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Reductions in non-point source pollution through different management practices for an agricultural watershed in the Three Gorges Reservoir Area

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Abstract

Non-point source water pollution generated by agricultural production is considered a major environmental issue in the Three Gorges Reservoir Area (TGRA) of China. The Annualised Agricultural Non-Point Source Pollution (AnnAGNPS) model was selected to assess the impact of the application of various management treats, including seven crops, five fertilizer levels and three-group management practice scenarios, on water quality from Heigou River Watershed in TGRA. The scenario subsets include conservation tillage practice (CTP), conservation reserve program (CRP) and conversion of cropland into forestland program (CCFP). Results indicated that tea can not be replaced by other crops because comparatively tea resulted in a higher sediment yield. CTP with no-tillage was more effective to reduce sediment yield, but could increased nutrient loss. CRP reduced sediment yield significantly, but slightly benefited on nutrient loss. CCFP reduced not only sediment yield but also the nutrient loss significantly. The conversion of cropland with a slope greater than 10° into forestland was found to be the best scenario as the sediment yield export is less than 5 tons/ha and nutrient loss is within the permissible limit.

Key words: non-point pollution; management practice; reduction; the Three Gorges Reservoir Area
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Introduction

The Three Gorges Project on the Yangtze River of China is one of the biggest waterconservancy andhydropower projects in the world. The Three Gorges Reservoir Area (TGRA) of China has now become one of the most ecologically sensitive areas in China. Non-point source (NPS) pollution tends to dominate pollutant loss in TGRA agricultural watershed (Wang et al., 2006). Transport and deposition of eroded material as well as substances dissolved in runoff and attached to soil particles lead to negative impacts on agricultural land and the Three Gorges Reservoir including water quality decline (Richards, 2002), eutrophication (Zemenchik, 2002), which are generally thought to be caused by land use changes of converting forest resources to agriculture in watersheds (Ouyang et al., 2008). On the basis of the available field data and existing practices of cultivation, the Chinese government has carried out sustainable agricultural management practices and conservation programs suited to local conditions to reduce sediment and pollutant loss from agricultural areas. The programs include conservation tillage practice (CTP) (Andraski et al., 2003; Daverede et al., 2003; Dabney et al., 2004), conservation reserve program (CRP) practices such as grass filter strips and riparian buffers (Cooper and Lipe, 1992; Robinson et al., 1996; Hussein et al., 2007), and the so-called 'Conversion Cropland to Forestland Program' (CCFP) (Ouyang et al., 2008). Lots of field plot experiments were initiated in TGRA to investigate the efficiency of such widely recommended researchable options for soil conservation at the same time.

However, there is no adequate information available to show the benefits of these programs at the watershed scales. To assess the management practice effectiveness, field plot experiment or long-term monitoring is very expensive and time consuming, and it is quite difficult to assess the environmental quality improvements by extensive sampling and monitoring data. Under these conditions, application models become useful and efficient.

Heigou River Watershed (HRW) was selected as one of the benchmark watersheds here because it is characteristic of a large portion of TGRA landscape. It is now undergoing rapid land use and management changes. Many forested lands have been converted to urban areas and farmlands. An elevated level of nitrogen, phosphorus and other nutrients was found in the watershed (Ouyang et al., 2008).

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The present research employed the Annualized Agricultural Non-Point Source Model (AnnAGNPS), a hydrologic and water quality model to examine the hydrologic and water quality changes in a watershed in TGRA. The objectives of this article were: (1) to evaluate the impacts of seven crops (tea, groundnut, maize, mungbean, sorghum, soybean and sweet potato) and five fertilizer application rates on runoff, sediment yield and nutrients loss; (2) to evaluate the impacts of three-group management practice scenarios, i.e., CTPs, CRPs and CCFPs, on runoff, sediment yield and nutrients loss. Our goals were to suggest a feasible management practice that would help in reducing the adverse hydrologic and water quality effects, and to develop a protocol for a practical tool that could be used to model and postulate the plausible impacts of proposed landuse or land management changes in TGRA.

