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Determination of Optimal Timing of Poultry Waste Disposal by Meteorological, Hydrological, and Water Quality Modeling Techniques

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University of Arkansas
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ABSTRACT

DETERMINATION OF OPTIMAL TIMING OF POULTRY WASTE DISPOSAL BY METEOROLOGICAL, HYDROLOGICAL, AND WATER QUALITY MODELING TECHNIQUES

Approximately one million Mg of broiler litter were generated in conjunction with Arkansas' 1989 broiler production. Common practices for disposal of the waste have the potential to damage the quality of downstream rivers and lakes. This possibility is enhanced due to the concentration of broiler production in areas of the state with shallow soils, steep slopes, and limited suitable disposal area. Since the risk of pollution is greatest immediately following disposal and increases with rainfall depth and intensity, adverse water quality impacts may be mitigated by timing the application to coincide with low probability of surface losses of the nutrients responsible for eutrophication. The objective of this research was to identify the time of year which is optimal, in terms of surface water quality, for disposal of broiler litter under Arkansas conditions. This objective was accomplished by using the Erosion Productivity Impact Calculator (EPIC) model to simulate water quality impacts of land-applied broiler litter as a function primarily of weather variables. Nutrient losses were simulated for long periods using varying application dates. Output from the simulations was used to establish the relationship between application date and average nutrient losses, enabling the identification of optimal timing of disposal. The procedure was replicated for three areas of the state in order to characterize spatial variability in optimal timing of disposal. The results indicate that there exist "windows" within which waste application can minimize nutrient losses and maximize grass yields. These windows, however, vary depending on the parameter of interest and the location being simulated.

D.R. Edwards and T.C. Daniel

Completion Report to the U.S. Department of the Interior, Geological Survey, Reston, VA, June, 1991.

Keywords - Agriculture/Model Studies/Nutrients/Water Quality Control/Water Quality Modeling

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INTRODUCTION

Arkansas currently produces more commercial broilers than any other state in the U.S. (Arkansas Agricultural Statistics Service, 1989). The production value of the 896 million broilers produced in 1988 was approximately 1.25 billion dollars - only 4% less than the combined statewide production values of rice, soybeans and cotton (Arkansas Agricultural Statistics Service, 1989). Broiler production thus dominates all other commodities with respect to the state's agricultural economy.

The waste associated with broiler production, commonly referred to as litter (a combination of manure and bedding material), is periodically removed from the broiler houses and disposed of. The customary method of disposal is to spread the litter over fields in the vicinity of the broiler houses. In addition to preventing excessive accumulation of litter, this practice increases the fertility of receiving areas since broiler litter typically contains about 4.1% total nitrogen (N), 1.4% total phosphorus (P), and 2.1% potassium (dry basis) (Edwards and Daniel, 1992). The nutrients beneficial from a soil fertility perspective, however, can be detrimental to water quality. During storms, nutrients contained in the litter may be transported off the area of application and enter streams and lakes. The potential for nutrient loss and thus eutrophication promotion is greatest immediately following litter application when the quantity of available nutrients is greatest.

Concerns regarding water quality impacts of surface-applied broiler waste are increasing in areas such as Northwest Arkansas where production is heavily concentrated. Beaver Lake, the water source for approximately 100,000 persons in Northwest Arkansas, is quickly becoming a focal point of such issues due to intense broiler production in the White River basin and evidence of eutrophic nutrient loadings in the upper reaches of the lake. Compounding factors such as steep topography and shallow, cherty soils act to increase this apprehension. The potential problems associated with broiler litter production are not, however, unique to Northwest Arkansas. Significant broiler production occurs in the western and central portions of the state. As broiler production continues to expand, in terms of both number of facilities and areal extent, anxieties regarding the environmental implications of production will be shared by an increasing number of citizens, local governments, service agencies, and regulatory agencies.

It is within the capability of users of broiler litter to control, to some extent, adverse water quality impacts resulting from litter disposal. For example, nutrient loadings to streams and lakes may be reduced by spreading the litter on land with low slopes, by decreasing the application rate, and by timing the application to coincide with low likelihood of runoff-producing rainfall. Management options such as these are known as Best Management Practices, or BMPs. BMPs are ideally identified on the basis of experimental results and then communicated to end users by customary dissemination channels. In some cases, cost sharing incentives are offered to increase BMP implementation.

The role of BMPs in rectifying problems associated with broiler litter disposal is currently restricted by both practical and technical problems. The practical problems stem from the fact that the user of the litter may not have great latitude with respect to choosing the receiving slopes and soils; the user is often constrained to the existing situation insofar as it applies to these two variables. The technical problems are associated with a lack of theoretical and experimental investigations which precisely identify optimal loading rates and application times as a function of physical and biological variables. This is not to say that litter users receive no guidance regarding proper loading rate and application timing; the University of Arkansas Cooperative Extension Service currently recommends an application rate of from two to four tons of litter per acre, applied during the spring. However, this recommendation is ostensibly derived from plant/crop nutrient requirement considerations rather than from rigorous investigations of runoff water quality. It is thus uncertain whether practices which may be best from a plant growth perspective are always best from a water quality perspective.

Optimal timing of broiler litter disposal is likely the least expensive BMP determination and the easiest BMP to implement. The objective of this research was to establish the time of year which is best, from a water quality perspective, for disposal of broiler litter by customary means. Characterization of the spatial variability of optimal disposal timing is encompassed in this research objective.

RELATED RESEARCH

As Magette et al. (1988) have noted, poultry waste has not received the same amount of attention from researchers as other agricultural wastes such as dairy waste, swine waste, and others. A comprehensive review of the contribution of agricultural waste to non-point source pollution by Khaleel et al. (1980) contained no mention of the role of poultry waste. Although some studies have investigated water quality aspects of land application of poultry waste, the paucity of experimental information inhibits attempts to develop methods to alleviate any adverse environmental impacts of poultry waste.

Giddens and Barnett (1980) analyzed runoff from litter-treated plots for sediment and microbial content. Runoff from bare plots receiving higher application rates contained appreciable coliform bacteria; in some cases, the coliform content exceeded recreational and drinking water standards. The authors concluded that no water quality problems should result from application of "moderate" amounts of poultry waste unless "excessive" rainfall occurs. Since "excessive" rainfall inevitably occurs, the authors' conclusion suggests that the future research should investigate the role of rainfall intensities with regard to pollution from land-applied poultry waste.

McCleod and Hegg (1984) investigated surface water quality impacts of pastures treated with municipal sludge, commercial fertilizer, dairy manure, and poultry manure. Runoff from plots treated with these fertilizers was analyzed for total suspended solids, total Kjeldahl N, ammonium N, nitrate N, total P, and other parameters. The experiment demonstrated the dependence of runoff quality on the number of rainfall events after fertilizer application. Overall, runoff from plots treated with commercial fertilizer was worst in terms of water quality; runoff from the first rainfall event exceeded drinking water standards for nitrate N concentration. However, runoff from plots treated with poultry manure was second worst in terms of water quality. Total Kjeldahl N in runoff from poultry manure plots was practically identical to that from commercial fertilizer plots for the first rainfall event; total P runoff concentration was greatest for the poultry manure plot for the first rainfall event.

Westerman et al. (1983) conducted a factorial experiment to determine the relative importance of variables affecting surface losses of nutrients from land treated with poultry waste. The variables considered were soil type, rainfall intensity, manure type, application rate, and drying time. Both application rate and rainfall intensity were found to significantly affect surface nutrient losses. Identification of application rate as a significant causative variable is unsurprising, and the implications of this finding are straight forward. The identification of intensity as a significant causative variable, however, strongly suggests an influence due to application timing.

Since rainfall depths and intensities are known to exhibit definite annual trends, it follows that some times of the year are more likely to be associated with high rainfall intensities than others. Thus, waste application dates during periods with a relatively high probability of intense rainfall will likely be associated with relatively high surface nutrient losses.

