

NAPRA WWW 시스템의 민감도 분석

임경재 · 버니 엔겔¹ · 최예환 · 최중대 · 김기성* · 허성구 · 신용철

강원대학교 농업공학부, ¹퍼듀대학교 농업생명공학부

NAPRA WWW Sensitivity to Model Input Parameters

Kyoung Jae Lim · Bernard A. Engel¹ · Ye-Hwan Choi · Joong-Dae Choi · Ki-Sung Kim*
· Sung-Gu Heo and Yong-Chul Shin

Division of Agricultural Engineering, Kangwon National University, Chuncheon 200-701, Korea

¹Agricultural and Biological Engineering, Purdue University, West Lafayette, 47907-1146. IN, USA

ABSTRACT

NAPRA WWW 시스템 (<http://pasture.ecn.purdue.edu/~napra>) 은 각기 다른 영농방법이 수문, 토양유실, 그리고 수질에 미치는 영향을 평가하고 수체로의 영양물질 유입을 평가하는데 매우 적합한 시스템이다. 본 연구에서는 근역의 깊이, 농약의 사용 시기, 시비량, 그리고 경작방법이 NAPRA WWW 시스템 모의 수문, 토양유실, 농약유실, 그리고 영양물질의 유실에 미치는 영향을 평가하였다. 보다 정확한 NAPRA WWW 수문모의를 위해서대상 연구지역내 작물의 근역에 대한 정확한 정보가 필요하다. 근역의 깊이가 토양유실, 농약 및 영양물질의 유실에 많은 영향을 미치는 것으로 분석되었다. 농약의 사용 후 발생한 강우사상에 의해 상당부분의 농약이 유실되는 것으로 모의되었다. NAPRA WWW 장기모의시 이러한 이유로 인하여 특정연도 농약유실량이 상당히 높았다. NAPRA WWW 모의 결과 시비된 영양물질과 유실된 영양물질사이에는 선형적인 관계를 보였다. 경운방법이 NAPRA 모의결과에 미치는 영향 때문에 정확한 모의를 위해서는 각기 다른 경운방법을 고려한 NAPRA 모의가 필요하다. 본 NAPRA WWW 시스템의 민감도 분석결과 본 연구에 고려된 인자들은 NAPRA WWW 모의치에 상당 부분 영향을 미치는 것으로 판단되었다. 따라서 NAPRA WWW 시스템을 이용하여 각기 다른 영농방법이 수문, 토양유실, 그리고 수질에 미치는 영향을 모의하기 위해서는 본 연구에서 고려된 입력변수에 대한 심도 있는 연구가 선행되어야 한다.

Key words : GLEAMS, NAPRA, Sensitivity Analysis, Pesticides, Nutrients, Root Zone
Depthland use, No gauging station, Multi-linear regressed equation, Coefficient
of correlation

I. INTRODUCTION

The National Agricultural Pesticide Risk Analysis (NAPRA) World Wide Web (WWW) system (<http://pasture.ecn.purdue.edu/~napra>) was developed to simulate the effects of agricultural

management system on pesticides (Engel and Lee, 1998), and a nutrient component was incorporated into the NAPRA WWW system (Lim and Engel, 1998) to enable simulation of nutrient losses. Many features of the NAPRA WWW system have been enhanced to provide

* Corresponding author: Ki-Sung Kim, Tel: +82-33-250-6466, Fax: +82-33-251-1518, E-mail: kskim@kangwon.ac.kr

user-friendly interfaces as well as to enable the simulation of multiple pesticide applications in crop rotations (Lim and Engel, 1999; Lim and Engel, 2000; Lim and Engel, 2003).

The NAPRA WWW has been developed and evaluated by comparing the model predicted results with the measured surface and subsurface water quality data (Lim and Engel, 1998; Lim and Engel, 1999; Lim and Engel, 2000; Lim and Engel, 2004). When the NAPRA predicted surface water quality data were compared with the measured surface water quality data, it has been assumed that the percolation and pollutants in percolation multiplied by the percentage of subsurface drainage systems reach streams. Thus, estimated percolated water and pollutants combined with surface runoff and pollutants were used in the comparison to observed surface water quality (Lim and Engel, 1998; Lim and Engel, 2000; Lim and Engel, 2004). For modeled comparisons to ground water quality, the percolation and pollutants estimated to be intercepted by the drainage system were subtracted from the total estimated percolation and pollutants in percolation (Lim and Engel, 1999; Lim and Engel, 2000). Thus, proper partitioning of runoff and percolation is important in model evaluation. According to the Knisel and Davis (1999), the accurate definition of root zone depth is important in Groundwater Loading Effects of Agricultural Management Systems (GLEAMS) hydrology, especially simulated runoff and percolation. The NAPRA WWW system uses GLEAMS as a core model to simulate hydrology, erosion, pesticide losses, and nutrient losses. Thus, the effects of root zone depth on NAPRA hydrology need to be understood. In the NAPRA WWW system, all information provided by users, such as pesticide application date, in the input interface is assumed constant throughout the simulation period. Pesticides are not typically

applied when it rains or the soil moisture content is too high. However, it is not readily possible to change the application date depending on rain events every year in the current NAPRA WWW system to represent such conditions. Therefore, the effects of precipitation near pesticide application date on pesticide losses need to be examined. When the NAPRA WWW was run for watersheds (Lim and Engel, 2004), county specific nutrient values were used as model inputs. Nutrient application rates vary from field to field. Further, nutrients may not be applied to watersheds at the county rates. Thus, the effects of nutrient application rates need to be investigated to examine the validity of the assumption of uniform nutrient application. All input parameters provided in the NAPRA input interface including tillage are assumed constant throughout the simulation period. Although it is not possible to change the tillage information during a simulation with the current NAPRA WWW model, the effects of tillage systems, such as no tillage, conservation tillage, and conventional tillage, on the predicted pesticide and nutrient loadings need to be understood so model users can decide whether to run separate NAPRA scenarios for different tillage system.

