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Evaluation of Erosion Productivity Impact Calculator (EPIC) Model for Nitrogen Losses in Rice Paddy of Thailand

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ABSTRACT

Rice fields are commonly characterized by flooding conditions and high percolation rate. Nitrogen (N) is the most important nutrient for rice yield and is required in large quantities. In this article, the Erosion Productivity Impact Calculator (EPIC) 0509 version was used and was run using i-EPIC (interactive EPIC) interface, to validate this version and evaluate N losses in mineral rice soils. The results indicated that N losses of rice soil in terms of N loss in sediment, nitrate (NO_3) loss via runoff, NO_3 loss in subsurface and NO_3 leaching. The results revealed that the northern region of Thailand had the maximum average of 9.58 kg ha^{-1} during the major rice season, followed by the central, eastern, western, northeastern and southern regions, respectively. In the second rice season, NO_3 loss in the western region had the maximum average of 25.52 kg ha^{-1}, followed by the northern, central, eastern, northeastern and southern regions, respectively. In terms of N pool (humus mineralization, slow humus N pool, passive humus N pool, total N pool) the eastern region had the maximum average of 4,475.33 kg ha^{-1} during the major rice season, followed by the central, southern, northern, northeastern and western regions, respectively. Whereas, the second rice season found that the eastern region had also the maximum average of 6,909.03 kg ha^{-1}, followed by the central, southern, northern, northeastern and western regions, respectively. Furthermore, EPIC-simulated hydrology found that precipitation, runoff, percolation and soil temperature share a positive relationship with major rice yield.

Key words: Nitrogen losses, nitrogen pool, EPIC model, rice paddy, Thailand

INTRODUCTION

Thailand is an agricultural country and its main economic and well-known export commodity is rice. Rice in Thailand refers to the major rice which is the rice grown during the rainy season between June and December and the second rice which is the rice grown during the dry season between January and April every year. Farmers grow two to three crops of rice in one year. The average yield of second and major rice are about 4,231 and 2,594 kg ha^{-1} (Office of Agricultural Economics, 2012). Nitrogen (N) in soil is a vital nutrient for rice production in the country.

Nitrogen is the most yield-limiting element governing rice production, particularly in mineral rice soils. Mineralization of soil organic N is a key process for the supply of N to the tropical wetland rice (Manguiat *et al*., 1996). N mineralization means a process in which N turns into inorganic N (NO_3-N and NH_4-N) from organic N with the help of soil, animals and microorganisms (Yang and

Fan, 2003). Inorganic N is the main type of soil N that can be directly absorbed and utilized by plants, but only accounting to 1% in the total soil N (Das *et al*., 1997). The N mineralization rate determines the availability of N for the plant growth. N losses from the flooded soils occur via several pathways such as denitrification, ammonia volatilization, leaching and surface runoff. Freney *et al*. (1990) reported that the significant fertilizer-N losses from the irrigated flooded rice fields are usually attributed to ammonia volatilization and denitrification. Many studies showed that even in a field that has sufficient applied N fertilizer, uptake of N by rice through the mineralization of organic N well exceeds because of fertilizer (Kyuma, 2004). A study conducted by Koyama *et al*. (1973) in Thailand showed that more than 60% of total N taken up by rice plants by the time of harvest came from mineralization of soil organic N.

The Erosion Productivity Impact Calculator (EPIC) model (Willams, 1990) has been previously used as a manure management tool (Ramanarayanan *et al*., 1997; Edwards *et al*., 1994). EPIC model has been performed and applied in the U.S. and nationwide with widely environmental management conditions such as evaluation of sediment and nutrient losses, tillage systems, crop rotations and fertilizer rates (Phillips *et al*., 1993; King *et al*., 1996), nutrient losses from livestock manure applications (Edwards *et al*., 1994; Pierson *et al*., 2001), nitrate-nitrogen (NO_3-N) losses via subsurface tile drainage (Chung *et al*., 2001, 2002) and nutrient cycling as a function of cropping system (Cavero *et al*., 1998; Bernardos *et al*., 2001); EPIC also simulates N transformations in the soil, plant and water matrix. N can be lost to surface water by runoff and erosion and can percolate to groundwater depending upon rate of water flow through soil profile. More details on the model can be found by Willams (1990).

EPIC has also been used in studies related to NO_3-N, an important component of water quality (Phillips *et al*., 1993). The soil N balance in EPIC is dependent on the soil water and soil temperature routines. Thus, improvements in these routines should improve estimates of N balance. Bouzaher *et al*. (1993) suggested that the crop residue decomposition routine require changes to improve the N balance simulation. Within this context, accurate estimation of organic Carbon (C) is a requirement because it is a component of the N balance in EPIC. The aims of this study are to validate the i-EPIC model version 0509 and appraise rice yield and N losses in rice paddy.