Having established that rainfall intensity plays a significant role in pollution due to poultry waste application, it would be desirable find an account of using this knowledge in conjunction with N and P kinetics to determine application timings which, on the whole, minimize runoff pollution. Unfortunately, there are no published results of research to address timing effects on runoff water quality. The reason for this lack of information can be traced to the fact that there is no mathematical simulation model developed specifically to predict water quality impacts resulting from disposal of poultry waste. However, the recently-developed EPIC model (Williams et al., 1983, 1989, 1990a, 1990b) contains all the components necessary to answer the question of optimal timing of poultry waste application. This comprehensive simulation model predicts runoff, sediment yield, plant growth, nutrient uptake, and runoff losses ~~of nitrate, organic N, and P. EPIC also computes nutrient~~ mineralization, denitrification, and immobilization.

PROCEDURE

This research followed the modeling approach in identifying optimal timing of broiler litter disposal. The model used was the Erosion Productivity Impact Calculator (EPIC) model (Williams, et al., 1983, 1989, 1990a, 1990b). EPIC is a comprehensive model which simulates runoff, erosion, nutrient transport and transformations, crop growth, and numerous other processes. EPIC can accommodate varied management practices such as timing of fertilizer application, composition of fertilizer, irrigation, and others. Thus, the EPIC model is very flexible in terms of conditions and management options it can use in computing water quality impacts. EPIC has been validated (Jones and Williams, 1986) and applied in a wide variety of analyses.

Site/management input files were constructed for hypothetical fields at three locations in Arkansas: Texarkana, Stuttgart, and Fayetteville. General model input data for the locations are given in Appendix A. The soils used in the simulations were Sacul loamy sand, Crowley silt loam, and Captina silt loam for Texarkana, Stuttgart, and Fayetteville, respectively. These soils were selected as representative of the respective regions. The data used to describe the soils appear in Appendix A. The fields were taken as 2 ha with Bermuda grass planted at each site. The Bermuda grass was simulated as being harvested for hay on four to six seek intervals; the precise harvest schedule varied with location and was specified so as to reflect common haying practices.

The fertilizer for the fields was simulated as being of approximately the same composition as broiler litter. All nitrogen and phosphorus was assumed to be in organic form, and the fertilizer was taken as containing 4.5% total N and 2.5% total P (dry basis). Single applications of 7.4 Mg/ha-year (dry basis) were used, and the fertilizer was simulated as being lightly incorporated.

Meteorological data required by the EPIC model (maximum and minimum daily temperatures, solar radiation, relative humidity, and wind run) were obtained from the Weather Generator (Richardson and Wright, 1984) model as modified by Edwards and Mayfield (1990) and from EPIC's internal weather data generation algorithm.

EPIC was used to simulate 50 years' surface losses of N (organic and nitrate) and P (sediment bound and soluble) at each location for each of 12 different fertilizer application dates (January 15, February 15,...,December 15). Mean annual losses of these parameters were computed, and statistical tests were performed to determine the effect of fertilizer application date on surface N and P losses. In addition, mean annual grass yields were computed and tested to analyze application timing effects.

RESULTS

Mean annual N losses as a function of fertilizer timing for the Texarkana field appear in Table 1. Mean annual nitrate N and total N losses are grouped with labels. The organic N losses, however, can not be grouped with labels; Table 2 shows individual comparisons of mean annual organic N losses as a function of fertilizer application date. Table 3 lists mean annual phosphorus losses as a function of application timing. The relationships between nutrient losses and fertilizer application timing are depicted in Figures 2 and 3. Organic N losses are lowest for applications during June through December, while nitrate N losses are minimized for application during October through April. As indicated by the grouping of means, application timing makes little difference in the magnitude of surface losses of total N. Sediment-bound P losses are seen to be minimized for applications during June through December. Soluble P losses, however, demonstrate little dependence on fertilizer application timing. Total P losses are generally less for applications during the second half of the year.

Simulated mean annual surface N losses for the Stuttgart field are shown in Table 4. Nitrate N losses could not be grouped with labels; t-test results of comparisons between means are shown in Table 5. Simulated P losses appear in Table 6. and t-test results of sediment-bound P (which could not be grouped with labels) losses are given in Table 7. The simulated mean

Table 1. Simulated mean annual N losses for the Texarkana field.

Application Date	Organic N[a] (kg/ha)	Nitrate N[b] (kg/ha)	Total N[b] (kg/ha)
January	11.23	3.84 bc	15.07 ab
February	11.74	3.77 bc	15.51 ab
March	12.35	3.84 bc	16.19 ab
April	13.07	4.08 bc	17.14 a
May	11.63	4.55 abc	16.18 ab
June	8.70	5.23 abc	13.93 ab
July	9.18	5.98 ab	15.16 ab
August	7.18	7.38 a	14.56 ab
September	9.60	4.18 abc	13.78 ab
October	8.60	4.44 abc	13.04 b
November	8.53	4.10 bc	12.63 b
December	9.48	3.54 c	13.02 b

[a] Organic N losses cannot be grouped with labels.

[b] Means with the same letters within the same column are not significantly different by t-test at the 0.05 level.

Table 2. t-Test Results of simulated mean annual organic N losses for the Texarkana field.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Jan	-											
Feb	NS[a]	-										
Mar	NS	NS	-									
Apr	NS	NS	NS	-								
May	NS	NS	NS	NS	-							
Jun	S[b]	S	S	S	S	-						
Jul	NS	S	S	S	S	NS	-					
Aug	S	S	S	S	S	NS	S	-				
Sep	NS	NS	NS	S	NS	NS	NS	NS	-			
Oct	NS	S	S	S	S	NS	NS	NS	NS	-		
Nov	NS	S	S	S	S	NS	NS	NS	NS	NS	-	
Dec	NS	NS	S	S	NS	NS	NS	S	NS	NS	NS	-

[a] Not significantly different at the 0.05 level.

[b] Significantly different at the 0.05 level.

Table 3. Simulated mean annual P losses for the Texarkana field.

Application Date	Sediment P[a] (kg/ha)	Soluble P[a] (kg/ha)	Total P[a] (kg/ha)
January	23.07 abcde	8.46 a	31.54 abc
February	24.10 abcd	8.52 a	32.62 abc
March	25.31 ab	8.49 a	33.79 ab
April	26.89 a	8.36 a	35.25 a
May	24.52 abc	8.42 a	32.93 abc
June	18.85 defg	8.65 a	27.50 bcde
July	19.81 bcdef	8.52 a	28.33 abcde
August	15.09 g	8.71 a	23.81 e
September	19.58 bcdefg	8.10 a	27.68 abcde
October	17.22 efg	8.16 a	25.38 cde
November	16.99 fg	7.88 a	24.87 de
December	18.92 cdefg	7.50 a	26.42 bcde

[a] Means with the same letters within the same column are not significantly different by t-test at the 0.05 level.

