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Simulation and Evaluation of Alternative Nutrient Management Practices on a Demonstration Watershed.

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Summary:

Long-term simulations with GLEAMS were used to evaluate the effects of alternative nutrient management practices on surface and ground water loading. The study area is in a USDA Water Quality Demonstration watershed in Duplin County, NC. Results indicate that simulated nutrient losses can be reduced from 10 to 40% with the alternative management practices.

Keywords:

Hydrology, Simulation Models, Water Quality

Simulation and Evaluation of Alternative Nutrient Management Practices on a Demonstration Watershed.

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Abstract

Nonpoint pollution of surface and ground water from agricultural management practices is a major water quality concern. A five-year joint project among state and federal agencies was initiated in 1990 to address this problem on a demonstration watershed located in the Cape Fear River Basin of North Carolina. The GLEAMS model was used to perform simulations of the nutrient interactions with the implementation of improved management practices. The model was evaluated for both conventional nutrient and animal waste applications of nutrients on row crops and pasture.

Introduction

Nonpoint source pollution of surface and ground waters is becoming a major concern in the Eastern Coastal Plain as well as other areas of the country. These factors are especially critical in the Eastern Coastal Plain because of shallow ground water levels and coastal estuaries that can be affected by nonpoint source pollution. Alternative or improved management practices that reduce erosion, runoff, and the discharge of pollutants into surface and ground waters have been developed but not extensively implemented.

Simulation models are important tools to utilize when implementing a system of alternative management practices. Models can evaluate potential management alternatives and provide a basis for guiding management and regulatory decision making.

Groundwater Loading Effects of Agricultural Management Systems (GLEAMS) is a mathematical model developed for field-size areas to evaluate the effects of agricultural management systems on the movement of agricultural chemicals within and through the plant root zone (Leonard et al., 1987). The GLEAMS model utilizes soil input data by soil horizon and can accommodate depth-specific parameters. The original version of GLEAMS consisted of hydrology, erosion, and pesticide components. Recently the model has been extended to include a nutrient component. The nutrient component in GLEAMS includes nitrogen fixation by legumes, land application of animal waste, distinction between

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ammonium and nitrate fertilizers and their uptake by crops, and improved nitrogen and phosphorus cycling algorithms.

The objective of this work was to use the GLEAMS model to evaluate and compare the potential impacts of alternative production practices with conventional production practices. These alternative practices should reduce the agricultural nonpoint source pollution from the watershed.

Background

A water quality demonstration project involving private industry, local land owners, and federal, state, and local agencies, was initiated in 1990 on a watershed located in the Cape Fear River Basin in Duplin County, North Carolina. The 2044-ha demonstration watershed, Herrings Marsh Run (HMR), is one of the eight original demonstration projects funded as part of the USDA's Presidential Water Quality Initiative. It is located within the Goshen Swamp Watershed, one of the 37 original Hydrologic Unit Area Projects (United States Department of Agriculture and Cooperating State Agencies, 1989). Duplin County has many characteristics of an intensive agricultural county in the eastern Coastal Plain of the USA. It has the highest agricultural revenue of any county in North Carolina. In 1990, it had the highest population of turkeys and the fourth highest population of swine of any county in the United States (North Carolina Dept. of Agriculture, 1990).

Agricultural management practices on the watershed are typical for the eastern Coastal Plain and include 1093 ha of cropland, 708 ha of woodlands, and 212 ha of farmsteads, poultry facilities, and swine facilities. The major agricultural crops on the watershed include tobacco (131 ha), corn (415 ha), soybeans (273 ha), wheat (121 ha), and vegetables (162 ha). The predominant soil series in the watershed is Autryville (Loamy, siliceous, thermic Arenic Paleudults); secondary soil series are Norfolk (Fine-loamy, siliceous, thermic Typic Kandiudults), Marvyn-Gritney (Clayey, mixed, thermic Typic Hapludults), and Blanton (Loamy siliceous, thermic Grossarenic Paleudults).

Current annual nutrient input for crop production on the watershed is estimated at 145 metric tons of nitrogen, 64 metric tons of phosphorus, and 243 metric tons of potassium. Although swine and poultry operations produce sufficient quantities of waste to supply over half the needed nutrients, 90% of the nutrients applied to cropland are supplied by commercial fertilizers. The application of large quantities of commercial fertilizers, coupled with the production of large quantities of animal waste, provides a potential for nitrogen and phosphorus contamination of surface and ground water. The objective of the project was to evaluate the effect of current agricultural management practices on stream and ground water quality within the watershed.

