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EPIC Simulation of Water Quality from Land Application of Poultry Litter

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Abstract □ Two application rates (9 and 18 t/ha) of poultry litter and a recommended rate of commercial fertilizer were studied to determine their effects on nutrient (N and P) losses in surface and subsurface runoff and loadings in soil layers from conventionally-tilled corn plots. The EPIC model was used to simulate surface and subsurface water quality affected by the treatments. The model predicted higher sediment losses than observed data from all treatments. The overpredicted sediment losses resulted in overprediction of organic-N and sediment-P losses in surface runoff. Simulated soluble-P losses in surface runoff were close to observed data, while NO_3-N losses in surface runoff were underpredicted from all treatments. Observed NO_3-N concentrations in leachate at 1.0-m depth from commercial fertilizer treatment were fairly well predicted. But the concentrations were overpredicted from poultry litter treatments due to high simulation of organic-N mineralization simulated by the model.

Keywords □ land application, EPIC, water quality, modeling, simulation

I. Introduction

Nearly 60% of broiler production in the U.S. is concentrated in the southern states of Alabama, Arkansas, Georgia, and North Carolina (USDA, 1991). Alabama produces more than 850 million broilers and layers annually (Alabama Agricultural Statistics Service, 1994). This generates approximately 2 million metric tons of poultry litter each year (Mitchell et al., 1989). The common practice of disposing of poultry litter is to spread it on areas of crop and pasture lands as a fertilizer. Although poultry litter has been shown to be an effective nutrient source for crop production (Flynn et al., 1993), land application of poultry litter may result in water quality problems, especially in regions of highly concentrated production (Kingery, et al., 1992).

Runoff and erosion are the main processes controlling surface losses of potential pollutants present in the soil-waste system. Surface water quality impacts of land-applied poultry litter depend on many variables which influence runoff and soil erosion including soil type, rainfall intensity and duration, soil surface characteristics and topography. Management factors such as timing of application, loading rate, and incorporation methods are important factors in controlling nutrient losses via runoff and sediment. However, water quality impacts associated with poultry litter disposal are primarily related to the quantity and forms of N and P present in the litter and soil.

In simulated rainfall studies (McLeod and Hegg, 1984), the first runoff-producing storm following application of poultry litter has been found to result in high concentrations of waste constituents. Edwards and Daniel (1993) applied poultry litter at 0, 218, 435, and 870 kg N ha^{-1} to plots established with fescue to determine constituent losses in runoff. Concentrations of TKN, TP, dissolved reactive P (DP), and COD significantly decreased with increasing runoff intensity because of more rainfall and the associated dilution. However, mass nutrient losses via runoff significantly increased with both application rate and rainfall intensity. Studies in poultry producing areas of Maryland, Delaware, and Alabama indicate that a high percentage of wells exceeds the 10 mg NO_3-N L^{-1} limit for primary drinking water supplies (Ritter and Chirnside, 1982).

Mathematical simulation models such as EPIC (Environmental Policy Integrated Climate formerly Erosion-Productivity Impact Calculator) have the capability of assessing water quality impacts and identifying potential management technologies for disposing of animal wastes (Sharpley and Williams, 1990). EPIC was developed and has been maintained by the USDA-ARS, is composed of physically-based components for processes of soil erosion, plant growth, weather, hydrology, nutrient cycling, tillage, soil temperature, and economics. The model uses the SCS curve number method with antecedent moisture condition II to calculate runoff and six optional methods {Universal Soil Loss Equation (USLE), USLE modified by Williams (1975), and USLE modified by Onstad and Foster (1975), MUSLE, MUST, MUSI} to calculate soil erosion. Hydrologic and nutrient cycling components simulate a number of nutrient fluxes important to surface water and groundwater quality. These include N losses in surface runoff, subsurface transport, percolation, organic-N transport by sediment, soluble-P loss in surface runoff, and P transport by sediment.

The EPIC tillage component was designed to mix nutrients and crop residue within the plow depth, simulate the change in bulk density, and convert standing residue to flat residue. Other functions of the tillage component include simulating ridge height and surface roughness. In fertilizer options, EPIC allows simulation of different types of animal waste as organic fertilizer. Details of the model are found in the EPIC user's manual (Mitchell et al., 1998). The model has been mostly applied to estimate reductions in long term crop yields due to soil erosion (Steiner et al., 1987; Martin et al., 1993; Moulin and Beckie, 1993), as the model was initially designed. The water quality component of EPIC makes it possible to use the model to evaluate water quality impact from various field management practices. The objective of this study was to apply EPIC to evaluate its capability of simulating nutrient (N and P) losses in surface and subsurface runoff from cropped fields where two rates of poultry litter and a commercial fertilizer were applied.

