MANURE NITROGEN MANAGEMENT ISSUES IN CONSERVATION TILLAGE

John P. Chastain, Ph.D.

Associate Professor
Department of Agricultural and Biological Engineering
239 McAdams Hall
Clemson University, Clemson, SC USA
jchstn@clemson.edu

ABSTRACT

A new model of ammonia volatilization losses following application of animal manure and granular fertilizer has been developed based on data from the literature and new data obtained by researchers at Clemson University. The new ammonia-N loss model was combined with a range of organic-N mineralization factors from the literature to provide estimates of the plant available nitrogen (PAN, lb/ac), ratio of PAN to total nitrogen (TN), and the mass of ammonia-N lost per acre following application of fertilizer and animal manure to a field covered with crop residue.

The new model was compared to the current estimates provided by Clemson University Extension. It was determined that current Clemson Extension estimates of ammonia-N loss differ from the new model by 2% to 95%. The differences in estimates in the value of PAN/TN ranged from -23% to 21%.

The new model was used to estimate the ammonia-N losses following application of granular fertilizer, lagoon supernatant, broiler litter, and untreated dairy manure to a no-till field. Broadcast application resulted in ammonia-N losses ranging from 0.4 lb NH_3-N/ac for lagoon supernatant to 48 lb NH_3-N/ac for dairy manure. The ammonia-N loss for granular fertilizer (25 lb NH_3-N/ac) was greater than for poultry litter (7.4 lb NH_3-N/ac).

The influence of application methods such as band spreading, band spreading with immediate soil coverage, direct injection, immediate incorporation with light tillage, and incorporation with irrigation was studied using the model. The results indicated that these practices could reduce the mass of ammonia-N lost per acre by 51% to 94%. Model results indicate that the time lag between application and incorporation should be no more than 24 h for granular fertilizer, 6 h for poultry litter, and 12 h for dairy manure.

INTRODUCTION

Current conservation tillage practices generally do not include the use of tillage to incorporate granular fertilizers or animal manure. In all cases, nitrogen will be lost to the atmosphere by ammonia volatilization to some extent. Ammonia volatilization loss of nitrogen equates to a financial loss to the farmer. Ammonia volatilization is also of environmental concern due to the potential for acid rain formation and deposition into sensitive ecosystems that are a significant distance from the farm.

The economic and environmental impacts associated with ammonia losses have given rise to a need for better estimates of the amount of ammonia-N lost from no-till fields. Better estimates of ammonia-N losses can be used to evaluate practices to reduce the release of ammonia to the atmosphere.

A significant amount of work has been conducted at Clemson University to better quantify ammonia volatilization losses following land application of animal manure. Recent data by Montes (2002) and analysis presented elsewhere in these proceedings by Chastain and Montes (2005) have indicated that ammonia volatilization losses during irrigation of animal manure is insignificant at the 95% level of probability. In addition, new data have been obtained to quantify ammonia-N losses following application of lagoon supernatant and poultry litter on forestland. Pooled analysis of the new data with data from the literature indicated that ammonia-N loss from the plant residue on the forest floor, hay, grass, and crop residue were not significantly different. All available data were combined to develop a new model that represents ammonia volatilization losses following application of granular fertilizer and animal manures.

The objectives of this paper are to: (1) provide a summary of the new ammonia volatilization model, (2) compare the new model to current Clemson University Extension estimates, and (3) compare the ammonia-N losses from no-till fields fertilized with lagoon supernatant, poultry litter, dairy manure, and granular ammonium fertilizer using various application methods.

METHODS

Nitrogen can be present in manure as ammonium-N, ammonia-N, organic-N, and nitrate-N. Not all of the nitrogen in manure is immediately available for plant use. The nitrogen that is available for plant use is called the plant available nitrogen (PAN).

Most animal manure contains very little nitrate-N and as a result it is typically not measured. However, manure that receives aerobic treatment, i.e. composting or aeration, should be analyzed for nitrate-N.

Most laboratories measure the total ammoniacal nitrogen content (TAN) of animal manure, which is NH_4^+-N + NH_3-N. The total ammoniacal nitrogen concentration is reported as ammonium-N (NH_4^+-N) by many university laboratories.

