently sample soil to depths that include the wetting front created by effluent application. We found it was possible to achieve reproducible results if the soil sampling area was uniform or relatively small, thus reducing soil variability.

Effluent application during cool and calm weather increased the amount of N received at the soil surface. The greatest N availability was observed during November, where 58 to 66% of applied NH_4–N was available 72 h after application. Conversely, effluent application during warm, windy weather can lead to greater NH_3 losses during and after sprinkler application. Measurements during summer months resulted in as little as 27% of the total applied NH_4–N available 72 h after application. These differences in measured N losses and N availability can result in N excesses or deficiencies if not accounted for properly. Therefore, producers and crop advisers need to use the appropriate seasonal N availability estimates to determine the appropriate effluent application rates for their nutrient management plans.

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