Best Nitrogen Management Practices Can Reduce the Potential Flux of Nitrogen Out of the Arkansas Delta

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Abstract: Some studies have reported that nitrogen losses in the Arkansas Delta can contribute to the flux of nitrogen into the Mississippi River Basin, which can in turn contribute to the nitrate load that the hypoxia problem in the Gulf of Mexico has been attributed to. The need to reduce nitrogen losses in this region can be addressed with the development and validation of robust, new assessment tools that can be used to quickly evaluate management practices and their effects on the environment in terms of potential nitrogen losses and other factors. The recently developed concept of trading nitrogen in air and water quality markets can be used in conjunction with field studies to assess the potential benefits of nitrogen management. In 2008 and 2009, field studies were conducted to collect data to test the new Nitrogen Loss and Environmental Assessment Package (NLEAP) and its ability to simulate nitrate dynamics for different cropping systems grown in three different locations in the Arkansas Delta. Simulation by the NLEAP conducted for cotton, soybean, and corn grown in the Arkansas Delta showed that the model was able to simulate the effects of management on residual soil nitrate ($P < 0.01$). The simulation showed that residual nitrate can range from about 10 to 240 kg NO_3-N ha^{-1} in the top 1.5 m of soil, in agreement with measured values. In addition, long-term NLEAP simulation analysis showed that rotations of soybeans into corn systems significantly reduced emissions of N_2O across this region and reduced NO_3-N leaching losses at the field level.

Key words: delta nitrogen NLEAP, nitrogen trading tool, NTT trading.

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Studies using the ^{15}N isotope have shown that a significant amount, or about one third of the nitrogen fertilizer that is being applied to agricultural fields, can be lost from the root zone (Delgado et al., 2010b; Randall et al., 2008). Quiroga-Garza et al. (2009) used ^{15}N-labeled manure and reported that when manure is applied in excessive quantities, less than 10% of the nitrogen from the applied manure is taken up by the aboveground forage biomass, increasing the potential for nitrogen losses. It is important that we continue developing methods and tools that can help us quickly evaluate the effects of management practices on potential losses of nitrogen to the environment and identify site-specific practices that can be applied to reduce N losses at a particular site.

Two of the main pathways for reactive nitrogen losses to the environment are runoff and leaching (Follett and Delgado, 2002; Meisinger and Delgado, 2002), although in conditions that are conducive to ammonia volatilization a significant amount of NH_3-N can be lost if N sources susceptible to volatilization are applied without following recommended best management practices (Meisinger and Randall, 1991; Hutchinson et al., 1982). Denitrification can also be a major pathway for losses of nitrogen to the atmosphere if anaerobic conditions are developed (Mosier et al., 2002; Meisinger and Randall, 1991; Peoples et al., 1995). Extensive data have been published showing that management is key to reducing N losses via leaching, runoff, denitrification, and ammonia volatilization (Mosier et al., 2002; Meisinger and Delgado, 2002; Meisinger and Randall, 1991; Delgado and Follett, 2010).

Large bodies of water throughout the world are being impacted by eutrophication, including coastal areas (Rabalais et al., 2002a, 2002b). Nitrogen lost from agricultural systems has been reported as being among the nutrients that are flowing to these large bodies of water and contributing to this environmental issue (Mitsch and Day, 2006; Bricker et al., 2007). One of the largest hypoxic zones on earth is between the outlet of the Mississippi River and the northern part of the Gulf of Mexico (Rabalais et al., 2002a, 2002b). It has been reported that a correlation exists between the nitrogen flux from the Mississippi River watershed to the outlet of the Mississippi River and the hypoxic zone in the Gulf of Mexico (Goolsby et al., 2001; Mitsch and Day, 2006).