1 Materials and methods

1.1 Study area

The study area, HRW in TGRA, locates in Zigui County, Hubei Province, China (Fig. 1) at 30°51′45″N latitude and 110°54′50″E longitudes. The total watershed area is about 144.4 ha with elevation ranges from 195 to 1400 m. The mean annual temperature is about 20°C with a maximum of 35°C in July and a minimum of 2°C in January. The watershed average value of slope is 33.7°, and majority of land has extreme slope. The soils of the watershed are, in general, sandy loam in texture, with gravels and acidic in reaction. The land use of watershed was found to be a mixed type. About 26.7% of land area is covered by forest, 45.8% for cropland, 17.2% for rangeland and 10.3% for other uses.

1.2 Model description

AnnAGNPS is a continuous simulation, watershed-scaled model, that can be used to evaluate NPS pollution in watersheds up to 300,000 ha (Bingner and Theurer, 2003). It operates on a daily step with a minimum simulation period of 1 year. The model includes an input editor, which aids in an input file generation, a pollutant loading model (AnnAGNPS) which is a continuous model that predicts runoff and pollutant loadings, a climate generating model (GEM), and a subset of the topographic analysis model (TOPAZ). Output is available on an event, monthly or annual basis. A watershed in the model is represented by a system of amorphous spatial discretization unit and point sources connected by channel network through which the water and pollutants are routed. Rainfall excess is determined based on soil water balance for constant sub-daily time steps. The SCS curve number technique (SCS, 1972) was used within AnnAGNPS to determine overland runoff, and TR-55 method was used to calculate peak flow (SCS, 1986). Runoff in channels was calculated using Manning's equation. Soil erosion is predicted by Revised Universal Soil Loss Equation, sediment delivery by Hydro-geomorphic Universal Soil Loss Equation. Sediment reach routing is based on a modified Einstein deposition equation using the Bagnold suspended sediment formula for the transport capacity by particle size class. Algorithms for nutrient dynamics are largely similar to Erosion Productivity Impact Calculator (Williams et al., 1984) and Groundwater Loading Effects of Agricultural Management Systems (Leonard et al., 1987) models. Bingner and Theurer (2003) provided detailed description on the technical processes for AnnAGNPS model. Understanding the technical processes of the model is essential as the study attempts to modify input parameters that best suit the local conditions.

1.3 Development of the database

The basic database for HRW mainly includes DEM (digital elevation model), soil and landuse maps, as well as climate and land management data (Table 1). A 5-m resolution DEM got from a contour map (1:10,000) of HRW was used to delineate AnnAGNPS cells and generate network. HRW was divided into 49 cells using a CSA (critical source area) value of 2 ha and a MSCL (minimal source channel length) value of 30 m. These values were chosen based on the observation of topography

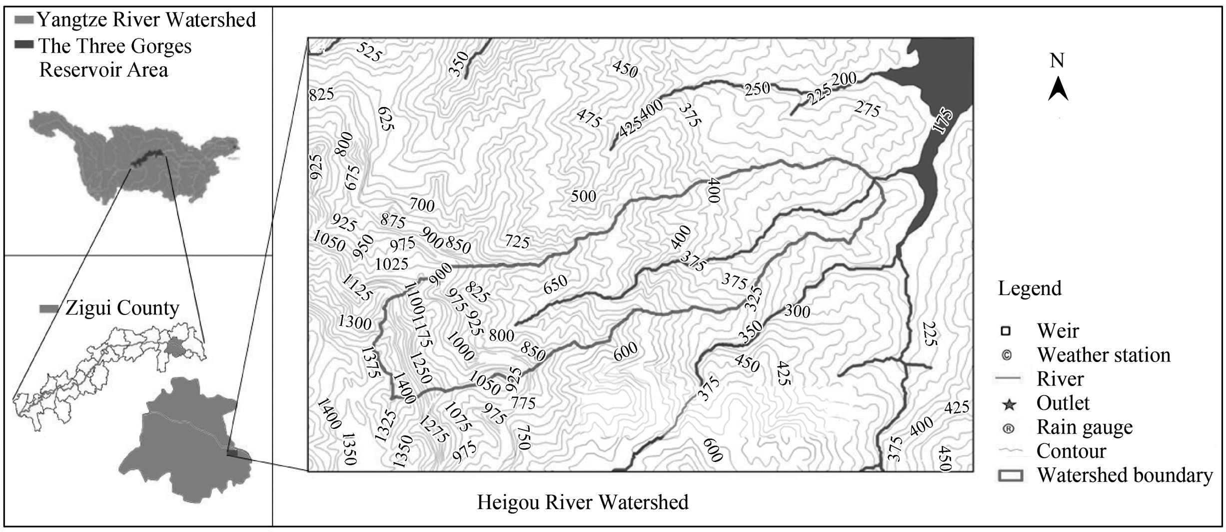

Fig. 1 Location map of Heigou River Watershed (HRW).