Therefore, the goals of this study were to investigate the sensitivity of NAPRA to: Root zone depth, Timing of pesticide application, Nutrient application rates, and No tillage, conservation tillage, and conventional tillage

II. REVIEW OF LITERATURE

The GLEAMS model is a field scale, physically-based, continuous time step computer model to simulate the effects of agricultural management systems on water quality (Knisel et al., 1992). Hydrology processes are responsible

for providing the transport medium for sediment and agricultural chemicals and nutrients (Knisel et al., 1992). In the GLEAMS model, the percolated water below the root zone is assumed lost to shallow groundwater (Knisel and Davis, 1999). Knisel and Davis (1999) recommended careful definition of root zone depth in GLEAMS model runs to properly partition runoff, soil water, and percolation since hydrology is the input of other model components.

Sediment is one of the major sources of water pollution in Indiana. Sediment causes water to become cloudy and creates an unsuitable environment for many aquatic creatures (Brichford et al., 1993). About 84 million tons of topsoil is eroded in Indiana every year (Eck et al., 1994). Baker and Richards (1990) found large variability in peak and average pesticide concentrations, and in pesticide loadings, depending on the frequency, duration, and intensity of runoff generating rainfall events in relation to the timing of pesticide application. Because of complex behaviors and movements of pesticides, the WWW-based NAPRA system was developed to estimate the site-specific effects of land use and management on water quality with respect to pesticides (Engel and Lee, 1998), and the nutrient component was added to the NAPRA WWW (Lim and Engel, 1998). The NAPRA WWW system has been evaluated by comparing the results with the measured data within Indiana (Lim and Engel, 1998; Lim and Engel, 1999; Lim and Engel, 2000; Lim and Engel, 2004), and it was found that NAPRA has potential in identifying critical areas from a nitrate perspective and more researches are required for pesticide modeling. In the current version of NAPRA system, user specified pesticide application date is used throughout the simulation period, irrespective of occurrences of the storm events on pesticide application day. This can

result in the greater amounts of pesticide losses for the higher soluble pesticides.

In NAPRA model runs for the Indiana White River basin (Lim and Engel, 2004), model limitations were discussed to explain the mismatches of model results with the measured data. To improve the NAPRA predictive ability (Lim and Engel, 2004). Thus, it would be desirable to use long-term pesticide and nutrient data taken at spatially and temporarily unbiased location and time for the evaluation of the model predicted result (Lim and Engel, 2004).

III. METHODOLOGY

The sensitivities of root zone depth, timing of pesticide application, nutrient application rate, and tillage operations on NAPRA predicted results were investigated in this study.

1. Sensitivity Analysis of Root Zone Depth

To estimate the effects of root zone depth on model results, the NAPRA WWW system was run with root zone depth from 66.04 cm (26 inches) to 86.36 cm (34 inches) with state average atrazine and chlorpyrifos pesticide application - no county level pesticide application rate is available - and county specific nutrients application rates. The predicted runoff, percolation, pesticide losses, and nutrient losses were compared.

2. Sensitivity Analysis of Pesticide Application Timing

To examine the effects of precipitation near pesticide application on pesticide losses, precipitation scenarios were prepared as described in Table 1, and NAPRA WWW was run for Decatur County, Indiana. It was assumed that

Table 1. Fifteen precipitation scenarios considered

Scenario	Precipitation	Scenario	Precipitation
30000	7.62 cm (3 in.) of Precip. on April 30	02100	5.08 cm (2 in.) on May 1 and 2.54 cm (1 in.) on May 2
03000	7.62 cm (3 in.) of Precip. on May 1	01200	2.54 cm (1 in.) on May 1 and 5.08 cm (2 in.) on May 2
21000	5.08 cm (2 in.) on April 30 and 2.54 cm (1 in.) on May 1	00120	2.54 cm (1 in.) on May 2 and 5.08 cm (2 in.) on May 3
12000	2.54 cm (1 in.) on April 30 and 7.62 cm (2 in.) on May 1	00210	5.08 cm (2 in.) on May 2 and 2.54 cm (1 in.) on May 3
11100	2.54 cm (1 in.) on April 30, May 1, May 2	00300	7.62 cm (3 in.) of Precip. on May 2
20100	7.62 cm (2 in.) on April 30 and 2.54 cm (1 in.) on May 2	00030	7.62 cm (3 in.) of Precip. on May 3
10200	2.54 cm (1 in.) on April 30 and 5.08 cm (2 in.) on May 2	00003	7.62 cm (3 in.) of Precip. on May 4
11010	2.54 cm (1 in.) on April 30, May 1, May 3		

no precipitation occurred other than on April 30, May 1, May 2, May 3, and May 4 every year, and atrazine was applied on May 2. The scenario "30000" indicates 7.62 cm (3 inches) of precipitation on April 30 and no precipitation on other days, and the code "01200" means 2.54 cm (1 inch) of precipitation on May 1 and 5.08 cm (2 inches) of precipitation on May 2. In these NAPRA runs with continuous corn and fall chisel/spring disk tillage operations, 1.51 kg/ha (1.35 lb/ac) of atrazine was surface applied to NASIS soil "IN031AvA Avonburg" in Decatur County on May 2. The predicted runoff and atrazine losses were compared.

3. Sensitivity Analysis of Nutrient Application Rate

Nitrogen applications, varying from 56 kg/ha to 560 kg/ha, were simulated with 56 kg/ha (50 lb/ac) increments. Commercial fertilizer "16-20-0" (16% of N and 20% of P) was surface applied on May 18 and liquid swine manure (3.9 kg/1000

liter of N and 3.2 kg/1000 liter of P) was applied on May 9. The NAPRA WWW with a continuous corn and fall chisel/spring disk was run for NASIS soil "IN031AvA - Avonburg" in Decatur County. Table 2 shows the fertilizer and manure applications simulated.

4. Sensitivity Analysis of Tillage Operations

The effects of no tillage, conservation tillage, and conventional tillage on the predicted pesticide losses and nutrient losses in surface water and sediment were investigated. Continuous corn was simulated for no tillage, conservation tillage with spring disk, and conventional tillage with fall chisel/spring disk tillage operations. On May 19, atrazine was surface applied at 1.51 kg/ha (1.35 lb/ac) and 379.7 kg/ha (339 lb/ac) of anhydrous ammonia, 192.6 kg/ha (172 lb/ac) of superphosphate, and 39,675 l/ha (4243 gal/ac) of liquid swine manure in spring and fall to the NASIS soil "IN031AvA Avonburg".

