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Evaluation of EPIC model of soil NO_3-N in irrigated and wheat-maize rotation field on the Loess Plateau of China

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Abstract: EPIC model has been evaluated and used world wide, however there is still some disagreements on the simulation results of nitrogen cycle. Based on field experimental data, simulation results of soil NO_3-N was evaluated and the parameter sensitivity for simulated NO_3-N was analyzed in irrigated winter wheat / summer maize field on the Loess Plateau of China. Results showed 1) EPIC model estimated soil NO_3-N content and its movement among different soil layers well, with the mean RRMSE value of 0.46, for irrigated winter wheat / summer maize cropping system in the semi-humid region of the Loess Plateau. 2) Simulation results of soil NO_3-N was more sensitive to soil parameters, compared with crop parameters and meteorological parameters. 3）To improve the parameter value of BN2, HI, TB, WA, CNDS, BD and FC was better to the EPIC model to simulate soil NO_3-N on the Loess Plateau of China.

Key word: NO_3-N; Parameter sensitivity; EPIC model; The Loess Plateau;

Introduction

Nitrogen is one of the macronutrients necessary for plant growth[1] and plays an important role in increasing crop yield during the past century[2], however it also causes NO_3-N contamination of groundwater in areas of intensive agriculture, due to the over use of nitrogen by farmers on the Loess Plateau of China[3]. In general, any downward movement of water through the soil profile will cause the leaching of NO3-N, with the magnitude of the loss being proportional to the concentration of NO3-N in the soil solution and the volume of leaching water[4-5]. There is potential for NO3-N to be leached wherever rainfall or water supply exceeds evapo-transpiration. A common conclusion reported by many researchers is that proper fertilizer, crop, water, and soil management can minimize leaching of NO3-N and increase crop yield[6-7]. However, it is difficult to make a decision considering so many factors at the same time by field experiment. With the developing of computer, crop model has been used to solve this kind of problem by simulation method.

As an multi-crop model, EPIC model (Environmental Policy Integrated Climate Model) has been evaluated and used world wide to simulate crop yield[8], soil water[9] and nutrition cycle[10] for different cropping system with different fertilizer and irrigation managements. Gaiser et al. (2010) reported that EPIC model can explain about 80% of the variance in crop yield in tropical sub-humid West Africa and semi-arid Brazil

[11]. Wang and Li (2010) showed that EPIC model can estimate soil water and crop yield well with the new database built up for the Loess Plateau [8]. Several validation studies (Cavero et al. 1998 and 1999) found that EPIC satisfactorily simulated measured soil nitrogen (N) and/or crop N uptake levels [12-13]. However, less accurate soil N and crop N uptake results were reported in EPIC validation studies by Chung et al. (2002) [14]. Therefore its necessary to evaluate EPIC model before using EPIC model to simulate soil NO_3-N in irrigated field on the Loess Plateau of China.

Objectives of this paper were to evaluate EPIC model of simulated soil NO3 in irrigated field with different fertilizer levels and to point out some advices for the better application of EPIC model in the world.

1. Material and method

1.1 Site description

Yulin (E108.07°, N34.26°), as a typical intensive agriculture place of semi-humid region on the Loess Plateau, is located at the southern part of Shanxi providence. It is an arid continental monsoon climate zone and is a main wheat and maize area of China. Its annual precipitation is 550~600mm and 50% of them dropped in July, August and September. Its mean annual temperature is 10℃ with the mean frost-free period of 152 d, and the mean sunshine hours of 2158h. Predominant soil used for winter wheat/summer maize in this area is Lou soil, with the field capacity and wilting point of 210~222 g/kg and 110-120 g/kg respectively.

1.2 Field experiment

The field experiment, for irrigated winter wheat / summer maize cropping system, was carried out at Yangling eco-agriculture station from 1994 to 1997. Its fertilizer treatments were as follows: (1) no nitrogen fertilizer (N0), (2) 130 kg pure N/hm^2 (N130), (3) 260 kg pure N/hm^2 (N260), (4)390kg pure N/hm^2 (N390), (5) 520kg pure N/hm^2 (N520). Phosphorous fertilizer applied for each treatment was the same, 52 kg/hm^2 of P_2O_5. All experiments were established in 15 plots of 10.26m×6.5m (with a buffer zone of 1m between plots). Plots were arranged in a Randomized Complete Block Design (RCBD) with three replications. According to the requirement of crops, 150mm underground water were used to irrigate winter wheat and summer maize each year.

