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Simulation of Effects of Swine Manure Application Rates on Nitrate Concentration in Runoff, Indiana, USA

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ABSTRACT: Livestock manure is an important source of nutrients for crop production. However, farmers typically do not know the exact nutrient values for livestock manure. In many instances, manure has been viewed as a waste, and as a result it is applied close to the source resulting in over application of nutrients. Thus, the goal of nutrient application has often been applied to reduce the application expense rather than to maximize crop income. This results in wasted money and potentially negative impacts on water quality. Several livestock manure management scenarios were created based on agronomic nutrient requirements using the Utilization of Animal Manure as a Plant Nutrient (AMANURE) software to investigate water quality impacts with the National Agricultural Pesticide Risk Analysis (NAPRA) WWW modeling system. Application of manure at agronomic rates can result in high nitrate-nitrogen losses for some soil types, especially when applied in late fall. The application of manure at an agronomic rate does not necessarily equate to adequate water quality protection, and farmers must take care applying manure at agronomic rates, because nitrate-nitrogen loss potential varies spatially and temporarily. Nutrient loss probability maps for Indiana at 5%, 10%, 25%, and 50% values were created to demonstrate potential water quality impacts when livestock manure is applied to cropland at agronomic rates. The NAPRA WWW system coupled with AMANURE can be used to identify site-specific livestock manure management plans that are environmentally sound and agronomically appropriate.

Key Words: Livestock Manure, AMANURE, NAPRA WWW, Water Quality

INTRODUCTION

Significant amounts of livestock manure are used as fertilizer for crop production. In the United States, approximately 6.5 million tons of nitrogen is applied to cropland annually from 11.5 million tons of nitrate fertilizer and 7 billion tons of manure from farm animals every year[1)]. Approximately 75 percent of the nutrients fed to livestock are excreted in manure[2)]. These nutrients are worth over $20,000 per year for average sized farms in U.S[2)].

Farmers often apply fertilizer to crop fields to maximize crop yields without worrying about its potential environmental impacts. However, only approximately 50% of the nutrients applied are used by the crop,[3)] while the remaining portion may return to the atmosphere as some form of nitrogen gas or is converted into readily leachable nitrate in the soil that may eventually end up in ground water[1,4)] As a consequence, the disposal of livestock manure has become a significant issue due to potential negative impacts on the environment.

It is important to assess nutrient values in the

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livestock manure so appropriate amount of nutrients is applied to croplands because the nutrient loss from livestock manure is directly affected by manure application rate, manure application method and timing, crop rotation, crop management, and soil properties. Thus, software called Utilization of Animal Manure as a Plant Nutrient (AMANURE) model was developed in the early 1990s to assist Indiana farmers in the USA in using manure as a more efficient fertilizer[2].

To estimate the water quality impacts of various livestock manure rates, estimated using the AMANURE, on surface and subsurface water quality, a model capable of simulating the nutrient cycle in the soil and agricultural cropping systems is needed. Many hydrologic and water quality models have been integrated with Geographic Information Systems (GIS)[5-8] because the nature of agricultural nonpoint source (NPS) is essentially spatial and temporal. These GIS integrated models have the advantages of ease and efficiency of storing, retrieving, and formatting the many types of spatial and tabular data required for hydrologic/water quality modeling[9].

The Web-based National Agricultural Pesticide Risk Analysis (NAPRA) decision support system was developed for such needs[10]. The NAPRA WWW system uses the Groundwater Loading Effects of Agricultural Management Systems (GLEAMS) model[11] as a core model to simulate hydrology, erosion, pesticide, and nutrient losses in runoff, sediment, and to shallow groundwater[10]. The NAPRA WWW system has been validated in many studies. Lim and Engel[12] compared the NAPRA WWW predicted nitrate values with instream modeling capability with measured nitrate data at 22 locations in the White River basin, Indiana, USA. The R^2 values for the comparison of simulated nitrate values with measured nitrate values with instream modeling using QUAL2E were 0.65. Lim and Engel[12] compared the NAPRA estimated nitrate and atrazine values with the USGS well nitrate and atrazine data in Indiana, USA. The NAPRA WWW system correctly categorized 84% of the High and Very High nitrate observation. The NAPRA WWW system also correctly categorized 69% of the High and Very High atrazine observations. The NAPRA WWW showed the potential to identify areas where groundwater is vulnerable to nitrate and atrazine NPS pollution. The water quality impacts of using AMANURE's recommended agronomic manure application rates on cropland were investigated in this study.