Table 2. The amount of nutrients used in sensitivity test

Nitrogen (lbs/ac)		Amount Applied	N (kg/ha)	Total N (kg/ha)	P in P ₂ O ₅ (kg/ha)	Total P (kg/ha)
56 kg/ha of N	16 20 0 (kg/ha)	198.5	31.75	56	39.65	59.2
	Swine Liquid (liter/ha)	6168.4	24.25		19.49	
112 kg/ha of N	16 20 0 (kg/ha)	396.9	63.50	112	79.41	118.4
	Swine Liquid (liter/ha)	12336.7	48.50		38.98	
168 kg/ha of N	16 20 0 (kg/ha)	590.8	94.53	168	118.16	177.3
	Swine Liquid (liter/ha)	18692.0	73.47		59.14	
224 kg/ha of N	16 20 0 (kg/ha)	793.9	127.02	224	158.82	236.9
	Swine Liquid (liter/ha)	24673.4	96.98		78.06	
280 kg/ha of N	16 20 0 (kg/ha)	992.3	158.77	280	198.46	296.0
	Swine Liquid (liter/ha)	30841.8	121.23		97.55	
336 kg/ha of N	16 20 0 (kg/ha)	1181.6	189.95	336	236.32	354.6
	Swine Liquid (liter/ha)	37384.0	146.94		118.27	
392 kg/ha of N	16 20 0 (kg/ha)	1384.7	221.55	392	276.98	414.2
	Swine Liquid (liter/ha)	43365.4	170.45		137.20	
560 kg/ha of N	16 20 0 (kg/ha)	1975.5	316.97	560	395.14	591.5
	Swine Liquid (liter/ha)	7436.8	243.92		196.34	

IV. RESULTS AND DISCUSSION

1. Sensitivity Analysis of Root Zone Depth

The predicted pesticide losses and nutrient losses in runoff and shallow groundwater for each root zone depth are shown in Table 3. Estimated runoff increases very slightly and percolation decreases with increased root zone depth. Similar trends were observed for the pesticides and nutrients in runoff and percolation. Figure 1 shows the percentage increases of runoff, percolation, pesticide losses, and nutrient losses in runoff and percolation compared to a 76.2 cm (30 in) root zone depth with respect to different root zone depths. The magnitude of atrazine and chlorpyrifos increases in runoff differs. This can be explained in that the organic carbon adsorption coefficient (K_{oc}) value of atrazine is 100 ml/g and

that for chlorpyrifos is 6,070 ml/g. The K_{oc} represents how tightly pesticides are adsorbed to soil particles. The higher the K_{oc} value is, the stronger the tendency to attach to and move with the soil. Pesticide K_{oc} values greater than 1,000 indicate strong adsorption to soil, while pesticides with lower K_{oc} values, less than 500, tend to move more with water than adsorbed to sediment. Thus, atrazine is highly soluble and chlorpyrifos is less soluble and easily adsorbed to sediment. This is the why the percentage of atrazine increase in runoff is higher than that of chlorpyrifos. The estimated chlorpyrifos in sediment is higher than atrazine in sediment for all root zone depths examined (66.04 cm ~ 86.36 cm). The model predicted chlorpyrifos and PO₄ in percolation are 0 in all cases. This is because chlorpyrifos and PO₄ are easily adsorbed to the soil particles and do not move with the percolated water.

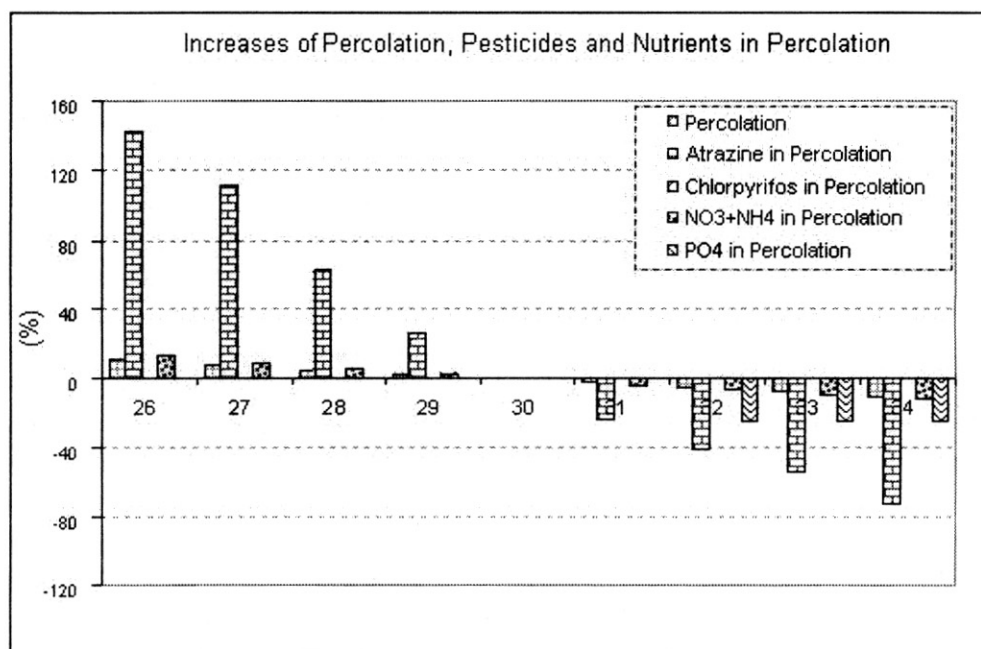
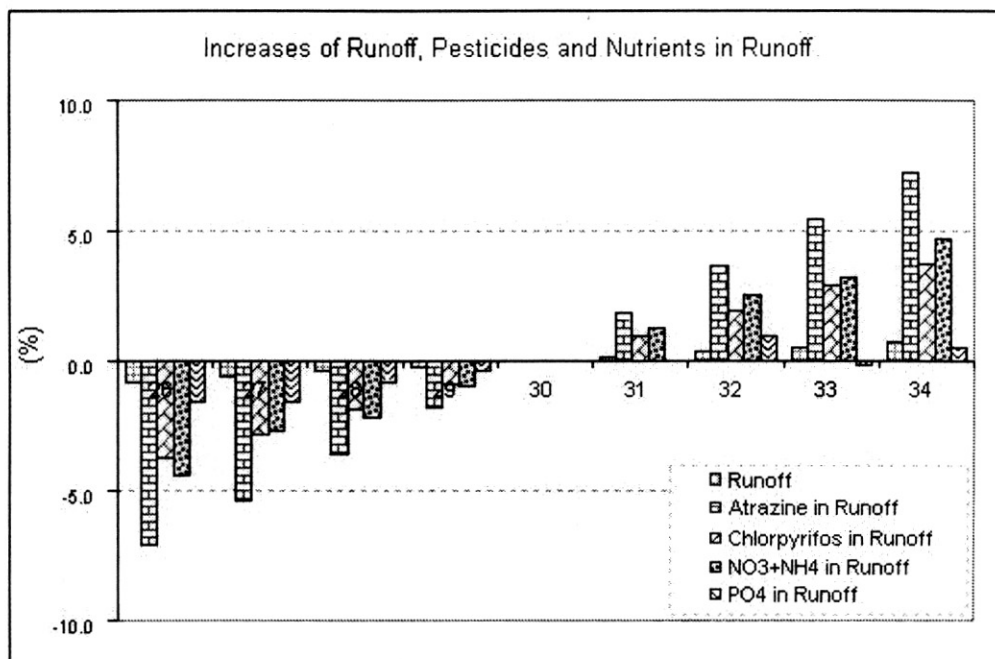