MATERIALS AND METHODS

EPIC model: In the early 1980s, EPIC, also known as the Environmental Policy Integrated Climate was created by teams of scientists of the U.S. Department of Agriculture, belonging to the following services: Agriculture Research Service (ARS), Soil Conservation Service (SCS) and Economic Research Service (ERS) (Sharpley and Williams, 1990). EPIC was designed to simulate biophysical processes and the interaction of cropping systems over long periods of time, during which changes in the environment occur at a relatively slow rate. A wide range of soils, climates and crops can be simulated, using predefined management practices, in an efficient and convenient manner (Smith, 1997).

EPIC is able to simulate processes such as weather, soil erosion, hydrological and nutrient cycling, tillage, crop management and growth/yield. Crop growth is calculated on a daily basis with the required weather inputs, precipitation, maximum and minimum daily temperature, solar radiation and wind speed as well as numerous crop parameters such as morphology, phenology, physiology etc., (Gassman *et al*., 2003, 2005; Zhang *et al*., 2010; Rinaldi and De Luca, 2012). The crop growth routine calculates the potential daily photosynthetic production of biomass which is decreased by stresses caused by shortages of radiation, water and nutrients, temperature extremes and inadequate soil aeration. The value of the most severe stress is used to reduce biomass accumulation, root growth, harvest index and crop yield (Brown *et al.*, 2000; Izaurralde *et al.*, 2006; Rinaldi and De Luca, 2012).

In this study, the EPIC0509 version was used and run using i-EPIC interface. The i-EPIC Model is a program that is linked to the EPIC Model, an upgraded model that provides more accurate analysis (Willams*et al.*, 2006). This model is not only an efficient tool for analyzing a large amount of data, but also displays the results in tables, making it easier to view and analyze. The input information and display of results are accomplished in Microsoft Access software. The i-EPIC model and its user manual can be downloaded from http://www.public.iastate.edu/~tdc/i_epic_main.html.The current EPIC community code can be downloaded from http://epicapex.brc.tamus.edu.

Preparation and data collection: Essential data and information for i-EPIC Model include:

- **Soil data:** From the survey of soil nutrient status in Thailand during 2004-2008, 6,422 soil nutrient test results (pH, organic matter content, available phosphorus and available potassium contents) were collected in the laboratory of the Office of Science for Land Development, Land Development Department
- **Weather data:** Monthly weather data was obtained from the Thai Meteorological Department for the period 1988-2007. i-EPIC requires monthly weather variables such as precipitation, minimum/maximum air temperature, solar radiation, wind speed and relative humidity
- **Crop management:** Conditions required are (1) The land must be tilled and (2) Under biological control of insects and pests. In this research, relevant crop parameters and rotation operation (Table 1 and 2) were modified on the basis of the measured and published data. In

Table 1: Overview about crop parameter values of major and second rice in Thailand

Parameter	Original	Major rice	Second rice
Years until trees are mature	0	0.4	0.4
Potential heat units	158.08	1630	1100
Population(#/m^2)	8.5	250	250
Fertilizers (kg ha^{-1})	134.4	187.5	187.5
Potential ET	Hargreaves	Penman-Montieth	Penman-Montieth
CO_2 concentration (ppm)	350	385	385
Biomass energy ratio (kg ha^{-1} MJ^{-1})	25	25	25
Harvest index	0.5	0.5	0.5
Temperature for growth (minimum)	10	15	15
Temperature for growth (optimal)	25	33	33
Aluminum tolerance	3	3	3

Table 2: Rotation operation of major and second rice in Thailand

	Major rice		Second rice	
Rotation operation	Date	Month	Date	Month
Tillage	1	June (06)	1	January (01)
Planting	15	June (06)	15	January (01)
Fertilizer	1	September (09)	1	February (02)
Harvest	31	December (12)	30	April (04)
Kill	31	December (12)	30	April (04)

the EPIC model, potential evaporation was calculated by the Penman-Monteith method. In addition, the period of plantation used in this research follows the Land Development Department planting calendar. The general chemical fertilizers were 16-20-0 and 46-0-0 which are considered appropriate for rice growth (Department of Agricultural Extension, 2010). Meanwhile, soil losses were computed using the Universal Soil Loss Equation (USLE)

GIS includes: (1) Land utilization of 2007, (2) Digital Elevation Model (DEM), (3) Slope, (4) Sets of soil data in a form of Geographical Information System (GIS) Digital File, (5) Location of 81 weather stations and (6) Simulation Units (SU) (a polygon type of data). In this study, a 0.1×0.1° SU is created and each grid covers an area of 11.11×11.12 km. Because rice production land is emphasized in this study, the researcher separated the rice production area from land used for other purposes by overlapping the Land Utilization data of 2007 provided by the Land Development Department with the developed SU. The selected SU of the study is an overlapping area covering more than 50% of the rice production area which consists of 1219 units.