The objectives were:

1) to evaluate the water quality effects of different agronomically-based manure management scenarios and;

2) to create NAPRA WWW predicted nutrient loss probability occurrence maps from various livestock manure management scenarios for livestock manure management plans.

Methodology

Estimation of Agronomic Nutrient Requirements

Agronomic manure application rates were estimated using the AMANURE software. In AMANURE runs, 9,400 kg/ha of potential yield for continuous corn was used as a corn production goal, and manure from total swine herd stored as a liquid swine manure was used an input data to the AMANURE software. AMANURE recommended manure application rates were estimated for two application methods: broadcasting and injection. AMANURE suggested that 85,237.8 l/ha of liquid swine manure should be surface applied or 70,298.9 l/ha of liquid swine manure should be injected to meet the agronomic nitrogen requirements for cropland with 9,400 kg/ha potential corn yield.

Ten nutrient management scenarios were created based on AMANURE estimated agronomic manure application rate and using the state average nutrient application rates (171 kg/ha)[13]. In these nutrient management scenarios, state average nutrient application rates were used instead of county specific nutrient application rates. This is because this study was intended to evaluate the water quality effects of agronomically based manure management scenarios for different soil and weather conditions, not for different nutrient application amounts.

If 33,406 l/ha of liquid swine manure were surface applied, around 71 kg/ha of plant available nitrogen would be applied to the field. With surface applied manure, additional anhydrous ammonia, injected at 122 kg/ha, would meet the overall nitrogen requirement for corn based on AMANURE's recommendation. If 33,406 l/ha of liquid swine manure were injected, around 86 kg/ha of plant available nitrogen would be injected in the field. With injected manure, additional anhydrous ammonia, injected at 104 kg/ha, would meet the overall nitrogen requirement for corn based on AMANURE's recommendation. Nutrient application rates were computed for eight other scenarios (Table 1). The following nutrient application scenarios were used: 'No manure application', 'Fall manure application', 'Spring manure application', 'No commercial fertilizer application', and 'Spring commercial fertilizer application'. Scenarios 6 - 9 (Table 1) are the same as scenarios 1, 2, 4, and 5 except that manure is applied in the spring (April 1) rather than in the fall (November 1).

NAPRA runs with nutrient scenarios

The NAPRA WWW system was run only for cropped areas in nine counties surrounding Tippecanoe County, Indiana, USA (Fig. 1) using the nutrient application scenarios shown in Table 1. The NAPRA WWW was run for the combinations of soil and weather prepared with a GIS for the nine counties. There are up to 21 components with different soil properties and component area reported in each Map Unit ID (MUID) in the state soil geographic database (STATSGO). However, no spatial information is associated with each component. Thus, the NAPRA WWW predicted values for each combination of STATSGO soil and weather were obtained by averaging the NAPRA WWW predicted values based on the relative percentage of areas of each component in a MUID.

The NAPRA WWW system was modified to create nutrient loss probability maps. To obtain 5%, 10%, 25%, and 50% nitrate (nitrate-nitrogen, hereafter denoted as "nitrate") and phosphorus loss (mass and concentration) probability maps, the NAPRA predicted annual values were sorted in descending order for each soil type in each county. Then, the corresponding values for 5%, 10%, 25%, and 50% probabilities were determined. Fig. 2 shows it is expected nitrate concentration value of 4.4 mg/l in runoff for 50% of time, nitrate concentration of 6.2 mg/l in runoff for 25% of time, and nitrate concentration of 11.7 mg/l in runoff

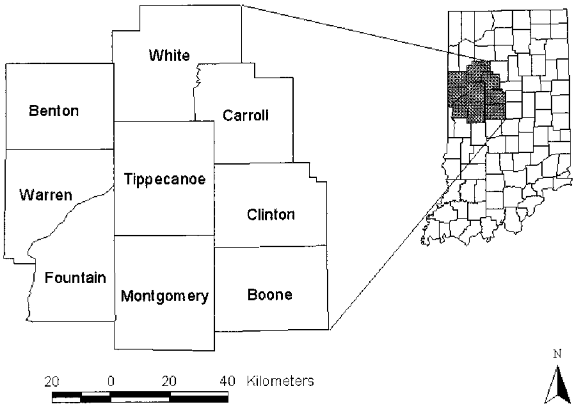


Fig. 1. Location of nine counties in Indiana for NAPRA runs with agronomic manure application rate.

