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Application of AGNPS Water Quality Computer Simulation Model to a Cattle Grazing Pasture

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Abstract

This research compared the observed and model predicted results that include; runoff, sediment yield, and nutrient losses from a 2.71 ha cattle grazing pasture field in North Alabama. Application of water quality computer simulation models can inexpensively and quickly assess the impact of pasture management practices on water quality.

AGNPS single storm based model was applied to the three pasture species; Bermudagrass, fescue, and Ryegrass. While comparing model predicted results with observed data, it showed that model can reasonably predict the runoff, sediment yield and nutrient losses from the watershed. Over-prediction and under-prediction by the model occurred during very high and low rainfall events, respectively. The study concluded that AGNPS model can be reasonably applied to assess the impacts of pasture management practices and chicken litter application on water quality.

Keywords : Runoff, Sediment, Nutrients, Cattle Grazing Pastureland, AGNPS

I. Introduction

Computer simulation models are the most effective tools that have been used for soil conservation planning and design in the United States, to predict soil erosion and nutrient losses from pasture fields and agricultural areas (USDA, 2002). It is not easy to monitor the influence of every agricultural management practice in all ecosystems and climatic conditions. Erosion prediction tools are mainly used to rank alternative agricultural practices with regards to their impact. Modeling soil erosion is the process of mathematically describing soil particles detachment, transport, and deposition on land surfaces. Erosion prediction is the most widely used and effective tool for soil conservation planning and design (Laflen, 1991).

The erosion prediction models that have been developed recently require input parameters in

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detail to predict the results more accurately. Most of the plant species and soil types are not readily found. In many cases, they need interpretations from other measurable plant characteristics. As a consequence, plant species parameters and soil archives have been developed. The database currently supports the Revised Universal Soil Loss Equations (RUSLE), Water Erosion Prediction Project (WEPP), and Agricultural Non Point Source Pollution (AGNPS). Soil type and topography are normally the parameters that users can not change easily. There is thus only the cover crop management parameter where the users have flexibility to hypothesize different alternative crops and field operations to choose the Best Management Practices (BMPs).

The AGNPS is an event-based model. It has been used to calculate runoff from agricultural watershed and transport processes of sediment, nitrogen, phosphorous, and organic carbon. The AGNPS Model was developed at USDA-ARS as a single-event watershed model for evaluation of alternative agricultural management scenarios (Young et al., 1987). The model can be used to identify critical pollution source areas within a watershed. Watersheds are represented by square cells of 0.4-16 ha or polygons. Each cell is characterized by twenty-two parameters that include: SCS curve number, terrain description, channel parameters, soil-loss equation data, fertilization level, soil texture, channel and point source indicators, and oxygen demand factor. Sediment runoff is estimated from the modified version of USLE (Universal Soil Loss Equation) and its routing is performed for five soil particle size classes (clay, silt, sand, small aggregates and large aggregates). Calculations of the nutrient transport are divided into soluble and sediment-adsorbed phases. The application of AGNPS can be made to about 200 km^2 watersheds or larger (Young et al., 1994).

The GIS-ArcView Interface AGNPS water quality simulation model is an advanced version of AGNPS with single storm based and continuous simulations modes. The AGNPS model can extract data from the Digital Elevation Model (DEM) and AGNPS Input Editor allows users to import the extracted data from the DEM and/or manually enter data (Bingner and Yuan, 2000).

The AGNPS model has been applied and validated in many parts of the United States. Validation of the model for sediment and runoff was shown by Koelliker and Humbert (1989) for five watersheds in Kansas. The model was used in different circumstances to calculate sediment yields and nutrient loading due to non point source pollution in watersheds (Binger et al., 1989). Leon et al., 2002 applied the AGNPS model for Duffins creek watershed in Southern Ontario. The single event AGNPS was found highly sensitive to antecedent conditions to predict nutrient concentrations from the Duffins creek watershed. However, the model appeared to be well suited for application in Southeren Ontario.