The plant available nitrogen in animal manure, compost, or sludge can be estimated as:

$$\text{PAN} = A_f\,\text{TAN} + m_f\,\text{Organic-N} + \text{Nitrate-N}. \quad (1)$$

Where:

A_f = the ammonium-N availability factor, and

m_f = the organic-N mineralization factor.

Therefore, the plant available nitrogen is the sum of the TAN that is not lost by volatilization, the portion of the organic-N that is mineralized during the growing season, and all of the nitrate nitrogen.

The fraction of the TAN that can be used by a crop is expressed as the ammonium-N availability factor (A_f). The ammonium-N availability factor is calculated from the ammonia-N lost as:

$$A_f = (1 - AL(\text{t}))/100. \quad (2)$$

Where,

$AL(t)$ = the ammonia-N lost following application expressed as percentage of TAN applied = 100 (NH_3-N(t) /TAN-applied).

The current recommendations by Clemson University Extension for A_f are (CAMM, 2005):

- 0.5 for surface applied manure with no incorporation,
- 0.8 for surface application followed by incorporation within 24 hours
- 0.8 for irrigation of lagoon supernatant or liquid manure, and
- 1.0 for direct injection or immediate incorporation.

A new model of ammonia-N loss following application of animal manure has been under development at Clemson University over the past few years. The relationship to describe the ammonia-N loss following application of animal manure or granular fertilizer is:

$$AL(t) = f_S\, f_A\, AL_{\max}\left(1 - e^{-Kt}\right). \qquad (3)$$

Where,

f_S = a soil factor that ranges from 1.0 for application to a standing crop, grass, or crop residue down to 0.7 for application of high TS manure to bare soil,
f_A = application method factor that depends on the method of application,
$AL_{\max}$ = the maximum ammonia-N loss possible ,100 (NH_3-N/TAN-applied), and
K = a rate constant that is a function of manure type and wind speed (h^{-1}).

Values and relationships for f_S , f_A , $AL_{\max}$, and K are tabulated in Appendix A for a variety of application methods, several types of animal manure, and granular fertilizer.

At the present, Clemson University Extension recommends that a value of 0.6 be used for the mineralization factor for all types of animal manure. Therefore, 60% of the organic-N is assumed to be available in all cases using Clemson Extension's recommendations.

The actual amount of organic-N that will be mineralized depends on manure type, level of treatment, soil pH, soil temperature, soil moisture content, and soil type. Evanylo (2000) provided a detailed review of the research related to the factors that effect mineralization of animal manure. Evanylo determined that animal species and manure treatment were the main factors that could be practically considered to estimate values for m_f.

The new model includes the results of Evanylo's review and a few other reviews of the literature. The values of m_f used with the new model are given in Table 1. The ranges of m_f are also given to indicate the large amount of variation in the available data.

Animal manure contains all 13 of the essential plant nutrients that are used by plants. These include nitrogen (N), phosphorous (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), manganese (Mn), copper (Cu), zinc (Zn), chlorine (Cl), boron (B), iron (Fe), and molybdenum (Mo). Plant nutrients originate from the feed, supplements, medications, and water consumed by the animals. Using animal manure as a fertilizer for crops may provide a portion, or all, of the plant requirements. The amount of nutrients provided depends on the nutrient content of the manure (lb of nutrient / 1,000 gal of manure or lb / ton) and the amount of manure applied (gal/ac or tons/ac). The amount of manure applied per acre, or application rate, is typically based on the nitrogen needs of the crop. However, phosphorous requirement can also be used to determine the application rate.

Table 1. Estimates of organic-N mineralization factors for use in the new model (Evanylo, 2000; Mikkelsen, et al., 1995; and Rynk et al., 1992).