Table 1. Ten nutrient management scenarios created based on AMANURE's agronomic nutrient r-ecommendation

Scenarios	Swine Liquid			Anhydrous Ammonia		
	Date	Amount	Method	Date	Amount	Method
Scenario 1	Nov. 1	35,406 l/ha	Surface App.	May 15	122 kg/ha	Injection
Scenario 2	Nov. 1	35,406 l/ha	Injection	May 15	104 kg/ha	Injection
Scenario 3		No Manure Applied		May 15	209 kg/ha	Injection
				May 15	560 kg/ha of Super Phos.	
Scenario 4	Nov. 1	85,184 l/ha	Surface App.		No Fertilizer Applied	
Scenario 5	Nov. 1	70,491 l/ha	Injection		No Fertilizer Applied	
Scenario 6	Apr. 1	35,406 l/ha	Surface App.	May 15	123 kg/ha	Injection
Scenario 7	Apr. 1	35,406 l/ha	Injection	May 15	104 kg/ha	Injection
Scenario 8	Apr. 1	85,184 l/ha	Surface App.		No Fertilizer Applied	
Scenario 9	Apr. 1	70,491 l/ha	Injection		No Fertilizer Applied	
Scenario 10	Nov. 1	70,491 l/ha	Surface App.		No Fertilizer Applied	

for 5% of time for a given agricultural management system.

To compute 5%, 10%, 25%, and 50% nutrient loss probability values, simulated weather data for 60 years- Climate Generator (CLIGEN)[14] generated precipitation data and Generation of Weather Element for Multiple Applications (GEM)[15,16] generated temperature data - were used in the NAPRA/GLEAMS runs. The NAPRA predicted nutrient output results were compiled for each soil and weather combination using area-weighted method. ArcView GIS was used to process the results to create nutrient loss probability maps.

Results and Discussion

The NAPRA WWW simulated nutrient loss probability results were compiled for each soil in each county. These nutrient loss maps at different probability values are available at http://cobweb.ecn.purdue.edu/~napra/amanure. These maps show the spatial variations in nutrient losses in runoff and to shallow groundwater due to differences in soil properties, weather, and different nutrient application scenarios. Annual average nitrate concentration values in runoff for White County from different nutrient management scenarios computed at a 5% probability value are shown in Fig. 3. Although the county wide average values were lower than 10 mg/l, there might be areas with nitrate concentrations in runoff exceeding 10 mg/l.

The NAPRA WWW predicted annual average nitrate concentration runoff losses varied depending on nutrient application rates, timing, and methods used. The predicted nitrogen losses from scenarios 4 and 10 were higher than those from other nutrient application scenarios (Fig. 3). In scenarios 4 and 10 (Table 1), livestock manure was surface applied at 85,184 l/ha and 70,491 l/ha on November 1st. As expected, the model indicates manure surface applied had a greater chance of being lost in runoff than manure applied on the same date but injected. This was why the simulated nitrate concentration values in runoff from these scenarios were higher than those from other scenarios (Fig. 3). When livestock manure was injected, the nitrate losses in runoff were considerably lower than when surface applied (Fig. 3). When the same amount of livestock manure and fertilizer were surface applied on November 1st and April 1st(Scenarios 1 and 6, Scenarios 2 and 7, Scenarios 4 and 8, Scenarios 5 and 9) in Table 1, more nitrate was lost with runoff (213% more with fall manure application - Scenario 1, 161%, more with fall manure application - Scenario 2, 194% more with fall manure application - Scenario 4, and 125% more with fall manure application - Scenario 5 at a 5% probability value) when manure was applied on November 1st (Scenarios 1, 2, 4, and 5) (Fig. 3). The same trends for nitrate values in runoff were found for White County occurred in other counties also (Table 2).