Field Sites and Descriptions of practices

Soil and landuse data were obtained from county soil survey report and annual reports of the demonstration project (USDA-SCS, 1959, and NCSU, 1993). Specific cropping practices to be simulated were devised by local SCS and extension service personnel (Coffey, 1993, Personal communication). Autryville and Norfork soils were chosen in this work because they represented over 90% of the soils on the watershed.

The practices to be modeled are presented in Table 1. Detailed cropping practices and nutrient applications are shown in Tables 2-6.

Table 1. Conventional and alternative cropping practices simulated in the Herrings Marsh Run Demonstration Watershed.

Practice Number		General Description
Conventional	Alternative	
1	2	Corn production with mineral fertilizers
3	4	Corn production with organic and mineral fertilizers
5	6	Corn/wheat/soybean rotation
7	8	Cotton production
9	10	Coastal bermudagrass with swine effluent
11	12	Coastal bermudagrass with Poultry litter

A 17-year record of historical daily rainfall was used in the model simulations (Figure 1). Although a longer record would be more desirable, a station near the watershed was chosen for initial simulations. The location of the station, Fasion, NC, is the closest known station (approximately 10 miles) with a considerable rainfall record (1954 to 1970).

Simulations for each practice were run for 17 years using historical daily rainfall. The GLEAMS model was used to predict nutrient loadings in surface runoff and leachate. Hydrology and erosion files for the simulations were held constant for the different practices thereby providing results that are representative of the alternative nutrient management used in the simulations.

Results and Discussion

Predictions of average annual runoff, percolation, nitrate loading in runoff, and nitrate loading in percolation are shown in tables 7 and 8. Low surface runoff was predicted by the model that is characteristic of the soils used in the simulation, ie. sandy soils with relatively high infiltration rates. Runoff estimations for the Autryville soil were less than half those of the Norfork soil.

Simulated leaching of water from the root zones for both soils were very similar for each practice. Leaching from the root zones for the corn/wheat/soybean rotations for both soil types were considerably less than those from the other simulated practices. This was observed because high evaporation reduced percolation predictions in these rotations with a winter cover crop.

Nitrate loading in surface runoff is shown in tables 7 and 8. The low loading rates from the surface runoff are characteristic of soil in the watershed and coastal plain. Typical loading of streams in the coastal plain is from lateral flow from the water table that is usually at a relatively shallow depth (1.5 to 3 m) in these sandy soils (Stone et al., 1992).

Nitrate loading to ground water is shown in tables 7 and 8 for the two soil types simulated. Nitrate loadings from the root zone are much greater than those from the surface runoff. Several alternative nutrient management plans were intended not to over apply nutrients while maintaining potential yields. The first four management practices simulated reduced nitrate loading from the root zone caused by timing of applications and reducing of excess application amount. Practice 2 reduced nitrate loading to the ground water by 41% compared to practice 1 by reducing the quantity of sidedress nitrogen. Practice 4 reduced the nitrate loading by 16% compared to practice 3 by moving the fall application of poultry litter to the spring and by eliminating the side dress applications.

The alternative corn/wheat/soybean alternative practice reduced nitrate leaching by 13% compared to the conventional practice. Both practices simulated much more nitrate leaching from the root zone than did the other practices. This is thought to be caused by the greater amounts of nitrogen input into the production of the crops in this rotation and the timing of the fall applications of poultry litter.

Alternative cotton production reduced nitrate leaching by 20% compared to the conventional practice. Likewise, the alternative application of swine waste to bermudagrass pasture reduced nitrate leaching by 43% compared to the conventional practice.

Conclusions

The use of mathematical models to simulate the long-term impact of alternative nutrient management practices provide a means of supplementing field observations of BMP implementation. The analysis of long-term simulations of alternative nutrient management practices shows that reductions in surface runoff and ground water loading of nutrients can be achieved.