Material	Recommended value of m_f (range)
Dairy and beef manure (untreated)	0.4 (0.13 to 0.51)
Swine manure (untreated)	0.5 (0.25 to 0.50)
Poultry manure (litter and untreated layer manure)	0.6 (0.47 to 0.90)
Lagoon supernatant	0.7 (0.5 to 0.9)
Anaerobically treated manure or sludge	0.6 m_f (based on species)
Compost	0.12 (0.06 to 0.12)

The nutrient content of animal manure varies significantly based on species, amount of water added for handling, and level of treatment. Representative animal nutrient data are provided for common types of animal manure used in the Southeastern US in Table 2. Additional information on the nutrient content of animal manure is provided in the manuals of the Confined Animal Manure Managers Program (CAMM, 2005).

The material application rate (MAR, ton/ac or gal/ac), or the amount of manure needed per acre to provide the N requirement, is calculated as:

$$\text{MAR} = \text{N requirement (lb/ac)} \div \text{PAN}. \quad (4)$$

Where,

PAN = lb PAN / ton or lb PAN / gal.

The amount of ammonia-N lost per acre following application of animal manure or fertilizer was calculated as:

$$M_{AL} = (AL(t)/100) \cdot \text{TAN} \cdot \text{MAR}. \quad (5)$$

Where,

M_{AL} = mass of ammonium-N lost (lb/ac), and

TAN = lb TAN/ ton or lb TAN / gal.

Table 2. Nutrient and solids content of selected types of animal manure (Chastain et al. 2001; broiler litter data from Coloma, 2005).

Moisture	99.63%	98.0%	93%	24.4
Total Solids	0.37%	2%	7%	75.6
Manure Type	Swine Lagoon Supernatant	Untreated Swine Manure[1]	Untreated Dairy Slurry	Broiler Litter
Constituent	------------- lb/1,000 gal		--------------	lb / ton
TAN [2]	3.4	11.4	9.4	10
Organic - N	1.4	5.6	13.6	44
TN [3]	4.8	17.0	23.0	54
P_2O_5 [4]	2.8	13.4	14.0	66
K_2O [5]	6.1	14.2	21.0	57
Ca	0.86	3.7	10.0	44
Mg	0.46	2.4	4.8	9
Zn	0.03	0.28	0.21	0.6
Cu	0.02	0.26	0.05	0.6
Mn	0.01	0.12	0.18	0.6
S	0.31	1.3	3.1	10.6
Na	1.8	2.5	3.2	13.4

[1] The total solids content from flush and pit-recharge buildings will vary from 1.5% to 2.6% depending on building design and animal weight. A mean value of 2% is shown.
[2] TAN = NH_4^+-N + NH_3-N
[3] TN = Organic-N + TAN
[4] Total phosphorus expressed as P_2O_5. To get elemental P multiply by 0.44.
[5] Total potassium expressed as K_2O. To get elemental K multiply by 0.83.

ANALYSIS AND RESULTS

Comparison of Clemson Extension Recommendations with the New Model

Estimates of the plant available N in animal manure depends on the estimates of the ammonia-N availability factor and mineralization factor, and measurements of TAN and organic-N content of the material (equation 1). The ratio of PAN to TN is the fraction of the total nitrogen that can be used to meet crop needs.

The estimates of A_f, m_f, and PAN/TN based on Clemson University Extension recommendations and the new model are compared for four types of animal manure and ammonium-N fertilizer in Table 3. In all cases, the manure or fertilizer was assumed to be spread on a field with crop residue with no tillage, rain or irrigation for 7 days. Therefore, these results reflect the maximum ammonia-N loss.

The greatest difference between the two methods is in the estimate of ammonium-N availability. The differences in A_f range from 2% for untreated dairy slurry to -86% for untreated swine manure. The Clemson Extension value over predicts ammonia-N losses, (1- A_f), for irrigation of swine lagoon supernatant by 95% as compared to the new model.

Table 3. Comparison of ammonia availability factors (A_f), mineralization factors (m_f), and PAN/TN values for application of animal manure and fertilizer on no-till fields (no incorporation, irrigation or rain for 7 days).