Agricultural activities, including tile flow and transport of nitrate out of agricultural areas growing corn and soybean in this watershed, are reported to be contributors to this nitrogen flux (Goolsby et al., 2001; Mitsch and Day, 2006). The Arkansas Delta, which is part of the Mississippi River watershed, has also been reported as a contributor to the nitrogen flux to the Gulf (Mitsch and Day, 2006). Nitrate leaching from tile systems in the Midwest has been identified as one of the pathways contributing to the flux of nitrogen from agricultural lands to water bodies (Turner and Rabalais, 2003; Randall et al., 2008; Randall et al., 2010; Mitsch and Day, 2006; Rabalais et al., 2002a; Goolsby et al., 2001). In addition, nitrate leaching from agricultural systems has been reported to contribute to nitrogen levels in groundwaters (Follett and Walker, 1989; De Paz et al., 2009). Ribaudo et al. (2011) reported that the cost to remove nitrate contributed by agricultural land management from U.S. drinking water is about 1.7 billion U.S. dollars per year.

Although quantification of nitrogen losses can be a difficult and complicated process, the use of nitrogen tools (e.g., GPFARM, EPIC, LEACHM, Nitrogen Loss and Environmental Assessment Package (NLEAP), GLEAMS, RZWQM, *ecosys*) can be an approach to quickly estimating the effects of best

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management practices on nitrogen losses (Shaffer et al., 2001; Delgado, 2002; Delgado et al. 2008). A new nitrogen trading tool (NTT) concept was developed as a mass balance method for quickly assessing the potential to use best management practices to increase system nitrogen use efficiency and reduce nitrogen losses to the environment (Delgado et al., 2008; Delgado et al., 2010a; Delgado et al., 2010c). The NTT approach can be used to assess the potential for increasing system nitrogen use efficiency at a field level while generating nitrogen savings that can be traded in water and air quality markets (Delgado et al., 2008, 2010a). The NTT accounts for the nitrogen inputs and outputs of the system (see Delgado et al., 2008, 2010, for additional details). The NTT can assess the total nitrogen losses from the system (including nonreactive losses) as well as total reactive nitrogen losses from the system. A management system that reduces the nitrogen losses is defined as a system that has a higher efficiency and a higher potential for trade of nitrogen savings (Delgado et al., 2008, 2010). In the NTT, a new scenario is compared with a baseline scenario under the same period, and if the new scenario is more efficient, it will have lower reactive nitrogen losses and greater potential to trade nitrogen (Delgado et al., 2008, 2010). Such a tool could be valuable for policies such as water quality trading that require reliable, low-cost estimates of reductions in nitrogen loadings farmers could produce by adopting best management practices. Ribaudo et al. (2011) reported that water and air quality markets could provide financial incentives for farmers to increase system nitrogen use efficiency.

The NTT uses the new Nitrogen Loss and Environmental Assessment Package (NLEAP) (Shaffer et al., 2010; Delgado et al., 2010c), which is a more advanced and more user-friendly version of the Nitrate Leaching and Economic Analysis Package, which is the older, DOS version of the program (Shaffer et al., 1991; Delgado et al., 1998). The new NLEAP can use geographic information system (GIS) data, connect to Internet Web pages, and is capable of assessing the effects of nitrogen management on nitrate leaching, residual soil nitrate, crop uptake, nitrogen dynamics, and N_2O emissions (Beckie et al., 1995; Khakural and Robert, 1993; Delgado, 1998; Shaffer and Delgado, 2001; Delgado and Shaffer, 2008; Delgado et al., 2001; Xu et al., 1998). When this tool has been tested across different regions using basic data such as local weather, soil, and management information, it has performed well. More information about the capabilities and limitations of NLEAP is available in Shaffer and Delgado (2001), Delgado and Shaffer (2008), Shaffer et al. (2010), and Delgado et al. (2010c).