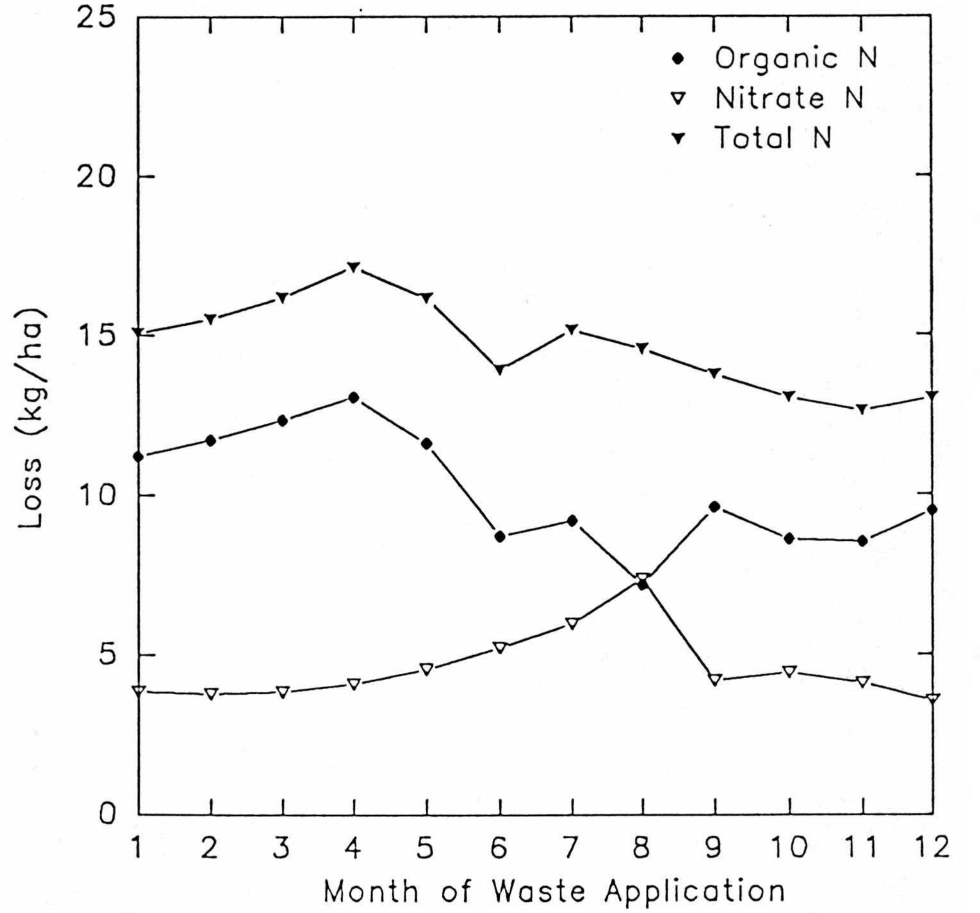

Fig. 1. Effect of application timing on N losses for the Texarkana field.

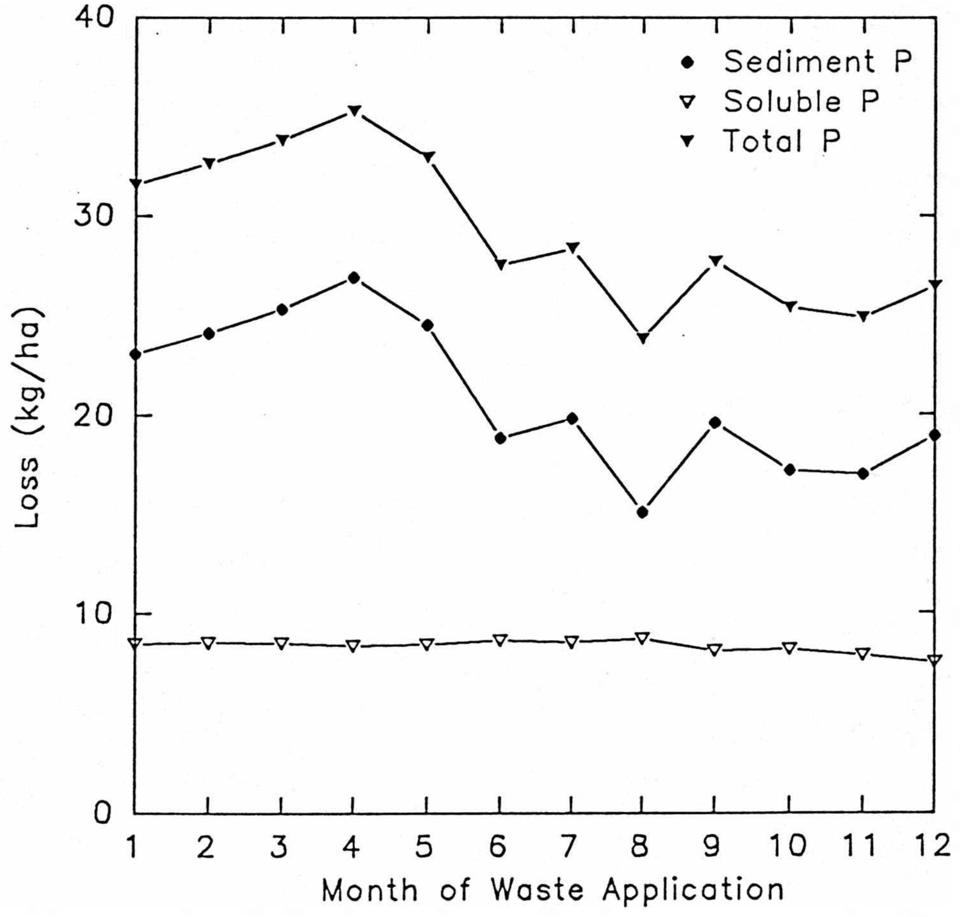

Fig. 2. Effect of application timing on P losses for the Texarkana field.

Table 4. Simulated mean annual N losses for the Stuttgart field.

Application Date	Organic N[a] (kg/ha)	Nitrate N[b] (kg/ha)	Total N[a] (kg/ha)
January	10.65 abc	6.97	17.62 ab
February	10.77 abc	6.97	17.74 ab
March	11.35 abc	6.71	18.07 ab
April	12.24 ab	6.08	18.32 ab
May	12.90 a	8.76	21.67 a
June	12.06 ab	9.33	21.39 a
July	9.00 c	8.97	17.96 ab
August	9.32 c	7.47	16.78 b
September	9.44 bc	7.95	17.39 ab
October	9.52 bc	9.52	19.05 ab
November	9.02 c	8.59	17.60 ab
December	9.60 bc	7.05	16.65 b

[a] Means with the same letters within the same column are not significantly different by t-test at the 0.05 level.

[b] Nitrate N losses cannot be grouped with labels.

Table 5. t-Test results of simulated mean annual nitrate N losses for the Stuttgart field.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Jan	-											
Feb	NS[a]	-										
Mar	NS	NS	-									
Apr	NS	NS	NS	-								
May	NS	NS	NS	S	-							
Jun	S[b]	NS	S	S	NS	-						
Jul	NS	NS	NS	NS	NS	NS	-					
Aug	NS	NS	NS	NS	NS	NS	NS	-				
Sep	NS	NS	NS	NS	NS	NS	NS	NS	-			
Oct	S	S	S	S	NS	NS	NS	NS	NS	-		
Nov	S	NS	S	S	NS	NS	NS	NS	NS	NS	-	
Dec	NS	NS	NS	NS	NS	NS	NS	NS	NS	S	NS	-

[a] Not significantly different at the 0.05 level.

[b] Significantly different at the 0.05 level.

Table 6. Simulated mean annual P losses for the Stuttgart field.

Application Date	Sediment P[a] (kg/ha)	Soluble P[b] (kg/ha)	Total P[b] (kg/ha)
January	19.82	22.94 a	42.76 a
February	19.95	23.33 a	43.28 a
March	21.03	22.69 a	43.72 a
April	22.72	22.08 a	44.80 a
May	25.11	21.66 a	46.77 a
June	23.79	21.78 a	45.57 a
July	17.49	22.74 a	40.22 a
August	17.99	22.45 a	40.44 a
September	17.67	22.28 a	39.96 a
October	17.56	21.53 a	39.09 a
November	16.26	21.09 a	37.35 a
December	17.28	20.45 a	37.74 a

[a] Sediment P losses cannot be grouped with labels.

[b] Means with the same letters within the same column are not significantly different by t-test at the 0.05 level.

Table 7. t-Test results of simulated mean annual sediment P losses for the Stuttgart field.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Jan	-											
Feb	NS[a]	-										
Mar	NS	NS	-									
Apr	NS	NS	NS	-								
May	NS	NS	NS	NS	-							
Jun	NS	NS	NS	NS	NS	-						
Jul	NS	NS	NS	S[b]	S	S	-					
Aug	NS	NS	NS	NS	S	S	NS	-				
Sep	NS	NS	NS	NS	S	S	NS	NS	-			
Oct	NS	NS	NS	NS	S	S	NS	NS	NS	-		
Nov	NS	NS	NS	S	S	S	NS	NS	NS	NS	-	
Dec	NS	NS	NS	NS	S	S	NS	NS	NS	NS	NS	-

[a] Not significantly different at the 0.05 level.

[b] Significantly different at the 0.05 level.

annual nutrient losses are depicted in Figures 3 and 4. Similar to the simulations for the Texarkana field, organic N losses for the Stuttgart field were greater for applications during the first half of the year whereas nitrate N losses were least for applications during January through April. Again, total N losses did not exhibit great dependence on the timing of fertilizer application. Sediment-bound phosphorus losses were greater for application during January through June, but soluble P losses as well as total P losses were largely independent of application timing.