Material	Clemson Extension [1]			New Model [2]		
	A_f	m_f	PAN/TN	A_f	m_f	PAN/TN
Untreated Dairy Slurry (TS = 7%)	0.50	0.6	0.56	0.49	0.4	0.44
Untreated Swine Manure (TS = 2%)	0.50	0.6	0.53	0.93	0.5	0.79
Broiler Litter (TS = 75.6%)	0.50	0.6	0.58	0.75	0.6	0.63
Lagoon Supernatant (TS = 0.37%)	0.80	0.6	0.74	0.99	0.7	0.91
Granular Fertilizer	1.0	NA[3]	1.0	0.80	NA	0.80

[1] Based on current recommendations from Clemson University Extension (CAMM, 2005).
[2] Based on a new model of ammonia volatilization under development at Clemson University (equation 3 and Appendix A).
[3] Not applicable

Mineralization rates differed between the two methods by 0% to 33%. The best agreement was for broiler litter and the worst agreement was for dairy slurry.

The value of PAN/TN encompasses the overall differences in the two methods to estimate PAN and is directly related to the economic value of manure. The differences in PAN/TN estimates ranged from -23% for lagoon supernatant to 21% for dairy manure. The best agreement in PAN/TN estimates was for broiler litter.

At the present, ammonia volatilization losses following application of fertilizer-N are ignored. The new model uses a mean value from the literature for A_f of 0.80. Therefore, 20% of the purchased N would be lost following broadcast application onto a no-till field. The economic importance of this loss depends on the price of N.

Variation in Ammonia Loss with Time Following Application to No-Till Fields

The new model provides a method to estimate the rate of ammonia-N loss as well as the total amount of N lost following application of manure and granular fertilizer. The rate of ammonia-N loss is controlled by the rate constant, K, in equation 3. The value of K varies with the material and wind speed. At the present, variation in wind speed is not included in the model. However, as wind speed increases, K increases. Recommended values for the rate constant for different types of manure and granular fertilizer are given in Table A4.

The influence of the rate constant on the rate of ammonia-N loss is shown in Figure 1 for animal manure and granular fertilizer. The ammonia-N loss was normalized to the maximum ammonia-N loss as: fraction of maximum ammonia-N Loss = $AL(t) / AL_{max}$.

The results in the figure indicate that the rate of ammonia-N loss is slowest for granular fertilizer. Therefore, substantial nitrogen savings can be obtained by providing incorporation by either a light tillage operation or irrigation of 0.5 in. of water 6 to 24 hours following a broadcast application.

Ammonia volatilization occurs more quickly for animal manure than granular fertilizer and the rate depends on manure consistency and the amount of liquid that can infiltrate into the soil. Lagoon supernatant quickly infiltrates into the soil and as a result, the volatilization only occurs for about 6 hours. The high porosity of poultry litter permits ammonia to be released more slowly than lagoon supernatant, but still much faster than a slurry (TS = 7%). Incorporation of litter must occur within 6 hours following application if any real benefit is to be obtained. Incorporation of untreated dairy manure (slurry) should occur 8 to 12 hours after a broadcast application to cut volatilization losses by 40% to 50%.