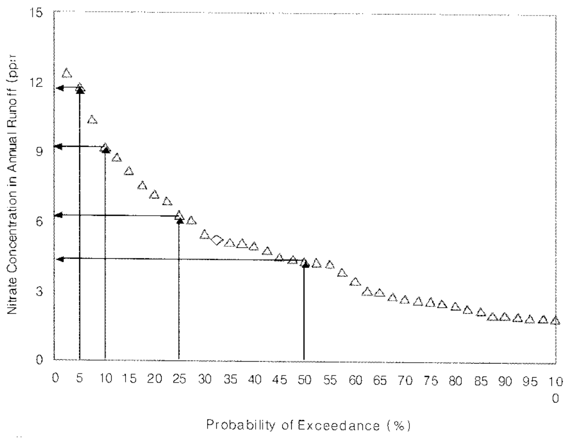


Fig. 2. Nitrate concentration in annual runoff presented as a probability of exceedance generated using NAPRA WWW decision support tool. 4.5 mg/l of nitrate concentration in runoff at a 50% level of probability.

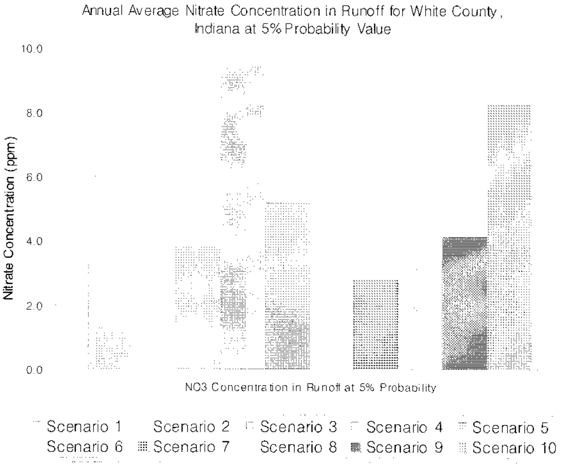


Fig. 3. Annual average nitrate concentration in runoff for White County at a 5% probability value for livestock manure application scenarios as shown in Table 1.

Table. 2 NAPRA Predicted Nitrate Concentration in Runoff for Nine Indiana Counties at 5%, 10%, 25%, and 50% Probability Level (Unit: mg/ l)

	5%	10%	15%	20%	5%	10%	15%	20%	5%	10%	15%	20%
	Benton				Boone				Carroll			
Scen. 1	4.2	3.9	3.4	2.8	5.7	4.6	3.6	3.0	5.7	5.2	4.0	3.2
Scen. 2	2.8	2.6	2.4	2.2	3.8	3.1	2.6	2.3	3.8	3.2	2.7	2.4
Scen. 3	2.7	2.6	2.4	2.2	3.5	2.9	2.4	2.2	3.4	3.0	2.6	2.4
Scen. 4	6.5	5.9	5.1	3.9	9.2	6.9	5.5	4.0	9.0	8.2	6.4	4.4
Scen. 5	3.1	2.9	2.5	2.3	4.4	3.6	2.9	2.5	4.2	3.6	3.0	2.5
Scen. 6	2.1	2.1	2.0	2.0	2.2	2.2	2.0	2.0	2.3	2.2	2.0	2.0
Scen. 7	2.1	2.0	2.0	2.0	2.2	2.2	2.0	2.0	2.3	2.2	2.0	2.0
Scen. 8	3.6	3.4	2.9	2.5	4.1	3.8	3.0	2.4	4.2	4.0	3.4	2.7
Scen. 9	2.7	2.6	2.3	2.2	3.3	3.0	2.4	2.2	3.4	3.0	2.6	2.3
Scen. 10	5.6	5.2	4.5	3.5	7.8	6.1	4.8	3.6	7.7	7.2	5.4	3.9
	Clinton				Fountain				Montgomery			
Scen. 1	4.7	3.8	3.3	2.9	4.4	3.9	3.3	2.8	6.1	5.2	4.3	3.6
Scen. 2	3.0	2.7	2.4	2.2	3.3	3.1	2.7	2.3	4.3	3.8	3.2	2.7
Scen. 3	2.9	2.6	2.4	2.2	2.8	2.6	2.4	2.3	3.6	3.3	2.8	2.5
Scen. 4	7.6	5.9	4.7	3.8	7.1	6.1	4.5	3.6	9.0	8.3	6.7	5.2
Scen. 5	3.2	2.9	2.6	2.3	4.1	3.7	2.9	2.6	5.3	4.5	3.8	3.1
Scen. 6	2.2	2.1	2.0	2.0	2.3	2.2	2.1	2.1	2.5	2.4	2.2	2.1
Scen. 7	2.2	2.1	2.0	2.0	2.3	2.1	2.1	2.1	2.5	2.3	2.2	2.1
Scen. 8	4.2	3.8	3.0	2.5	3.4	3.3	2.9	2.5	4.9	4.4	3.6	3.0
Scen. 9	3.3	2.8	2.4	2.2	2.9	2.7	2.4	2.2	3.8	3.3	2.8	2.5
Scen. 10	6.5	4.9	4.1	3.4	6.0	5.2	4.1	3.3	7.9	7.3	5.8	4.5
	Tippecanoe				Warren				White			
Scen. 1	5.4	4.6	3.7	3.1	4.8	4.4	3.9	3.2	6.0	5.3	4.2	3.5
Scen. 2	3.4	3.0	2.5	2.3	3.3	3.0	2.7	2.4	4.5	3.8	3.2	2.9
Scen. 3	3.2	2.8	2.5	2.3	3.0	2.8	2.6	2.3	3.9	3.4	3.1	2.9
Scen. 4	7.9	7.2	5.6	4.4	8.0	7.0	5.9	4.5	9.4	8.1	6.2	4.6
Scen. 5	3.9	3.3	2.8	2.4	3.8	3.5	3.0	2.5	5.2	4.3	3.5	3.1
Scen. 6	2.3	2.1	2.0	2.0	2.2	2.1	2.0	2.0	2.8	2.7	2.6	2.6
Scen. 7	2.2	2.1	2.0	2.0	2.2	2.1	2.0	2.0	2.8	2.7	2.6	2.6
Scen. 8	4.4	3.9	3.2	2.7	4.0	3.7	3.2	2.7	4.8	4.4	3.8	3.2
Scen. 9	3.3	2.8	2.5	2.2	3.0	2.8	2.5	2.3	4.1	3.4	3.1	2.9
Scen. 10	6.9	6.3	5.0	4.0	6.7	6.0	5.1	4.1	8.2	6.9	5.4	4.1

