Simulating Nitrate-Nitrogen Concentration from a Subsurface Drainage System in Response to Nitrogen Application Rates Using RZWQM2

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Computer models have been widely used to evaluate the impact of agronomic management on nitrogen (N) dynamics in subsurface drained fields. However, they have not been evaluated as to their ability to capture the variability of nitrate-nitrogen (NO_3–N) concentration in subsurface drainage at a wide range of N application rates due to possible errors in the simulation of other system components. The objective of this study was to evaluate the performance of Root Zone Water Quality Model2 (RZWQM2) in simulating the response of NO_3–N concentration in subsurface drainage to N application rate. A 16-yr field study conducted in Iowa at nine N rates (0–252 kg N ha^{-1}) from 1989 to 2004 was used to evaluate the model, based on a previous calibration with data from 2005 to 2009 at this site. The results showed that the RZWQM2 model performed "satisfactorily" in simulating the response of NO_3–N concentration in subsurface drainage to N fertilizer rate with 0.76, 0.49, and −3% for the Nash-Sutcliffe efficiency, the ratio of the root mean square error to the standard deviation, and percent bias, respectively. The simulation also identified that the N application rate required to achieve the maximum contaminant level for the annual average NO_3–N concentration was similar to field-observed data. This study supports the use of RZWQM2 to predict NO_3–N concentration in subsurface drainage at various N application rates once it is calibrated for the local condition.

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Nitrate-nitrogen (NO_3–N) has been deemed as a main source of pollution for shallow groundwater and surface water bodies. Twenty percent of the sampled shallow wells in agricultural areas exceeded the USEPA maximum contaminant level (MCL) of 10 mg N L^{-1} for NO_3–N (USGS, 2004). A state-wide rural well water survey in Iowa in 1988 and 1989 showed that 18% of Iowa's private rural drinking wells exceeded this limit (Kross et al., 1990). In addition to contaminating groundwater, NO_3–N impairs surface water bodies. Nitrate-nitrogen loading from the Mississippi River is suspected to be a main contributor to the hypoxic zone in the Gulf of Mexico (USEPA, 2007). The main source of NO_3–N in the Mississippi River Basin is linked to subsurface drainage (Lowrance, 1992; Keeney and DeLuca, 1993; David et al., 1997; Zucker and Brown, 1998). For example, in Iowa, where about 25% of agricultural land is subsurface drained, the NO_3–N loading to the Mississippi River Basin was approximately 204,000 to 222,000 Mg N yr^{-1} (26 kg N ha^{-1} yr^{-1}) (Schilling and Libra, 2000).

Reducing the N application rate is one of the most effective approaches to alleviate NO_3–N concentration in subsurface drainage (Dinnes et al., 2002). In a field experiment conducted by Baker and Johnson (1981), the drainage NO_3–N concentration in a corn–soybean–corn–oat rotation was approximately 20 mg N L^{-1} for a N rate of 90 and 100 kg N ha^{-1} to corn and 40 mg N L^{-1} for a N rate of 240 to 250 kg N ha^{-1} to corn. Jaynes et al. (2001) reported that the NO_3–N concentration in subsurface drainage flow exceeded the MCL at low (57–67 kg N ha^{-1}), medium (114–135 kg N ha^{-1}), and high (202–172 kg N ha^{-1}) N rates. In a three-phase study with four N rates (202, 168, 135, and 110 kg N ha^{-1}), Bakhsh and Kanwar (2007) documented the lowest NO_3–N concentration of 10.5 mg N L^{-1} in the subsurface drainage at a N rate of 110 kg N ha^{-1} for continuous corn and at 135 kg N ha^{-1} for a corn–soybean rotation. Field experiments with corn and soybean in Iowa measured NO_3–N losses of 26 to 55 kg N ha^{-1} yr^{-1} in the northeast (Weed and

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Abbreviations: ADWQ-RDS, Agricultural Drainage Water Quality-Research and Demonstration Site; ET, evapotranspiration; MCL, maximum contaminant level; NSE, Nash-Sutcliffe efficiency; PBIAS, percent bias; RSR, root mean square error to the standard deviation of measured data; RZWQM2, Root Zone Water Quality Model2.