1.3 Method

1.3.1 Soil NO_3^-

In this research, soil samples for different soil layers (0~0.1m，0.1~0.2m，0.2~0.4m，0.4~0.6m，0.6~0.8m，0.8~1.0m，1.0~1.4m，1.4~1.8m，1.8~2.2m，2.2~2.6m，2.6~3.0m，3.0~3.5m，3.5~4.0m) were collected by core break method, before planting and after harvest in each experiment plot. NO_3–N was abstracted using 1mol/L KCl solution, the content of NO_3-N was measured by Continuous Flow Analyzer.

1.3.2 Evaluation method

Relation index (R), root mean square error (RMSE), relative root mean square error (RRMSE)and relative error (RE) [8-9] was used to evaluate how well the EPIC model simulated soil NO_3-N in irrigated winter wheat / summer maize cropping system on the Loess Plateau of China.

In order to evaluate the simulation results of NO_3-N movement in different soil layers, equation 1 and 2 wer used to calculate the changing of NO_3-N in each soil layer.

$$\Delta O = OH - OS \quad (1); \qquad \Delta S = SH - SS \quad (2)$$

Where △O and △S was observed and simulated, respectively, changing of NO_3-N in one soil layer from planting to harvesting. OH and SH was observed and simulated, respectively, NO_3-N of one soil layer before planting. OS and SS was observed and simulated, respectively, NO_3-N of one soil layer after harvest.

Sensitivity of model parameters on simulated soil NO_3-N was analyzed using Extended Fourier Amplitude Sensitivity Test (EFAST) [15-16]. Model parameters and their interconnection together impacted the Variation of Simulation Results (VSR), therefore we use equation 3 to divide the variation of simulation results, based on EFAST method.

$$V = \sum_i V_i + \sum_{i \neq j} V_{ij} + \sum_{i \neq j \neq m} V_{ijm} + \cdots + V_{12\cdots k} \quad (3)$$

Where V_i indicated the contribution of parameter X_i to VSR by itself, V_{ij} indicated the contribution of parameter X_i to VSR through parameter X_j; V_{ijm} indicated the contribution of parameter X_i to VSR through parameter X_j and X_m. $V_{12\ldots k}$ indicated the contribution of parameter X_i to VSR through parameter X_1 , X_2 …..and X_k.

After dividing the variation of simulation results, a normalization processing was made to got the first order sensitivity index of parameter X_i, by equation 4, and the second order sensitivity index by equation 5, the third order sensitivity index by equation 6.

$$S_i = \frac{V_i}{V} \quad (4) \qquad S_{ij} = \frac{V_{ij}}{V} \quad (5) \qquad S_{ijm} = \frac{V_{ijm}}{V} \quad (6)$$

Where S_i was the first order sensitivity index of parameter X_i. S_{ij} was the second order sensitivity index of parameter X_i, S_{ijm} was the third order sensitivity index of parameter X_i. Then the total sensitivity of parameter X_i can be calculated using equation 7. Where S was the total sensitivity of parameter X_i.

$$S = S_i + S_{ij} + S_{ijm} + \cdots + S_{12\cdots i\cdots k} \quad (7)$$

2 Results

2.1 Content of NO_3-N in different soil layers for different treatments

EPIC model simulated soil NO_3-N content well with the mean R^2 value of 0.82 (figure 1). RMSE value of N0, N130, N260, N390 and N520 treatment was 1.016, 1.217, 2.781, 2.749, 3.873 mg/kg respectively, and the RRMSE value was 0.46, 0.43, 0.58, 0.33 and 0.39 respectively. Observed mean value of soil NO_3-N content was 3.96, 4.39, 8.63, 10.41 and 11.67mg/kg respectively, simulated mean value was 3.77, 4.22, 7.64, 10.15, 11.21 mg/kg respectively. simulated value was lower than observed value with the RE value of -0.05, -0.04, -0.11, -0.02 and -0.04 for N0, N130, N260, N390 and N520 respectively. Except N260 treatment, relationship between simulated and observe value of soil NO_3-N was significant, with the R value of 0.89, 0.86, 0.84 and 0.83 respectively(figure 1),