Hession and Huber (1989) evaluated the AGNPS model (v. 3.51) for its reliability in assessing BMP effectiveness on a monitored watershed by comparing pre-BMP, post-BMP and 100% forested conditions. Evaluation was not performed on specific storm events, but using design storms ranging from 25.40 mm to 152.40 mm for 1, 2, 5 and 10 year events. Input parameters were, therefore, selected to reflect average conditions. The 1,157 ha watershed contained five livestock producers, with only one using an animal waste storage facility, and excessive field applications of manure for pre-BMP conditions. Post-BMP included waste facilities for all animal operations and nutrient management plans to reduce fertilization to recommended application rates. No comparison was made with monitored data. Simulation showed that the state program's 40% nutrient reduction goal could be met with full implementation of BMPs.

Kirnak (2001) compared the erosion and runoff predicted by AGNPS models using GIS. The study was conducted for the Rock Creek watershed located in Seneca County, Ohio. The AGNPS produced reasonable results when applied to the Rock Creek watershed in the USA. The AGNPS model under-predicted average runoff and sediment yields by 17.50 % and 17 % respectively when compare to the average measured runoff and sediment yields of 17.95 $m^3 s^{-1}$, and 911.61 t, respectively, at the outlet of the watershed. The t-statistic showed that there was no statistically significant difference between model predictions and observed data at the 5 % level.

The general objectives of this study were to:

1) Quantify rainfall, runoff, sediments, and nutrient losses from a cattle grazing pasture field (Summerford watershed).

2) Evaluate single storm based runoff, sediment yields and nutrient losses from the Summerford watershed in different pasture conditions by applying AGNPS computer models.

3) Compare field observed and the AGNPS model predicted results for the Summerford watershed.

Ⅱ. Materials and Methods

This study was conducted at the Summerford watershed, a grazing pasture field located near Danville in north Alabama, USA (Fig. 1). The Latitude and Longitude of the watershed are 34°22'12" and 87°01'48", respectively. The total watershed area is about 2.71ha. Runoff from the watershed outlet is discharged to the Crowdabout creek. The soil types in the watershed were found as Abernathy, Sequatchie, and Waynesboro. One hundred percent of the watershed was used as a permanent pastureland under the Best Management Practices (BMPs) that includes; stream fencing, rotational grazing, haying, fertilization (chicken litter), and permanent pasture vegetations (Bermudgrass/Ryegrass/fescue).

The instrumentation site was located near the channel outlet of the watershed. The runoff from the watershed was diverted through the 60-cm H-flume (Fig. 2). The H-flume is equipped with a stilling well which has a float/1-foot pulley/counterweight system. Flow depth changes in the flume rotate the 0.3 m circumference pulley which is directly connected to a ten-turn 100 kΩ potentiometer. A CR10X datalogger (Fig. 3) records the water level in the flume by sensing the rotational position of the potentiometer. Each turn of the potentiometer represents 0.3 m (1 ft) of flow depth at an accuracy of 0.003 m.

Once the runoff passes through the H-flume, it is routed through a small trapezoidal shape basin where a suction tube is connected to the ISCO sampler. After a rainfall is detected by the datalogger and the potentiometer reading re