II. Procedures

1. Field Experiment

A field experiment was conducted from March 1991 to April 1993 on twelve 0.09 ha conventionally-tilled plots planted to a grain corn (Zea mays L.) at the Tennessee Valley Substation of the Alabama Agricultural Experiment Station at Belle Mina, Alabama. The plots are 30m by 30m square shape with downhill slope ranging 2.5～3.5%. All plots were planted with cereal rye (Secale cereale L.) as a winter cover crop. The experimental design was a randomized complete block with four replications. The treatments included: 1) commercial fertilizer (CF) applied at a recommended rate (450kg ha^{-1} ammonium nitrate, 112kg ha^{-1} triple superphosphate); 2) poultry litter applied at 18t ha^{-1} (PL18); and 3) poultry litter applied at 9t ha^{-1} (PL9). The soil at the study site is a Decatur silty clay (Clayey, kaolinitic, thermic Rhodic Paleudults) which is classified as a hydrologic soil group B (USDA Soil Conservation Service, 1972).

In 1991, the rye cover crop was removed on March 20. Soil amendments were applied with a pull-type spreader on March 27 and all plots were chisel plowed and disked immediately after application. Plots were planted with a grain corn (Dekalb 689) and banded with atrazine for weed control on April 4. The corn was harvested on September 3. Cereal rye was planted on October 14 with a Tye no-till grain drill as a cover crop over the winter of 1991/1992. In 1992, the rye was cut and paraquat was applied on March 26 to kill the rye. The soil amendments were applied on April 10 and each plot was chisel plowed and disked immediately after the application. Corn was planted on April 28. Each plot was cultivated for weed control on May 21. Corn was harvested on September 25 and cereal rye was planted on October 13.

Rainfall was measured with a 0.254mm tipping bucket rain gauge located near the plot area. Runoff was monitored with a 0.305 meter H-flume installed at the outlet of each plot. The data were recorded by a CR7X data logger (Campbell Sci. Inc., Logan, UT). A Model N-1 Coshocton runoff sampler and a runoff storage tank were used to collect aliquot of surface runoff for each plot (Fig. 1). The collected runoff was sampled for each runoff event in a one-liter bottle from each plot for laboratory analysis. Leachate from 1.0m below the surface was sampled approximately every two weeks from each plot using a wick lysimeter (Boll et al., 1990) installed in the center of each plot. The surface runoff and leachate samples were frozen and transported to an analytical laboratory at Auburn University. Composite soil samples were taken from each plot from six increments to a depth of 1.0m before the experiment started (March 26, 1991). The soil samples were analyzed for soil properties and initial nutrient contents by one or more of the methods described below.

Fig. 1. Equipment installed at the experimental plot.

Both runoff and leachate samples were filtered through a 0.45mm filter prior to nitrate (NO_3-N) and ammonium (NH_4-N) analyses. Unfiltered samples were analyzed for total nitrogen (N) by the Kjeldahl method (Bremner, 1965). Total phosphorus (P) in water and sediment and extractable P in soil samples were analyzed by Jarrell-Ash inductively coupled argon plasma spectroscopy (ICAP 9000, Thermo Jarrell-Ash, Franklin, MA). Soil NO_3-N and NH_4-N were determined by standard colorimetric procedures (Keeney and Nelson, 1982) on a Lachat autoanalyzer (Lachat QuikChem Systems, Milwaukee, WI).

2. Model Simulation

EPIC (PC version 5300) model was used to simulate the effects of the three treatments on water quality without parameter calibration. Simulation was performed using the best available estimates of the required parameters recommended in the EPIC user's manual in the absence of measured parameter values. Modified USLE (MUSLE) by Williams (1975) was selected in this simulation to calculate sediment loss. This method simulated the closest sediment loss to observed data on the average among the options given in the model. Most of the initial parameter values were selected from the physical and climatic conditions of the field and the recommended built-in default values in the model. Weather data measured at the study site and used in the model were rainfall, ambient temperature, and solar radiation. Wind velocity and relative humidity data were generated in the model.

