Optimal Application of Swine Effluent under Stochastic Weather Conditions in the Texas and Oklahoma Panhandles

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A target MOTAD model was used to determine optimal application strategies for swine effluent. The most efficient timing occurs at night with low wind speed and with high relative humidity. Significant nitrogen loss can be prevented and potential benefits in terms of crop yield and net return can be obtained by switching to efficient irrigation timing practices.

Key words

Ammonia Volatilization, Animal Waste, Irrigation, Swine Effluent, Target MOTAD

Producers in the Southern High Plains, especially in the Texas and Oklahoma Panhandle areas apply swine effluent through irrigation systems because it is the most economical way to dispose of swine effluent. However, if inadequately managed, swine manure can impose a critical threat to the quality of air and water close to disposal lands. Much of the nitrogen in anaerobically digested swine effluent is in the ammonium form (NH4-N), which can convert to ammonia (NH3) gas and volatilize during or after field application (Liu et al., 1997). A significant portion of nitrogen is lost as volatilized ammonia before the effluent reaches the ground. Ammonia volatilization is indirectly related with soil acidification and water eutrophication as a major source of atmospheric ammonia (Sutton et al 1995). Ammonia loss from agriculture is now considered a threat to the global environment and is a challenge for agri-environmental policy.

Nitrogen losses take place via ammonia volatilization, leaching, denitrification, and plant uptake and removal in the harvested portion of the crop. Ammonia volatilization commonly happens in all ammonium type fertilizers like anhydrous ammonia, urea and swine effluent and is affected by various soil characteristics and weather conditions following application. Generally, ammonia volatilization increases in high soil pH, temperature, crop residue, and soil moisture content and decreases when nitrogen fertilizers move below the soil surface through tillage incorporation and movement by irrigation and rain (Jones et al., 2007). Al-Kaiser et al. (2002) found that the percent of N lost through volatilization is not greatly affected by N concentration in effluent but that air temperature and wind speed are important factors for N loss.

Swine effluent can be a good source of crop nutrients if properly managed. Many efforts have been conducted to quantify amount of ammonia volatilization of swine effluent from the soil source for the better nutrient management. A recent field experiment at the Oklahoma State University Research Station in Goodwell, OK showed that 37 to 90 percent of applied nitrogen in the form of ammonia can volatilize to the atmosphere as ammonium (NH4) within a few days following swine effluent application to a Richfield clay loam soil, a calcareous type of soil in the Oklahoma Panhandle (Zupanic et al. 1999 and Warren 2001). The level of volatilization depends on the climatic conditions following application. The high volatilization occurred during hot, dry weather conditions with low relative humidity, and brisk wind speeds (Zupancic 1999). A mechanistic model was developed using parameters from field experiments with flood and sprinkler irrigation (Wu et al. 2003). This model was designed to predict ammonia volatilization rate and cumulative volatilization from liquid and soil surfaces and the simulated ammonia volatilization rate and cumulative volatilization closely matched data from field irrigation experiments.

Management of animal wastes from animal confinement facilities has been one of the important issues in swine and poultry farming. Moreover, ammonia loss from agriculture is now considered a threat to the global environment and is a challenge for agri-environmental policy. However, previous analyses of nitrogen losses have mainly focused on water pollution from nonpoint sources and little economic study of nitrogen loss through ammonia volatilization has been conducted.

The objectives of this study are 1) to determine efficient choices of irrigation timing with swine effluent in the pre-plant season to minimize nitrogen loss based on historical weather (wind and temperature) data 2) to compare nutrient loss (i.e. nitrogen) between the optimal application schedule and conventional application timing; and 3) calculate economic benefits from adopting the optimal irrigation timing with application of swine effluent.

Data and Method

Hourly weather data of first two weeks in April between 1998 and 2005 such as temperature, precipitation, relative humidity, wind speed, and solar radiation were collected from Mesonet in the Oklahoma Panhandle. The cumulative amount of nitrogen lost via ammonia volatilization for each six-hour time block was calculated for a pre-plant season (e.g. April) using a mechanical model developed by Wu et al (2003). Initial conditions and other important factors in simulating ammonia volatilization are shown in Table 1.

The timing commonly adopted in the region for application of swine effluent to corn field is at approximately the 6-leaf (V6) corn growth stage, which typically occurs about 3 weeks after seedling emergence. This stage varies from late April to early June but actual timings when swine effluent was applied in the experiment station were considered the conventional timing of application in this research. The economic profitability of alternative strategies of applying swine effluent was calculated as the return (corn price times yield) above specified costs. The recent three-year average price of corn (2006-2008), US \$126.11 Mg^{-1} was used. Fertilizer application cost of swine effluent is presented in Table 2.

Method

Target MOTAD

Efficient irrigation timing is determined in the target MOTAD programming model that minimizes total expected nitrogen loss with constraints that require nitrogen loss to not exceed a target level. A target level is flexible because the average annual deviations from a target level of N loss are incorporated. The objective of this model is to determine the optimal irrigation timing that will minimize expected ammonia loss rate (ALR) with respect to the target ammonia volatilization rate. The target MOTAD model in this research can be written

$$(1) \quad \min_{X_j} EALR = \sum_{j=1} CMEAN_j X_j$$

$$\text{s.t} \quad \sum_{j=1} a_j X_j \leq b$$

$$\sum_{j=1} C_{tj} X_j + Y_t \leq TGT\ ALR,$$

$$\sum_t Y_t \Pr ob_t = \lambda$$

where $CMEAN_j$ is expected ammonia loss rate (ALR) from time block j, X_j is time block j, Y_t is value of any deviation in ALR below the target in state of nature t, C_{tj} is ALR from timing block j in state of nature t, $TGT\ ALR$ is target ALR, $\Pr \text{ob}_t$ is probability of a state of nature t, and λ is allowable average deviation from the target ALR.