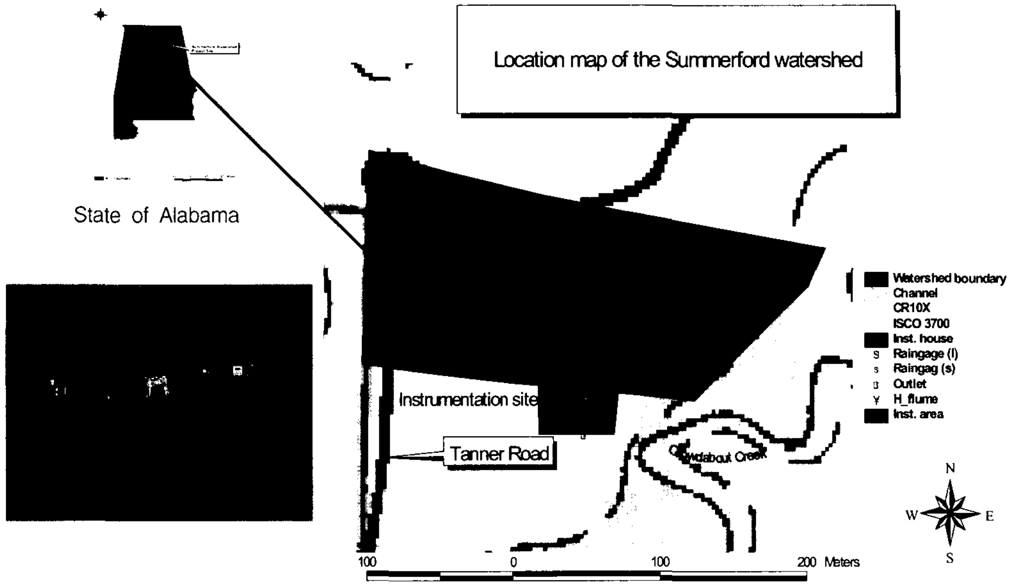

Fig. 1 Location map and cattle grazing pasture of the Summerford watershed

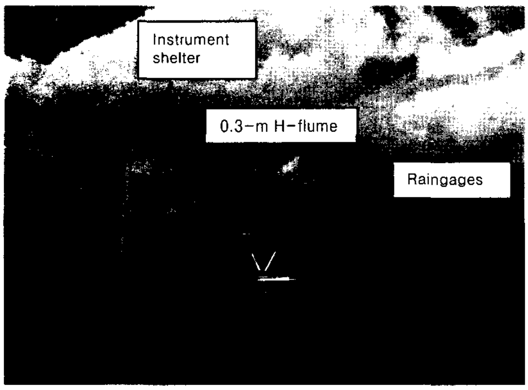

Fig. 2 Instrumentation

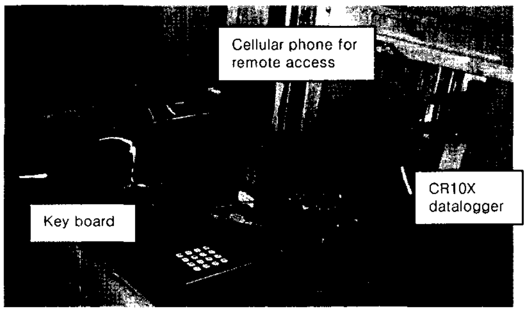

Fig. 3 CR10X datalogger

aches greater than the standard level in the flume (potentiometer reading at the bottom of the flume) the sampler starts pumping. The sampler was programmed to collect 20 ml per sample every three-minute interval during runoff event.

Runoff samples were collected using an automatic ISCO 3700 sampler (Fig. 4). After every major storm event, the project site was visited to collect the runoff sample. The runoff collected in the ISCO sampler was vigorously stirred and collected in a 1-litter bottle and brought to a local chemistry laboratory (ENERSOLV, Decatur, AL). The laboratory determined water quality parameters that include; Total Suspended Solids (TSS), Ammonia Nitrogen (NH3N), Nitrate and Nitrite (NO3+NO2), Total Kjeldahl Nitrogen (TKN), Total Phosphorus (TP), and Total Nitrogen (TN).