Simulated mean annual nutrient losses for the Fayetteville location are given in Tables 8 through 10 and are illustrated in Figures 5 and 6. The trends established by the data for Texarkana and Stuttgart held for the Fayetteville data. Organic N losses were greater for applications from January through August, and nitrate N as well as total N losses were greater for applications during May through September. Sediment-bound phosphorus losses were greatest for March through August applications, but both soluble and total P losses were not appreciably influenced by the timing of fertilizer application.

Table 11 shows the yields resulting from different fertilizer application dates for the three fields simulated. This table shows rather vividly that yield is significantly affected by the time of year at which the fertilizer is applied. The best time of year to apply, from the standpoint of obtaining maximum forage

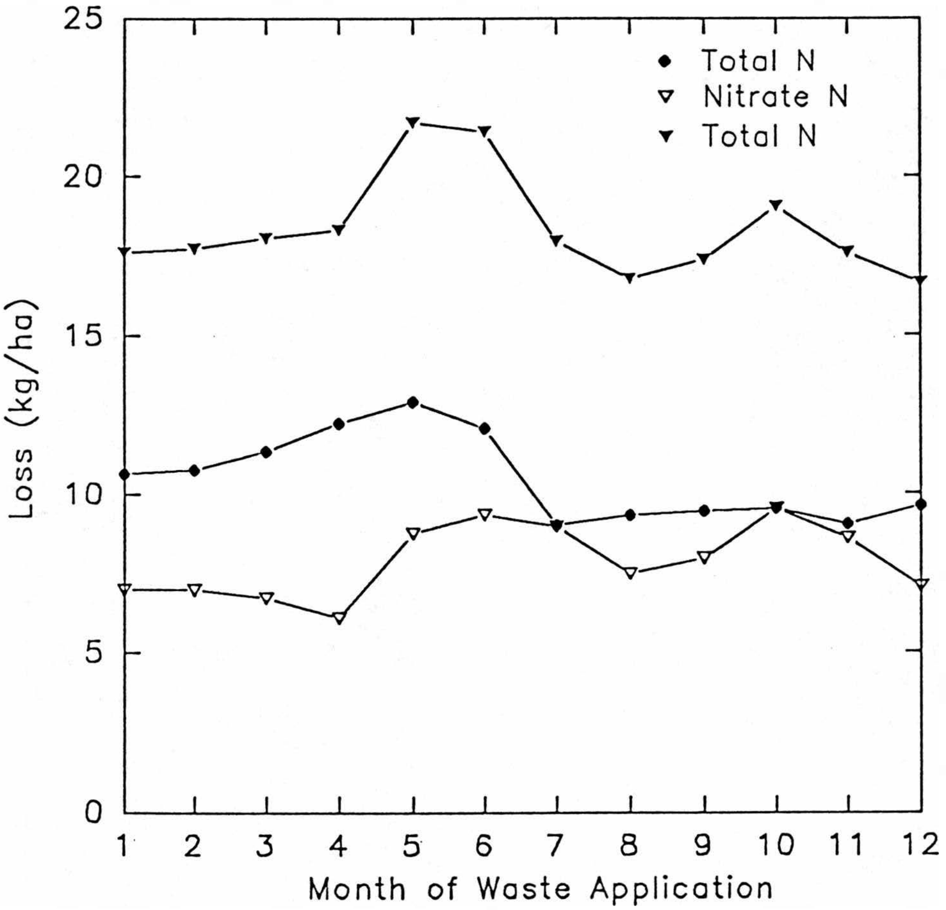

Fig. 3. Effect of application timing on N losses for the Stuttgart field.

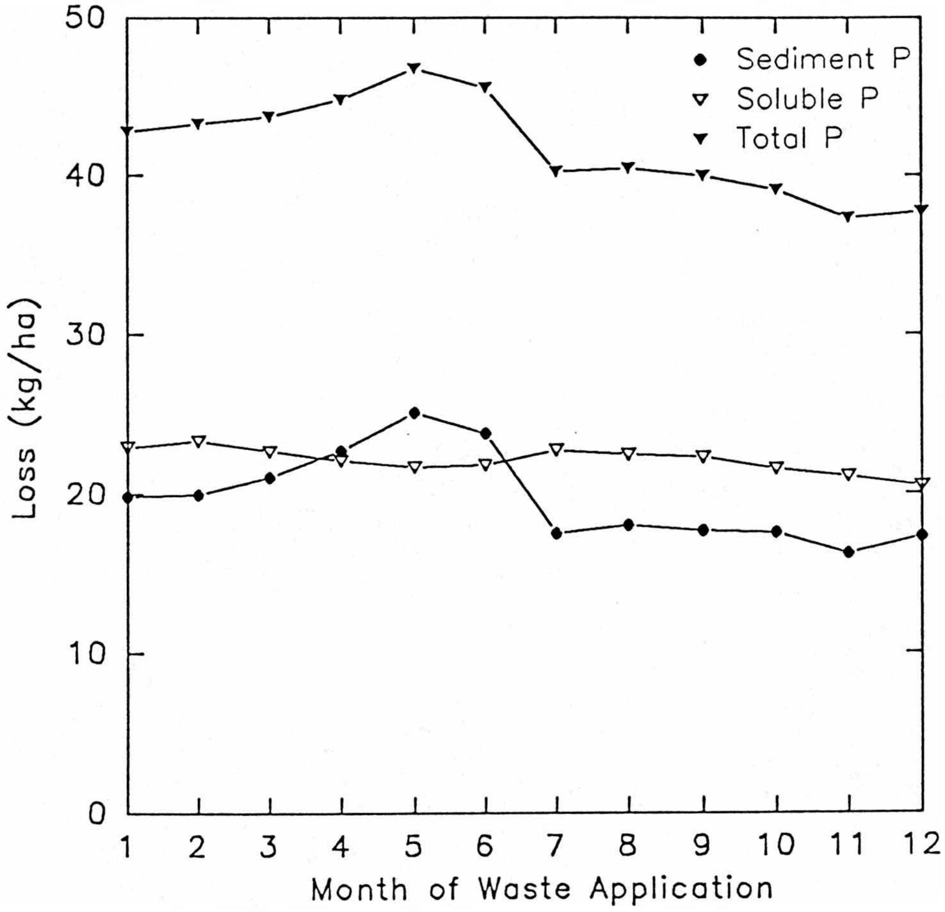

Fig. 4. Effect of application timing on P losses for the Stuttgart field.

Table 8. Simulated mean annual N losses for the Fayetteville field.

Application Date	Organic N[a] (kg/ha)	Nitrate N[b] (kg/ha)	Total N[a] (kg/ha)
January	5.26 ab	2.44	7.70 abc
February	5.33 ab	2.52	7.84 abc
March	5.47 ab	2.44	7.90 abc
April	5.81 ab	2.56	8.36 abc
May	5.87 ab	3.28	9.15 abc
June	5.70 ab	3.79	9.49 ab
July	6.15 a	3.48	9.62 a
August	5.25 ab	3.83	9.08 abc
September	5.05 ab	4.21	9.26 abc
October	4.79 ab	2.58	7.37 bc
November	4.46 b	2.56	7.02 c
December	4.85 ab	2.29	7.14 bc

[a] Means with the same letters within the same column are not significantly different by t-test at the 0.05 level.

[b] Nitrate N losses cannot be grouped with labels.

Table 9. t-Test results of simulated mean annual nitrate N losses for the Fayetteville field.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Jan	-											
Feb	NS[a]	-										
Mar	NS	NS	-									
Apr	NS	NS	NS	-								
May	NS	NS	NS	NS	-							
Jun	NS	NS	NS	NS	NS	-						
Jul	NS	NS	NS	NS	NS	NS	-					
Aug	NS	NS	NS	NS	NS	NS	NS	-				
Sep	S[b]	S	S	S	NS	NS	NS	NS	-			
Oct	NS	NS	NS	NS	NS	NS	NS	NS	S	-		
Nov	NS	NS	NS	NS	NS	NS	NS	NS	S	NS	-	
Dec	NS	NS	NS	NS	NS	NS	S	S	S	NS	NS	-

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[a] Not significantly different at the 0.05 level.