Fig. 1. The percentage of runoff, percolation, and pesticides and nutrients in runoff and percolation increases compared to those with 30 inch root zone depth.

Table 3. Pesticides and nutrient loss masses for each root zone depth

(Unit: g/ha for pesticides, and kg/ha for nutrients)

Root Depth (cm)	66.04	68.58	71.12	73.66	76.2	78.74	81.28	83.82	86.36
Runoff (cm)	22.45	22.50	22.53	22.58	22.63	22.66	22.71	22.76	22.78
Percolation (cm)	13.74	13.39	13.06	12.73	12.40	12.04	11.71	11.40	11.07
Atrazine in Runoff	12.02	12.24	12.47	12.70	12.93	13.17	13.40	13.63	13.87
Atrazine in Percolation	1.02	0.89	0.69	0.53	0.42	0.32	0.25	0.19	0.12
Chlorpyrifos in Runoff	7.60	7.67	7.75	7.82	7.90	7.97	8.05	8.12	8.19
Chlorpyrifos in Percolation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NO ₃ plus NH ₄ in Runoff	18.80	19.14	19.24	19.48	19.68	19.92	20.16	20.30	20.60
PO ₄ in Runoff	2.73	2.73	2.75	2.76	2.77	2.77	2.80	2.77	2.79
NO ₃ +NH ₄ in Percolation	101.00	97.10	94.42	91.63	88.81	85.13	82.48	79.93	77.78
PO ₄ in Percolation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 4. Annual average runoff and atrazine in runoff for precipitation described in table 1

Scenario	Annual Average Runoff (cm)	Atrazine in Runoff (g/ha)	Scenario	Annual Average Runoff (in)	Atrazine in Runoff (g/ha)
30000	1.85	0.607	02100	0.81	18.608
03000	1.85	0.600	01200	1.08	50.966
21000	0.81	0.419	00120	1.08	17.267
12000	1.08	0.273	00210	0.81	27.013
11100	0.30	19.188	00300	1.85	39.396
20100	0.81	18.226	00030	1.85	38.942
10200	1.08	50.701	00003	1.85	38.050
11010	0.30	18.553			

As shown in Table 3 and Figure 1, more runoff and pollutants in runoff are predicted with magnitude of percentage increases are greater for percolation and pollutants in percolation. Atrazine in percolation is the most sensitive to the root zone depth. Inaccuracies in defining the root zone depth could account for some of the differences/mismatches in model evaluation either surface or subsurface water qualities.

2. Sensitivity Analysis of Pesticide Application Timing

The annual average runoff and atrazine loss in runoff are shown in Table 4 for the precipitation in Table 1. As shown in Table 4, the timing of pesticide applications affects the pesticide loss in runoff. The atrazine loss in runoff was highest

when 5.08 cm (2 inch) of precipitation occurred on May 2 with 2.54 cm (1 inch) of precipitation on a previous day, such as cases with scenarios "10200" or "01200". The atrazine loss in runoff with a scenario "10200" or "01200" is bigger than that with "00300". This is because the antecedent soil moisture is higher due to 2.54 cm (1 inch) of precipitation when 2.54 cm (2 inches) of precipitation occur on May 2. The runoff amounts and atrazine loss generated from rainfall events were investigated. Table 5 shows more detailed runoff and atrazine loss from three

precipitation scenarios. More runoff and atrazine loss were generated from the 5.08 cm (2 inches) of precipitation on May 2 in the case of "01200" than in the case of "10200". This is because the antecedent soil moisture is higher when 5.08 cm (2 inches) of precipitation occurs on May 2 in "01200". Although 1.95 cm (0.76 in) of runoff was generated from the 7.62 cm (3 inches) of precipitation that occurred on May 3, the atrazine loading in runoff was smaller than that for "10200" or "01200".

To explore the effects of additional precipitation

Table 5. Runoff and atrazine loading in runoff for each storm event

Scenario	Storm Event	Runoff	Atrazine Loading in Runoff
10200	2.54 cm (1 in.) of Precip. on April 30 5.08 cm (2 in.) of Precip. on May 2	0.02 cm (0.008 in) 1.11 cm (0.437 in)	0.0296 g/ha 56.3269 g/ha
01200	2.54 cm (1 in.) of Precip. on May 1 5.08 cm (2 in.) of Precip. on May 2	0.02 cm (0.008 in) 1.14 cm (0.449 in)	0.0291 g/ha 57.8991 g/ha
00030	7.62 cm (3 in.) of Precip. on May 3	1.95 cm (0.768 in)	44.9196 g/ha