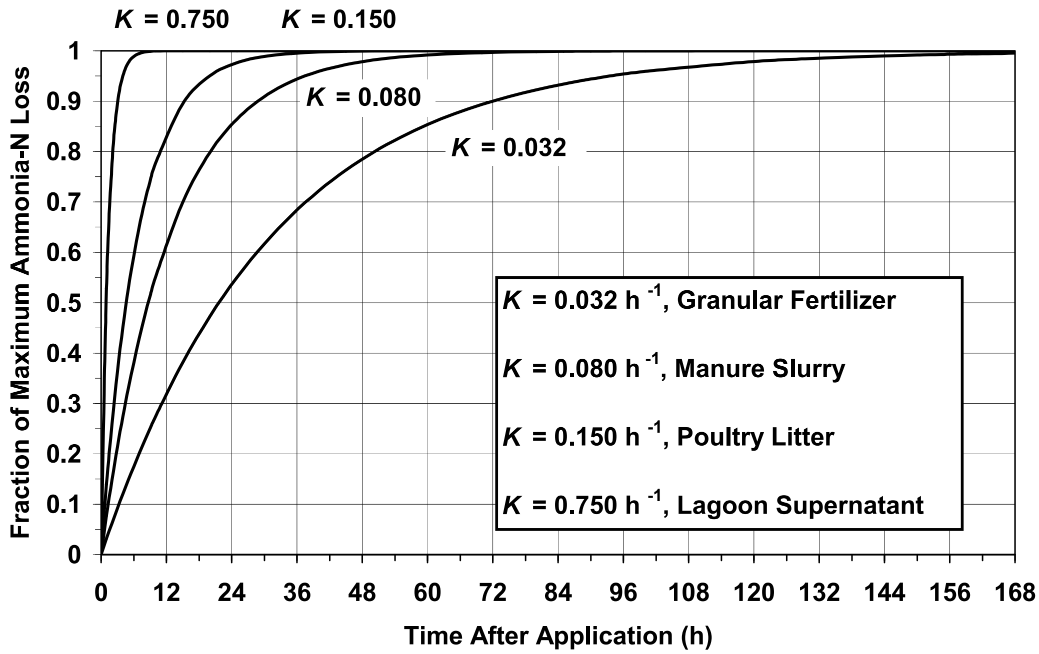

Figure 1. Rate of ammonia-N loss as determined by the value of the rate constant (K).

Influence of Land Application Techniques on Ammonia-N Loss per Acre

Several application techniques can be used with granular fertilizer and animal manure to reduce ammonia-N losses from no-till fields. No-till drills that plant, spread a band of fertilizer, and cover with coulters can provide immediate incorporation. Spreaders that place bands of fertilizer (drop/side dress) or manure (trail hose) on the surface can be used. Irrigation with a least 0.5 in. of water within a few hours of spreading manure or fertilizer can also wash ammonium-N into the soil and greatly reduce volatilization losses. Towed hose or tank injectors are available to allow immediate incorporation of bands of liquid or slurry manure with minimal disturbance of crop residues.

The new ammonia volatilization model was used to calculate the ammonia-N lost following application of 100 lb of plant available nitrogen per acre for several application methods. Model results are compared for application of fertilizer, lagoon supernatant, broiler litter, and dairy slurry to no-till fields in Table 4. The values of f_A used in equation 3 are given in Table A3. Nutrient data used were from Table 2. The granular fertilizer was assumed to be 17% ammonium-N.

The material that had the highest ammonia nitrogen loss was a broadcast application of dairy manure. The losses were the highest because dairy manure had the lowest ammonium-N availability and the lowest organic-N mineralization rate (Table 3). Any method to reduce volatilization losses should be considered if untreated dairy manure is used as a plant nutrient source in conjunction with conservation tillage. Direct injection is one of the best options currently available for use with dairy manure. However, other implements that can provide the benefits of direct injection, but with lower tractor power requirements are needed.

Table 4. Comparison of ammonia nitrogen loss estimates following application of granular fertilizer and animal manure to provide 100 lb PAN/ac to fields covered with crop residue.

Description of Application Method	Granular Fertilizer	Lagoon Supernatant (TS = 0.37%)	Broiler Litter (TS = 75.6%)	Untreated Dairy Slurry (TS = 7%)
	Ammonia-N Loss (lb N/ac)			
Broadcast [1]	25	0.4	7.4	48
Band / trail hose	11	0.2	3.6	19
Trench with sliding foot	N/A	N/A[2]	N/A	4.0
Shallow injection	N/A	N/A	N/A	3.4
Injection or immediate incorporation	1.6 [3]	N/A	0.6	2.7

[1] Assumes no rain or irrigation for 7 days.
[2] Not applicable.
[3] No-till drill with band spreading and soil coverage with coulters.

The quantity of ammonia-N lost per acre following application of lagoon supernatant or litter to provide 100 lb PAN/ac was much lower than expected. The new model predicts a much lower value of A_f than many extension publication would suggest (e.g. Chastain et al., 2001; MWPS, 1993; NRAES, 1999). However, the model includes new data that was obtained in 2002 (Montes, 2002).

Many professionals often forget to include the affects of organic-N mineralization when the mass of ammonia-N lost per acre is computed. Available organic-N is a significant fraction of the PAN for these materials and is not subject to loss by volatilization yet influences the total amount of TAN applied (equations 4 and 5).