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Table 1 Data format and sources for HRW

Data type	Data format	Sources	Scale
DEM[a]	Grid (cell size 5 m × 5 m)	Topographic map	1:10,000
Soil	Vector map (polygon)	Field survey, ZFB[b]	1:10,000
Soil parameter	Text file	Field survey, ZFB	–
Land-use	Vector map (polygon)	Field survey, ZFB	1:10,000
Crop	Text file	Field survey, ZFB	–
Weather	Tables of daily values	ZFB	–
Land management	Text file	Field survey, ZFB	–

[a] DEM: digital elevation model; [b] ZFB: Zigui Forestry Bureau.

of the area to best represent a highly dissected relief. The 2003–2004 landuse maps and digital soil maps were obtained from Zigui Forestry Bureau (ZFB) of Hubei Province. Classification of soil was carried out according to USDA classification (Brown, 1999). Soil properties such as field capacity, bulk density and chemical properties were obtained from ZFB and other sources. Field operation, field management, crop and non-crop data and other data were obtained through field survey.

1.4 Model calibration and validation

The AnnAGNPS model is built with an attempt to simulate the processes physically and realistically as possible. AnnAGNPS has been widely used in the United States and other countries. Borah and Bera (2004) have extensively reviewed the various non-point source pollution models and their applications and indicated that AnnAGNPS is found to be sound and suitable for long-term continuous simulations in agricultural watersheds.

Calibration was done manually to select values for the parameters so that the model closely predicted runoff and sediment yield. At first calibration was focused on daily event flow volumes. Twenty-three rainfall-runoff events in 2003 were selected. The SCS curve number is the most important factor for accurate calculation of runoff (Baginska et al., 2003; Polyakov et al., 2007). Its values were adjusted by trial and error with the graphical comparison as well as the comparison of statistical parameters of measured and predicted runoff. Initial CN values were selected based on National Engineering Handbook (SCS, 1986).

The recent version of AnnAGNPS uses RUSLE to estimate the erosion and HUSLE for sediment yield. It is very difficult to adjust all those parameters for the calibration process. Sediment yield displayed more complex and often contradictory responses to changing input variables. The root mass, canopy cover and Manning's roughness coefficient values in each cell were adjusted by trial and error with the graphical comparison (Shrestha et al., 2006) as well as the comparison of statistical parameters of measured and predicted sediment yield.

Statistical values such as percentage error (PE) (Polyakov et al., 2007), coefficient of determination (R^2), and Nash-Suttcliffe efficiency (E) (Nash and Suttcliffe, 1970) were used to evaluate model performance. The equations to calculate PE, R^2 and E are shown as follows:

$$\mathrm{PE} = \frac{\sum_{i=1}^{N}(M_i - P_i)}{\sum_{i=1}^{N} M_i} \tag{1}$$

$$R^2 = \left\{ \frac{\sum_{i=1}^{N}\left(M_i - \overline{M}\right)(M_i - P_i)}{\left[\sum_{i=1}^{N}\left(M_i - \overline{M}\right)^2\right]^{0.5}\left[\sum_{i=1}^{N}\left(P_i - \overline{P}\right)^2\right]^{0.5}} \right\}^2 \tag{2}$$

$$E = 1.0 - \frac{\sum_{i=1}^{N}(M_i - P_i)^2}{\sum_{i=1}^{N}\left(M_i - \overline{M}\right)} \tag{3}$$

where, N is total number of daily events, M_i is the measured value; P_i is the predicted value and $\overline{M}$ and $\overline{P}$ are the average of all measured and predicted values, respectively.

In the validation process, the model was operated with input parameters obtained in the calibration process and other watershed in 2004. The same statistical techniques were used to assess the model performance under local conditions.