Table 6. Atrazine losses in runoff in the first simulation year

Scenario	Storm Event	Atrazine Losses in Runoff (g/ha)
10000200	2.54 cm (1 in.) of Precip. on April 27 5.08 cm (2 in.) of Precip. on May 2	52.4121
1000200	2.54 cm (1 in.) of Precip. on April 28 5.08 cm (2 in.) of Precip. on May 2	53.3774
100200	2.54 cm (1 in.) of Precip. on April 29 5.08 cm (2 in.) of Precip. on May 2	54.3724
10200	2.54 cm (1 in.) of Precip. on April 30 5.08 cm (2 in.) of Precip. on May 2	55.4106
01200	2.54 cm (1 in.) of Precip. on May 1 5.08 cm (2 in.) of Precip. on May 2	56.4969
00300	7.62 cm (3 in.) of Precip. on May 2	43.6228
00210	5.08 cm (2 in.) of Precip. on May 2 2.54 cm (1 in.) of Precip. on May 3	30.2441
00201	5.08 cm (2 in.) of Precip. on May 2 2.54 cm (1 in.) of Precip. on May 4	30.2033

scenarios, more precipitation data were prepared as shown in Table 6. When there is 2.54 cm (1 inch) of precipitation before the pesticide application on May 2, the atrazine losses in runoff

are higher than in the case of "00300". Because of the antecedent soil moisture, more atrazine is lost with the runoff generated with 5.08 cm (2 inches) of precipitation on May 2. The least soluble

pesticide considered was chlorpyrifos having a K_{oc} value of 6070 ml/g (highly adsorbed to organic matter) and water solubility of 0.4 mg/l. The predicted pesticide loss in runoff and with sediment was the highest with the scenario “00300”. The predicted chlorpyrifos loss in runoff and sediment are shown in Table 7.

The pesticide losses in runoff vary with precipitation scenarios. For the most soluble pesticide, the highest pesticide loss occurred with some precedent precipitation before the application to the field followed by additional precipitation on or following the date of application. For the least soluble pesticide, the highest pesticide loss occurred when there is precipitation on the same day the pesticide is applied. Therefore, the pesticide losses are dependent on the pesticide properties.

Figure 2 shows atrazine in runoff with precipitation scenarios described in Table 1. Figure 2 shows that the timing of pesticide application is important. Pesticides are generally not applied when soil moisture content is too high or it rains. However, the NAPRA WWW system does not adjust the timing of pesticide application based on previous rainfall, and it is not feasible to

find the “best” day to apply pesticides because there might be another rainfall if the timing of pesticide application is postponed. Figure 2 indicates that there is no distinct difference in the amount of pesticide washed away with 7.62 cm (3 inches) of precipitation on May 3 (the case of “00030”) and May 8 (the case of “000000003” – precipitation occurs 6 days after the pesticide application on May 2). If the timing of pesticide application is postponed by several days based on the amount of previous precipitation, the amount of pesticide in runoff will become smaller until the next precipitation occurs. However, the amount of pesticide washed away on a yearly basis doesn’t change too much, because the time interval between the pesticide application date and the next precipitation becomes smaller and can increase chances that the pesticide applied on the postponed date will be washed away with the precipitation.

The pesticide application date can be modified based on the occurrence of precipitation in the pesticide parameter file when the NAPRA WWW is applied to a small field for a couple of years. However, the pesticide application date cannot be modified in the NAPRA WWW system, because

Table 7. Chlorpyrifos losses in runoff and sediment in the first simulation year

Scenario	Storm Event	Chlorpyrifos Losses in Runoff (g/ha)	Chlorpyrifos Losses in Sediment (g/ha)
10200	1 inch of Precip. on April 30 2 inches of Precip. on May 2	13.84	2.48
01200	1 inch of Precip. on May 1 2 inches of Precip. on May 2	14.07	2.48
00300	3 inches of Precip. on May 2	23.72	5.02
00210	2 inches of Precip. on May 2 1 inch of Precip. on May 3	10.75	2.54
00201	2 inches of Precip. on May 2 1 inch of Precip. on May 4	10.68	2.53

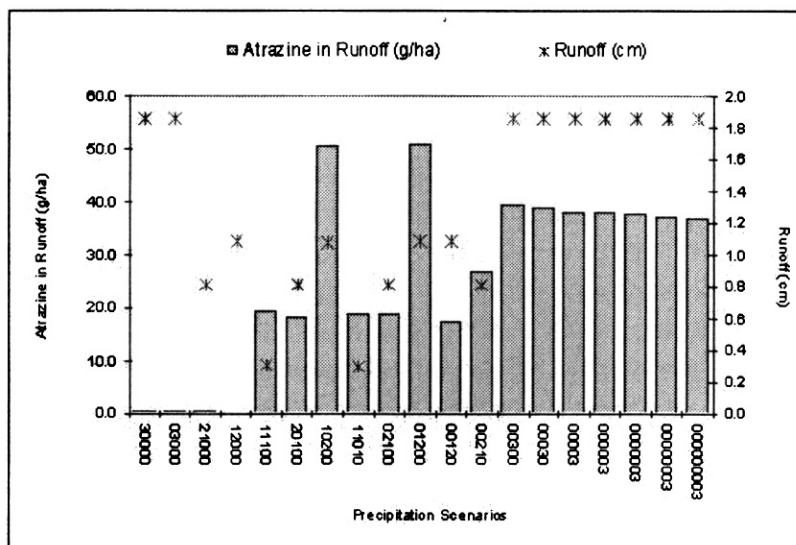


Fig. 2. Atrazine in Runoff with Precipitation Scenarios Described in Table 3 and Atrazine Application on May 2

Table 8. NAPRA predicted average annual nutrients in surface water

Nitrogen Application Rate (lb/ac)	NO ₃ +NH ₄ in Runoff (kg/ha)	NH ₄ in Sediment (kg/ha)	PO ₄ in Runoff (kg/ha)	PO ₄ in Sediment (kg/ha)
56 kg/ha (50 lb/ac)	5.836	0.570	3.796	2.249
112 kg/ha (100 lb/ac)	6.673	1.067	7.037	2.386
168 kg/ha (150 lb/ac)	7.827	1.553	10.214	2.519
224 kg/ha (200 lb/ac)	9.017	2.067	13.590	2.667
280 kg/ha (250 lb/ac)	9.965	2.571	16.913	2.773
336 kg/ha (300 lb/ac)	10.586	3.051	20.076	2.833

NAPRA WWW uses long-term daily precipitation data and uses the same hydrology, erosion, pesticides, and nutrient parameter files for the entire simulation periods. Thus, it is expected that the NAPRA WWW predicted pesticide losses are greater than the measured pesticide losses with the current timing of pesticide application approach. If the distributions of pesticide application date are obtained for each county, the sum of the NAPRA WWW predicted pesticide loss multiplied by the probability of each date of pesticide application can represent pesticide loss in each soil within the county.