Kanwar, 1996), 27 to 31 kg N ha^{-1} yr^{-1} in the central (Baker et al., 1975; Baker and Johnson, 1981; Kanwar et al., 1983), and 36 to 68 kg N ha^{-1} yr^{-1} in the north-central (Lawlor et al., 2008; Qi et al., 2011a). Lawlor et al. (2008) reported a three-phase field study in Pocahontas County, Iowa from 1989 to 2004, where nine fertilizer rates were applied to corn ranging from 0 to 252 kg N ha^{-1} for fields with corn and soybean. The annual flow-weighted average NO_3–N concentration varied from 3.9 mg L^{-1} (at 45 kg N ha^{-1}) to 28.7 mg L^{-1} (at 252 kg N ha^{-1}). The 16-yr study produced a regression equation of N concentration = 5.72 + 1.33 exp(0.0104 × N rate) (N rate in kg N ha^{-1}; r^2 = 0.65), where N fertilizer was only applied to the corn phase.

Studies conducted by Bakhsh et al. (2001) and Thorp et al. (2007) showed a successful simulation in subsurface drain flow and NO_3–N loss at different N rates using RZWQM. In contrast, most studies with RZWQM report that the Nash-Sutcliffe efficiency (NSE) was less than zero, which indicates poor model performance, for RZWQM simulation of annual flow-weighted nitrate concentration compared with field observations (Thorp et al., 2007; Bakhsh et al., 2004; Li et al., 2008; Malone et al., 2010), which could be due to poorly simulated nitrate concentration in subsurface drainage. The main improvement of RZWQM2 over the early version (RZWQM98) is that it is later linked with the DSSAT crop growth models (CERES and CROPGRO), which provides a better simulation of crop growth and nutrient uptake. Previous modeling studies were conducted using a limited number of N rates, which led to a narrow range of observed NO_3–N concentration. Overall, there is a need to test the model using field-measured data at a wider range of N application rates. The NO_3–N concentration in subsurface drainage varies significantly from place to place. For example, at N application rates of 90 to 100 kg N ha^{-1}, Baker and Johnson (1981) reported a NO_3–N concentration of 20.1 mg N L^{-1}, which is twice as much as the observed concentration at the similar N rate in Lawlor et al. (2008). This indicates that a site-specific calibration is needed when using RZWQM2 to simulate NO_3–N concentration in subsurface drainage. The objective of this study was to evaluate the site-specifically calibrated RZWQM2 model in simulating the response of average annual NO_3–N concentration for a wide range of N application rates so that the model may be used to advise agricultural water quality management when long-term field investigation is not applicable.

Materials and Methods

Field Experiment

The field study was conducted at the Agricultural Drainage Water Quality-Research and Demonstration Site (ADWQ-RDS, formerly the Agricultural Drainage Well Site) near Gilmore City in Pocahontas County, north-central Iowa. The predominant soils are Nicollet (fine-loamy, mixed, superactive, mesic Aquic Hapludoll), Webster (fine-loamy, mixed, superactive, calcareous, mesic Typic Endoaquolls), Canisteo (fine-loamy, mixed, superactive, calcareous, mesic Typic Endoaquolls), and Okoboji (fine, smectitic, mesic Cumulic Vertic Endoaquolls) (USDA, 1985). This site included 76 individually drained plots with the same layout. Each plot was 38 m in length and 15.2 m in width. Plots were established after the installation of corrugated plastic drain pipe through the center and both boundaries parallel to the long dimension (7.6 m spacing) at a depth of 1.06 m. The two border drains, which were installed to help prevent lateral flow from adjacent plots, have an outlet to the surface at a remote location. Only the center drainage line is monitored for drainage volume and pollutant concentrations. Drainage water from the center line is collected in an aluminum culvert with automatic pumping, volume monitoring, and water sampling systems (Lawlor et al., 2008).