Soil texture and organic matter content of each soil layer were obtained from the field data. Other soil properties such as saturated hydraulic conductivity, porosity and wilting point were estimated from the recommended EPIC soil data. Data from the field soil samples were used for organic-N and NO_3-N concentrations in each soil layer. The initial labile phosphorus concentration of each soil layer was estimated from the measured concentration of double acid P with a relationship

Table 1. Physical properties of the broiler litter applied at the study site. Moisture is wet base and other properties are dry base by weight.

Properties	1991	1992
Moisture (%)	24.9	5.7
pH	8.5	7.0
Total C (%)	25.0	33.7
Total N (%)	2.6	4.4
NO_3-N (mg/kg)	12.0	363.5
NH_4-N (mg/kg)	6652.0	5898.0
Total P (%)	1.48	3.4
K (%)	1.95	4.8
Ca (%)	1.95	4.5

developed by Sharpley et al. (1984). Selected chemical properties of composite samples of the poultry litter applied at the study site are shown in Table 1. These data were used for the organic fertilizer input in the model.

III. Results and Discussion

Table 2 shows total observed and simulated total runoff and losses of sediment and nutrients during the study period. Observed data in this table show replication means and standard deviations. The GLM (General Linear Model) statistical analysis procedure of SAS (SAS Inst, Inc., 1985) was used to analyze the observed data. The analysis showed that there were no significant differences among the soil treatments with regard to runoff and sediment and sediment-P losses. The sediment loss includes all solids, organic and inorganic, in surface runoff, which were transported from the plots. Losses of organic-N and soluble-P from PL18 treatment were the highest among the treatments. There were no treatment effects on these variables between CF and PL9 treatments. NO_3-N losses from CF and PL18 treatments were higher than those from PL9 treatment. PL9 and CF treatments showed similar amounts of all nutrient losses, while PL18 yielded higher losses.

The runoff predicted by EPIC was the same from all treatments (Table 2). Simulated sediment losses did not match with observed data in their order and magnitude, with simulated sediment losses being higher than observed data for all treatments. As discussed later, most of this difference can be attributed to events occurring in December of 1991. Soil

Table 2. Observed and simulated surface runoff and losses of sediment and nutrients during the study period (March 1991–November 1992)#. Observed data show replication mean, with standard deviation in parenthesis. Means followed by the same letter are not different at the 0.05 significance level.

	Observed			Simulated			Coefficient of Determination		
	PL18	PL9	CF	PL18	PL9	CF	PL18	PL9	CF
Runoff (mm)	309.9a (67.2)	274.3a (121.8)	292.2a (60.0)	554.9	554.9	554.9	0.72	0.75	0.70
Sediment (kg/ha)	1688.2a (1171.3)	954.3a (477.0)	944.1a (431.1)	20,115	21,252	36,985	0.00	0.03	0.54
NO_3-N (kg/ha)	9.4a (3.6)	4.6b (1.9)	10.8a (2.8)	2.85	1.42	2.57	0.001	0.06	0.18
Organic-N (kg/ha)	6.4b (2.0)	3.6a (1.6)	2.5a (1.5)	31.1	31.6	52.0	0.01	0.15	0.56
Soluble-P (kg/ha)	1.76b (0.49)	0.63a (0.28)	0.33a (0.11)	2.81	1.58	0.71	0.46	0.33	0.0002
Sediment-P (kg/ha)	1.5a (0.43)	1.2a (0.77)	0.9a (0.22)	8.19	5.37	5.45	0.01	0.16	0.54

#Total rainfall during this period is 2,370 mm.

loss factors were calculated by the model based on tillage operation, crop growth stage, and amount of crop residue. EPIC considers organic fertilizers such as poultry litter as crop residues, which resulted in the simulated sediment losses from PL treatments being lower than those simulated from CF treatment. The large simulated sediment losses contributed to the large amounts of simulated organic-N and sediment-P losses. Total NO_3-N losses from all treatments were simulated less than observed data. simulated of soluble-P losses was close to observed results.

Table 2 also shows coefficient of determination between measured and simulated values. The coefficient of determination showed good association between measured and simulated runoff. But poor relationship were found between measured and simulated sediment/ nutrients losses. The results showed that EPIC simulation was acceptable for runoff but not close to observed sediment/nutrient transport in surface water.