3. Sensitivity Analysis of Nutrient Application Rate

With the nutrient information, the NAPRA WWW was run, and its predicted values of average annual nutrients in runoff are listed in Table 8. The amount of nitrogen in runoff and phosphorus in sediment are proportional to the amount of nutrients applied to the field as shown in Table 8.

Figure 3 shows the linear relationship between nutrient values lost in runoff and the amount of nutrients applied to the field. Figure 4 shows the

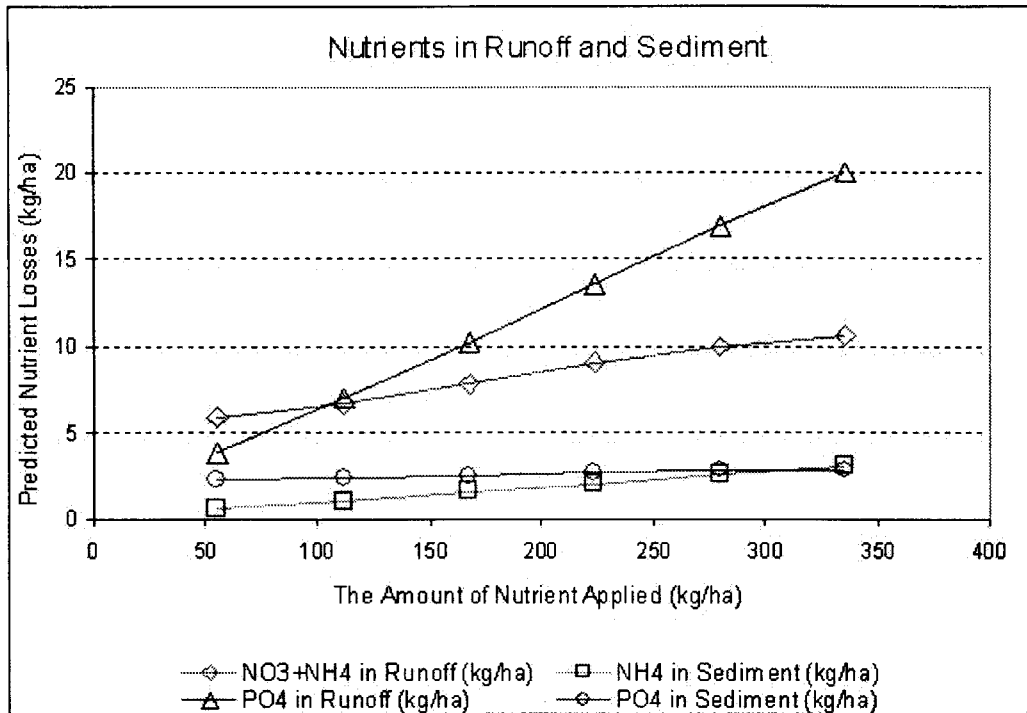


Fig. 3. Sensitivity analysis of the amount of nutrient applied.

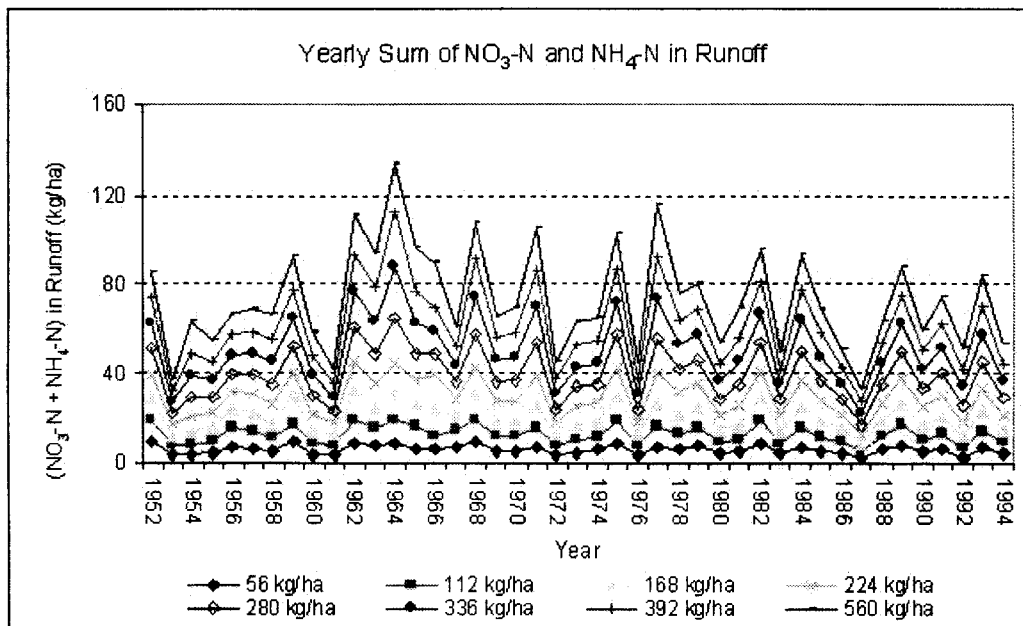


Fig. 4. Predicted yearly nutrient values in runoff with different amounts of nutrients applied for 1952 to 1994 simulation period.

yearly predicted average nutrient values lost in runoff for each year with different amounts of nutrient. For most of the simulation period, the predicted values are proportional with the amount of nutrients applied.

Although nitrogen uptake by crops decreases as a percentage of nitrogen applied as more nitrogen is applied to the field, nitrogen losses to groundwater and losses to the air through denitrification increase (Figure 5). Also, the rate of mineralization of organic matter decreases at higher nutrient levels. This can explain why nitrogen losses in surface water are proportional to the amount of nutrients applied to the field.