The primary goal of this field study was to investigate the effect of N application rate on NO_3–N concentration and the loss in subsurface drainage with rotated and combined corn–soybean. The experiment consisted three phases (Lawlor et al., 2008): Phase I was implemented from 1989 to 1993 with N application rates of 0, 56, 112, and 168 kg N ha^{-1} for corn–soybean rotation; Phase II was conducted from 1994 to 1999 with N rates of 45, 90, 134, and 179 kg N ha^{-1} with the plots split evenly to accommodate corn and soybean; and Phase III included half corn and half soybean in rotation with N rates of 168 and 252 kg N ha^{-1} from 2000 to 2004. Liquid 28% urea ammonium nitrate was the fertilizer source from 1989 to 1999, whereas commercial-grade 28% aqueous ammonia-N was used from 2000 to 2004. The liquid fertilizers were injected mid-row only to corn in spring at planting or as an early-season sidedress, contingent on the weather conditions. Each fertilization treatment was randomly assigned to three plots in Phase I and II and five plots in Phase III. Every fall, corn residue was chopped and chisel plowed, and in spring the corn and soybean fields were disked and field cultivated before planting. Detailed information on this field study can be found in Lawlor et al. (2008).

RZWQM2 Simulation

The RZWQM2 is a one-dimensional agricultural system model consisting of hydrology, nutrition, and pesticide transport and transformation, plant growth, and management practice components (Ahuja et al., 2000; Ma et al., 2005; Ma et al., 2006). Infiltration from rainfall, irrigation, or snow melt is computed by a modified Green-Ampt approach, and the water redistribution in the soil profile, considering plant uptake as a sink, is simulated by the Richards equation. Subsurface drainage flux is calculated using the steady-state Hooghoudt equation. The lateral flow is quantified by the user-defined parameters of lateral hydraulic gradient. The nutrient chemistry processes model incorporated in RZWQM2 is OMNI (Shaffer et al., 2000), a state-of-the-art model for C and N cycling in soils. The coupled DSSAT family (Jones et al., 2003) of crop growth models enhanced the capability of RZWQM2 in describing crop establishment and water and nutrient uptake.

The RZWQM2 model was calibrated and validated using field-measured data on hydrology, crop growth, N uptake, and NO_3–N loss in 2005 to 2009 at a N rate of 140 kg N ha^{-1} at this ADWQ-RDS site (Qi et al., 2011b). Input parameters for soil hydraulic properties were determined by site-specific measurements that included bulk density, particle size distribution, soil water retention curve, and soil hydraulic conductivity (Qi et al., 2011b). Nutrient parameters were mainly adopted from Thorp et al. (2007), and the crop parameters were calibrated by Qi et al. (2011b).

In this study, the calibrated and validated RZWQM2 model using data from 2005 to 2009 was adopted to simulate the response of NO_3–N concentration in subsurface drainage to the nine N application rates at this site from 1989 to 2004. The rainfall and temperature data from 1989 to 2004 were measured on-site and prepared by Singh et al. (2006), but snowfall data in December, January, and February were replaced with observed snowfall depth at Humboldt, Iowa, which is 15 km east of this ADWQ-RDS site. Solar radiation, wind speed, and relative humidity data were from a weather station at Kanawha, Iowa, which is approximately 50 km northeast of the ADWQ-RDS site. All the off-site weather data are available at the Iowa Environmental Mesonet website. Other inputs of the RZWQM2 model, such as planting date, harvest date, and tillage management, can be found in Qi et al. (2011b).