Expected Net Return

Optimal irrigation strategy is compared with the conventional irrigation timing in terms of expected profits of two strategies based on estimated crop response functions Expected profit function of a farmer can be written

$$(2)\ \ \pi = p \cdot \mathrm{E(Y)} - r \cdot NA - TVC$$

$$Y = f(TAN,\ \ pH),$$

$$TAN = NA(1 - Nloss) + SN,$$

where Y is corn response function, p is the price of corn, r is the price of nitrogen fertilizer, TAN is total available nitrogen for plant, NA is the amount of nitrogen fertilizer, pH is soil pH level, TVC is total variable cost of all inputs except fertilizer, $Nloss$ is a nitrogen loss rate via ammonia volatilization and SN is the soil nitrate-nitrogen level.

We are only interested in major plant nutrients such as nitrogen and soil pH levels in this study. Therefore, the functional form for corn yield used in this study is a modified quadratic function, thus,

$$(3)\ \ Y_t = \alpha + \beta\ TAN_t + \rho\ (TAN_t)^2 + \kappa\ pH_t + u_t + \varepsilon_t\ ,$$

where Y_t is a corn yield at year t, α, β, ρ and κ are the parameters to be estimated, TAN_t is the total available nitrogen in year t, pH_t is the soil pH level at year t, u_t is random year effects, $u_t \sim N\left(0,\ \sigma_u^2\right)$, and ε_t is an error term, $\varepsilon_t \sim N\left(0,\ \sigma_\varepsilon^2\right)$. Parameter estimates are presented in Table 3.

Results

Results of the target MOTAD programming model in Table 4 show the most efficient timing is expected with low wind speed and with high relative humidity at night. Assuming that three times of effluent application were required, the best application timing is a time block from midnight to 6:00 am on April 7, April 11 and April 12. The expected ALR from the model is 0.15, which is much lower compared to 0.46, an averaged level of actual ALR between 1998 and 2005. Two application strategies were compared in terms of crop yield and net return (Table 4) Switching to efficient irrigation timing practices resulted in higher yield (162 Kg/ha) and net return ($20.40).

Conclusion and Discussion

A target MOTAD model was used to determine efficient application strategies of swine effluent. As predicted, results showed that the most efficient timing occurs at night with low wind speed and with high relative humidity. Significant nitrogen loss can be prevented by switching to efficient irrigation timing practices. In addition, potential benefits in terms of crop yield and net return can be obtained. Therefore, this new approach to irrigation timing has the potential to both reduce environmental impact and increase producer income.

However, some caution should be taken in interpreting results. The adoption of a mechanical model is only appropriate in the Texas and Oklahoma Panhandle area because the calcareous nature of soil in the region increases risks associated with N losses due to ammonia volatilization that occurs under increased pH levels found in Gruver soils.

Further research is necessary to address more realistic application strategies under stochastic weather condition because the application of swine effluent at night can create nuisance problems (i.e. odor) among communities near disposal land.

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Table 1. Factors and Condition in Simulating Ammonia Volatilization

Factor	Values	Unit
Ammoniacal N Concentration in swine effluent	1.1605	g/L
Soil pH	7.75	
Effluent pH	7.5	
a target application rate of nitrogen	168	Kg/ha
Soil nitrogen in top 15 cm	90.5	Kg/ha
Pre-Plant Application Date	April 1 to April 14	

Table 2. Fertilizer Application Costs of Swine Effluent (SE) (kg ha^{-1})

Item	56	168	504
Operating Costs			
Tractor			
Fuel and lube	0	0	0
Labor	0	0	0
Repair	0	0	0
Pump[a]			
Fuel and lube	11.86	25.45	65.49
Labor	6.25	7.3	8.11
Repair	0.24	0.24	0.24
Fixed Costs[b]			
Pump and Pipe			
Depreciation	6.73	6.73	6.73
Interest	3.65	3.65	3.65
Insurance	1.06	1.06	1.06
Total	29.79	44.43	85.28

[a]Pump costs include only the pumping costs of SE from the lagoon to the center pivot. Operating and fixed costs of applying irrigation water are not included

[b]Fixed costs for tractor and irrigation equipment are not included in application cost calculations since they are not exclusively required for fertilizer operations.

[c]Total variable costs (TVCs) per hectare are assumed to be $200.

Table 3. Maximum Likelihood Parameter Estimates of Irrigated Corn Yield Function for Swine Effluent (kg/ha/year)

Variables	Symbol	Parameter Estimates	Standard Errors
Intercept	α	-3,509	7.43
TAN	β	9.30	3.10
TAN squared	ρ	-0.015	0.001
Soil pH	κ	1,304	61.62
Variance of random year effect	σ_u^2	517,439	0.0004
Variance of error term	σ_ε^2	1,544,913	0.04

Note: all parameters are significant at the 5 % level.

Table 4. Results of a Target MOTAD and Benefits by Adopting Optimum Strategy

	Ammonia Loss Rate	Expected Yield (Kg/ha)	Expected Net Return ($/ha)
Optimal timing	0.15	7952	758.43
Ordinary timing	0.46	7790	738.02
Difference	-0.31	162	20.40