Figure 6 shows the predicted phosphorus losses with different amounts of phosphorus applied. The differences between the increasing rate of phosphorus uptake and mineralization of organic phosphorus are negligible. Based on the sensitivity analysis of nitrogen and phosphorus losses in runoff, it is reasonable to assume county level

nutrient application values for each county are uniformly applied to fields.

4. Sensitivity Analysis of Tillage Operations

As shown in Figure 7, atrazine and nutrient loadings in runoff with conventional tillage are higher than those with conservation tillage. However, predicted pesticide and nutrient values with no tillage are higher than those with conservation tillage. This can be explained in that the soil is not disturbed because no tillage was performed in this case. Thus, most pesticides and nutrients applied to the surface stayed on the surface and were more easily washed away with runoff. There were some differences in the NAPRA WWS predicted results with no tillage, conservation tillage, and conventional tillage. Therefore, the NAPRA WWS needs to be run considering tillage information for each county.

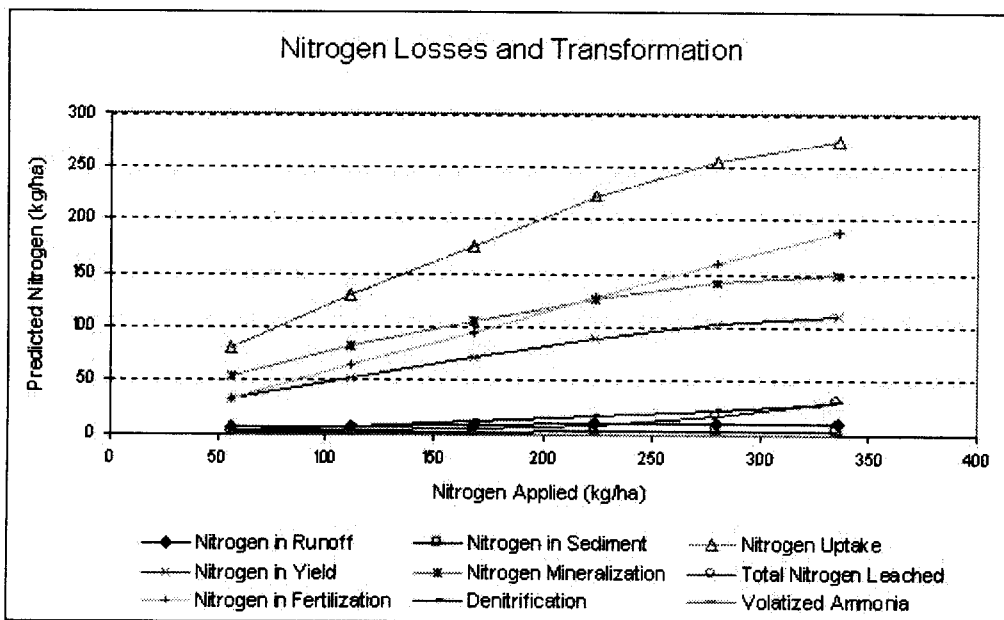


Fig. 5. Nitrogen losses and transformations.

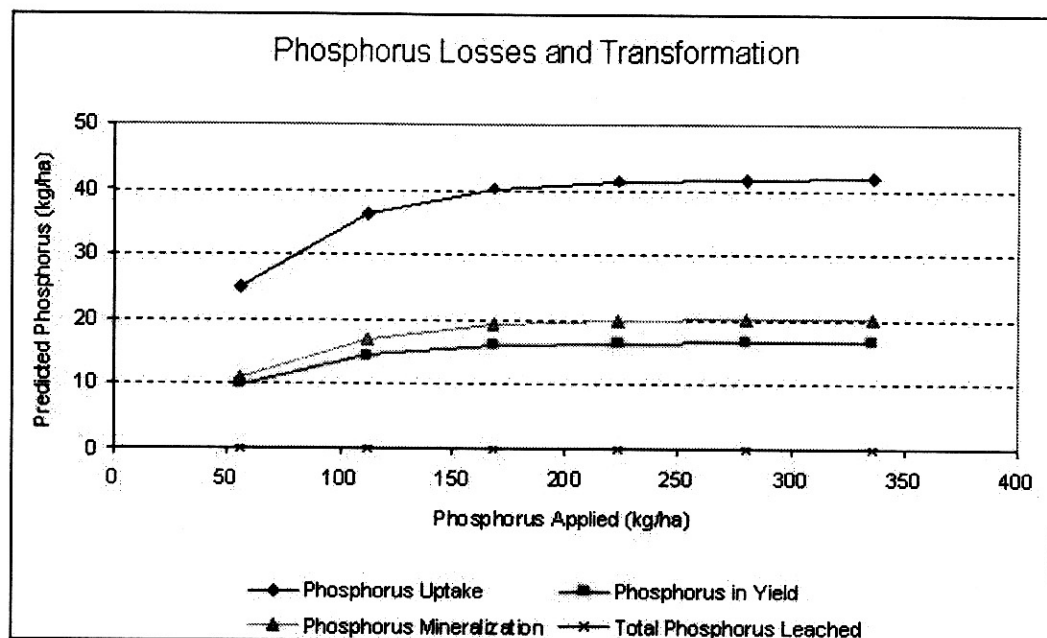


Fig. 6. Phosphorus Losses and Transformations.