A RZWQM2 scenario was set up to simulate the NO_3–N concentration at each N rate in each phase (5 yr for Phase I and III and 6 yr for Phase II) based on the information provided in Lawlor et al. (2008). For each N rate, the scenario was run twice with corn–soybean and soybean–corn rotations. Before this 16-yr field measurement, the carbon and nitrogen pools in the model were initialized using weather and agronomic management data from 1960 to 1988, which is the same methodology used in Qi et al. (2011b). The simulated NO_3–N concentration in all the years of the study was compared with observed values.

Statistics and Curve Fitting

Three statistics in Moriasi et al. (2007) were used to evaluate the performance of RZWQM2 in simulating NO_3–N concentration and subsurface drain flow at different N application rates when compared with observed data. They are NSE, ratio of the root mean square error to the standard deviation of measured data (RSR), and percent bias (PBIAS):

$$\mathrm{NSE} = 1 - \frac{\sum_{i=1}^{n} (O_i - P_i)^2}{\sum_{i=1}^{n} (O_i - \overline{O})^2} \qquad [1]$$

$$\mathrm{RSR} = \frac{\mathrm{RMSE}}{\mathrm{STDEV_{obs}}} = \frac{\sqrt{\sum_{i=1}^{n} (O_i - P_i)^2}}{\sqrt{\sum_{i=1}^{n} (O_i - \overline{O})^2}} \qquad [2]$$

$$\mathrm{PBIAS} = \frac{\sum_{i=1}^{n} (O_i - P_i)100}{\sum_{i=1}^{n} O_i} \qquad [3]$$

where O_i is the ith observed NO_3–N concentration (mg N L^{-1}) at the ith N rate, P_i is the ith simulated value for the NO_3–N concentration at the ith N rate, $\overline{O}$ is the mean of observed NO_3–N concentration at all the N rates, and n is the total number of observations. Of note is that the NSE = 1 – RSR^2. Because this field experiment was conducted on a plot scale rather than on a watershed scale as discussed in Moriasi et al. (2007), we adapted the criteria to: The model performance can be judged as "satisfactory" for the simulation of NO_3–N concentration when NSE >0.50, RSR ≤0.70, and PBIAS is within ±25% and can be judged as "satisfactory" for the simulation of annual drainage flow when NSE >0.65, RSR ≤0.50, and PBIAS within ±15%.

Nitrate-nitrogen concentration in the subsurface drain flow as a function of N application rate was fitted following the equation in Lawlor et al. (2008):

$$\mathrm{FWANC} = y_0 + a \times e^{b \times N \text{ rate}} \qquad [4]$$

where FWANC is the flow-weighted average NO_3–N concentration (mg N L^{-1}), and y_0, a, and b are regression coefficients. The coefficients of the regression equation along with the 95% confidence interval were obtained using SigmaPlot 10.0 (SYSTAT Software, 2007).

Results and Discussion

The performance of the RZWQM2 in simulating the response of NO_3–N concentration in subsurface drainage to N application rate can be judged as "satisfactory" (Table 1). The statistics of NSE, RSR, and PBIAS were 0.76, 0.49, and −3%, respectively. In general, the simulated NO_3–N concentration matched the trend of observed values with respect to N application rate. This finding suggests that the RZWQM2 can be used as a valid tool to simulate the N concentration in subsurface drainage with N rates repeated in 5 to 6 yr, although it was reported that computer models such as RZWQM2 were not able to capture the year-to-year variance at a given N application rate (Thorp et al., 2007).