Data analysis: The SU was developed from the application of GIS combined with a program called ArcGIS 10, resulting in 1219 SUs representing the actual rice yield areas. The 1219 SUs can be divided into different provincial areas as follows: Central areas, 322 SUs; Eastern provincial areas, 29 SUs; Northern provincial areas, 48 SUs; Northeastern provincial areas, 793 SUs; Southern provincial areas, 12 SUs and Western provincial areas, 15 SUs. The calculated rice production from the i-EPIC Model is then compared to Thailand's rice yield data of 2007 to test the model's accuracy. Although, rice land is distributed over much of Thailand (Fig. 1), nearly half of the rice land is located in the northeast interior region, where the majority of the rice fields are rain-fed.

In addition, evaluation of N losses was performed by using the following procedures: (1) EPIC input database files for all SUs, (2) Running the simulations, (3) Extracting the output files and transferring to the database and (4) Analyzing the results.

Model validation and statistical analysis

Model validation: The validation process focused on the rice yield and total N using the observed values of yield that were collected from the Agricultural Statistics of Thailand for years 1996-2011 which were generated by the Office of Agricultural Economics (OAE), Ministry of Agriculture and Cooperatives (MOAC). The observed values of total N were collected from the Land Development Department of Thailand for the 2004-2008 period.

Statistical analysis: A statistical measure was calculated to represent different aspects of model performance. The ability of the model to simulate the variation of yield and total N was examined by comparing Standard Deviations (StDev) of the model simulated yield and Total N with that of observed values. The statistical analysis was implemented using statistical package for the social science (SPSS; IBM, USA):

- Mean relative error:

$$MRE = \sum_{i=1}^{n} \frac{y_i - x_i}{x_i}$$

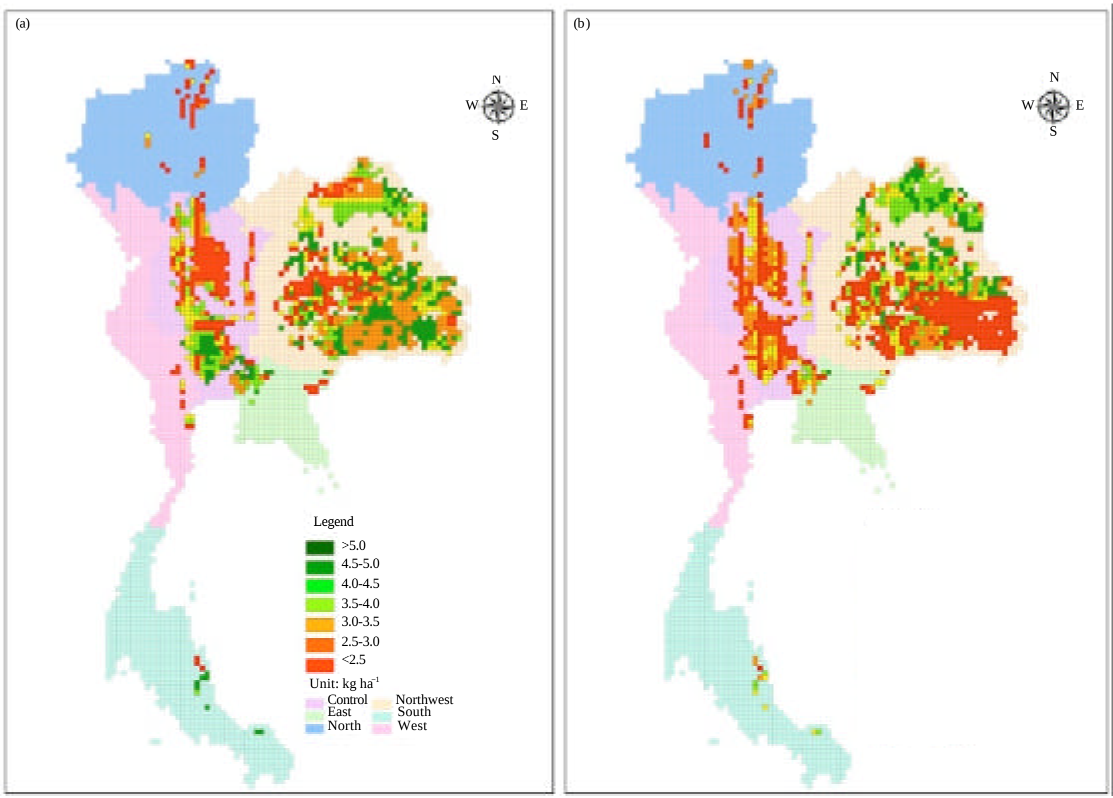

Fig. 1(a-b): Spatial distribution map of simulation unit representing the actual rice yield areas (a) Major rice yield and (b) Second rice yield. Source: Pumijumnong and Arunrat (2012)