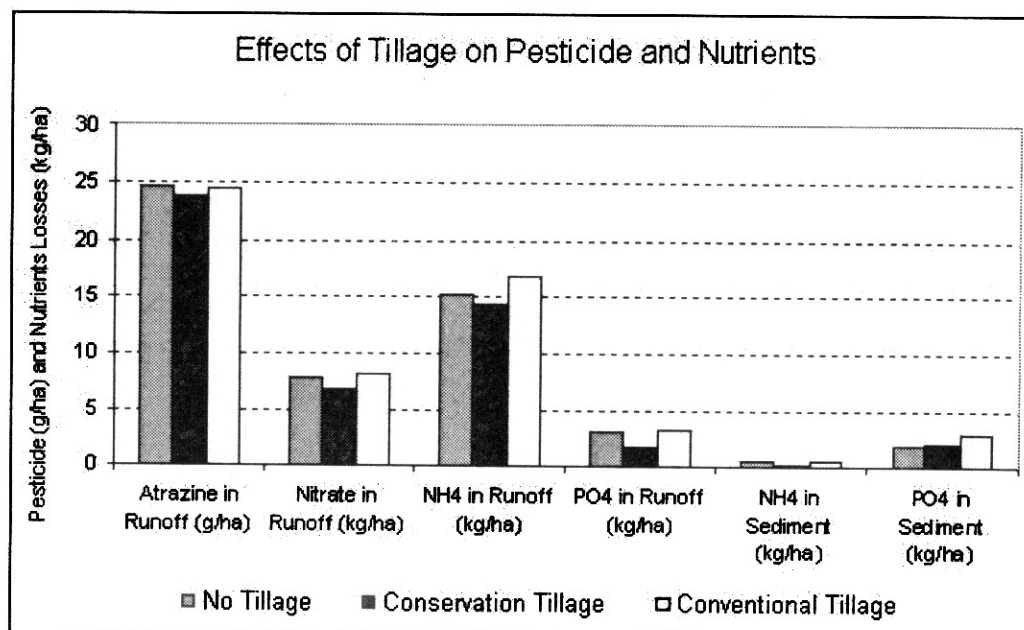


Fig. 7. NAPRA WWW predicted pesticide and nutrient losses with no tillage, conservation tillage, and conventional tillage.

V. CONCLUSIONS

The sensitivities of root zone depth, timing of pesticide application, nutrient application rate, and tillage operations to the NAPRA predicted values were investigated in this study. The assumption that these input parameters are the same throughout long simulation periods needs to be modified if possible, although the current version of the NAPRA WWW doesn't allow this.

The correct definition of root zone depth is essential in model evaluation, although many model users select the default value of root zone depth in NAPRA input interface. Although there are differences in magnitude of changes of hydrology, pesticides, and nutrients with different root zone depth, the root zone depth is a very sensitive factor in modeling of hydrology, and pesticide and nutrient losses.

Although farmers won't apply pesticides to the field when it rains or soil moisture is too high, the user specified pesticide application date in the input interface is used throughout the NAPRA simulation period, irrespective of rainfall patterns. As found in this study, the timing of pesticide application on days with rain or high soil moisture in NAPRA is responsible for greater pesticide losses in the predicted results.

The county specific nutrient application rate values were used in the study by Lim and Engel (2004) due to the lack of detailed information where these nutrients are applied spatially. Some of the study watersheds considered in the study by Lim and Engel (2004) are smaller than a county, so county specific nutrients may not be appropriate. Linear relationships were found for the predicted nutrients values with different amounts of nutrients applied. This indicates that the assumptions of uniform nutrients application based on county average nutrient rate are reasonable, although more detailed spatial

information on application is necessary for improved model predictions.

Different tillage operations affect the predicted atrazine and nutrient losses in runoff and sediment, although its magnitude is not that great. Thus, it may be reasonable to run NAPRA with information about the percentages of the three different tillage systems for each county.

The sensitivity analyses indicate that the input parameters considered in this study are sensitive factors influencing the NAPRA predicted results. The correct estimation of root zone depth, the use of site-specific nutrient application rates, the modification of NAPRA to enable the different management practice during the simulation period are needed for a better model prediction. In NAPRA model runs over the study watersheds, many spatially variable information, such as soil, land uses, cropping, tillage, precipitation, temperature, pesticide and nutrient application rate, the percentage of drainage system, were used although there are many changes in these parameters over the simulation period. Thus, the sensitivity analyses of temporal changes of some of these parameters need to be investigated because the model predicted values are compared with the historic measured data in model evaluation.

VI. REFERENCES

- Eck, K.J., P. R. Hill, and J. R. Wilcox. 1994. Estimating Corn and Soybean Residue Cover. Cooperative Extension Service, Purdue University, West Lafayette, Indiana.
- Baker, D. B., and R. P. Richards. 1990. Transport of Soluble Pesticides Through Drainage Networks in Large Agricultural River Basins. In. Long Range Transport of Pesticides. 241-270. Chelsea. Michigan. Lewis Pub.
- Brichford, S. L., B. C., Joern, and F. Whitford.

1993. Agriculture's Effect on Environmental Quality: Key Management Issues. Cooperative Extension Service, Purdue University and USDA.
- Engel, B. A., and J. Lee. 1998. WWW Based Hydrologic/Water Quality Modeling Decision Support System. In: Seventh International Conference on Computers in Agriculture. F. Zazueta and J. Xin(eds.), St. Joseph, Michigan, 359-367.
- Knisel, W. G., and F. M. Davis. 1999. GLEAMS Version 3.0 Manual.
- Knisel, W. G., R. A. Leonard, and F. M. Davis. 1992. GLEAMS Version 2.10 Manual. USDA ARS, Grassland, Soil & Water Lab. Temple, Texas.
- Lim, K. J., and B. A. Engel. 2003. Extension and Enhancement of National Agricultural Pesticide Risk Analysis (NAPRA) WWW Decision Support System to Include Nutrients. *Computers and Electronics in Agriculture*. 38(3): 227-236.
- Lim, K. J., and B. A. Engel. 2004. NAPRA WWW Decision Support System with Instream Modeling Capability. In Revision for Agricultural Systems.
- Lim, K. J., and B. A. Engel. 1998. An Extension of the National Agricultural Pesticide Risk Analysis (NAPRA) Approach to Include Nutrients. ASAE Paper No. 98-3188, American Society of Agricultural Engineering, Orlando, Florida.
- Lim, K. J., and B. A. Engel. 1999. Evolution and Evaluation of Nutrient Enabled NAPRA WWW Decision Support System. ASAE Paper No. 99-2151, Toronto, Ontario, Canada.
- Lim, K. J., and B. A. Engel. 2000. Evolution and Evaluation of Nutrient Enabled NAPRA WWW Decision Support System with GLEAMS 3.0. ASAE Paper No. 00-2173, American Society of Agricultural Engineering, Milwaukee, Wisconsin.
- Lim, K. J., B. A. Engel, Y. Kim, B. Bhaduri, and J. Harbor. 1999. Development of the Long Term Hydrologic Impact Assessment (LTHIA) WWW Systems. ASAE Paper No. 99-2009, Toronto, Ontario, Canada.