The simulated NO_3–N concentration also responded reasonably well to the variation in weather conditions. The field data demonstrated that the observed concentration in Phase II showed lower values than that in Phase I even at a higher N rate. For example, at the N rate of 56 kg N ha^{-1} in Phase I, the observed NO_3–N concentration was 9.5 mg N L^{-1}; however, in Phase II, the observed concentration was lower (8.1 mg N L^{-1}) at a higher N rate of 90 kg N ha^{-1}. The RZWQM2 model captured this trend, giving predicted NO_3–N concentrations of 10.8 and 7.3 mg N L^{-1} for the N rates of 56 and 90 kg N ha^{-1} in these two phases, respectively. This can be explained by higher simulated denitrification and immobilization in Phase II, including increased crop N uptake (Table 2). Simulation results showed that denitrification increased 49% (10.0 versus 14.9 kg N ha^{-1}) and immobilization increased 14% (13.5 versus 15.4 kg N ha^{-1}) at the N rate of 90 kg N ha^{-1} in Phase II compared with the N rate of 56 kg N ha^{-1} in Phase I. The simulation also showed that, at the same N rate, denitrification and immobilization increased in Phase II from Phase I. For example, at the N rate of 90 kg N ha^{-1}, the simulated denitrification in Phase II was 19% higher than the denitrification in Phase I (14.7 kg N ha^{-1}), compared with 12.4 kg N ha^{-1}. This could be due to mild weather conditions in Phase II, with high relative humidity and low wind speed during the growing season, which resulted in higher soil water content in the soil profile (data not shown).

This simulation also showed an overestimation of NO_3–N concentration in Phase I and a general underestimation in Phase II and III (Fig. 1). The PBIAS values were 16, −19, and −9% in NO_3–N concentration simulation for the three phases, respectively. The overestimation of NO_3–N concentration in Phase I could be a result of underestimated subsurface drain flow, and the underestimation of NO_3–N concentration in Phase II could be attributed to the overestimated drain flow. Field observation showed that there was no significant difference in drain flow among N rate treatments in 13 of the 16 yr (Lawlor et al., 2008), so the simulated and observed drain flow were averaged across all N rate treatments and are included in Table 3, along with other simulated hydrologic components. In general, the annual drainage was simulated "satisfactorily," with 0.72, 0.53, and −7.8% for NSE, RSR, and PBIAS, respectively. However, during the high-drainage period of Phase I from 1989 to 1993, the drainage flow was generally underestimated by 28%, whereas in Phase II from 1994 to 1999 it was overestimated by 36%. The simulated average evapotranspiration (ET) over these 16 yr was 46.6 cm, which is comparable to the estimated ET of 46.8 cm in 1996 to 2005 in northeast Iowa (Thorp et al., 2007). In some relatively dry years, such as 1989 and 1997, the simulated sum of ET and runoff exceeded the precipitation, indicating a net loss of soil water stored in the soil profile. Simulated results in other components, such as runoff and soil water storage change, were similar to those listed in Thorp et al. (2007).

The simulation in total NO_3–N load through subsurface drainage system at different N rates can be judged as "satisfactory," with −16%, 0.64, and 0.60 for the statistics of PBIAS,

Table 1. Observed and simulated annual flow-weighted average nitrate-nitrogen concentration and losses at various nitrogen application rates for the three-phase field experiment in Lawlor et al. (2008).

N rate	Phase no. (years)	NO_3–N concentration		NO_3–N loss	
		Observed	Simulated	Observed	Simulated
kg N ha^{-1}		mg N L^{-1}		kg N ha^{-1}	
0	Phase I (1989–1993)	8.9	8.9	50	34
45	Phase II (1994–1999)	5.9	7.0	7	15
56	Phase I (1989–1993)	9.5	10.8	48	37
90	Phase II (1994–1999)	8.1	7.3	21	15
112	Phase I (1989–1993)	11.7	12.8	68	44
134	Phase II (1994–1999)	11.9	8.7	18	18
168	Phase I (1989–1993)	11.9	15.9	58	54
168†	Phase III (2000–2004)	14.9	14.2	35	31
179	Phase II (1994–1999)	14.6	11.2	9	24
252	Phase III (2000–2004)	23.3	20.6	63	44
Average		12.1	11.7	38	32
PBIAS‡			−3%		−16%
NSE§			0.76		0.64
RSR¶			0.49		0.60

† Nitrogen application rate of 168 kg N ha^{-1} was implemented in Phase I and III.