Fig. 4 showed the NAPRA WWW predicted nitrate concentration (mg/l) in runoff at a 5% probability level for White County, Indiana. The values shown in Fig. 3 were the average nitrate concentrations values for a MUID of the STATSGO. As shown in Fig. 4, the average nitrate concentration values from livestock manure application scenario 4 (only manure surface application in the fall) was estimated below 10 mg/l in most areas. However, there were some locations where the NAPRA WWW simulated nitrate concentration losses in runoff exceeded 10 mg/l due to different soil properties in those areas. Specific livestock manure application plans should be created

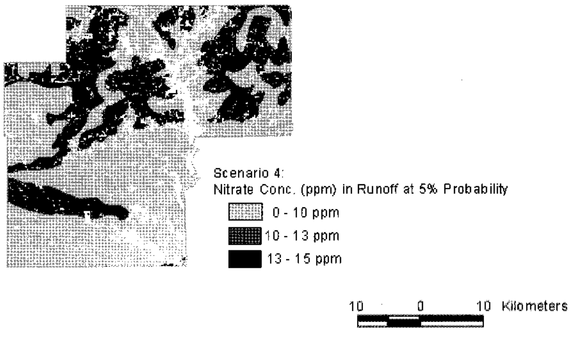


Fig. 4. The NAPRA WWW predicted nitrate concentration in runoff for White County for scenario 4 – livestock manure surface application in fall without commercial fertilizer application.

for these sensitive areas if manure is to be applied to the crop field as a nutrient source.

Each MUID in the STATSGO soil database is composed of components and each component has different soil properties. However, no spatial information is associated with each component. Thus, each MUID polygon contains soil properties for up to 21 soil components. The nitrate concentration value for each component was investigated to examine the maximum nitrate concentration for each component through the simulation period. Fig. 5 shows the yearly nitrate concentration in runoff for ten soil components of IN081, one of the soil MUIDs in White County. The annual average nitrate concentration values in runoff were lower than 10 mg/l, the drinking water quality standard for nitrate concentration. However, the yearly nitrate concentration values in runoff from scenarios 4 and 10 were higher than 10 mg/l for several years during the simulation period (Fig. 5). The nitrate concentration values for year 44 were very large, exceeding 30 mg/l for soil component 6, one of 13 soil components of IN018, as shown in Fig. 5. The maximum nitrate concentration in runoff from scenario 4 was 36 mg/l for soil component 6. At a 3.33 % probability level, the nitrate concentration values exceeded 10 mg/l for ten soil components of MUID IN018. The maximum nitrate concentration from scenario 10 was 31 mg/l for soil component 6. At a 2.67 % probability level, the nitrate concentration values exceeded 10 mg/l for