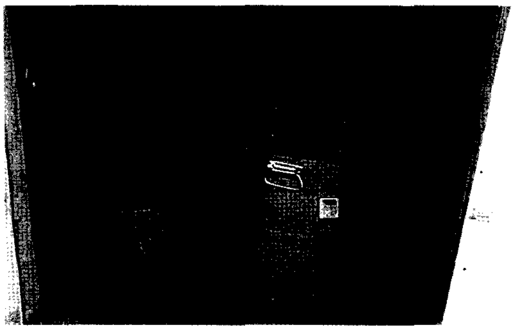

Fig. 4 ISCO 3700 runoff sampler

Two rain gages (1/100th inch and 1/10th mm sensors) were installed and connected to the CR10X datalogger. Two rain gages were installed to collect rainfall data with the idea that when one rain gage fails the other one collect back up data. The wind-blowing dusts, and grass cutting activities in the watershed often clog the orifice of the raingages. The CR10X datalogger was programmed to collect 15-minute interval rainfall. The CR10X was also programmed to collect daily ambient temperatures.

These data were regularly collected from the instrumentation site. The Palm m105 series PDA was used to download data from the CR10X datalogger. A routine maintenance works that include; cleaning raingages, checking potentiometer, stilling well and flume were done to ensure normal operation of the system.

Ⅲ. Data Analysis

The data downloaded from the field were brought to the Department of Biosystems Engineering at Auburn University. The data saved in the PDA was downloaded to a desk top computer. The data was analyzed by using PC208W computer program provided by Campbell Scientific Inc. The software was used to create rainfall data files for hourly, daily, and fifteen-minute interval, and runoff data file for three-minute interval. A spreadsheet program (Excel, Microsoft, Inc.) was used to create rainfall charts and hydrographs for each rainfall event. The program was also used to calculate the total rainfall amount, duration and intensity of rainfall, volume of runoff, peak discharge, and runoff duration and depth for each storm event.

There were numbers of small or large storm

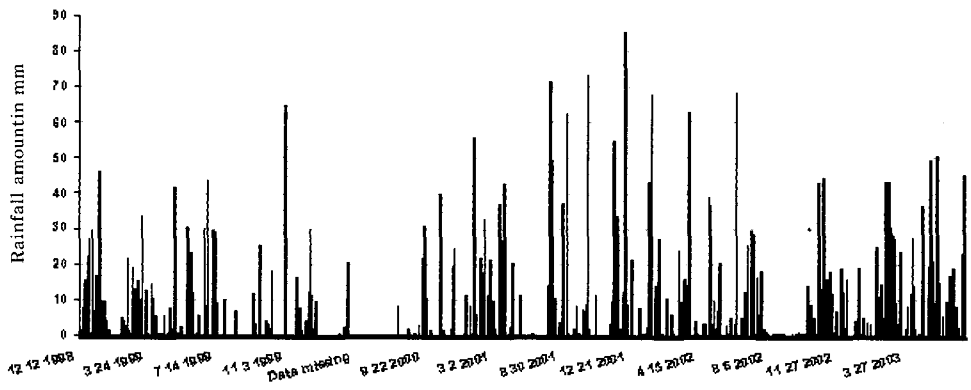

Fig. 5 Daily rainfall record from 12/12/1998 - 07/03/2003

events during the period as shown in the daily rainfall data (Fig. 5). There were one hundred and seventy storm events which were greater than 5 mm during the study period. However, only nine runoff events were recorded. Runoff events that were not recorded due to a system failure are not included in this study. Small rainfall events and even rainfall events at 25mm after long dry spell did not generate runoff. One of reasons for this is the potential high infiltration rates at the watershed. Infiltration rates were determined using double-ring infiltrometers and presented in this paper later.

Ⅳ. AGNPS (AGricultural NonPoint Source) Computer Model

AGNPS model was developed to simulate losses of nitrogen (N), phosphorus (P), organic carbon (C), sediment, and runoff from agricultural watersheds for specific storm events (Young et al. 1989). The hydrology model of AGNPS is based on a water balance equation, which is based on a simple bookkeeping of inputs and outputs of water during a day. The erosion calculation from RUSLE is based on whether there has been any runoff for each day. The amount of soil moisture is used to determine the effect of the SCS curve number and is thus the basis for the surface and subsurface runoff in the model. The following equation is used to determine soil moisture for each time step in a day (Bingner, 2001a).