‡ Percent bias.

§ Nash-Sutcliffe efficiency.

¶ Root mean square error to the standard deviation of measured data.

Table 2. Simulated nitrogen mineralization, denitrification, and immobilization.

Phase	N rate	Mineralization	Denitrification	Immobilization
		kg N ha^{-1}		
Phase I	0	101.1	6.8	10.3
	56	105.5	10.0	13.5
	112	110.2	14.2	14.8
	168	114.4	19.3	15.7
Phase II	45	103.0	11.5	14.0
	90	108.4	14.9	15.4
	134	113.2	18.5	16.5
	179	118.5	23.7	17.0
Phase III	168	112.4	20.5	15.7
	252	118.6	33.3	16.2
Average		110.5	17.3	14.9
Phase I		107.8	12.6	13.6
Phase II		110.8	17.2	15.7
Phase III		115.5	26.9	15.9

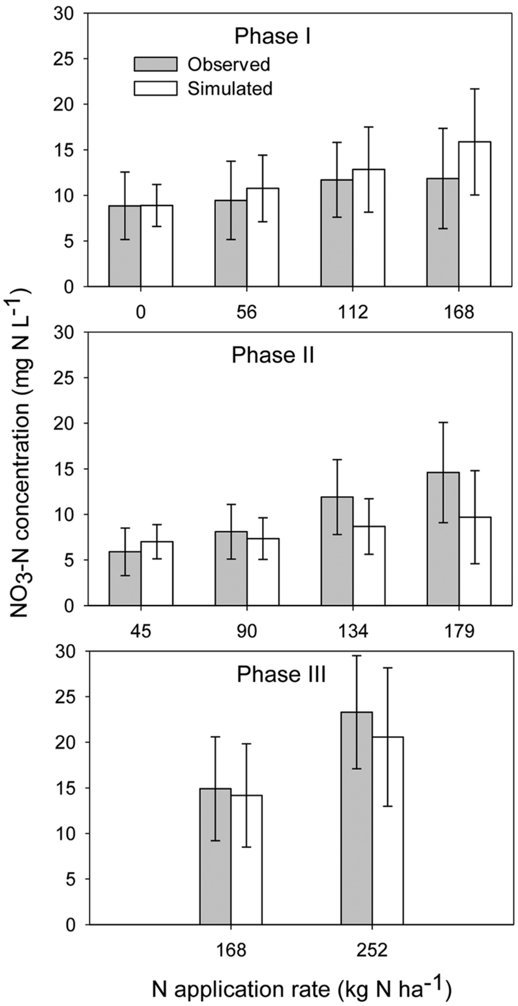

Fig. 1. Simulated and observed NO_3–N concentration in each phase under various N application rates. Bars represent ± 1 SD of annual NO_3–N concentration in each phase.

Table 3. Observed precipitation and drainage and simulated evapotranspiration, runoff, and drainage for all three phases.†

	Year	Precipitation	Evapotranspiration	Runoff	Soil water storage change‡	Subsurface drainage	
						Observed	Simulated
		cm					
Phase I	1989	50.6	55.8	1.8	−7.0	0.0	0.4
	1990	88.2	47.3	1.5	9.5	44.4	28.5
	1991	94.1	50.0	4.1	−0.5	55.2	33.0
	1992	82.6	45.2	3.6	4.3	46.2	34.5
	1993	96.6	44.2	4.7	−1.2	59.6	51.4
Phase II	1994	65.9	46.0	1.9	−0.7	7.4	15.3
	1995	74.6	47.5	3.4	−1.3	16.4	24.2
	1996	77.6	42.6	2.2	3.1	30.8	25.5
	1997	54.4	44.0	4.2	−3.7	3.7	16.0
	1998	71.4	45.4	2.4	−0.5	22.9	23.5
	1999	66.7	50.4	1.6	−8.1	9.8	19.2
Phase III	2000	68.5	44.7	1.6	12.0	1.9	7.9
	2001	71.2	43.3	3.5	0.4	26.4	27.8
	2002	69.5	48.7	1.1	−2.1	24.8	22.1
	2003	67.2	45.3	1.2	−12.8	32.6	30.0
	2004	77.0	45.6	2.4	12.1	29.0	19.4
Average		73.5	46.6	2.6	0.2	25.7	23.7
Phase I		82.4	48.5	3.1	1.0	41.1	29.6
Phase II		68.4	46.0	2.6	−1.9	15.2	20.6
Phase III		70.7	45.5	2.0	1.9	22.9	21.5