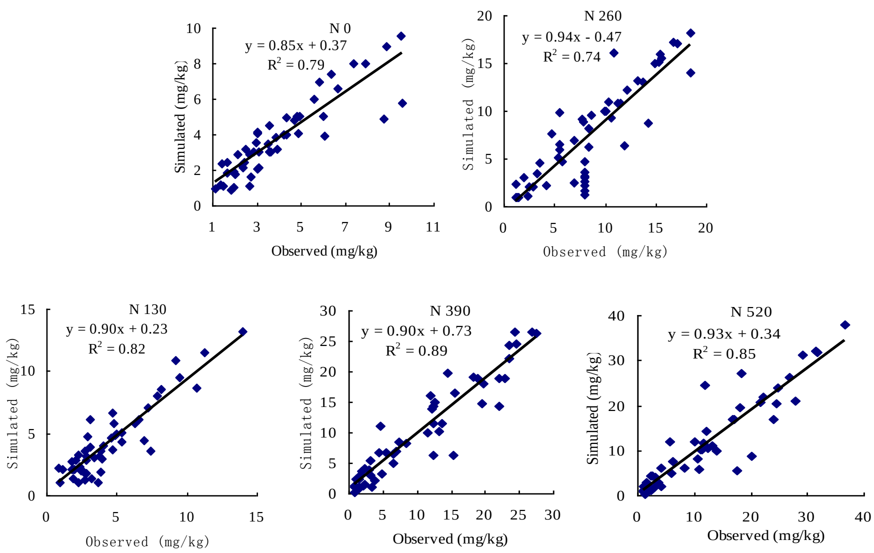

Figure 1 Comparison between simulated and observed soil NO_3-N content for different fertilizer treatments in irrigated winter wheat / summer maize field at Yangling

2.2 Changing of soil NO_3-N content for different treatments

Changing direction (increase or decrease) of △S (Simulated value of increasing NO_3-N conteny) agreed well with △O (Observed value of increasing NO_3-N content) except N260 treatment (figure 2). Mean value of △O for N0, N130, N260, N390 and

N520 was 1.95, 2.01, 4.46, 4.44, 5.59 mg/kg respectively, and mean value of △S was 1.96, 1.92, 3.09, 4.79, 6.12 mg/kg. △S was higher than △O, with the RE value 1%, 8% and 9% for N0, N390 and N520 respectively，and was lower than △O with the RE value of -4% and -31% for N130 and N260 respectively. The EPIC model estimated well the variation of soil NO_3-N in irrigated winter wheat / summer maize field, with the RMSE value of 0.99, 1.447, 3.611, 3.014, 4.604 mg/kg, for N0, N130, N260, N390 and N520 respectively, the RRMSE value of 0.51, 0.75, 1.17, 0.63 and 0.70 respectively.

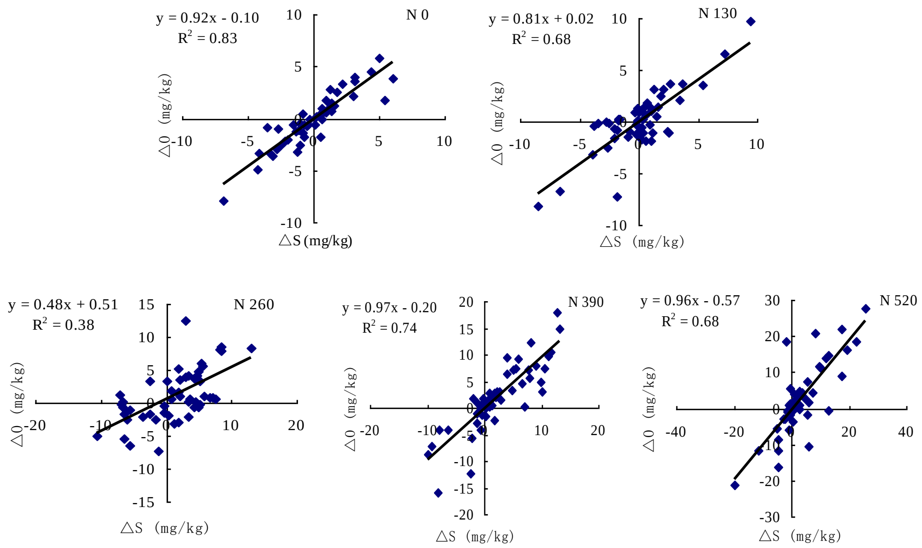

Figure 2 Comparison between simulated and observed changing of soil NO_3-N content for different treatments in irrigated winter wheat / summer maize field at Yangling

△ S was simulated value of increasing soil NO_3-N content in one layer, △ O was observed value of increasing soil NO_3-N content in one layer.