$$SM_{t+1} = SM_t + (WI_t - Q_t - PERC_t - ET_t - Q_{lat} - Q_{tile})/Z \quad \cdots\cdots (1)$$

where SM_t = moisture content for each soil layer at the beginning of time period (fraction), SM_{t+1} = moisture content for each soil layer at the end of time period (fraction), WI_t = water input, consisting of precipitation or snowmelt plus irrigation water (mm), Q_t = surface runoff (mm), $PERC_t$ = percolation of water out of each soil layer (mm), ET_t = potential evapotranspiration (mm), Q_{lat} = subsurface lateral flow (mm), Q_{tile} = tile drainage flow (mm), Z = thickness for soil layer (mm), and t is the time period.

In order to run the AGNPS watershed model, the methodology developed by Young et al. (2002) was used. The Digital Elevation Model (DEM) of the watershed area was used to extract input data of hydrologic cells and reaches using AGNPS interface. The soil layers of the Summerford watershed was extracted from the State Soil Geographic Database (STATSGO) of Alabama and the soil input data for the AGNPS model was derived from the Map Unit Use File (MUFF) (Baumer, et al., 1994)

Ⅴ. Results and Discussion

The results of AGNPS computer models are presented in Fig. 6 to 9. The average observed and predicted runoff, sediment yield, and nutrient losses (TN and TP) for the selected storm events in three pasture management options are presented in Tables 1 to 4. While analyzing the observed and predicted data, Bermudagrass pasture management predicted the least sediment losses. Nutrient losses from all management options were found similar because the operations were considered similar for all vegetations except for canopy heights, 0.30 m, 0.40 m, and 0.50 m for Bermudagrass, fescue, and Ryegrass, respectively. The canopy heights affect the final drop height of rainfall in the model.

The mean sediment losses predicted by AGNPS in Bermudagrass, fescue, and Ryegrass were 1.93, 2.28, and 2.62 kg/ha, and RMSE (Root Mean Square Error) were 2.10, 2.88, and 3.71, respectively. The management practices predicted data were statistically not significantly different at 5% level.

The average observed runoff, sediment yields, total nitrogen, and total phosphorus were 5.18 mm, 2.19 kg/ha, 0.182 kg/ha, and 0.211 kg/ha, respectively at the outlet of the watershed. Hence, the results obtained from model analysis revealed that model could be reasonably applied to simulate runoff, sediment yields, and nutrient losses in agricultural watersheds.

1. Runoff

Fig. 7 shows the distribution of AGNPS model predicted runoff for each pasture management condition in different storm events and their comparison with observed data. Since runoff simulation is based on hydrological equation, no single method of statistical evaluation is sufficient to judge model adequacy (Pennell et al. 1990). Statistical analysis of the results shows that AGNPS over-predicted the average runoff (Fig. 6 and Table 1) in all pasture management

Table 1 Statistical comparison of observed (O) and model predicted (P) runoff (mm) for Summerford watershed

Statistical parameters				
O	Mean (mm)	5.18		
	St. dev. (mm)	5.92		
		AGNPS		
		B	F	R
P	Mean (mm)	10.71	10.71	10.71
	St. dev.	7.30	7.30	7.30
	RMSE	21.28	21.28	21.28
	Intercept	1.78	1.78	1.78
	Slope	0.32	0.32	0.32
	d	0.27	0.27	0.27
	p-value	0.10	0.10	0.10