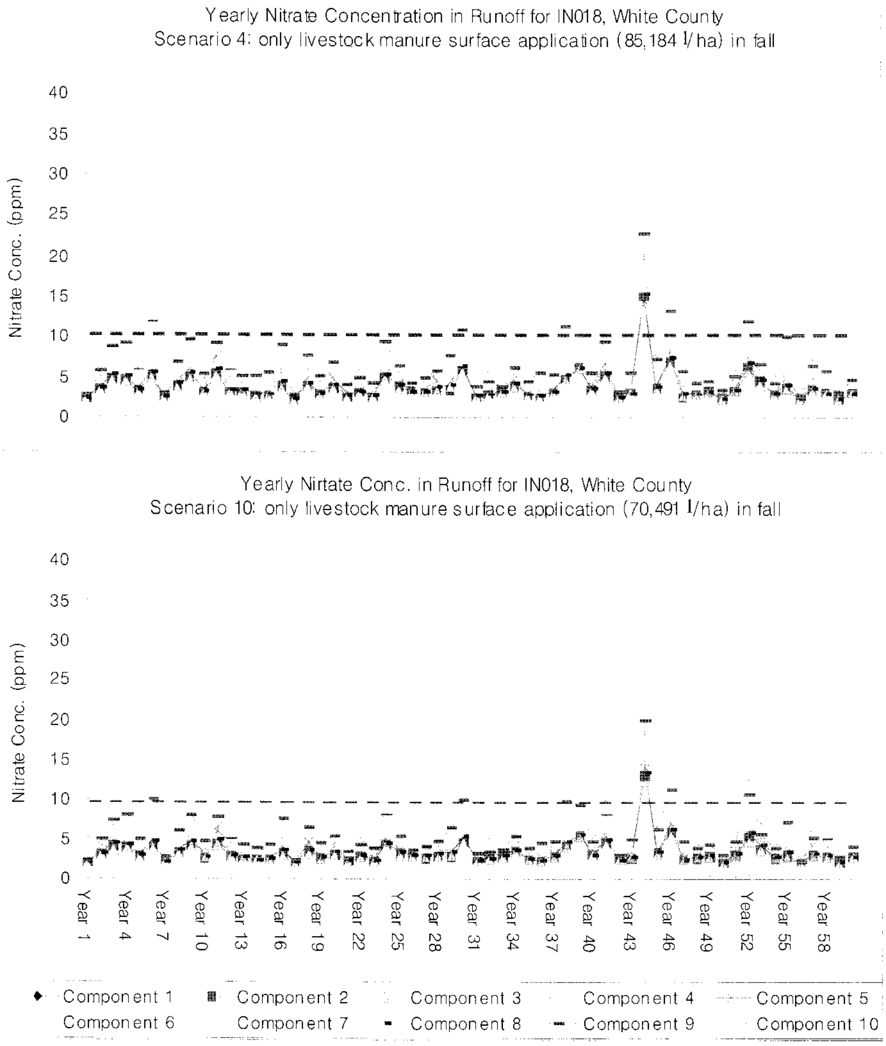


Fig. 5. Nitrate concentrations for soil MUID IN018 in White County for scenarios 4 and 10. Scenario 4 – only livestock manure surface application (85,184l/ ha) in the fall, scenario 10 - only livestock manure surface application (70,491 l/ ha) in the fall.

ten soil components of MUID IN018 for scenario 10. To explain the higher nitrate concentration over several years, the yearly precipitation, runoff, and nitrate concentration values were computed from scenarios 4 and 10 as shown in Fig. 6. Lower runoff and higher nitrate losses from fall livestock manure applications are responsible for higher nitrate concentration values for several years.