[b] Significantly different at the 0.05 level.

Table 10. Simulated mean annual P losses for the Fayetteville field.

Application Date	Sediment P[a] (kg/ha)	Soluble P[a] (kg/ha)	Total P[a] (kg/ha)
January	9.79 abc	8.61 a	18.40 ab
February	9.93 abc	8.55 a	18.48 ab
March	10.17 abc	8.63 a	18.80 ab
April	10.81 abc	8.64 a	19.45 ab
May	11.16 ab	8.61 a	19.78 ab
June	11.26 ab	8.40 a	19.66 ab
July	12.36 a	8.33 a	20.69 a
August	10.39 abc	8.36 a	18.74 ab
September	9.45 abc	8.02 a	17.47 ab
October	8.75 bc	7.62 a	16.37 ab
November	8.00 c	7.45 a	15.45 b
December	8.71 bc	7.57 a	16.28 ab

[a] Means with the same letters within the same column are not significantly different by t-test at the 0.05 level.

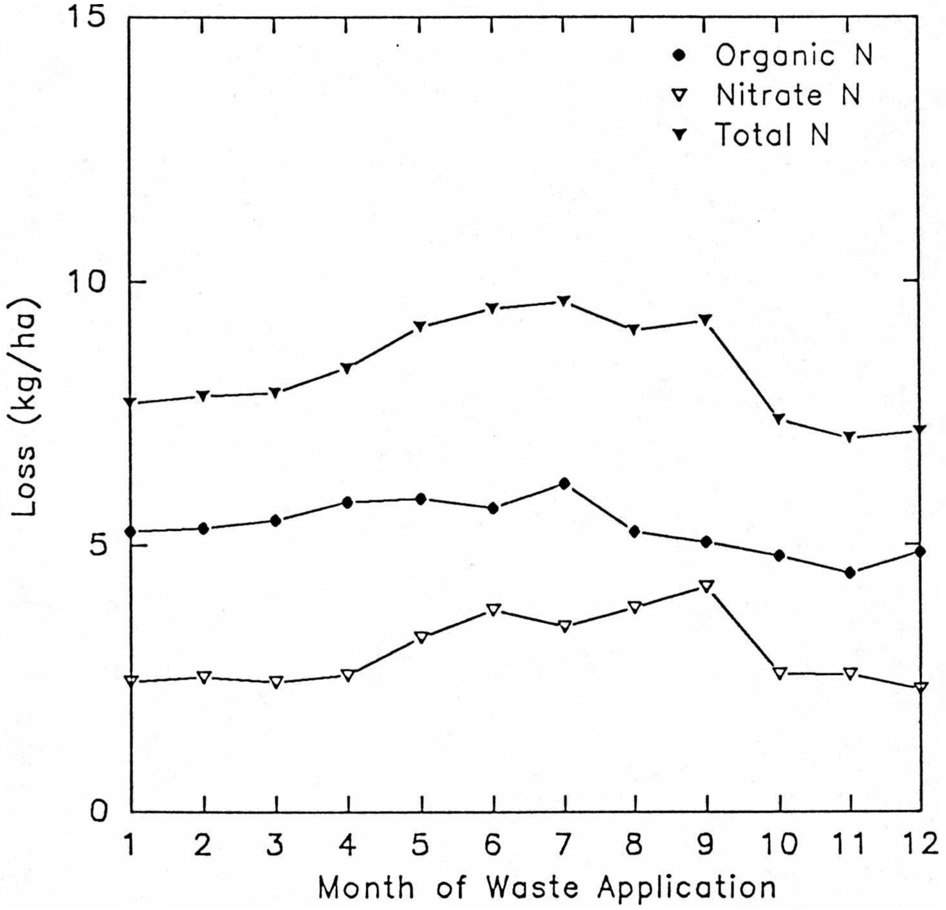

Fig. 5. Effect of application timing on N losses for the Fayetteville field.

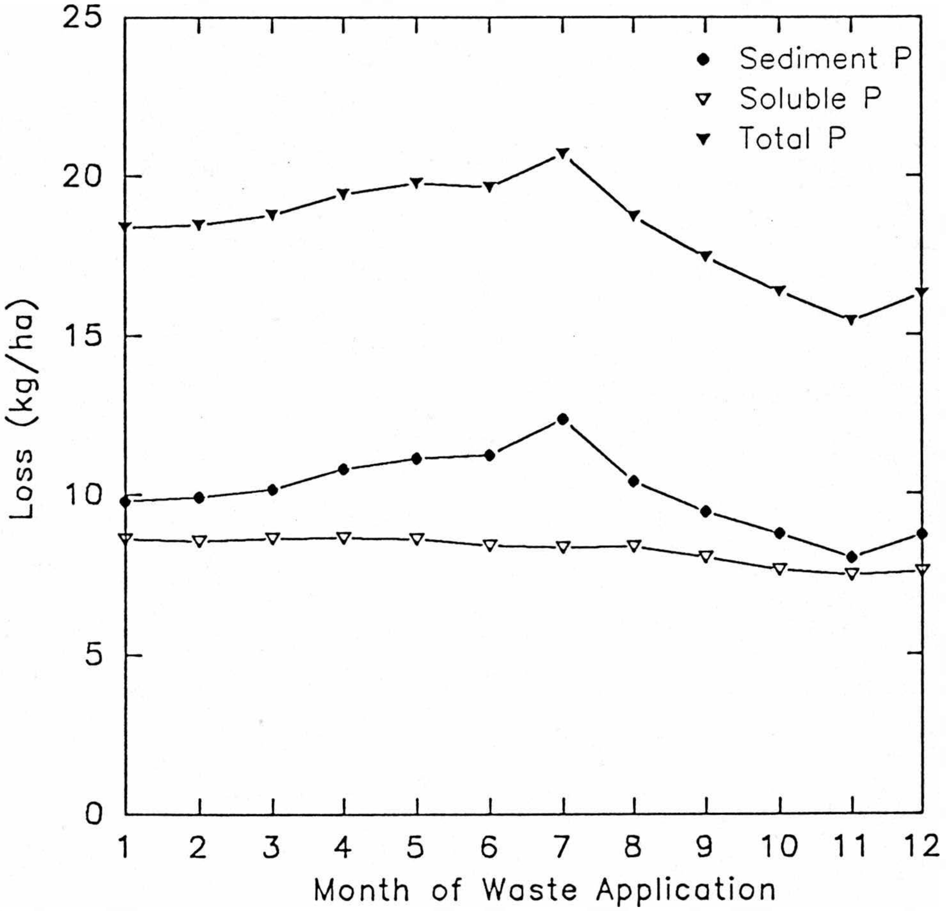

Fig. 6. Effect of application timing on P losses for the Fayetteville field.

Table 11. Simulated mean annual grass yields.

Application Date	Yield (Mg/ha)		
	Texarkana[a]	Stuttgart[a]	Fayetteville[a]
January	7.61 a	8.61 a	11.28 a
February	7.59 a	8.93 a	11.24 a
March	7.62 a	8.94 a	11.26 a
April	7.22 ab	8.67 ab	11.02 a
May	6.26 c	4.89 d	9.49 b
June	5.27 d	3.83 f	8.57 c
July	5.22 d	4.08 ef	6.94 d
August	5.73 d	4.23 e	7.44 d
September	6.36 c	4.94 d	8.51 c
October	6.94 b	6.73 c	9.99 b
November	7.40 a	8.12 b	10.94 a
December	7.51 a	8.52 ab	11.10 a

[a] Means with the same letters within the same column are not significantly different by t-test at the 0.05 level.

yield, is without exception during the months of November through April. The dependence of grass yield on application timing is shown in Figure 7.