B = Bermudagrass F = fescue R = Ryegrass

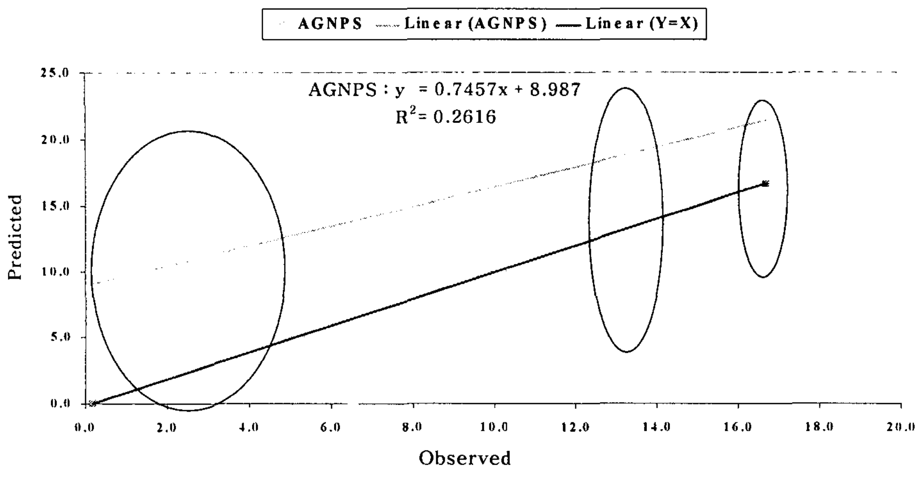

Fig. 6 Observed vs. predicted runoff in mm

conditions. While statistically comparing model predicted data with each pasture condition, AGNPS prediction had no significant difference between observed and model predicted data. AGNPS model prediction had RMSE of 21.28. AGNPS model prediction had indexality of agreement (d) value 0.67.

2. Sediment Yields

AGNPS under-predicted average sediment yields by 11 % in Bermudagrass but over-predicted by 4 % and 19 % in fescue and Ryegrass, respectively. AGNPS model prediction had RMSE of 2.1, 2.88, and 3.71 for Bermudagrass, fescue, and Ryegrass, respectively. The model prediction had lower RMSE in Bermudagrass than fescue and Ryegrass. AGNPS model prediction had indexality of agreement (d) of 0.96, 0.94, and 0.91 for Bermudagrass, fescue, and Ryegrass, respectively. AGNPS prediction had lower RMSE and higher d of Bermudagrass than those of fescue and Ryegrass. AGNPS predicted sediment yields reasonably in the most of conditions as presented in Fig. 7 and Table 2. The model predicted sediment yields reasonably as compared to the observed data in all management conditions.

Table 2 Statistical comparison of observed (O) and model predicted (P) sediment yield for Summerford watershed

Statistical parameters				
O	Mean (kg/ha)	2.19		
	St. dev.	3.41		
		AGNPS		
		B	F	R
P	Mean (kg/ha)	1.93	2.28	2.62
	St. dev.	3.16	3.19	3.26
	RMSE	2.10	2.88	3.71
	Intercept	0.07	0.47	0.54
	Slope	0.85	0.82	0.80
	d	0.96	0.94	0.91
	p-vlue	0.87	0.96	0.79