Suggestions for further work and planned work

There are several ongoing plans that are to be implemented to build on this work. The first is to expand the simulations to include other minor soil series and other crops grown in the demonstration watershed. Second, expand the simulations to include the modeling of pesticide movement and fate in the watershed along with the nutrients. Third, compare the GLEAMS model simulation results with those predicted by EPIC in coordination with personnel at the North Carolina State University, Agricultural Engineering Department. Fourth, link the GLEAMS model with a Geographical Information System for predicting nutrient and pesticide losses on a watershed scale. Fifth, link the individual field systems as modeled in GLEAMS into an overall watershed model using a method similar to BASIN (Heatwole et al., 1986).

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Table 2. Continuous corn production using mineral and organic fertilizers.

Conventional Corn Production (1)		Alternative Corn Production (2)	
Mineral fertilizers only			
March 1:	disk	March 1:	disk
March 29:	apply fertilizer - 20 lbs N (400# 5-10-30)	March 29:	apply fertilizer - 20 lbs N (400# 5-10-30)
April 1:	plant corn	April 1:	plant corn
April 29:	row cultivate	April 29:	row cultivate
May 15:	side-dress N - 160 lbs N (30% N soln)	May 15:	side-dress N - 100 lbs N (30% N soln)
Sept 1:	harvest	Sept 1:	harvest
Organic and mineral fertilizers			
Conventional Corn Production (3)		**Alternative Corn Production (4)**	
March 1:	disk	March 27:	apply poultry litter - 130 lbs N (3.5 tons litter)
March 29:	apply starter fertilizer - 20 lbs N (400# 5-10-30)	March 29:	apply starter fertilizer - 20 lbs N (400# 5-10-30)
April 1:	plant corn	March 30:	disk
April 29:	row cultivate	April 1:	plant corn
May 5:	side-dress fertilizer - 130 lbs N (30% N solns)	April 29:	row cultivate
Sept 1:	harvest	Sept 1:	harvest
Nov 1:	apply poultry litter - 123 lbs N (3.5 tons litter)		

Table 3. Corn/wheat/soybean rotation with organic and mineral fertilizers.

Conventional Corn/Wheat/Soybean Rotation (5)		Alternative Corn/Wheat/Soybean Rotation (6)	
	-Year 1-		-Year 1-
March 1:	disk	March 27:	apply poultry litter - 130 lbs N (3.5 tons litter)
March 29:	apply starter fertilizer - 20 lbs N (400# 5-10-30)	March 29:	apply starter fertilizer - 20 lbs N (400# 5-10-30)
April 1:	plant corn	March 30:	disk
April 29:	row cultivate	April 1:	plant corn
May 5:	side-dress fertilizer - 130 lbs N (30% N soln)	April 29:	row cultivate
Sept 1:	harvest	Sept 1:	harvest
	-Year 2-		-Year 2-
Oct 20:	disk	Oct 20:	disk
Oct 31:	apply poultry litter - 130 lbs N (3.5 tons litter)	Oct 31:	apply poultry litter - 130 lbs N (3.5 tons litter)
Nov 1:	disk	Nov 1:	disk
Nov 1:	plant wheat	Nov 1:	plant wheat
March 1:	topdress nitrogen - 100 lbs N (30 gal. 30% N soln)	June 15:	harvest
June 15:	harvest		
June 20:	burn wheat straw	June 20:	disk
June 21:	apply starter fertilizer - 10.5 lbs N (350# 3-7-27)	June 21:	plant soybeans
June 21:	disk	July 15:	cultivate
June 22:	plant soybeans	Nov 20:	harvest
July 16:	cultivate		
Nov 20:	harvest		

Table 4. Conventional and alternative cotton production scenarios.

Conventional Cotton Production (7)		Alternative Cotton Production (8)	
April 15:	apply fertilizer - 60# K20 (100# 0-0-60)	April 15:	apply fertilizer - 60# K20 (100# 0-0-60)
April 22:	disk	April 22:	disk
April 29:	disk	April 29:	disk
April 30:	plant picker cotton	April 30:	plant picker cotton
April 30:	apply fertilizer - 30# N (26 gal. 10-34-0)	April 30:	apply fertilizer - 14# N (12 gal. 10-34-0)
May 13:	cultivate	May 13:	cultivate
May 20:	cultivate	May 20:	cultivate
		June 3:	cultivate
June 3:	cultivate	June 17:	cultivate
June 17:	cultivate	June 17:	apply side-dress N - 56# (20 gal. 30% N soln)
June 17:	apply side-dress N - 56# (20 gal. 30% N soln)	Sept 20:	defoliate cotton
Sept 20:	defoliate cotton	Sept 30:	harvest
Sept 30:	harvest	Nov 1:	cut cotton stalks
Nov 1:	cut cotton stalks		
Dec 1:	disk		

Table 5. Coastal bermudagrass with swine effluent.