- Mean absolute error:

$$\text{MAE} = \sum_{i=1}^{n} | y_i - x_i |$$

- Model efficiency:

$$\text{EF} = \frac{\sum_{i=1}^{n}(x_i - \bar{x})^2 - \sum_{i=1}^{n}(y_i - x_i)^2}{\sum_{i=1}^{n}(x_i - \bar{x})^2}$$

- Root mean square error:

$$\text{RMSE} = \left[\sum_{i=1}^{n}(y_i - x_i)^2\right]^{0}.5 \times \frac{100}{\bar{x}}$$

In these equations, x_i and y_i refer to the observed and predicted values, respectively, $\bar{x}$ refers to the mean of observed values and n signifies the sample No. (n = 1219).

RESULTS AND DISCUSSION

EPIC simulation of N release was in two ways: (1) As crop removal and (2) Losses to the air and water. N contained in the plant material is partitioned between that which is removed from the field with the harvested crop yield and that portion remaining in the residue which is added into the organic pools. N losses include nitrates dissolved in surface runoff, percolation and lateral subsurface flow; organic N attached to wind and waterborne sediment and ammonia and N oxides lost to the atmosphere. N losses in surface water runoff, lateral subsurface flow and percolation are estimated as products of the volume of water and the average concentration of NO_3 in the soil layer.

Validation: The model simulates and gives results for predicted major and second rice production. We then compare between the predicted and observed rice production. The results are as follows: major rice 2.92 and 3.14 ton ha^{-1} and second rice 3.77 and 3.88 ton ha^{-1}, respectively. Based on the statistical analysis, the RMSE (%) of major and second rice production were 6.43 and 3.22%, respectively, as shown in Table 3. The total N comparison shows that the predicted total N average was 0.060%, whereas the observed total N average was 0.058% which gives an RMSE (%) of 5.00%, as shown in Table 4. An important positive slope in the regression line was also observed together with a positive intercept by the linear regression relationship between observed and predicted rice yields (both major and second rice), as shown in Fig. 2 and total N, as shown in Fig. 3. Moreover, comparing among each region of Thailand, a positive slope in the regression line was observed as well (Fig. 4).

Nitrogen loss in soil: Estimation of N losses with EPIC is partially controlled by soil water content through its effect on NO_3-N movement, N mineralization and nitrification. N of rice paddy illustrates that the average N loss in sediment of both major and second rice production during the growing season were 12,175 and 23.974 kg ha^{-1}, respectively, whereas the NO_3 loss via runoff averaged 0.658, 6.632, 0.171 and 0.217 kg ha^{-1} for NO_3 loss in subsurface, 0.855 and 0.953 kg ha^{-1} for NO_3 leaching and 6,682.964 and 7,032.357 kg ha^{-1} for N pool, respectively. In addition, EPIC-simulation found that the humus mineralization averaged 360.789 and 399.367 kg ha^{-1}, slow humus N pool averaged 3,131.461 and 3,306.300 kg ha^{-1} and passive humus N pool averaged 3,410.284 and 3,581.164 kg ha^{-1} during the major rice growing season and the second rice growing season, respectively. When comparing the major and second rice seasons, it was found that the above-mentioned averages for second rice season was higher than major rice season in every region of Thailand.

Table 3: Simulation results of EPIC model error and reliability analysis of rice yield

Parameters	Observed yield average (ton ha^{-1})	Predicted yield average (ton ha^{-1})	MRE (%)	MAE (%)	RMSE (%)	EF (%)
Major rice	3.14	2.92	7.30	0.32	6.43	89.81
Second rice	3.88	3.77	2.89	0.17	3.22	94.28

MRE: Mean relative error, MAE: Mean absolute error, RMSE: Root mean square error and EF: Model efficiency

Table 4: Simulation results of EPIC model error and reliability analysis of total N

Parameters	Observed total N (%)	Predicted total N (%)	MRE (%)	MAE (%)	RMSE (%)	EF (%)
All seasons crop	0.058	0.060	3.45	0.024	5.00	81

MRE: Mean relative error, MAE: Mean absolute error, RMSE: Root mean square error and EF: Model efficiency