Graphical comparisons were used to compare observed and simulated results. Observed data in the figures show observation ranges and median values. Figs. 2 and 3 show observed and simulated monthly surface runoff and sediment losses, respectively. Results of runoff simulation were close to observed data except for December, 1991, when simulation was higher than the observed data. Observed sediment losses were generally low through the study period. However, the model simulated higher than observed sediment losses. High sediment losses were simulated in December of 1991 from all treatments because of the combination of the high simulated runoff and the model's inaccurate simulation of the surface cover by the winter rye. The winter rye was observed to be dense over all plots in this period, which protected the surface from erosion. MUSLE (Williams, 1975) option was

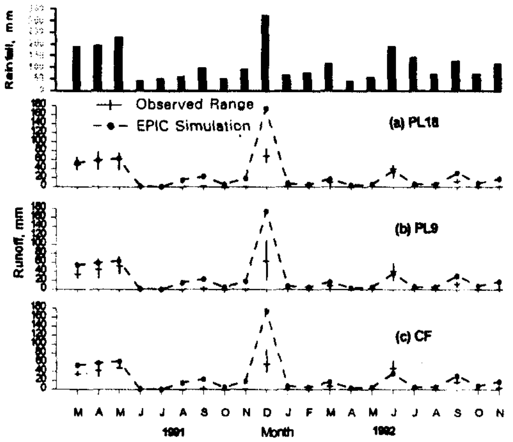

Fig. 2. Observed rainfall, and observed(range and median) and simulated runoff from PL18, PL9, and CF treatments

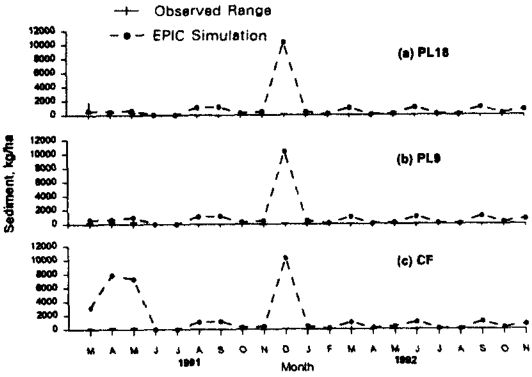

Fig. 3. Observed (range and median) and simulated monthly sediment losses.

selected for soil erosion simulation in the model. MUSLE computes the erosion energy by runoff erosivity alone. This caused high simulation of soil erosion when runoff volume and rate are high relative to rainfall erosivity under high antecedent moisture conditions.

High sediment losses were also simulated early in the season in 1991 from CF treatment, while PL treatments showed low simulated losses, which was not observed on-site. Considering overall high simulation of sediment through high runoff period, simulation of sediment losses from PL treatments did not follow general trend of simulation. The model considers applied organic fertilizer such as the poultry litter as additional crop residue cover. As shown in Table 3, EPIC simulated large amounts of crop residue cover for PL treatments compared to CF treatment. The residue cover was used to calculate the cropping management factor (C) in the model.

Fig. 4 shows monthly observed and simulated NO_3-N losses in surface runoff. The observed losses were high in the early runoff events after application of the soil amendments in 1991. NO_3-N losses from PL treatments were lower than those from CF treatment in March, 1991, due to the different initial N compositions in the amendments. Initially, concentrations of organic- and ammonium-N were higher than that of NO_3-N from PL treatments. Therefore, in the surface runoff which occurred immediately after amendment application, NO_3-N concentrations were high from CF treatment. Field data showed that NO_3-N concentrations were increased in surface runoff from PL treatments in the second and third runoff events after the application. This is due to time required for mineralization or nitrification of the applied PL. All treatments showed high NO_3-N losses in June, 1992 when the first significant runoff event occurred after the application. The high NO_3-N losses observed from all treatments in June, 1992 were due to the mineralization and nitrification of the applied PL. Field data showed that treatment effects on NO_3-N losses appeared only from a few large runoff events immediately after PL and CF applications.

Table 3. Simulated crop residue in the top 1.0-cm layer immediately before and after amendment applications.

Year	Date	Simulated crop residue (t/ha)		
		PL18	PL9	CF
1991	3-26	0.03	0.03	0.03
	3-27*	3.44	1.74	0.11
	3-28	3.40	1.72	0.11
	3-29	3.38	1.71	0.11
1992	4-9	0.50	0.50	0.53
	4-10*	4.67	2.45	0.32
	4-11	4.60	2.42	0.31
	4-12	4.49	2.36	0.30

* Poultry litter and fertilizer application dates

EPIC underpredicted monthly NO_3-N losses in surface runoff when high losses were observed from all treatments. The applied soil amendments were incorporated at 0.1 to 0.15-m depth in all treatments. EPIC estimates the amount of NO_3-N in surface runoff by calculating concentration of NO_3-N and water lost from the top soil layer depth (10mm thickness) only. The model did not properly consider the possible incomplete or nonuniform mixing of the soil amendments under field