1.5 Identification and prioritization of critical areas

The critical areas in HRW were identified on the basis of average annual sediment yield and nutrient loss from the cells during the period of 2003 to 2004. In this context, annual sediment yields were simulated for each cell and priorities were fixed on the basis of ranks assigned to each critical cell. Soil loss tolerance value of 5 tons/ha for annual sediment yield under TGRA conditions as described by standard SL 190-2007 was considered as criterion for identifying the critical areas. From the point of view of nutrient loss, the threshold values of 2.0 mg/L for NH_3-N and 0.4 mg/L for TP (total phosphorous) as described by standard GB 3838-2002 were considered as criterion for identifying the critical cells.

1.6 Effects of crops and fertilizer application rates on runoff, sediment yield and nutrients loss

Nutrients running off from cropland occupied a dominant part in non-point pollution loading. Non-point pollutant output rate of different field crops is an important parameter for the adjustment of agricultural planting structure. Reduction rates of sediment and nutrient yields by various crops (Table 2) were evaluated to identify suitable field crops under current agricultural management practices on the basis of that cropland is sole cropped.

Nutrient requirement of each crop is different and hence the rate of fertilizer applied depends upon the crop grown. Considering the N:P requirement of different crops, Organic manure in conjunction with different chemical sources of nutrients at different levels for various crops was evaluated to maintain soil fertility and productivity on a sustainable basis. The fertilizer application rates were obtained from a survey of local farmers. Information on recommended variable rates (Table 2) was obtained from

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Table 2 Crops, and N and P application rates for HRW

Crops	N:P application rate				
	Existing	70% of existing	Recommended	70% of recommended	30% of recommended
Groundnut (*Arachis hypogaea*)	190:130	150:90	105:63	75:45	45:27
Maize (*Zea mays*)	220:120	180:90	130:65	90:45	45:27
Mungbean (*Phaseolus aureus*)	150:95	120:75	90:42	60:36	30:18
Sorghum (*Sorghum bicolor*)	230:150	180:120	135:90	90:60	45:30
Soybean (*Glycine max*)	150:95	120:75	90:55	60:38	30:19
Sweet potato (*Ipomoea babatas*)	280:240	230:180	172:135	115:90	56:45
Tea (*Melaleuca alternifolia*)	300:130	240:100	180:70	120:50	60:25

Agricultural Consulting Firm, Hubei Province Agricultural Department.

1.7 Alternative management scenarios

Alternative scenarios were evaluated to assess their effectiveness in reducing nutrient and sediment within the HRW. Brief descriptions of different management practices are presented in Table 3, and further details were given in literature (Mostaghimi et al., 1997; Santhi et al., 2006; Ouyang et al., 2008).

AnnAGNPS simulations were performed to estimate sediment and nutrient transport with actual watershed rainfall, landuse and field management during a 2-year period (2003–2004), which were used as a baseline or a reference to which we compared simulation reflecting impacts of management practices. Based on landuse conditions of all management scenarios, the regional water flow, soil erosions, TN and TP loads were estimated respectively using the calibrated AnnAGNPS model. All the input parameters, except those representing the state of management practice implementation, were the same for all simulations.

Table 3 Description of management practice scenarios simulated for HRW

Management scenarios and description
Existing tillage practice
Existing conventional tillage practices and fertilizer level (CT)
Conservation tillage practice (CTP)
No-tillage applied to cropland (NT)
Mulch-tillage applied to cropland (MT)
Ridge-tillage applied to cropland (RT)
Conservation reserve program (CRP)
Grass filter strips applied to critical areas (GFS)
Riparian buffers applied to critical areas (RB)
Grassed waterways applied to critical areas (GW)
Conversion of cropland into forestland program (CCFP)
Cropland with slope greater than 25° converted to forestland (CCF1)
Cropland with slope greater than 10° converted to forestland (CCF2)
All cropland converted to forestland (CCF3)

2 Results and discussion

2.1 Calibration and validation of AnnAGNPS

Statistical parameters of runoff and sediment yield as obtained from calibration of the model are presented in Table 4. Daily observed and simulated values of runoff and sediment yield are plotted and their distribution along with 1:1 line are presented in Fig. 2. It was observed that simulated values were uniformly distributed about 1:1 line. Regression analysis shows the best-fit relation between the observed and simulated sediment yield values. The model slightly underpredicted the mean runoff and sediment yield by 5.0% and 5.3%, respectively, as compared to the measured values. The coefficient of determination (R^2) was found to be 0.93 for runoff and 0.63 for sediment yield, respectively. Model simulation efficiency (E) for observed and simulated runoff and sediment was found to be 0.87 and 0.77, respectively. This was a satisfactory result attributed to the maximum possible calibration.