Conventional Bermuda (9)		Alternative Bermuda (10)	
April 15:	apply 100 lbs. N (58,800 gal. swine effluent)	April 15:	apply 75 lbs. N (44,100 gal. swine effluent)
May 27:	cut hay	May 27:	cut hay
June 3:	apply 100 lbs. N (58,800 gal. swine effluent)	June 3:	apply 75 lbs. N (44,100 gal. swine effluent)
July 1:	cut hay	July 1:	cut hay
July 8:	apply 100 lbs. N (58,800 gal. swine effluent)	July 8:	apply 75 lbs. N (44,100 gal. swine effluent)
Aug 5:	cut hay	Aug 5:	cut hay
Aug 12:	apply 100 lbs. N (58,800 gal. swine effluent)	Aug 12:	apply 75 lbs. N (44,100 gal. swine effluent)
Sept 16:	cut hay	Sept 16:	cut hay

Table 6. Coastal bermudagrass with poultry litter.

Conventional Bermuda (11)		Alternative Bermuda (12)	
April 15:	apply 100 lbs. N (3.5 tons poultry litter)	April 15:	apply 75 lbs. N (2.6 tons poultry litter)
May 27:	cut hay	May 27:	cut hay
June 3:	apply 100 lbs. N (3.5 tons poultry litter)	June 3:	apply 75 lbs. N (2.6 tons poultry litter)
July 1:	cut hay	July 1:	cut hay
July 8:	apply 100 lbs. N (3.5 tons poultry litter)	July 8:	apply 75 lbs. N (2.6 tons poultry litter)
Aug 5:	cut hay	Aug 5:	cut hay
Aug 12:	apply 100 lbs. N (3.5 tons poultry litter)	Aug 12:	apply 75 lbs. N (2.6 tons poultry litter)
Sept 16:	cut hay	Sept 16:	cut hay

Table 7 : Runoff and Leaching for an Autryville soil over a seventeen year simulation period using GLEAMS.

Practice	RUNOFF		LEACHED	
	Nitrogen (kg/ha)	Water (cm)	Nitrogen (kg/ha)	Water (cm)
Corn Production with mineral fertilizers				
(1) Conventional	2.82	29.93	1574.46	598.10
(2) Alternative	2.01	29.89	932.08	597.23
Corn production with mineral and organic fertilizers				
(3) Conventional	5.09	29.91	2126.81	597.13
(4) Alternative	3.33	29.88	1796.87	596.78
Corn/Wheat/Soybean rotation using mineral and organic fertilizers				
(5) Conventional	3.01	28.24	2756.47	461.41
(6) Alternative	3.21	28.22	2443.01	460.25
Cotton Production				
(7) Conventional	1.67	27.36	749.85	543.96
(8) Alternative	1.66	27.36	596.82	544.29
Coastal bermudagrass with swine effluent				
(9) Conventional	15.56	29.08	1720.71	481.62
(10) Alternative	12.06	30.03	985.63	505.56
Coastal bermudagrass with poultry litter				
(11) Conventional	18.55	30.64	2472.91	500.22
(12) Alternative	12.32	30.82	1498.76	523.58

Table 8: Runoff and Leaching for an Norfolk soil over a seventeen year simulation period using GLEAMS.

Practice	RUNOFF		LEACHED	
	Nitrogen (kg/ha)	Water (cm)	Nitrogen (kg/ha)	Water (cm)
Corn Production with mineral fertilizers				
(1) Conventional	12.21	95.76	1262.31	555.69
(2) Alternative	9.33	95.72	775.82	555.57
Corn production with mineral and organic fertilizers				
(3) Conventional	26.98	95.71	1800.46	555.35
(4) Alternative	20.48	95.76	1462.82	555.75
Corn/Wheat/Soybean rotation using mineral and organic fertilizers				
(5) Conventional	17.04	91.53	2302.62	433.87
(6) Alternative	21.18	91.45	1948.25	432.88
Cotton Production				
(7) Conventional	6.82	91.28	609.39	507.61
(8) Alternative	6.32	91.27	492.97	507.76
Coastal bermudagrass with swine effluent				
(9) Conventional	107.07	93.08	1150.58	435.37
(10) Alternative	80.93	93.60	673.16	447.15
Coastal bermudagrass with poultry litter				
(11) Conventional	93.04	94.24	1789.42	450.59
(12) Alternative	71.60	95.20	1088.58	472.80