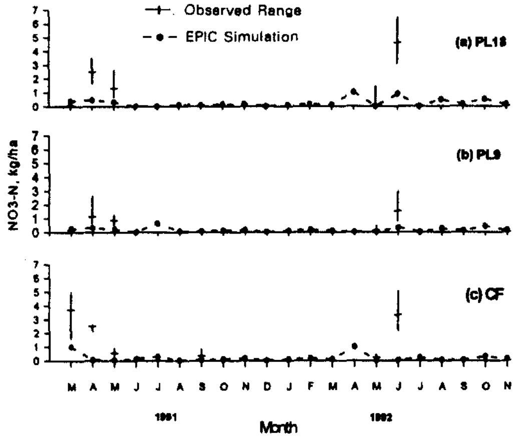

Fig. 4. Observed (range and median) and simulated monthly NO_3-N losses in surface runoff.

conditions.

Figs. 5 and 6 show monthly observed and simulated soluble- and sediment-P losses in surface runoff, respectively. Among the treatments, highest soluble-P losses were observed from PL18 treatment. Observed soluble-P losses were higher from poultry litter treatments than from CF treatment. EPIC simulated these treatment effects similar to the observed trend. The model predicted higher amounts of sediment-P losses than those observed mainly due to the high simulated sediment losses, especially from CF treatment in early 1991 and from all treatments in December, 1991. The simulated trend of sediment-P losses was similar to that of the simulated sediment losses for all treatments.

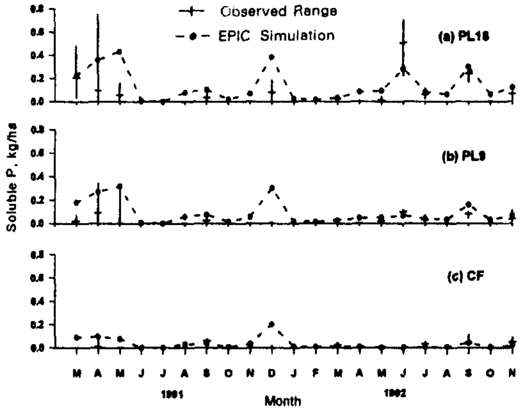

Fig. 5. Observed (range and median) and simulated monthly soluble P losses in surface runoff.

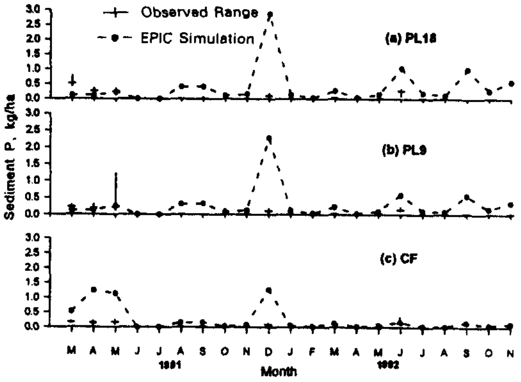

Fig. 6. Observed (range and median) and simulated monthly sediment-bound P losses in surface runoff.

Fig. 7 shows observed and simulated NO_3-N concentrations in the leachate collected at 1.0 m below the surface. The sampled leachate represents the soil water collected over approximately two-week period. On several occasions, NO_3-N concentrations from CF and PL18 treatments exceeded the drinking water standard of 10mg L^{-1}. The weighted averages of simulated daily concentrations of the two-week period were compared with observed biweekly data. EPIC simulation reflected the effects of PL application rates: higher NO_3-N concentrations from PL18 than from PL9 treatment. The simulated NO_3-N concentrations from CF treatment were close to observed data compared to PL simulation. But the simulation did not follow the observed data from PL treatments. The simulation was extremely high for NO_3-N from PL18 treatment in early 1991 and late 1992. The model predicted continuously increasing concentrations up to 82mg L^{-1} from PL18 treatments which field data did not show, indicating that the EPIC simulation of organic-N mineralization modeling did not correspond well to the actual in-field process. Poultry litter includes easily decomposable poultry manure and less decomposable bedding material such as wood chips, while EPIC account for whole organic nitrogen as readily mineralizable nitrogen. Variable decay rates should be adopted for the simulation of mineralization of organic-nitrogen in poultry litter.