The preceding results have indicated that the best time of year to apply lightly-incorporated waste having the same composition as broiler litter varies depending on which pollutant losses one wishes to minimize. This optimal timing may be different if instead of minimizing simulated mean annual pollutant losses, one wishes to maximize yield. This point is illustrated in Table 12, which lists the best time of year to apply waste for each of the three locations as a function of different criteria. Table 12, however, lists optimal application timing based solely on the magnitudes of simulated nutrient losses and yields. It would be more proper, based on the results of the significance testing, to speak in terms of optimal "windows", within which the resulting nutrient losses and yields are not significantly different. These optimal application windows are presented in Figures 8 through 10. Figure 8 indicates that for Texarkana, application during November minimizes all nutrient losses and results in maximum yield. Application during other months either does not minimize nutrient losses and/or does not maximize yield. Figure 9 shows that for Stuttgart, the optimal window is broader from December through March. For Fayetteville, as shown in Figure 10, the optimal window is broader still. Applications during the

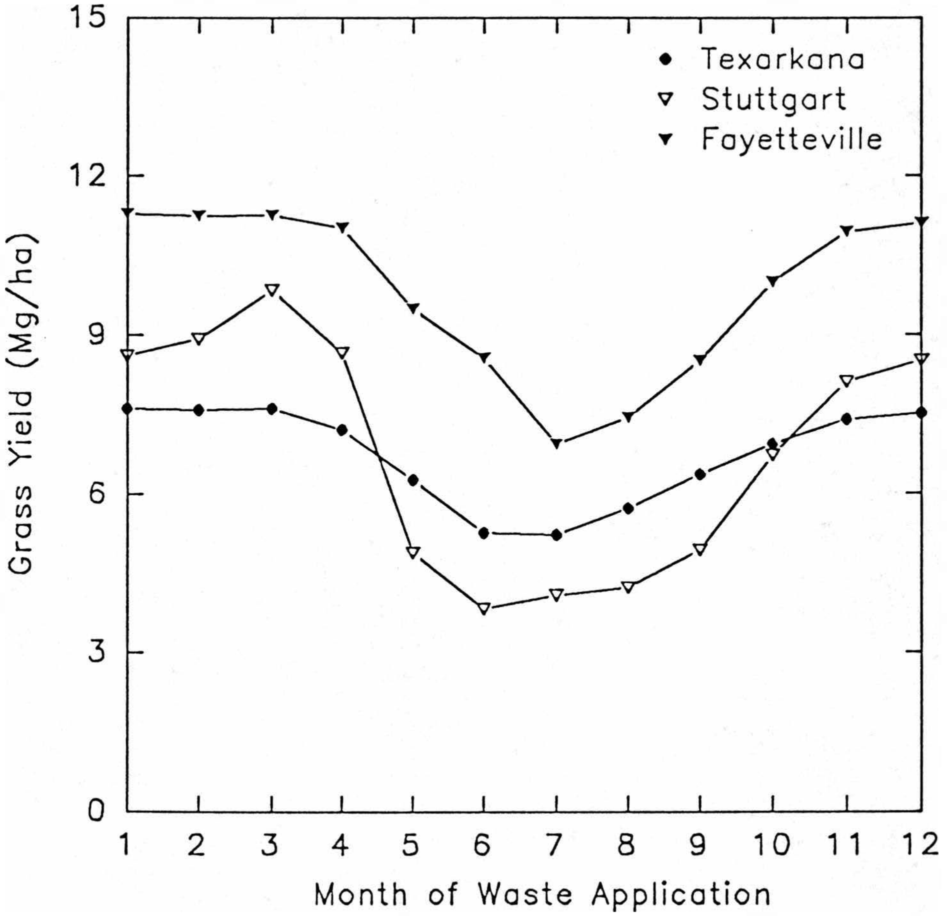

Fig. 7. Effect of application timing on grass yields.

Table 12. Optimal timing of waste disposal based on simulation results.

Criterion	Location Texarkana	 Stuttgart	 Fayetteville
Minimize annual organic N loss	August	July	November
Minimize annual nitrate N loss	December	April	December
Minimize annual total N loss	November	December	November
Minimize annual sediment P loss	August	November	November
Minimize annual soluble P loss	December	December	November
Minimize annual total P loss	August	November	November
Maximize annual grass yield	March	March	January

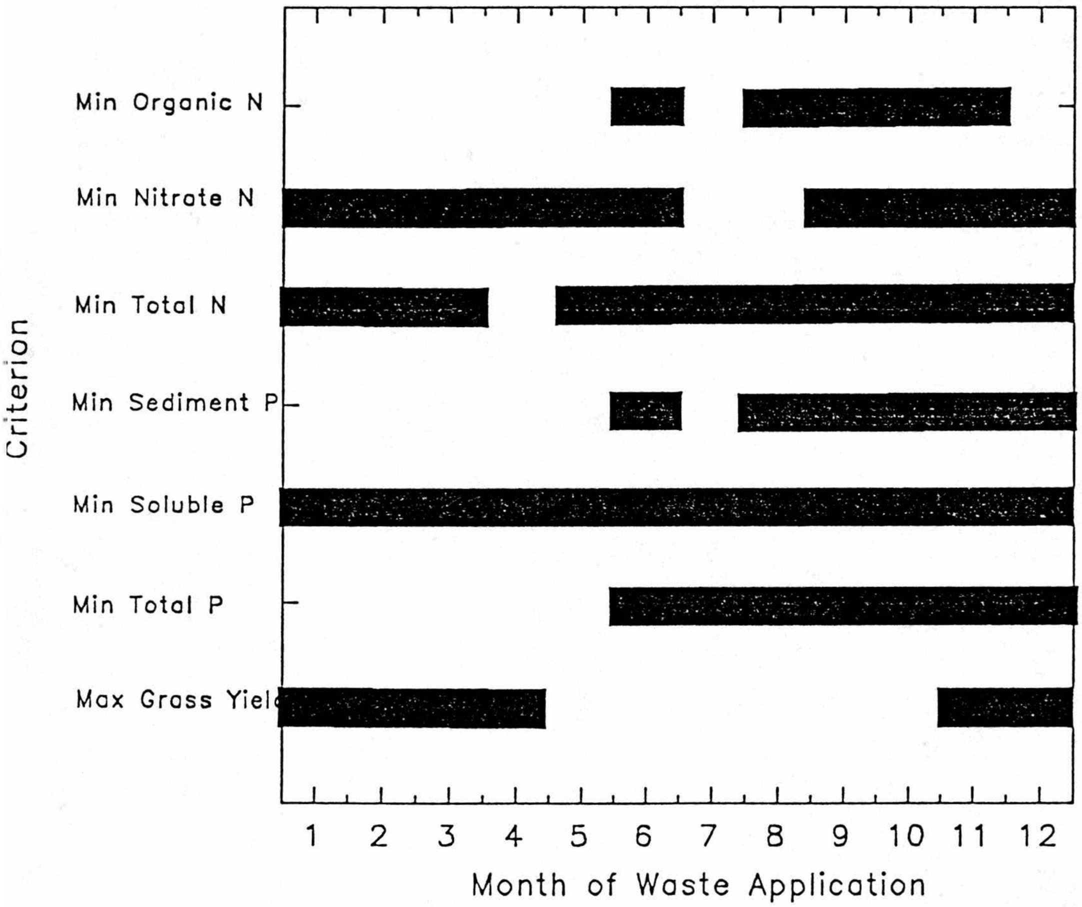

Fig. 8. Optimal application timing windows for the Texarkana field.