For model validation, data of 49 rainfall-runoff events of 2004 were taken and remaining input variables were used

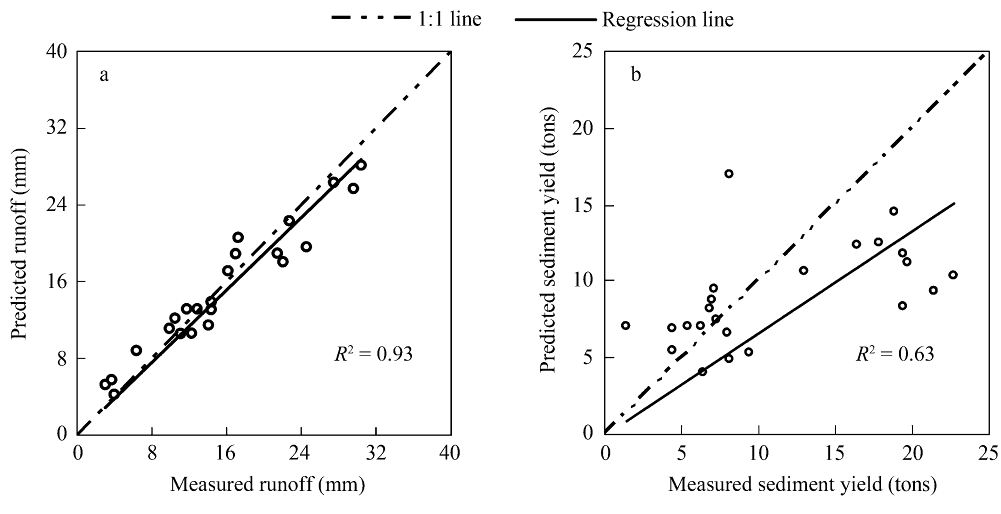

Fig. 2 Comparison between observed and simulated data of daily runoff (a) and daily sediment yield (b) for model calibration.

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Table 4 Evaluation of Annualised Agricultural Non-Point Source Pollution (AnnAGNPS) performance

Evaluation method	Calibration		Validation			
	Runoff	Sediment	Runoff	Sediment	TN	TP
PE (%)	–5.0	–15.1	–5.3	–13.5	20.3	23.5
R^2	0.93	0.63	0.90	0.66	0.68	0.65
E	0.87	0.77	0.79	0.69	0.53	0.43

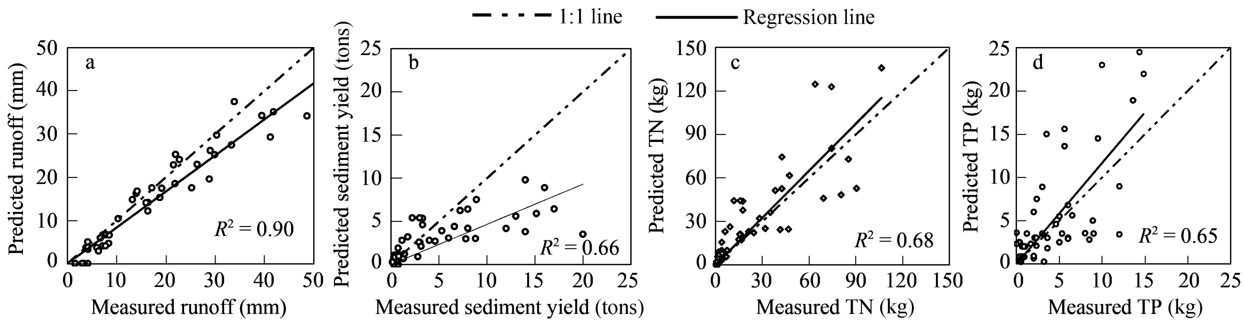

Fig. 3 Comparison between observed and simulated of daily runoff (a), sediment yield (b), daily TN (c), and daily TP (d) for model validation.