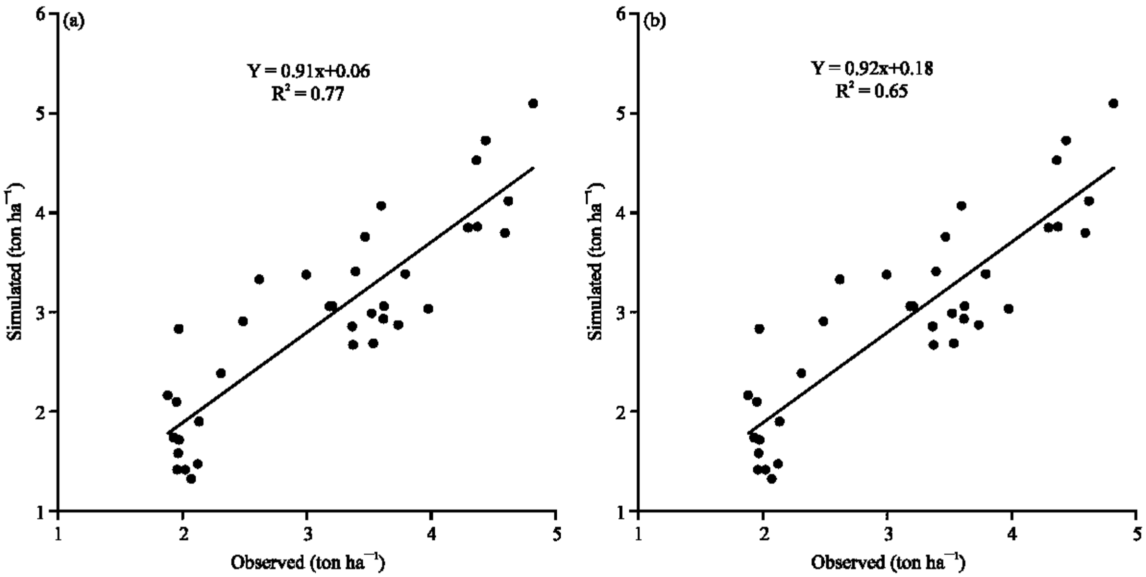

Fig. 2(a-b): Comparison of rice yields between EPIC-simulated and observed for (a) Major rice yield and (b) Second rice yield

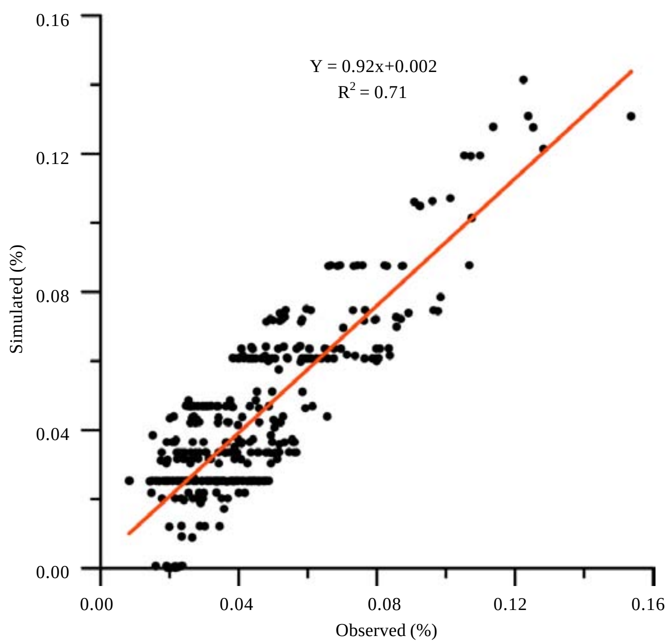

Fig. 3: Comparison of total N between EPIC-simulated and observed in rice paddy of Thailand

As shown in Table 5 the results in the major rice season revealed N loss in sediment, NO_3 loss via runoff, NO_3 loss in subsurface, NO_3 leaching and humus mineralization in descending order were as follows: Northern>central>eastern>western>northeastern>southern. Vice versa the second rice season revealed N loss in sediment, NO_3 loss via runoff, NO_3 loss in subsurface and NO_3 leaching in ascending order were as follows: Southern>northern>eastern>central>northern> western.