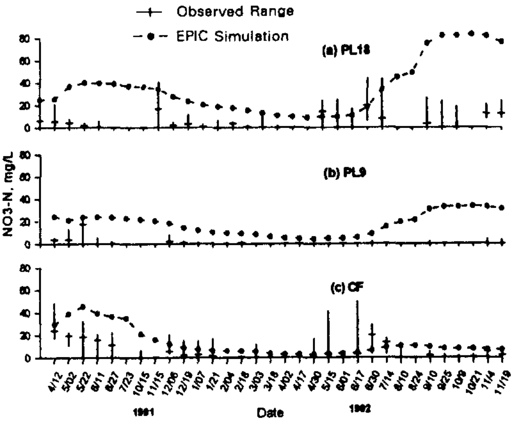

Fig. 7. Observed (range and median) and simulated NO_3-N concentration in leachate at 1.0m depth below surface.

Fig. 8 shows observed and simulated NO_3-N concentrations in soil layers after corn harvesting in 1992. Soil samples were collected from four soil layers. However, the simulation was conducted for eight soil layers. Field data showed that PL18 treatment showed significantly higher NO_3-N concentrations than other treatments. The model predicted the highest NO_3-N concentrations from PL18 treatment and the lowest concentrations from CF treatment.

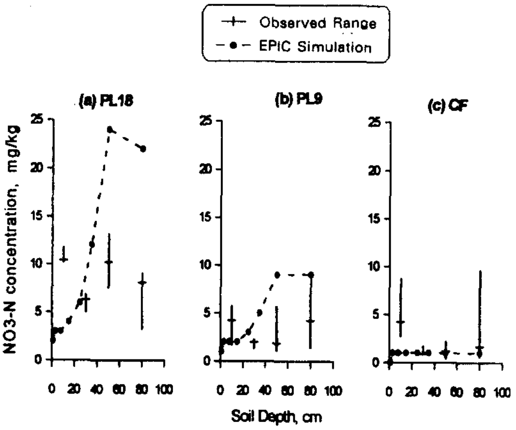

Fig. 8. Observed (range and median) and simulated NO_3-N concentration in soil layers after harvesting.

V. Summary and Conclusions

The effects of different application rates (9 and 18t ha^{-1}) of poultry litter (PL) and a recommended rate of commercial fertilizer (CF) on nutrient (N and P) losses in surface and subsurface runoff were investigated. Field data were collected from the three treatments, each replicated four times on 0.09ha plots of a grain corn. Cereal rye was planted as a winter cover crop to all plots. Surface runoff samples were measured and collected for individual storms and leachate from 1.0m below the surface was sampled biweekly.

The EPIC water quality model was used to simulate the effects of the three treatments on water quality without parameter calibration. Most of the initial parameter values were selected from the physical and climatic conditions in the field and the recommended built-in default values of the model. Runoff simulation was close to observed data but high sediment losses were simulated from all treatments. The model predicted lower sediment losses from PL treatments than from CF treatment, which was different from observed data. Overpredicted sediment losses resulted in the overprediction of sediment-P losses in surface runoff. EPIC predicted soluble-P losses in surface runoff from all treatments fairly well. However, the monthly NO_3-N losses were underpredicted from all treatments, when high losses were observed. NO_3-N concentrations in leachate at 1.0m depth were fairly predicted from CF treatment. But the concentrations from PL treatments were overpredicted.

The results of this study showed that EPIC simulation was acceptable for runoff but not close to observed nutrient/sediment transport in surface and subsurface water. The model was primarily designed to simulate crop production affected by soil erosion from conventional cropping systems even though it has organic fertilizer option to handle land application of animal wastes. It was found that the organic fertilizer option in the model did not reliably respond to the applied poultry litter as a fertilizer for the studied field conditions. The following are recommended to be revised to improve and solve some of the problems found in this simulation.

1. Simulation capability of soil erosion by MUSLE: MUSLE tends to simulate high soil erosion when runoff volume and rate are high under high antecedent moisture conditions.
2. Effect of applied organic fertilizers to simulate surface residue cover: EPIC considers organic fertilizers to account surface residue cover which strongly affect soil erosion simulation. This component should be revised for better simulation of surface cover condition.
3. Simulation of surface cover effect by winter cover crops under warm climatic conditions: Winter cover crop is an important ground condition to prevent soil erosion during the rainy winter period in the area of warm weather conditions.
4. Simulation of organic nitrogen mineralization of applied poultry litter: The continuously increased simulation NO_3-N in leachate from poultry litter applied plots was due to excessive availability of this compound to be transported through the soil profile.

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