as such. Statistical parameters of runoff and sediment yield as obtained from validation of the model are presented in Table 4. Distribution of daily runoff and sediment yield along with 1:1 line is presented in Fig. 3a, b. It was observed that the modeled values of runoff and sediment yield are uniformly distributed about 1:1 line. The values of R^2 were found to be 0.90 and 0.66, which show close agreement between the observed and simulated runoff and sediment yield. The mean values of observed and predicted runoff and sediment yield were not differing significantly at 95% confidence level. The E value of 0.79 and 0.69 shows a close agreement between the measured and simulated values of runoff and sediment yield, respectively. Figure 3c shows the plot of predicted versus measured TN loading with regression and 1:1 lines. The regression line was above but close to the 1:1 line, indicating over calculation (PE = 20.3%). Despite noticeable inaccuracies in TN predictions ($R^2 = 0.68$, $P < 0.05$), the results demonstrated a degree of stability. The TP coefficient of determination R^2 was found to be 0.65 ($P < 0.05$) (Fig. 3d), which meant that the model was only able to explain about 65% of the variability in the measured data. The results for PE and E were poor at 23.5% and 0.43, respectively. Results revealed that, in general, the AnnAGNPS model can be used in simulating runoff, sediment and nutrients loads in HRW of TGRA with mixed types of land uses and steep slopes.

2.2 Identification and prioritization of critical cells

The annual sediment and nutrient loss were simulated for each cell. The critical cells were identified and prioritized on the basis of actual sediment rate and nutrient loss. Sediment yield from cells to the watershed outlet was highly spatially variable. As shown in Table 5, approximately 14.7% of the watershed areas fell under slight soil group of soil erosion classes (0–5 tons/ha) as described for TGRA conditions and it did not present threat as a sediment-generating areas. However, approximately 32.9%, 20.6%, 7.0% and 24.7% fell under moderate (5–25 tons/ha), high (25–80 tons/ha), severe (80–150 tons/ha), very severe erosion classes (larger than 150 tons/ha), respectively. There was no significant spatial correlation between land cover type and sediment yield. Both forest and shrub provided dense canopy and ground residue protection for the soil. Similarly to the land cover type, slope gradient also was not significantly spatially correlated with sediment yield. In view of annual soil loss, runoff and nutrient loss, cells were considered for execution of the management practice scenarios as per erosion potential order to reduce the sediment and nutrient loss.

2.3 Effect of crops and fertilizer application rates on runoff, sediment yield and nutrients loss

Figure 4 shows the impacts of crops under existing tillage practices and fertilizer level on runoff, sediment yield and nutrient loss. As compared to tea, other crops such as groundnut, maize, mungbean, sorghum, soybean and sweet potato reduced the runoff by 6.37%, 3.25%, 2.92%, 5.66%, 4.96% and 4.62%, respectively; and increased sediment yield by 35.7%, 21.7%, 21.9%, 40.0%, 30.7% and 37.9% respectively. On the basis of the results, it was concluded that tea could not be replaced by any other crops from sediment yield point of view.

Fertilizer treatments and their effects on runoff, sediment yield, TN and TP are shown in Table 6. It was found that runoff and sediment yield were not affected due to

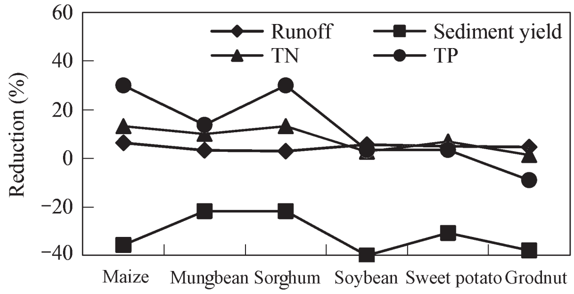

Fig. 4 Effect of crops on average annual yields under existing tillage practices and fertilizer levels comparing with tea.