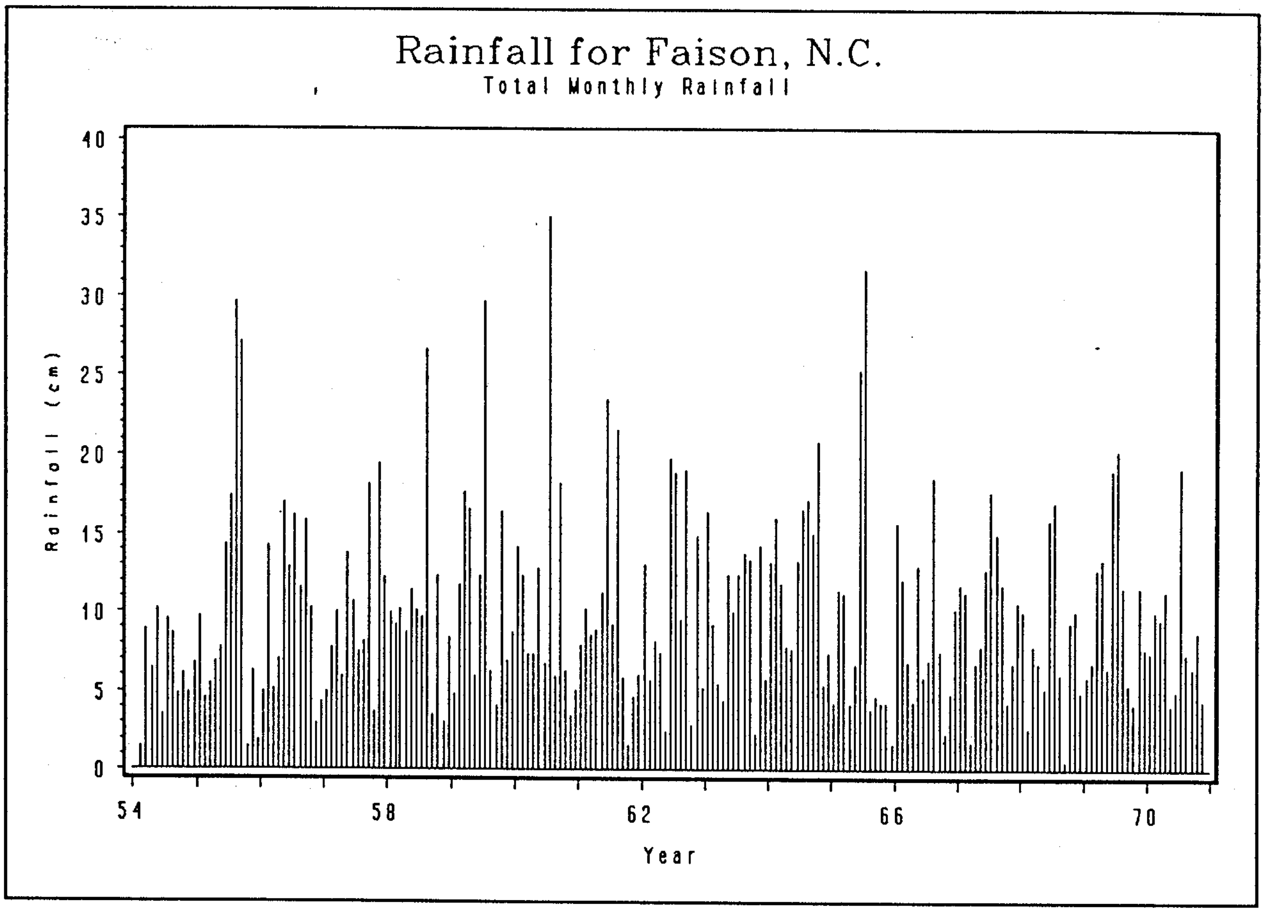

Figure 1. Monthly total rainfall for Faison, NC. from 1954-1970.