Nitrogen is present in the liquid manure in NH_4^+ forms which is immediately available and organic N (Org-N) which must be mineralized for plant uptake and NH_4^+ can be nitrified to NO_3^- in days to weeks[17]. In addition, rainfall events immediately after manure application are likely to be associated with increased nutrient runoff losses[18,19]. It is because the formation of a surface seal, or capping of a soil exposed to rainfall, can reduce infiltration and increase runoff [20]. Smith et al[21]. studied that the average soluble nitrogen concentration in runoff of > 14 mg/l for application of organic manures. As shown in Fig. 7, nutrient loss probability maps for Indiana were generated using nutrient management scenario 3 (no manure application, only commercial fertilizer applied) and scenario 4 (only manure surface applied) (Table 1). With statewide nutrient loss probability maps, farmers can develop site-specific manure management plans. As shown in this study, the NAPRA model predicted that nitrate concentration losses in runoff were higher than 10 mg/l for some soils, although agronomic nutrient rates of manure application were

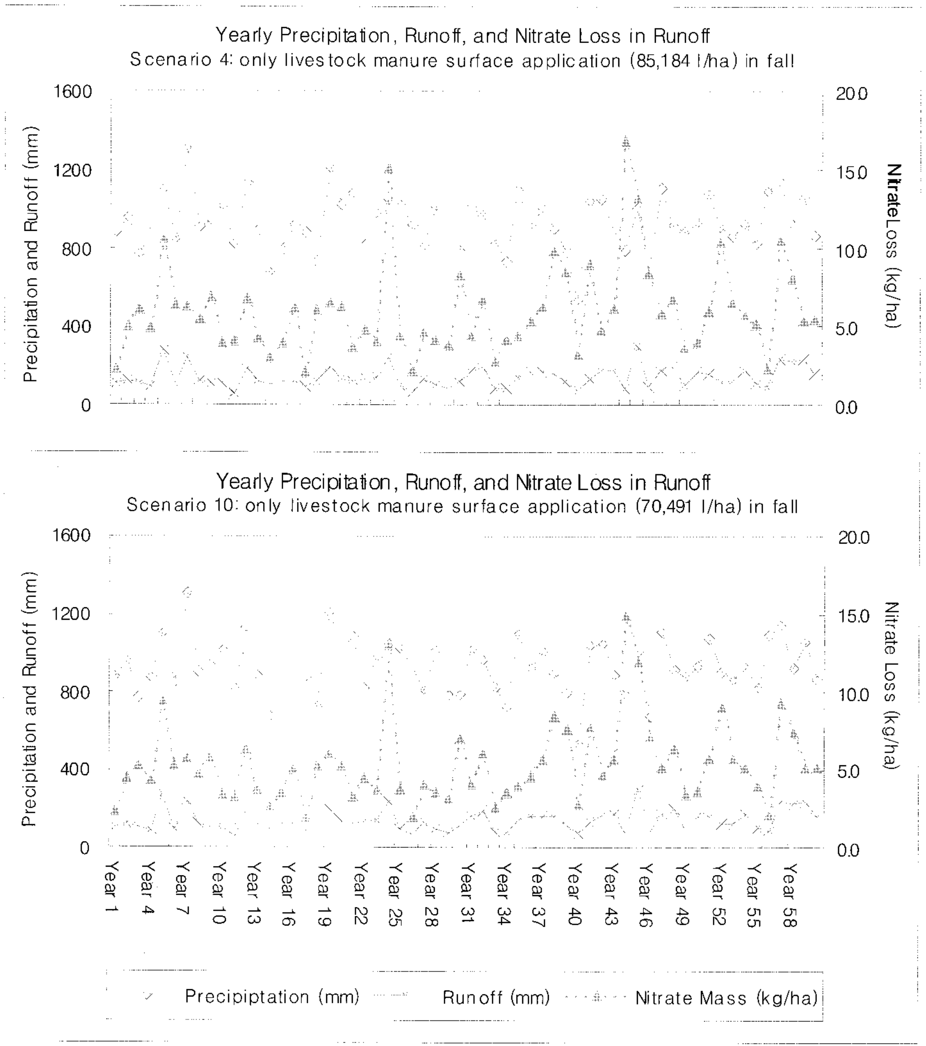
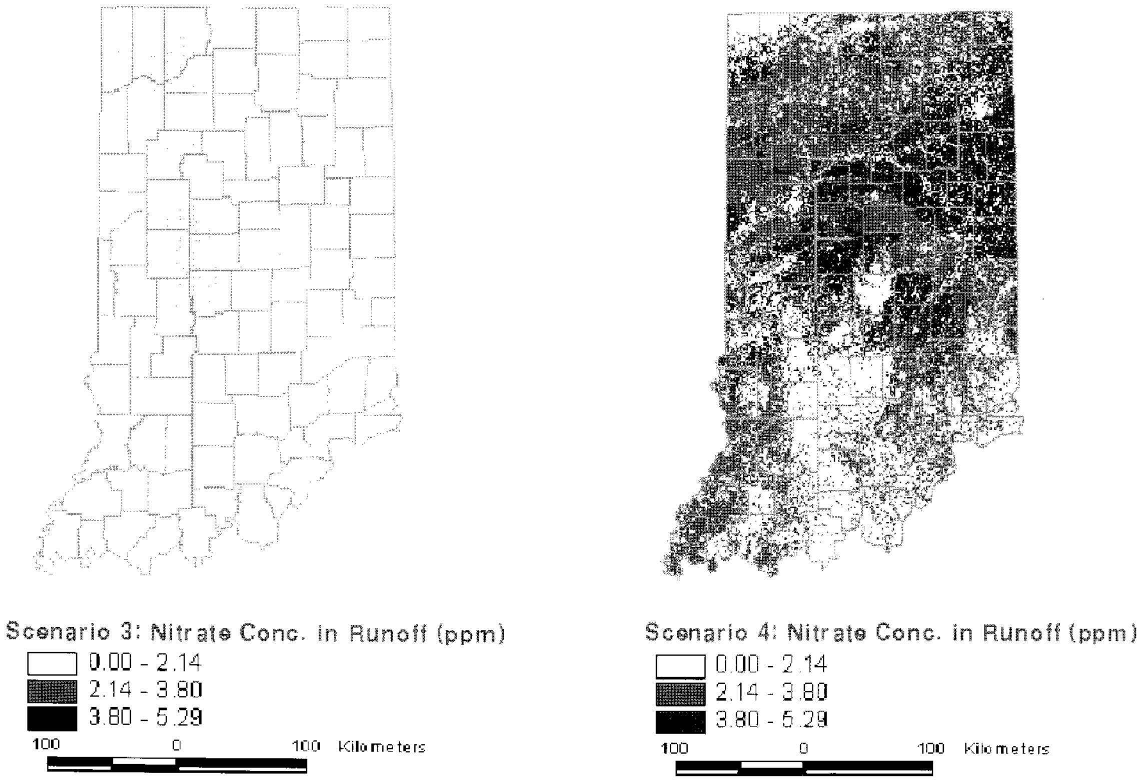