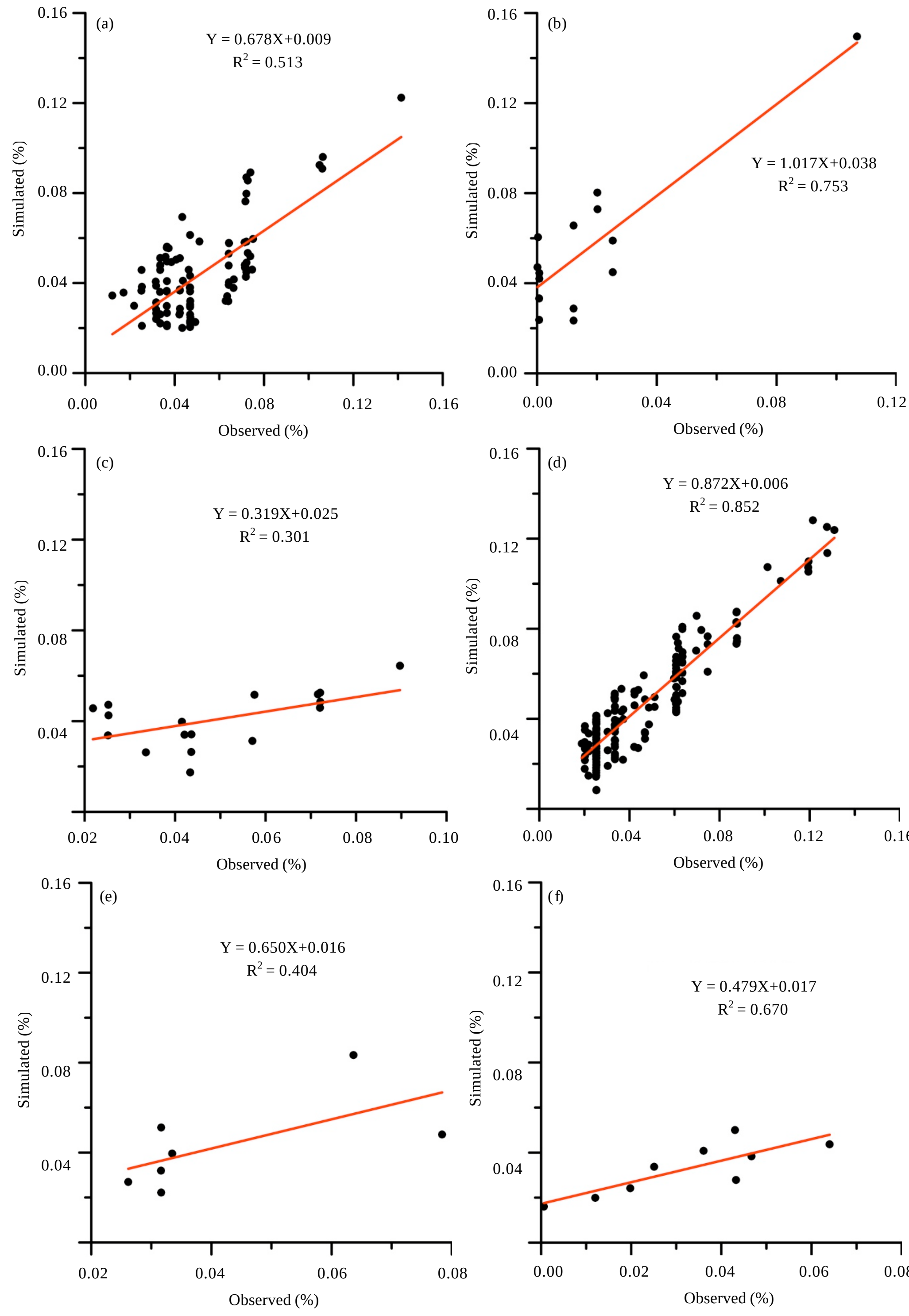

Fig. 4(a-f): Comparison of total N between EPIC-simulated and observed for (a) Central region, (b) Eastern region, (c) Northern region, (d) Northeastern region, (e) Southern region and (f) Western region of Thailand

Table 5: Simulation results of nitrogen loss in the major rice season (kg ha^{-1})

Region	N loss sediment	NO_3 loss runoff	NO_3 loss subsurface	NO_3 leaching	Humus mineralization	Slow humus N pool	Passive humus N pool	Total N pool
Central	23.393	0.643	0.186	1.092	408.185	3,416.525	3,692.739	7,276.661
East	17.570	0.481	0.107	0.287	239.061	4,226.276	4,475.310	8,960.655
North	34.984	0.803	0.265	2.269	458.845	3,357.729	3,685.479	7,190.563
Northeast	1.335	0.770	0.126	0.429	327.428	2,506.269	2,738.106	5,349.858
South	0.000	0.643	0.254	0.516	378.298	3,588.833	3,978.333	7,680.917
West	13.337	0.607	0.091	0.537	352.917	1,693.133	1,891.733	3,639.133

Table 6: Simulation results of nitrogen loss in the second rice season (kg ha^{-1})