Data and model results indicate that little development is needed to reduce ammonia-N loss following irrigation of lagoon supernatant. However, new equipment or litter treatments are needed to make poultry litter more compatible with no-till production systems.

Broadcast application of granular NH_4^+-N fertilizer is a poor choice for conservation tillage systems. For every 100 lb of PAN spread, 25 lb of nitrogen is wasted. The results given in the table indicate that band or side dress spreading, or use of a no-till drill that band spreads and covers fertilizer with soil should be used. Incorporation could also be achieved by providing 0.5 in. of water soon after a broadcast application.

Influence of Time Lag between Broadcast and Incorporation on Ammonia-N Loss per Acre

If irrigation or some sort of light tillage operation will be used to reduce nitrogen losses following application of fertilizer, poultry litter or dairy manure the rate of volatilization needs to be considered. If too much time elapses between application and incorporation, no benefit will be attained.

The affect of time lag between application and incorporation of fertilizer, broiler litter, and dairy manure is shown in Table 5. Assuming that incorporation must reduce nitrogen losses by half, model results indicate that incorporation should occur with 24 h for fertilizer, 6 h for poultry litter, and 12 h for dairy manure. On a very windy day, the maximum allowable time lag between application and incorporation will be much lower than indicated by the current model.

Table 5. Affect of time lag between application and incorporation on ammonia nitrogen loss from no-till fields fertilized to provide 100 lb PAN/ac.

Time between broadcast and incorporation or irrigation [1] (hr)	Granular Fertilizer	Broiler Litter (TS = 75.6%)	Untreated Dairy Slurry (TS = 7%)
	----- Ammonia-N Loss (lb N/ac) -----		
0	1.6	0.6	2.7
4	2.5	3.2	9.8
8	4.7	5.1	18
12	6.8	6.1	25
24	12	7.2	38
36	16	7.4	44
48	19	7.4	47
No incorporation [2]	25	7.4	48

[1] Irrigation of at least 0.5 in. is considered incorporation.
[2] Assumes no rain or irrigation for 7 days.

Incorporation of dairy manure or poultry litter within 24 h is a common recommendation to reduce nitrogen loss. However, the results given in Table 5 indicate that such a practice is of minimal benefit. Using an irrigation system to stop volatilization losses may also be impractical. Immediate incorporation using a second tractor with a light tillage implement or use of an implement that places the manure beneath the soil surface (injection) would be preferred. Many producers are reluctant to use a second tractor due to increased equipment and labor costs.

Additional research related to the quantification of soil conservation impacts of using minimum tillage with animal manure as compared to no-till is needed. New types of spreading equipment are also needed to minimize the equipment and operating cost associated with ammonium-N loss reduction techniques.

CONCLUSIONS

A new model of ammonia volatilization losses following application of animal manure and granular fertilizer has been developed based on data from the literature and new data obtained by researchers at Clemson University. The model includes the affects of manure type, total solids content, characteristics of the soil surface (bare or covered with a crop or residue), application method, and rate of ammonia-N loss.

The new ammonia-N loss model was combined with a range of organic-N mineralization factors from the literature to provide estimates of the plant available nitrogen (PAN, lb/ac), ratio of PAN to total nitrogen (TN), and the mass of ammonia-N lost per acre.

The new model was compared to the current estimates provided by Clemson University Extension. It was determined that compared to the new model, current Clemson Extension recommendations over predict ammonia-N losses following irrigation of lagoon supernatant by 95%. The best agreement in the estimate of ammonia-N loss was for dairy slurry (2%). The difference in mineralization factors used by the two methods ranged from 0% to 33%. The differences in estimates in the value of PAN/TN ranged from -23% to 21%.

The new model was used to estimate the ammonia-N losses following application of granular fertilizer (17% ammonium-N), lagoon supernatant, broiler litter, and untreated dairy manure to a no-till field. Calculations were performed to determine the amount of material required to provide 100 lb PAN/ac. Broadcast application, with no rain or irrigation for 7 days, resulted in ammonia-N losses ranging from 0.4 to 48 lb NH_3-N/ac. The highest loss was for dairy manure (48 lb NH_3-N/ac), and the lowest loss was for irrigation of lagoon supernatant (0.4 lb NH_3-N/ac). The ammonia-N loss for granular fertilizer (25 lb NH_3-N/ac) was greater than for poultry litter (7.4 lb NH_3-N/ac).

