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DEVELOPING EXTENSION GUIDANCE FOR MANAGEMENT EFFECTS ON AMMONIA LOSS: A COMPUTER SIMULATION MODELING APPROACH

Dan M. Sullivan
Dept. Crop and Soil Science, Oregon State University, Corvallis, OR
Dan.Sullivan@oregonstate.edu.

ABSTRACT

Computer simulation models provide insight into ammonia loss processes and the sensitivity of ammonia loss predictions to environmental and management variables.

As an example of how a simple computer simulation model can inform the Extension guideline development process, the ALFAM (Ammonia Volatilization from Field-Applied Animal Slurry) model was used to estimate NH_3 loss from surface-applied municipal biosolids: liquid (3% dry matter) and dewatered (22% dry matter). Model output was useful in demonstrating the probable effect of environmental variables (wind speed and temperature) upon NH_3 loss rate, and the impact of biosolids dry matter NH_3 loss dynamics. Using moderate inputs for temperature (10 and 20 ^oC; 50 and 68 ^oF) and wind speed (1 and 6 m sec^{-1}; 2 and 13 mph), ALFAM model estimates of cumulative NH_4-N retention were 40 to 60% for liquid biosolids, and 0 to 30% for dewatered biosolids. In all scenarios, over half of cumulative modeled NH_3 loss occurred during the first day after application, demonstrating that tillage more than 1 d after application will have small impact on NH_3 retention. The ALFAM model outputs provided additional justification for Pacific Northwest Extension guidance for agronomic biosolids application rates. Other simple computer simulation models may prove useful in examining Extension estimates of NH_3 loss from organic materials from a new perspective.

INTRODUCTION

This author initially set out to summarize existing research data on NH_4-N retention for different manure application scenarios, and to compare research data to existing Extension guidance. This quest proved difficult. For the Western Region, existing Extension guidance is mainly derived from Natural Resources Conservation Service and Midwest Plan Service guidance. Extension guidance for NH_3 management is generally not justified by research citations. An exception to this rule is an excellent review of Northeast U.S. research and Extension guidance on NH_3 volatilization from manures (Meisinger and Jokela, 2000). In addition, investigation of research findings from Europe and other regions of the U.S. revealed a common theme: no single factor controls ammonia retention, and experimental results are difficult to reproduce, even when experiments are repeated by the same researcher (Pain and Misselbrook, 1997; Sommer and Hutchings, 2001). So, instead of a literature summary, this author decided to illustrate a different approach to Extension guidance development, using a computer simulation model.

Why should Extensionists consider using models?

Using simulation models to evaluate and perhaps modify Extension guidelines for NH_4-N retention has many advantages:

- A third-party model (not created by Extension Specialist or the clientele) can serve as an independent "expert" in evaluation of existing guidelines. When conflicts arise about Extension guidelines that might involve lawsuits and upset people, the professional judgment of the Extension Specialist is not the only source of support for the Extension guidelines. If local experimental data is available, the Extension specialist can verify the appropriateness of the model for local conditions.
- After reasonable estimates of NH_4-N retention values are agreed upon for use in NRCS or other mandated nutrient management plans, an appropriate model can be used to estimate increases in NH_4-N retention associated with implementation of manure application methods or manure treatments that are designed to reduce NH_3 volatilization to the atmosphere. Technologies that show the greatest reduction in NH_3 loss can then qualify for the highest government cost-share.
- The shortcomings of the model chosen for informing Extension guidance can provide clear targets for future experimental research.
- Online simulation models can assist farmers and agricultural professionals in understanding the dynamics of the ammonia loss/retention processes.
- For processes like NH3 loss that are affected by many factors, a model offers the opportunity to consider a multitude of factors in a consistent manner. Researchers in most states will not be able to collect experimental data to represent the myriad of scenarios that occur in the field.

Models can assist in guidance development, but should be used with caution. Model users need to understand model limitations. Most models are useful in some way, but they are all less than 100% correct.

The ALFAM model

Recently, a major collaborative effort by European scientists resulted in a novel approach to estimating NH_3 loss, the ALFAM model (Søgaard, et al., 2002). This multiple regression model was derived from a database of NH_3 loss experiments conducted across Europe, from Italy to Norway. The model uses Michaelis-Menten kinetics to describe ammonia loss. Input values to the model affect two variables: N_{max}, the quantity of cumulative NH_3 loss, and K_m, the time to 50% of cumulative NH_3 loss (0.5 N_{max}). Model inputs are relatively simple and the model is easy to use; it is downloaded as an Excel file from the ALFAM website, http://www.alfam.dk.
As with all simple models, ALFAM has significant limitations:

- The model was developed only for dairy and pig slurry application by tractor. Application of lagoon water by sprinkler is not modeled. Beef or dairy drylot manures are not modeled.
- The model assumes constant temperature and wind speed during the simulation period.
- The model does not allow for differences associated with time of day manure is applied. Experimental data usually demonstrates a diurnal cycle of ammonia loss associated with changes in solar radiation, evaporation, and wind speed.
- The model predicts unrealistic values (> 100 % NH3 loss) with extreme model inputs (high temperature and high wind speed)