Region	N loss sediment	NO_3 loss runoff	NO_3 loss subsurface	NO_3 leaching	Humus mineralization	Slow humus N pool	Passive humus N pool	Total N pool
Central	16.112	5.544	0.169	0.545	388.339	3,593.211	3,864.003	7,629.755
East	1.570	0.548	0.087	0.369	441.211	4,957.655	5,269.069	10,500.379
North	46.972	11.432	0.307	1.528	418.826	3,384.708	3,683.083	7,219.771
Northeast	1.108	0.580	0.088	0.403	330.813	2,581.107	2,804.531	5,489.352
South	0.000	0.717	0.154	0.353	549.363	3,614.917	3,977.833	7,705.083
West	78.081	20.971	0.498	2.522	267.649	1,706.200	1,888.467	3,649.800

The minimum of both NO_3 loss via runoff and NO_3 loss in subsurface were the eastern region, followed by the northeastern, southern, central and northern regions, respectively. The region that had the minimum NO_3 leaching was the southern region, followed by the eastern, northeastern, central and northern regions, respectively. The levels of slow humus N pool, passive humus N pool and total N pool shown in Table 6 in descending order were as follows: Eastern>southern>central>northern>northeastern>western. Vice versa the humus mineralization in descending order were as follows: Southern>eastern>northern>central>northeastern>western.

This study clearly demonstrates both direct and indirect impact on the major factors driving loss processes and limiting crop growth and N uptake. Besides, application of specific nutrients in the form of fertilizer and organic resources can potentially influence soil available N, soil moisture conditions, cation status, or pest and disease dynamics (Vanlauwe *et al*., 2001). N losses from the flooded soils occur by several pathways such as denitrification, ammonia volatilization, leaching and surface runoff. The retention of plant residues or applications of other forms of organic matter to the soil surface can also substantially reduce N loss runoff.

Hydrology in rice paddy: EPIC can be used to simulate hydrology that includes surface runoff, percolation, lateral subsurface flow and evapotranspiration. Nutrient data simulations include NO_3loss in surface runoff, subsurface NO_3loss, NO_3-N leaching and denitrification. Moreover, weather data (precipitation), soil and temperature can be included. Table 7 and 8 show the simulation results of hydrology in rice paddy during the cultivation of both major and second season.

Overall, the results indicated that the main factors of hydrology in rice paddy during the major rice season were higher than second rice season for the averaged evapotranspiration, runoff and soil temperature. Most of the hydrology factors that had the maximum values in second rice season were precipitation, subsurface flow, percolation and denitrification. Particularly, as denitrification is an anaerobic microbial process occurring under saturated soil moisture conditions, it reduces nitrates to nitrogen oxides and is lost to the atmosphere (Neue, 1993). The several factors that

Table 7: Simulation results of hydrology in the major rice season

Region	Evapotranspiration (mm)	Precipitation (mm)	Runoff (mm)	Subsurface flow (mm)	Percolation (mm)	Denitrification (kg ha^{-1})	Soil temperature (°C)
Central	408.55	1,369.49	372.23	8.95	408.17	542.85	26.68
East	436.90	1,542.70	473.54	11.18	499.45	456.90	26.97
North	391.16	1,325.76	434.00	10.80	371.33	457.89	26.32
Northeast	387.98	1,572.30	582.44	13.21	648.43	441.58	26.78
South	414.80	1,498.25	633.54	16.40	633.70	565.57	26.68
West	370.53	1,242.99	484.32	10.65	556.43	533.75	26.37
Average	401.65	1425.25	496.68	11.87	519.59	499.76	26.63

Table 8: Simulation results of hydrology in the second rice season

Region	Evapotranspiration (mm)	Precipitation (mm)	Runoff (mm)	Subsurface flow (mm)	Percolation (mm)	Denitrification (kg ha^{-1})	Soil temperature (°C)
Central	390.64	1,223.19	340.82	9.620	466.76	566.16	26.64
East	388.74	1,452.29	428.56	12.690	607.82	529.58	26.87
North	391.62	1,230.09	422.70	10.890	392.05	642.63	26.30
Northeast	366.47	1,634.19	498.27	14.790	755.83	428.22	26.78
South	436.20	1,703.34	552.37	17.840	867.70	635.32	26.66
West	383.73	1,428.45	455.26	10.750	580.92	641.58	26.36
Average	392.90	1445.26	449.66	12.763	611.85	573.92	26.60

Table 9: Correlation analysis and stepwise regression analysis between hydrology factors and major rice yield

					Change statistics				
Model	R	R square	Adjusted R square	Std. error of the estimate	Sig. F change	R square change	F change	df1	df2
1	0.298(a)	0.089	0.088	1.17803	0.089	118.306	1	1217	0.000
2	0.369(b)	0.136	0.134	1.14756	0.047	66.476	1	1216	0.000

[a]Predictors: (Constant), soil temperature. [b]Predictors: (Constant), soil temperature, precipitation

influence the denitrification process in the flooded soils are pH, temperature, organic matter, oxygen, microorganisms, NO_3content, nitrification rate and fertilizer nitrogen (De Datta, 1981).