Fig. 6. Yearly precipitation, runoff, and nitrate loss in White County for scenarios 4 and 10. Scenario 4 – only livestock manure surface application (85,184 l/ ha) in the fall, scenario 10 - only livestock manure surface application (70,491 l/ ha) in the fall.



(a) No manure applied, only fertilizer applied **(b) only manure surface applied**

Fig. 7. The NAPRA WWW predicted nitrate in runoff from Scenarios 3 and 4. Scenario 3 - commercial fertilizer injection in spring without livestock manure application, scenarios 4 - livestock manure surface application in the fall without commercial fertilizer application.

simulated as shown Fig. 7. These results indicated that the application of manure at recommended agronomic rates does not always provide adequate water quality protection. Site specific manure management plans should be developed for a livestock operation before applying livestock manure to a field to reduce economic loss and water quality impacts.

Conclusions

The impacts on water quality of using agronomic livestock manure application rates were investigated in this study. Surface application of livestock manure in the fall without additional commercial fertilizer (Scenario 4) resulted in the highest nitrate concentration losses in runoff for the scenarios examined.

The NAPRA WWW system was run for cropped areas in nine Indiana counties. The average nitrate loss concentrations at 5% probability level for one (White County) of these counties examined in more detail were less than 10 mg/l. However, the yearly nitrate concentration values for some soils were higher than 10 mg/l for several years throughout the simulation period. The results show that application of livestock manure at an agronomic rate recommended for the expected crop yield could potentially result in high nitrate loss in runoff, consequently exceeding drinking water quality standards.

As shown in this study, the NAPRA WWW with AMANURE can be used to help livestock producers assess the water quality impacts of livestock manure application to the farm field and develop comprehensive nutrient management plans. This system can also be used to identify site specific environmentally sound and agronomically appropriate levels of livestock manure application rates, timing, and methods. In addition, the NAPRA WWW simulated results need to be compared with measured data to secure accuracy of the simulated results although the NAPRA WWW system has been evaluated at various studies.

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