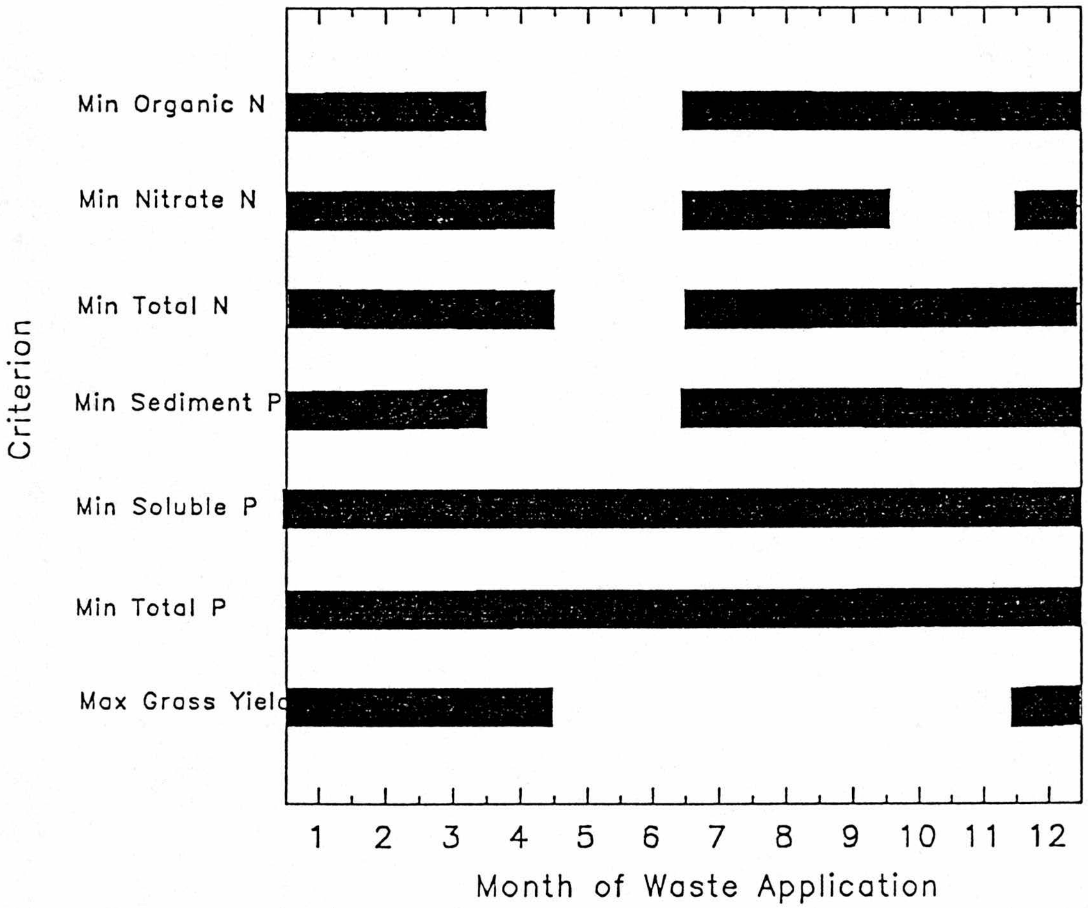

Fig. 9. Optimal application timing windows for the Stuttgart field.

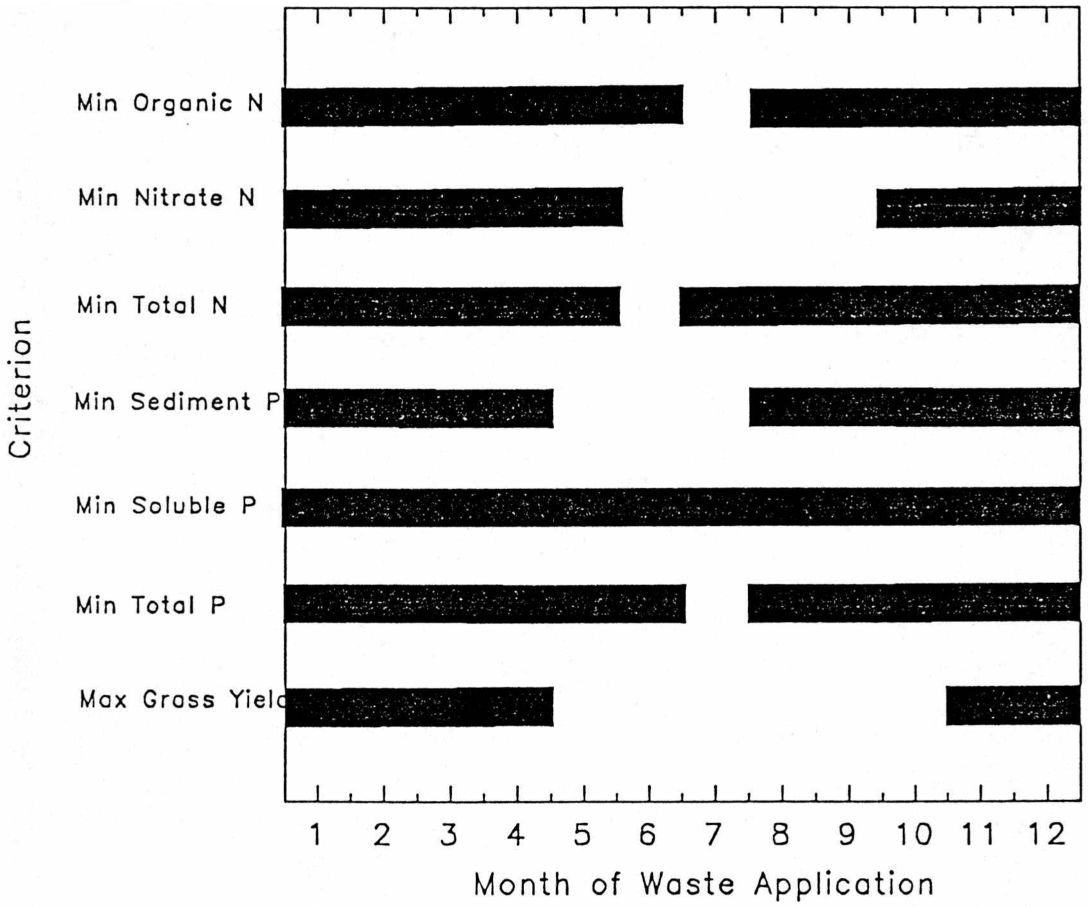

Fig. 10. Optimal application timing windows for the Fayetteville field.

months of November through April will result in minimum nutrient losses and maximum yields.

It may be that based on the nutrient status of downstream lakes, there is more concern about phosphorus losses from upstream fields than about nitrogen losses or vice versa. In such cases, one could use only the optimal timing windows that are related to losses of the nutrient of interest and develop more site-specific waste management strategies.

There are aspects of this study which potential users of this information should be aware of before drawing broad general conclusions. First, the relatively low grass yields for the Texarkana site and the relatively high yields for the Fayetteville site were unexpected. It is possible that the sandy soil used in the Texarkana simulations facilitated excessive nitrate leaching which could have depressed yields. Without further study to validate these results or to rectify the model and/or parameter values, however, it is not possible to say whether the simulated yield results accurately reflect actual conditions. In the event that the plant growth component of EPIC does merit further refinement for the situation studied, it is probable that such a refinement would have more impact on the magnitudes of simulated nutrient losses rather than the relative differences between nutrient losses as a function of application timing.

A very significant aspect of this study is that EPIC does not contain a nitrogen volatilization component. This is why the waste was simulated as being lightly incorporated rather that surface-applied as is most commonly practiced. It is well known that significant ammonia volatilization can occur following application of broiler litter. Since warm temperatures favor volatilization, it is likely that less surface losses of nitrogen would have been simulated for warm season applications if surface-application, rather than light incorporation, of the waste had been simulated. This would probably have the effect of further depressing yields with only a minor impact on simulated phosphorus losses. Thus, it is possible that the optimal application timing windows for yield and phosphorus losses identified for the scenario of lightly incorporated waste are similar to those which would be identified for a situation of surface-applied waste. Obviously, however, this should not be assumed until EPIC has been modified and a new study has been performed.

The general results of the EPIC simulations appeared quite reasonable. As has been stated earlier, the model has already been validated for selected situations. Before the model is used to aid in any type of policy development, however, it should be rigorously tested for the type of situation to which it is to be applied. It is most likely that further testing and modification would not result in results that are significantly different from those obtained with the current model (except in the instance of ammonia volatilization). Still, such an investigation should be performed in order for users of the model to gain confidence in model results and to ensure applicability of the results.

CONCLUSIONS

The following conclusions are drawn from the results of this study:

1. Simulated grass yield and surface losses of N and P due to light incorporation of waste with characteristics similar to broiler litter vary depending on the timing of the application.

2. Based on the results of the simulations, there are application "windows" within which the waste can be applied and cause minimum nutrient losses and maximum yields.

3. The location and length of these windows varies with location of the site being analyzed and is most likely related to meteorological variables.