The ALFAM model has been enhanced and made available online in British Columbia by Shabtai Bittman (Agriculture Canada, Agassiz, BC). The modified ALFAM calculator "Ammonia Loss from Applied Slurry Manure," available at www.farmwest.com, combines current and forecasted weather data with the ALFAM model. Because manure handling systems, climate, and field research findings for coastal BC are somewhat similar to those of Northern Europe, use of the ALFAM model for coastal BC is reasonable. For example, field research in BC demonstrates increased slurry N uptake by grasses when slurry is applied with a trailing shoe (surface banded) as compared to broadcast (Bittman et al., 1999). Similarly, the ALFAM model reduces NH_3 loss substantially when slurry is applied by trailing shoe, instead of broadcast.

METHODS

As an example of how a simple computer simulation model can inform the Extension guideline development process, I used the ALFAM model to estimate NH_3 loss from surface-applied liquid and dewatered biosolids. In using ALFAM in this way I made two assumptions to which modeling purists would object. First, I assumed that manures and municipal biosolids behave similarly following land application as far as NH_3 loss is concerned. Second, I assumed that I could use ALFAM to model NH_3 loss from dewatered biosolids cake (22% dry matter), although it is outside the range of dry matter values present in the European database. Model inputs to ALFAM were based on "typical" NH_4-N concentrations present in dewatered and liquid biosolids in the Pacific Northwest (Table 1).

Table 1. Inputs used for biosolids characteristics in ALFAM simulations.

Biosolids characteristics	Anaerobic dewatered	Anaerobic liquid
NH_4-N (mg kg^{-1} dry matter)	20000[a]	35000
Field application rate (dry ton/acre)	2	1
Application rate N (NH_4-N per acre)	80	70
Solids fraction (percent DM/100)	0.11[a]	0.03
NH_4-N concentration in wet biosolids (g kg^{-1})	2.2	1.05
Application rate of wet biosolids (Mg ha^{-1})	41	75

[a] For dewatered biosolids, 11% dry matter is upper limit allowed for input dry matter in ALFAM. For dewatered biosolids, input values for the simulation were chosen to reflect a typical field application rate of 4 dry ton/acre, assuming the biosolids contain 22% dry matter and 20 lb NH_4-N per dry ton. To input our typical values for dewatered biosolids into ALFAM, input NH_4-N concentration for dewatered biosolids were adjusted to twice the typical, and dry matter was adjusted to one-half the typical, resulting in "typical" NH_4-N concentration found in wet biosolids.

RESULTS AND DISCUSSION

Increased wind speed and temperature increased ALFAM modeled NH_3 loss (Table 2). For both liquid and dewatered biosolids, 50% of modeled cumulative ammonia loss (K_m) occurred during the first 20 h following application. Increasing temperature by 10 ^oC (18 ^oF) or increasing wind speed from 1 to 6 m sec^{-1} (2 to 13 mph) resulted in similar increases in NH_3 loss. At high temperature (30^oC) or high wind speed (6 m sec^{-1}), modeled NH_3 loss from dewatered biosolids exceeded 100%.

Table 2. Cumulative NH_3 loss (N_{max}) and time to 50% of cumulative loss (K_m) as predicted by ALFAM model for two kinds of anaerobically-digested biosolids.

Model Input[a]		Ammonia loss dynamics		
Air temp	Wind speed	Time to 50% cumulative NH_3-N loss (K_m)	Cumulative NH_3-N lost to atmosphere	Cumulative NH_4-N retained in soil
^oC	m sec^{-1}	h	% of NH_4-N applied	% of NH_4-N applied
		Anaerobic dewatered biosolids		
10	1	20	72	28
10	6	15	89	11
20	1	13	90	10
20	6	10	110[b]	-10 [b]
30	1	9	112[b]	-12 [b]
30	6	7	137[b]	-37 [b]
		Liquid biosolids		
10	1	9	34	66
10	6	7	42	58
20	1	6	43	57
20	6	5	53	48
30	1	4	53	47
30	6	3	65	35

[a]ALFAM model uses metric units for air temperature and wind speed. Equivalent English units: 10, 20 and 30 ^oC = 50, 68 and 86 ^oF; wind speed 1 and 6 m sec^{-1} = 2 and 13 miles per hour.
[b]Model result beyond the realm of possibility.

Extension guidance is typically given as a percentage of biosolids NH_4-N retained (100% - %N lost as NH_3). For liquid biosolids, modeled cumulative NH_4-N retention was 35 to 66%. For dewatered biosolids, modeled NH_4-N retention was 0 to 28% (Table 2; Figure 1). Modeled decreases in NH_3 retention after 72 h were small, supporting Extension recommendations that consider tillage after 3 d to be equivalent to no tillage (leaving biosolids on soil surface). The variation in NH_3 loss illustrated by the model output makes a strong case for using Extension guidance as a general planning estimate, and following up with post-application testing to refine N management.