† Percent bias = −7.8%; Nash-Sutcliffe efficiency = 0.72; root mean square error to the standard deviation of measured data = 0.53.

‡ Soil water storage change = soil water storage on the last day of the year − soil water storage on the first day of the year.

NSE, and RSR, respectively (Table 1). These data suggest that total NO_3–N loss can be predicted in a reasonable manner by the RZWQM2 model due to the reasonable performance in simulating NO_3–N concentration and drainage volume, despite that the over- or underestimation trend found within a phase in the NO_3–N concentration and drainage simulation.

The fitted curve of simulated NO_3–N concentration as a function of N rate is comparable to the fitted curve using field-observed data (Fig. 2). Statistical analysis indicated that the regression coefficients in the fitted equation of simulated NO_3–N concentration with respect to N rate were within the 95% confidence interval of the fitted curve using observed values. For example, the regression coefficients for simulated NO_3–N concentration were 6.51, 1.26, and 0.0096 for y_0, a, and b, which are within the 95% confidence intervals of observed regression coefficients of 5.72 ± 4.28, 1.26 ± 2.58, and 0.0096 ± 0.0062, respectively. Figure 2 also shows that the 95% confidence intervals of the regression equations overlap, indicating no significant difference between these two fitted curves.

The field experiment indicated that N application rates would need to be less than 112 kg N ha^{-1} to achieve the water quality goal of the MCL for subsurface drainage systems in this region of Iowa. The reductions in NO_3–N concentration were 20% (from 168 to 134 kg N ha^{-1}) and 10% (from 134 to 112 kg N ha^{-1}) (Lawlor et al., 2008). From the fitted curve based on the RZWQM2 simulation, the MCL goal can be reached when N rates were less than 107 kg N ha^{-1} (Fig. 2a). The reductions of NO_3–N concentration were 16% (from 168 to 134 kg N ha^{-1}) and 9% (from 134 to 112 kg N ha^{-1}) from the simulation. Using a curve fitted with simulated average NO_3–N concentration across experimental years, we can interpolate that the MCL goal can be achieved when N application rates are less than 110 kg N ha^{-1} (Fig. 2b). Simulation suggested a reduction in corn yield with reduced N application rates. A logarithm curve fitted using simulated corn yield data with respect to N rate indicated that corn yields were 7969, 7570, and 7180 kg ha^{-1} at N rates of 168, 134, and 107 kg N ha^{-1}, respectively. On the assumption that the price for corn and N were \$315 (\$8 bu^{-1}) and \$1143 metric ton^{-1}, respectively, the net income loss of reducing N rates from