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Table 5 AnnAGNPS simulation of current condition of HRW (average annual value for the period of 2003 to 2004)

Cell ID	Area (ha)	Runoff (mm)	Sediment yield (tons/ha)	TN (kg/ha)	TP (kg/ha)	Cell ID	Area (ha)	Runoff (mm)	Sediment yield (tons/ha)	TN (kg/ha)	TP (kg/ha)
22	2.29	310	16.26	12.90	2.19	163	4.35	335	4.56	1.42	0
23	6.7	303	38.58	10.10	1.7	171	2.33	495	96.58	6.26	0.71
43	2.27	330	3.66	2.52	0.32	172	6.76	490	93.66	5.22	0.63
52	1.88	310	14.35	11.54	1.79	183	6.68	488	92.39	5.10	0.84
53	0.88	330	1.56	1.78	0	191	2.48	490	95.54	5.22	0.63
62	2.6	310	15.12	11.8	1.76	192	2.09	490	108.96	5.62	0.71
71	2.25	500	135.24	4.74	2.24	193	1.58	495	42.00	3.90	0.55
72	2.05	335	25.00	12.58	1.87	201	1.53	488	83.08	5.54	0.84
73	0.84	320	20.25	11.74	1.87	212	6.74	320	23.94	9.12	1.22
82	3.42	278	66.69	16.16	2.51	213	1.12	335	1.87	0.90	0
91	2.10	278	72.21	15.24	2.43	221	2.21	488	83.26	5.10	0.89
93	0.71	320	18.69	12.6	1.84	223	5.15	495	109.99	4.98	0.77
102	3.84	278	26.59	7.94	1.26	231	1.07	320	15.98	13.32	2.59
103	3.46	289	82.3	20.58	3.00	241	2.09	335	3.06	1.78	0
112	2.15	300	36.23	9.42	1.58	242	2.97	335	3.13	1.9	0
113	6.24	450	12.97	16.22	2.76	243	3.15	335	3.66	0.9	0
121	3.18	341	56.98	12.68	1.97	251	2.54	320	40.00	10.34	1.55
123	1.00	320	17.89	12.14	1.87	252	1.05	341	57.89	11.38	1.73
132	3.30	320	20.54	12.12	1.92	253	2.11	320	16.88	13.08	2.61
141	2.48	320	16.59	12.62	1.95	261	2.13	500	183.93	4.48	0.55
142	4.52	330	24.37	11.9	1.95	262	2.07	495	39.85	4.24	0.55
143	7.49	310	9.54	12.68	1.97	271	2.10	330	1.59	2.44	0.32
153	0.95	335	1.57	1.26	0	272	2.13	500	127.89	3.74	0.45
162	0.64	320	12.58	11.62	1.92	281	10.81	303	37.99	9.66	1.61

Table 6 Effect of fertilizer application rates under existing tillage practices on runoff, sediment yield, TN and TP

Fertilizer application rate	Runoff (mm)	Reduction (%)	Sediment yield (tons/ha)	Reduction (%)	TN (kg/ha)	Reduction (%)	TP (kg/ha)
Existing	303	0	22.2	0	7.40	0	1.07
70% of existing	303	0	22.2	0	5.70	22.3	0.76
Recommended	303	0	22.2	0	4.70	36.4	0.56
70% of recommended	303	0	22.2	0	1.34	81.8	0.30
30% of recommended	303	0	22.2	0	0.45	93.9	0.06

the change in fertilizer doses. The increase in fertilizer dose increases the loss of TN and TP under existing management practices. There was a significant positive correlation between nutrient loss and fertilizer application rate. The availability of phosphorous was limited due to fixation, as the acidic nature of the soils existed in HRW. The poor availability of phosphorous in HRW results TP loss at a lower rate. The findings are in conformity with the findings of Tripathi et al. (2005) and Pandey et al. (2008).

According to local farmers, the yield of tea and other crops increased with the increase of fertilizer doses. No difference in the tea yield was observed under fertilizer treatments of the recommended and the existing. But as shown in Table 6, recommended fertilizer application rate could reduce TN and TP loss by 36.4% and 34.0%, respectively. Correct fertilizer management options is essential in terms of nutrient reduction. Only the recommended amount of fertilizer needed by each crop should be applied.

2.4 Evaluation of management practice scenarios on NPS pollution reduction

The effects of all the three-group practice scenarios on runoff and water quality are shown in Fig. 5. Based on the predictions for scenario NT, average annual sediment yield was reduced by 45.8%. On the contrary, runoff, TN and TP loadings were increased by 11.6, 6.8 and 5.8%, respectively, when compared with the scenario CT (current condition). The sediment reduction rate of scenario NT was higher than that for scenarios RT and MT. However, while these CTPs were effective in reducing sedimentation, they increased nutrient export from critical producing areas.