Correlation analysis and stepwise regression analysis were used in considering the relationship of hydrology factors and rice yield during the cultivation of both major and second rice, as shown in Table 9 and 10.

These results revealed that precipitation, runoff, percolation and soil temperature share a positive relationship with the major rice yield. The results of the stepwise regression analysis revealed that soil temperature and precipitation are in direct correlation with major rice yield (R = 0.369), with a 13.6% variation.

In addition, the analysis found that evapotranspiration, precipitation, percolation, NO_3 loss via runoff, NO_3 loss in subsurface, NO_3 leaching, denitrification and soil temperature by NO_3 loss via runoff, NO_3 loss in subsurface and NO_3 leaching exhibit a negative relationship with second rice yield. Meanwhile, the evapotranspiration, precipitation, percolation, denitrification and soil temperature have a positive relationship with this yield.

Stepwise regression analysis also revealed that evapotranspiration, precipitation, soil temperature, subsurface flow, NO_3 leaching, runoff and percolation have a direct relationship with the second rice yield (R = 0.875) with a 76.5% variation.

Table 10: Correlation analysis and stepwise regression analysis between hydrology factors and second rice yield

					Change statistics				
Model	R	R square	Adjusted R square	Std. error of the estimate	Sig. F change	R square change	F change	df1	df2
1	0.720[a]	0.519	0.518	1.10445	0.519	1311.986	1	1217	0.000
2	0.855[b]	0.730	0.730	0.82700	0.212	954.523	1	1216	0.000
3	0.868[c]	0.753	0.753	0.79161	0.023	112.177	1	1215	0.000
4	0.870[d]	0.757	0.757	0.78526	0.004	20.719	1	1214	0.000
5	0.873[e]	0.762	0.761	0.77863	0.004	21.759	1	1213	0.000
6	0.874[f]	0.764	0.763	0.77551	0.002	10.794	1	1212	0.001
7	0.875[g]	0.765	0.763	0.77400	0.001	5.734	1	1211	0.017
8	0.874[h]	0.765	0.763	0.77407	0.000	1.230	1	1211	0.268

[a]Predictors: (Constant), evapotranspiration. [b]Predictors: (Constant), evapotranspiration, precipitation, [c]Predictors: (Constant), evapotranspiration, precipitation, soil temperature, [d]Predictors: (Constant), evapotranspiration, precipitation, soil temperature, subsurface flow, [e]Predictors: (Constant), evapotranspiration, precipitation, soil temperature, subsurface flow, NO_3 leaching, [f]Predictors: (Constant), evapotranspiration, precipitation, soil temperature, subsurface flow, NO_3 leaching, runoff, [g]Predictors: (Constant), evapotranspiration, precipitation, soil temperature, subsurface flow, NO_3 leaching, runoff, percolation, [h]Predictors: (Constant), evapotranspiration, precipitation, soil temperature, NO_3 leaching, runoff, percolation

The results of relationship analysis revealed that during the cultivation of the major rice, soil temperature had the highest relationship with the rice yield, followed by the factors of precipitation, percolation and runoff. During the cultivation of the second rice, it was found that evapotranspiration has the highest relationship with rice yield, followed by NO_3 runoff loss, NO_3 subsurface loss and NO_3 leaching. If the rice yield increases, the amount of NO_3 loss decreases because the rice plantations can still utilize it.

Setyorini *et al.* (2004) indicated that N fertilizer show a high response on the growth of rice plants. Application of N fertilizers at higher doses cause higher leaching loss. Soils with low organic matter are cause more loss of N than soils with high organic matter (Sahu and Samant, 2006), can also induce adverse effect on terrestrial and aquatic ecosystems (Lovett and Tear, 2008) and increase N_2O emissions.

CONCLUSION

The N balance in the rice paddy depends on chemical fertilizer, N fixation, precipitation and irrigation water as inputs and N mineralization in the soil, rice harvest, evapotranspiration, percolation, runoff and N loss by denitrification as outputs. N losses were satisfactorily estimated by EPIC. N losses in rice paddy of Thailand were significant during the second rice season, particularly in the northern and central regions. In this present study, these regions had excessive application of N fertilizer for the rice production that resulted in reduced N recovery rates and environment pollution. We are concerned that in the long-term, accumulation of NO_3-N from leaching will no doubt constitute a potential risk of N contamination of the ground water and reservoir.

However, the settings utilized with EPIC do not seem to be sensitive enough to simulate the widely time-varying environmental conditions. Thus, EPIC is probably not appropriate for studying short-term trends dealing with individual events. The results obtained indicate that EPIC can be used for assessing long-term trends dealing with environmental quality and agricultural management systems.

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