The influence of application methods such as band spreading, band spreading with immediate soil coverage, direct injection, immediate incorporation with light tillage, and incorporation with irrigation was studied using the model. The results indicated that these practices could reduce mass of ammonia-N lost per acre by 51% to 94% for all materials. Irrigation of lagoon supernatant was shown to be equivalent to immediate incorporation.

The model was also used to determine the affect of time lag between application and incorporation of fertilizer, broiler litter, and dairy manure. Assuming that incorporation must reduce nitrogen losses by half, model results indicate that incorporation should occur within 24 h for fertilizer, 6 h for poultry litter, and 12 h for dairy manure.

These short time periods may not be practical in many situations. New types of spreading equipment are needed to minimize the equipment and operating cost associated with immediate incorporation of poultry litter and slurry manure to achieve ammonium-N loss reduction.

APPENDIX A

Values of AL_{max}, f_S, f_A, and K for the Ammonia Volatilization Model

Table A1. Recommended values for the maximum ammonia-N loss following surface application of animal manure and granular fertilizer on grass, stubble, forestland, or crop residue (based on data from Montes and Chastain, 2003, Montes, 2002, and literature reviews by Chastain et al., 2001 and Montes, 2002).

Material	Recommended Values for AL_{max} (%)	Variable Range
Lagoon Water	AL_{max} = 14.30 TS – 4.74 (R^2 = 0.791, n = 12, SE_y = 0.57%)	0.39% ≤ TS ≤ 0.57%
Swine Manure	AL_{max} = 3.284 TS (R^2 = 0.875, n = 23, SE_y = 7.35%)	0.57% < TS ≤ 19%
Dairy Manure	AL_{max} = 20.87 $TS^{0.461}$ (R^2 = 0.811, n = 18, S_{RES} = 10.45%)	0.9 % < TS ≤ 22%
Poultry Litter (bedded)	AL_{max} = 4.387 TS – 306.5 (R^2 = 0.658, n = 10, SE_y = 8.92%)	71% ≤ TS ≤ 79%
Poultry Manure (Layer or unbedded)	AL_{max} = 85.1 – 0.938 TS (R^2 = 0.584, n = 5, SE_y = 18.2%)	16% ≤ TS ≤ 61%
Urea, $(NH_4)_2SO_4$	AL_{max} = 20 (S = 14.3%, n = 13)	3.5% ≤ AL_{max} ≤ 50%

Table A2. Ammonia-N loss reduction factors for animal manure or granular fertilizer applied to bare soil (based on literature review by Montes, 2002).

Material	f_S
Fertilizer or manure with TS ≤ 2%	1.0
Manure with TS = 3.5%	0.9
Manure with TS =5.0%	0.8
Manure with TS ≥ 10 %	0.7

Table A3. Application method factors
(based on literature review by Chastain et al., 2001 and Montes, 2002).

Application Method	f_A
Broadcast or Irrigation	1.0
Band spreading (drop or trail hose)	0.5
Trenching with sliding foot	0.12
Shallow injection	0.10
Direct injection or immediate incorporation	0.08

Table A4. Recommended rate constants (*K*) for ammonia-N loss following surface application of animal manure and granular fertilizer (based on data and literature review from Montes, 2002).

Material	Recommended Values for *K* (h^{-1})	Range (h^{-1})
Lagoon Water	0.750 (S = 0.119, n = 12)	$0.528 \le K \le 2.09$
Animal Manure (Swine, Dairy, Poultry)	$K = 0.073 + 0.00103$ TS ($R^2 = 0.960$, n = 5, $SE_y = 0.007$)	$0.019 < K \le 0.18$ ($3.9\% \le TS \le 74\%$)
Poultry Litter	0.150 (S = 0.119, n = 9)	$0.105 < K \le 0.184$
Urea, $(NH_4)_2SO_4$	0.032	$0.02 < K < 0.20$

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