2.3 Sensitivity of model parameters

Soil parameters have the greatest impact on simulation results of NO_3-N, then was the crop parameters and the metrology parameters was the third. Mean S value for soil parameters, crop parameters and meteorological parameters was 0.30, 0.27 and 0.23 respectively, and mean S1 value was 0.16, 0.13 and 0.11 respectively. The fact that S value of BN2, HI, TB and WA was higher than other crop parameters means that crop parameters of BN2, HI, TB and WA can be used to improve the simulation results of NO_3-N of EPIC model. The same results was founded for soil parameters of CNDS, BD, and FC; for meteorological parameters of PRCP and RAD. Though the crop parameters HI and TB got an higher value of S, their value of S1 was lower comparing with WA, this means that though using HI and TB can improve the simulation results of NO_3-N in EPIC model, using other related parameters may be the better way. Similar results was founded for soil parameters of SLMX and CBN.

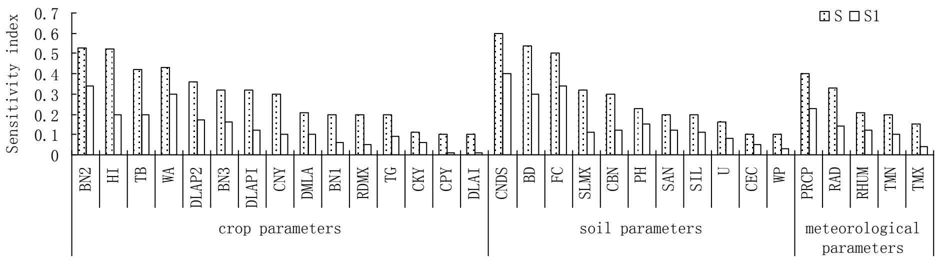

Figure 3 Sensitivity of model parameters for simulated soil NO_3-N in irrigated winter wheat / summer maize field at Yangling.
S was the total sensitivity of parameter X. S_1 was the first order sensitivity index of parameter X.

3. Discussion

For N260 treatment, the RRMSE value between simulated and observed soil NO_3-N content was higher than 0.5, and it was higher than 1.0 between △O and △S. This fact indicated that a far distance existed between simulation results and observed results. However, checking observed results carefully, we found that soil NO_3-N content was the same (7.97mg/kg) from top soil to deep soil after the harvest of winter wheat in 1995. If not considering these error values, the RRMSE value between △O and △S was 0.46, and it was 0.34 between simulated and observed soil NO_3-N content. Therefore, it is the error of observed value that cause the higher value of RRMSE value for N260 treatment.

Engelke and Fabrewitz (1991) found that EPIC estimates of denitrification and mineralization were plausible[17]; however, Richter and Benbi (1996) described EPIC's mineralization predictions as very poor[18]. Edwardset al. (1994) found that annual EPIC estimates of nutrient losses were significantly correlated with measured values, except for nitrate-N [19]. Chung et al. (2002) found that EPIC model estimated N loss in tile flow in Iowa region for corn and cotton[14]. Our results found that Except N260, simulated soil NO_3-N content was consistent with observed (figure 1), and simulated changing of soil NO3-N was similar with observed (figure 2). So EPIC model is an effective tool to simulate NO_3-N in irrigated cropping system on the Loess Plateau of China.

A sensitivity analysis by Benson et al. (1992) showed that EPIC N leaching estimates can be very sensitive to choice of evapo-transpiration routine and soil moisture estimates[20]. Niu et al (2010) found that most of model uncertainties introduced by input data that are not site-specific but commonly used[10]. Our results found that 1) to improve soil parameters was better for EPIC model to got a better simulation results of soil NO_3-N. 2) Simulation results of NO_3-N was sensitive to crop parameters of BN2, HI, TB and WA, soil parameters of CNDS, BD and FC, meteorological parameters of PRCP and RAD.

4. Conclusion

1) EPIC model estimated soil NO_3-N content and its movement among different soil

layers well, with the mean RRMSE value of 0.46, for irrigated winter wheat / summer maize cropping system in the semi-humid region of the Loess Plateau.

2) Simulation results of soil NO_3-N was more sensitive to soil parameters, compared with that to crop parameters and that to meteorological parameters. To improve the parameter value of BN2, HI, TB, WA, CNDS, BD and FC was better to the EPIC model to simulate soil NO_3-N on the Loess Plateau of China.

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