The ALFAM model results are in approximate agreement with NH_4-N retention values reported by Cowley and Henry (1999) for Pacific Northwest biosolids. They measured retention of 60 to 80% of applied NH_4-N for liquid biosolids, and 0 to 49% of applied NH_4-N for dewatered biosolids after surface application in a series of microplot studies.

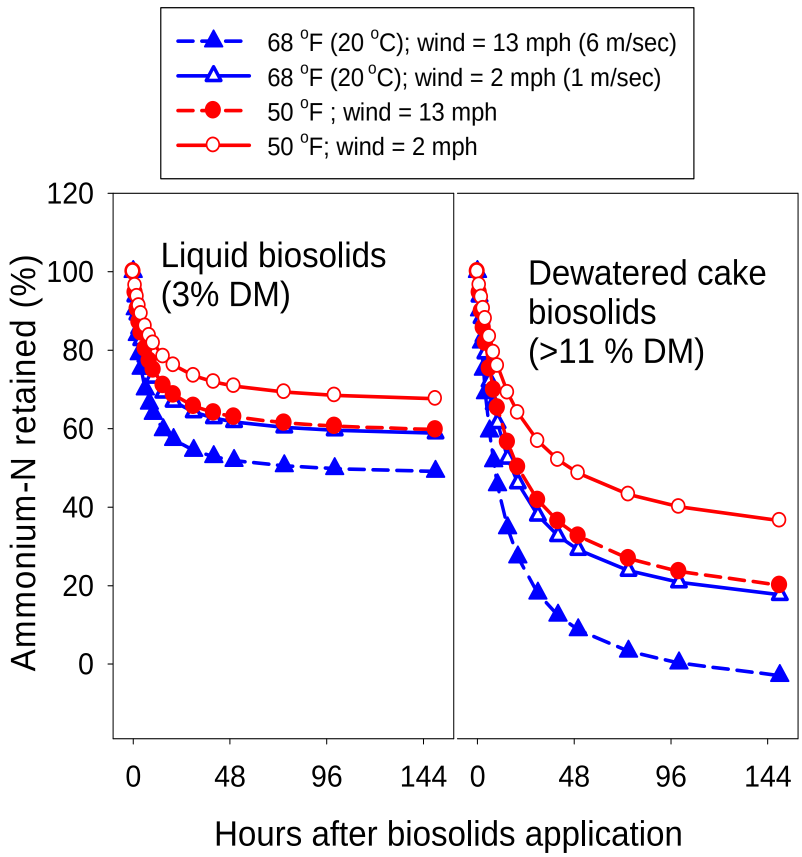

Figure 1. Ammonium-N retained following municipal biosolids application as estimated by ALFAM model. Biosolids characteristics are listed in Table 1.

There are some obvious differences between slurry manure (ALFAM model) and dewatered municipal biosolids that should be considered in extrapolating the model outputs shown. First, a surface crust typically forms on the surface of dewatered biosolids, restricting diffusion of NH_3 from inside large biosolids chunks, usually 1/2 to 2 inches in diameter. Second, the jello-like consistency of dewatered biosolids (synthetic polymers are added to biosolids to flocculate organic colloids at the treatment plant) restricts NH_3 diffusion from biosolids particles in the field. These factors suggest that it is unlikely that all NH_4-N is lost; some NH_4-N is retained following biosolids application. Oven-drying or air drying dewatered biosolids usually retains about 10% to 30% of the NH_4-N present in fresh (wet) biosolids (personal experience of author).

Estimates of NH_4-N retention that are given in updated Pacific Northwest Extension guidance for calculating agronomic biosolids application rates in Pacific Northwest Extension Publication 511 (PNW 511) are shown in Table 3. The revised 2007 biosolids guidance is in general agreement with current literature on manure NH_3 loss as summarized by the ALFAM model.

Table 3. Planning values given for estimating NH_4-N retention from municipal biosolids in the Pacific Northwest[a].

Extension guidance (1999)			Extension guidance (2007)		
Time to incorporation by tillage (d)	Liquid biosolids	Dewatered biosolids	Time to incorporation by tillage	Liquid biosolids	Dewatered biosolids
		NH_4-N retained, percent of applied			
0 to 2	80	60	Immediate	95	95
3 to 6	70	50	After 1 d	70	50
over 6	60	40	After 2 d	60	30
			no incorporation	55	20

[a]Pacific NW Extension publication 511, Cogger and Sullivan (1999; revised 2007).

SUMMARY

ALFAM model output was useful in demonstrating the effect of environmental variables (wind speed and temperature) upon NH_3 loss rate, and the probable impact of biosolids dry matter on NH_3 loss dynamics. In all modeled scenarios, over half of the cumulative NH_3 loss occurred during the first day after application, demonstrating that delayed tillage will be ineffective in conserving NH_4-N. ALFAM model outputs, together with accumulated field research data, and the best professional judgment of the author, provided justification for modifying planning values for NH_4-N retention in PNW Extension guidance.

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