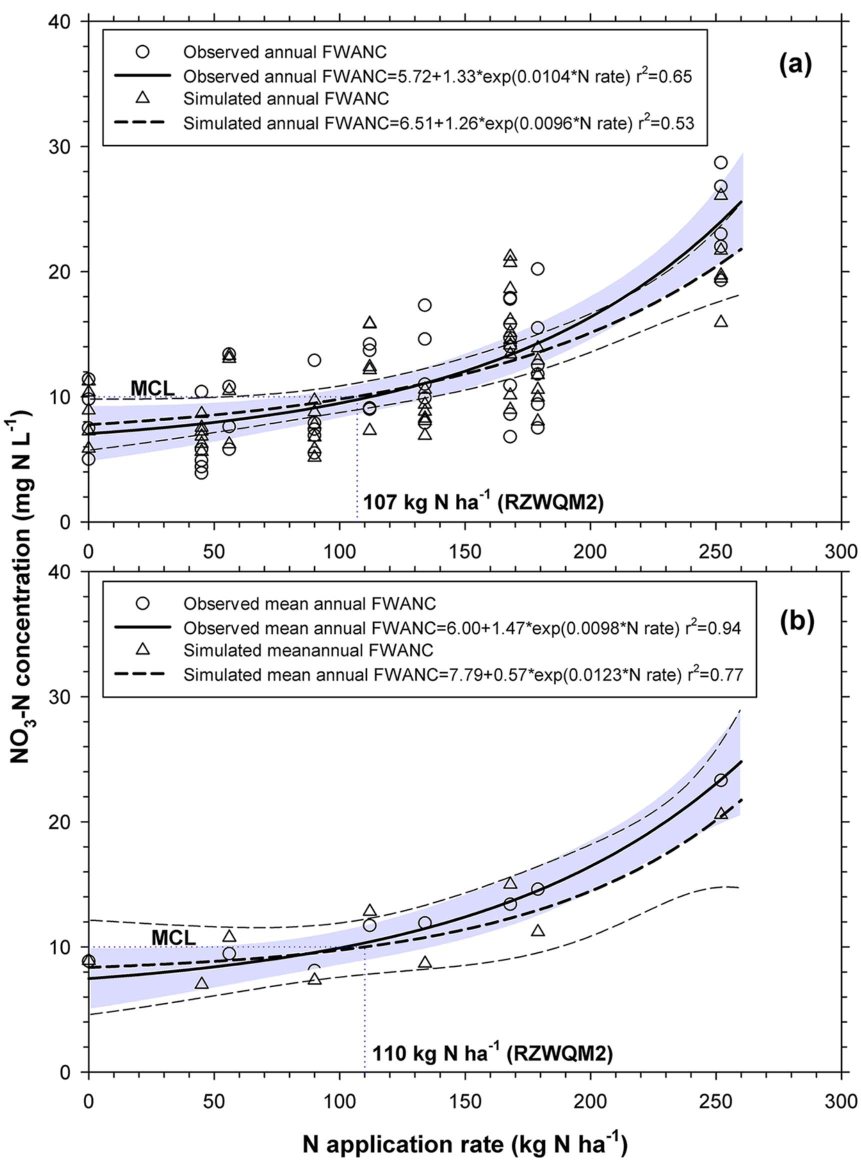

Fig. 2. Observed and simulated NO_3–N concentration at different N rates and their fitted curves using data (a) in individual year and (b) averaged across years (adapted from Lawlor et al., 2008). The shaded areas are within the 95% confidence interval for the fitted curves based on observed NO_3–N concentrations. The thinner short dash lines are the upper and lower boundary of 95% of confidence interval for the fitted curves based on the simulated values. FWANC, flow-weighted average NO_3–N concentration (mg N L^{-1}); MCL, maximum contaminant level; RZWQM2, Root Zone Water Quality Model version 2.0.

168 and 134 to 107 kg N ha^{-1} in corn field were \$31 and \$19 ha^{-1}, respectively.

This study suggests that, with site-specific calibration, the RZWQM2 model is in general a valid tool to simulate the response of NO_3–N concentration at various N application rates in spite of phasic trends in drain flow simulation. To achieve the MCL goal for NO_3–N concentration in drainage effluent, the simulated N application rate is close to the suggested value based on the long-term field investigation. Under a circumstance of limited resources for long-term field experiment, the site-specifically calibrated RZWQM2 model can be used to advise agricultural water quality management.

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