B = Bermudagrass F = fescue R = Ryegrass

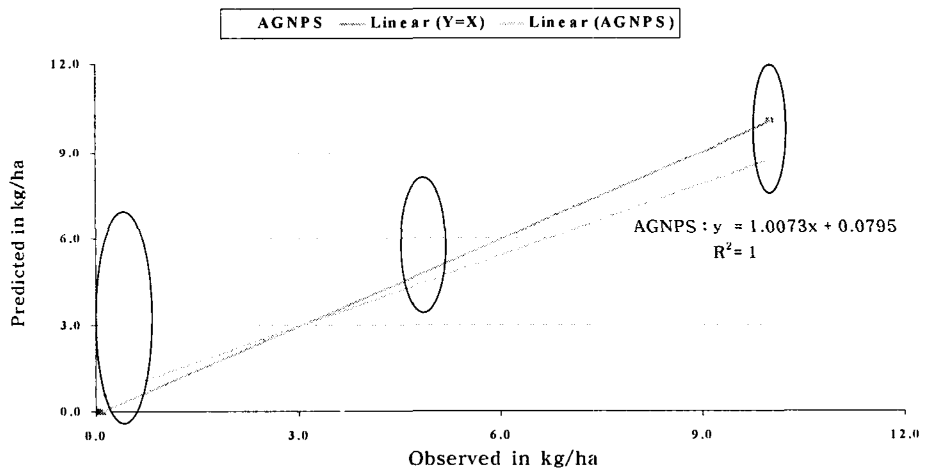

Fig. 7 Observed vs. predicted sediment yield in kg/ha

3. Nutrient Losses

AGNPS predicted the average total nitrogen losses at 0.061 kg/ha from all pasture management conditions. Whereas the model predicted the average total phosphorus at 0.93 kg/ha, 0.94 kg/ha, and 0.94 kg/ha in Bermudagrass, fescue, and Ryegrass pasture management conditions, respectively as presented in Figs. 8 and 9 and Tables 3 and 4. There was no big difference of nutrient losses prediction by model because in all pasture conditions same input files that includes; soil, fertilizer application rate, cell data, reach data, and runoff curve number were used. Additionally, single storm event simulation deals with the amount of rainfall and crop residues remaining in the ground.

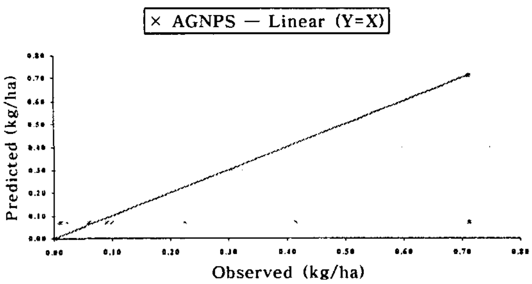

Fig. 8 Observed vs. predicted total nitrogen in kg/ha

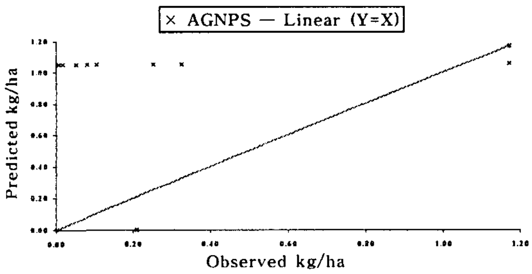

Fig. 9 Observed vs. predicted total phosphorus in kg/ha

Table 3 Statistical comparison of observed (O) and AGNPS predicted (P) total nitrogen for Summerford watershed

Statistical parameters				
O	Mean (kg/ha)	0.182		
	St. dev.	0.238		
		B	F	R
P	Mean (mm)	0.062	0.062	0.062
	St. dev.	0.024	0.024	0.024
	RMSE	0.480	0.480	0.480
	Intercept	0.219	0.219	0.219
	Slope	0.604	0.604	0.604
	d	-0.310	-0.310	-0.310
	p-vlue	0.167	0.167	0.167

B=Bermudagrass F=fescue R=Ryegrass

Table 4 Statistical comparison of observed (O) and AGNPS predicted (P) total phosphorus (kg/ha) for Summerford watershed

Statistical parameters				
O	Mean (mm)	0.211		
	St. dev.	0.371		
		B	F	R
P	Mean (mm)	0.934	0.935	0.936
	St. dev.	0.350	0.351	0.351
	RMSE	2.388	2.388	2.388
	Intercept	0.207	0.207	0.207
	Slope	0.004	0.004	0.004
	d	-2.240	-2.240	-2.240
	p-vlue	0.110	0.110	0.110

B=Bermudagrass F=fescue R=Ryegrass

Ⅵ. Conclusion

The prediction of runoff, sediment and nutrient losses by the AGNPS model was reasonable for all pasture management conditions. The model predicted sediment yield was more varied in each management conditions than with nutrient. Since the Bermudagrass caused the least mean sediment (1.93 kg/ha) and nutrient losses from the watershed, it can be said the Bermudagrass is the best management option among the three tested vegetations. Bermudagrass also showed higher value of the indexality of agreement (d).

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