CRP scenarios were designed to evaluate the impacts on the same critical areas. The predicted average annual reduction for CRP scenarios in sediment loading varied from 23.7% to 32.55%. The average annual reductions in TN and TP were all less than 7%. Based on the evaluations of available information, CRPs had the beneficial effects of improved erosion and sediment control, but slight of nutrient reduction.

The management practice effectiveness values of this

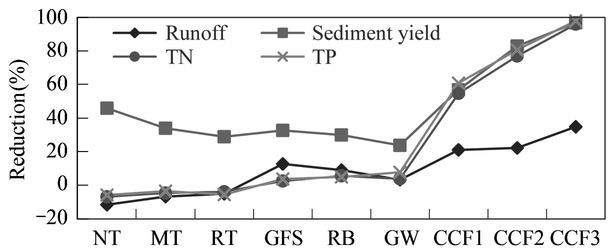

Fig. 5 Annual pollutant reductions by different management practice scenarios. NT–CCF3 refer to Table 3.

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study are not in conformity with the findings of others (Lee et al., 2000; Gitau et al., 2005). Several studies have reported BMP (best management practice) effectiveness values for reducing pollutant load. The proportion by which a BMP decreases nutrient loading is called a "BMP reduction factor". These factors are different for various pollutants as well as for various BMPs. The studies contains a wide range of factors associated with each BMP since a BMP's effectiveness can be measured at different scales, e.g., plot-, field- or farm-level studies (Magette et al., 1989; Lee et al., 2000) as well as watershed level studies (Inamdar et al., 2001; Gitau et al., 2004). In addition, because of specificity in terms of landscape, topography, landuse, hydrology and meteorology vary, the effectiveness of BMPs likewise varies.

None of the scenarios mentioned above could reduce sediment yield, TN and TP loads to tolerance level. This observation led to the consideration of CCFP scenarios under existing conditions. In scenario CCF1, agricultural land on slope bigger than 25° was transferred into forest and other landuse did not change; therefore, agricultural land dropped to 55.5 ha and forest area climbed to 56.9 ha. In scenario CCF2, agricultural land on slope bigger than 10° was all converted to forest, which resulted in forest area that rose to 102.3 ha and agricultural land that decreased to 28.1 ha. Scenario CCF3 considered a hypothetical situation where all the cropland was converted to forest. As shown in Fig. 5, the sediment and TN and TP loads could be reduced, respectively, by 56.8%, 54.6% and 60.8% for scenario CCF1, 82.8%, 76.9%, 80.7% for scenario CCF2, and 96.8%, 96.0% and 98.0% for scenario CCF3. Although CCFP implemented showed significant reductions in sediment and nutrient at the watershed level, the implementation areas of the measures were major compared to the area of the watershed. Since the conversion of all areas of cropland to forest would make the option very costly, the scenario CCF3 was not as practicable as the ones already discussed. Scenario CCF2 is more realistic which reduced sediment yield, TN and TP loads to tolerance level. Based on the above discussion, the best scenarios for HRW may be the CCF2.

3 Conclusions

Physically based model AnnAGNPS was calibrated and validated for runoff and sediment yield prediction from HRW in TGRA. The model accurately simulates runoff, sediment yield and nutrient loss of HRW on daily basis, and can successfully be used for identifying critical areas for developing management practices. The baseline analysis for HRW revealed that phosphorus, nitrogen and sediment pose the greatest risk to future water quality protection. The tea crop cannot be replaced by crops such as groundnut, maize, mungbean, sorghum and soybean in view of sediment and nutrient loss. There was a significant positive correlation between nutrient loss and fertilizer application rate. Due to the special TGRA conditions, the conservation tillage practices and conservation reserve programs could not meet the long-term goal of reduction rates in pollutant loadings. Conversion of cropland with slope greater than 10° into forestland met the reduction goal was largely practicable. Based on the results obtained from this study, it appears that the modeling approach can be extended for hydrologic evaluation of TGRA watersheds under similar conditions.

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