4. Under the conditions studied, the application window resulting in minimum nutrient losses and maximum grass yields for Texarkana is the month of November; for Stuttgart, the window is December through March; for Fayetteville, the window is November through April.

The following additional issues must be addressed to extend the applicability of this type of study:

1. A volatilization component should be added to EPIC to describe nitrogen dynamics in the situation of unincorporated waste application.

2. The plant growth component of EPIC should be adjusted to result in predicted yields of magnitudes more similar to observed yields.

3. The model should be rigorously tested using actual water quality data from fields in Arkansas which are treated with broiler litter.

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APPENDIX A

MODEL INPUT DATA

Table A.1. Common input variable values

Variable	Value
Drainage area (ha)	2.0
Distance from outlet to furthest point (km)	0.14
Average channel slope	0.02
Channel roughness factor	0.04
Surface roughness factor	0.24
Slope length (m)	118.0
Slope steepness	0.02

Table A.2. Input variable values for different locations

	Texarkana	Stuttgart	Fayetteville
Curve number	71	78	71
Latitude	33° 27′	34° 28′	36° 06′
Elevation (m)	110	60	387

Table A.3. Input data used to describe the Sacul soil[a]

	Layer								
	1	2	3	4	5	6	7	8	9
Albedo[b]	0.15								
Depth from surface (m)	0.01	0.15	0.25	0.51	0.66	0.97	1.35	1.75	2.03
Bulk density (Mg/m^3)[c]	1.47	1.47	1.46	1.45	1.45	1.65	1.43	1.51	1.51
Sand content (%)	73.6	73.6	67.7	27.9	20.7	19.9	27.5	56.9	44.8
Silt content (%)	25.3	25.3	25.1	22.8	28.6	30.3	29.1	16.5	29.9
pH	5.5	5.5	5.7	5.3	5.1	5.0	4.9	4.7	4.6
Sum of bases (cmol/kg)	1.2	1.2	1.4	5.4	4.3	3.6	2.2	1.5	1.1
Organic carbon (%)	0.29	0.29	0.23	0.17	0.06	0.06	0.06	0.06	0.06
Cation exchange capacity (cmol/kg)	4.2	4.2	4.2	24.5	20.4	21.2	22.0	16.0	13.5

[a] Taken from Laurent and Johnson (1975) and Laurent (1984) unless otherwise specified.

[b] Assumed the same as Ruston series in Williams et al. (1990b)

[c] Assumed the same as Bowie-B in Williams et al. (1990b)

Table A.4. Input data used to describe the Crowley soil[a]

	Layer						
	1	2	3	4	5	6	7
Albedo[b]	0.14						
Depth from surface (m)[c]	0.01	0.05	0.15	0.30	0.46	0.66	0.76
Bulk density (Mg/m^3)[c]	1.17	1.17	1.41	1.52	1.53	1.40	1.36
Field Capacity at 33 kPa (cm^3/cm^3)[c]	0.26	0.26	0.24	0.22	0.25	0.35	0.38
Sand content (%)	3.2	3.2	3.4	7.0	1.4	1.2	1.2
Silt content (%)	78.0	78.0	76.1	72.2	36.6	36.5	36.5
pH	5.2	5.2	5.6	4.4	4.6	4.7	4.7
Sum of bases (cmol/kg)	8.3	8.3	9.0	3.8	8.9	11.5	11.5
Organic carbon (%)	0.92	0.92	0.81	0.40	0.73	0.62	0.62
Cation exchange capacity (cmol/kg)	18.2	18.2	18.8	13.7	42.1	44.4	44.4
Saturated Conductivity (mm/h)[c]	77.2	77.2	28.7	5.5	6.5	0.1	3.8

[a] Taken from Rutledge et al. (1975) unless otherwise specified.

[b] Assumed the same as Grenada series in Williams et al. (1990b)

[c] Taken from Scott et al. (1986)

Table A.5. Input data used to describe the Captina soil[a]

	Layer									
	1	2	3	4	5	6	7	8	9	10
Albedo[b]	0.15									
Depth from surface (m)	0.01	0.15	0.30	0.45	0.61	0.76	0.91	1.06	1.22	1.37
Bulk density (Mg/m^3)	1.28	1.38	1.38	1.44	1.52	1.51	1.48	1.53	1.50	1.39
Field capacity at 33 kPa (cm^3/cm^3)	0.33	0.29	0.28	0.28	0.31	0.32	0.33	0.34	0.33	0.34
Sand content (%)	23.2	23.2	18.8	17.2	15.6	16.0	16.8	16.4	20.3	14.5
Silt content (%)	68.5	67.1	66.2	62.3	58.4	54.9	52.7	52.4	48.6	54.0
pH	5.2	5.2	5.6	6.1	6.0	5.1	5.1	5.1	5.1	4.9
Sum of bases (cmol/kg)[c]	3.2	3.2	3.9	5.3	7.3	6.9	6.9	6.9	6.9	11.9
Organic carbon (%)[c]	0.52	0.52	0.43	0.30	0.28	0.12	0.12	0.12	0.12	0.13
Cation exchange capacity (cmol/kg)[c]	9.1	9.1	9.4	11.1	14.9	16.5	16.5	16.5	16.5	19.5
Saturated Conductivity (mm/h)	1.35	1.24	1.29	1.36	1.54	2.36	1.67	0.82	1.02	0.83

[a] Taken from Thiesse (1984) unless otherwise specified.

[b] Assumed the same as Nixa series in Williams et al. (1990b)

[c] Taken from Rutledge (1977).

APPENDIX B

SELECTED SIMULATED METEOROLOGICAL OUTPUTS

Table B.1. Simulated Mean Monthly Precipitation

Month	Precipitation (mm)		
	Texarkana	Stuttgart	Fayetteville
January	97.2	101.0	53.0
February	98.2	76.8	42.8
March	103.7	121.4	107.6
April	127.9	124.6	105.6
May	134.0	112.3	129.5
June	124.8	109.5	125.2
July	102.2	78.5	83.5
August	99.4	72.7	77.1
September	107.7	68.5	126.1
October	103.1	94.5	118.4
November	135.3	119.5	105.2
December	136.3	127.5	89.7
Total	1369.8	1206.9	1163.8

Table B.2. Simulated Mean Monthly Runoff

Month	Runoff (mm)		
	Texarkana	Stuttgart	Fayetteville
January	2.0	10.1	1.8
February	2.7	8.7	0.9
March	3.0	13.6	1.9
April	3.6	17.3	1.4
May	4.1	12.1	5.2
June	4.1	7.3	5.0
July	1.2	4.9	2.5
August	5.5	4.1	1.3
September	7.5	4.5	6.4
October	2.7	7.2	4.0
November	5.9	18.5	4.4
December	7.6	17.2	4.7
Total	49.9	125.5	39.5

Table B.3. Simulated Mean Monthly Solar Radiation

Month	Solar Radiation (MJ/m^2)		
	Texarkana	Stuttgart	Fayetteville
January	9	8	9
February	11	11	11
March	15	14	15
April	19	19	19
May	23	22	22
June	24	24	24
July	24	25	24
August	22	22	22
September	18	18	18
October	14	14	14
November	10	10	10
December	9	8	8

Table B.4. Simulated Mean Monthly Maximum and Minimum Temperatures

Month	Temperature (^{0}C)					
	Texarkana		Stuttgart		Fayetteville	
	Max	Min	Max	Min	Max	Min
January	10.3	-2.0	8.6	-1.3	7.5	-4.5
February	13.3	-0.1	10.4	-0.5	9.5	-2.5
March	17.0	2.9	15.6	4.7	14.0	2.3
April	22.7	8.8	20.9	9.7	20.2	7.7
May	27.0	13.1	25.9	14.9	23.7	11.6
June	30.8	17.6	30.7	19.7	28.3	16.7
July	33.5	20.3	33.1	22.2	31.6	19.9
August	33.6	20.2	32.8	21.7	32.2	19.8
September	31.1	17.5	29.5	17.8	28.9	16.6
October	25.3	10.9	24.8	11.8	22.6	9.8
November	18.8	5.5	17.6	6.5	15.5	3.6
December	13.7	0.8	11.6	1.2	10.6	-1.1