The NTT has not previously been evaluated and tested in the Arkansas Delta. Because the Arkansas Delta is a contributor to the Mississippi River watershed and the Mississippi River outlet that connects to the Gulf, there is the need to evaluate the tool's capability to assess nitrogen dynamics in this region. One of the goals of this article was to evaluate and compare the effects of different cropping systems on observed residual soil nitrate in this region and the ability of the new NLEAP-GIS 4.2 to assess nitrogen practices at the field level and to simulate residual soil nitrate. Another goal was to test the ability of the new NTT to assess the benefits of better management practices in terms of the potential to reduce nitrogen losses to the environment in Arkansas and make these nitrogen savings available for potential trade by farmers.

MATERIALS AND METHODS

Field Studies

Field studies were conducted at the Judd Hill Plantation during 2008 and 2009 where cotton (*Gossypium hirsutum* L.) and corn (*Zea mays* L.) were grown, respectively; at the University of Arkansas during 2008 where corn and soybean (*Glycine max* L.) were grown; and at a commercial farmer's field during 2009 where corn was grown. At each site, a series of plots (20.9 m^2) were established. A procedure similar to that described by Delgado et al. (2000, 2001) was used to study and validate the transport and dynamics of nitrate in the soil profile. Initial and final soil nitrate were measured for each plot at each site. At each site, a complete randomized design was established with three, four, and five replicate plots at the Arkansas State University, Judd Hill Plantation, and the commercial farmer's sites, respectively.

Soil Samples

A soil auger was used to collect soil cores for the initial sample before planting and for the final soil sample collected after harvesting in each plot (Delgado et al., 2000, 2001). At each sampling time, two soil samples were collected in each plot. Each soil sample was collected by sampling in 0.3-m intervals down to 1.5 m. Both soil samples were kept in cool, sealed bags until they were brought to the laboratory, where they were dried, thoroughly mixed, and sent to the Agriculture Diagnostic Laboratory, University of Arkansas, for inorganic N analysis. The initial and final inorganic soil NO_3-N content was determined by extracting dried soil samples with 2N KCl. The NH_4-N and soil organic matter contents were determined for the surface soil sample. The inorganic nitrogen content was determined colorimetrically by an automated flow injection analysis. The dominant soil types at Arkansas State University, Judd Hill, and the commercial field site were Collins silt loam (coarse-silty, mixed, active, acid, thermic Aquic Udifluvents) with a hydrology type C, Dundee silt loam (fine-silty, mixed, active, thermic Typic Endoaqualfs) with a hydrology type C, and Beulah fine sandy loam (coarse-loamy, mixed, active, thermic Typic Dystrudepts) with a hydrology type B, respectively.

Management Information, Weather Information, and Statistical Analysis

Irrigation date and application rate; N fertilizer application date, source, and rate; planting, cultivation and harvesting dates; and other agricultural management practices and information were recorded. The fertilizer rate for the cotton (2008) and corn (2009) grown at the Judd Hill Plantation were 123 kg UAN-N ha^{-1} and 267 kg urea-N ha^{-1}, respectively. The fertilizer rate for corn and soybeans grown during 2008 at Arkansas State University were 209 and 44 kg urea-N ha^{-1}, respectively. The fertilizer rate for corn grown at the commercial farmer's field during 2009 was 224 kg UAN-N ha^{-1}.

Grain yields were collected at harvest for each plot. Climatic data such as daily rain amount, evapotranspiration, and maximum and minimum air temperature at the site were collected from the nearest weather station. Data needed for model calibration/validation and technology transfer efforts were entered into the NLEAP-GIS model, and simulations were conducted. Simulated outputs for NO_3-N in the soil profile were compared with observed NO_3-N in the soil profile for each plot. Correlation between predicted and observed values was calculated using SAS Proc Reg analysis. The simulated values were compared using PROC analysis of variance least significant difference means separation.

Soil Types Used in NTT Assessment

The NTT approach from Delgado et al. (2008, 2010a) using a long-term simulation was used to evaluate the effects of different management scenarios on the N losses from the field, accounting for factors such as the level of N inputs, crop rotations,

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and other management options. This NTT approach was used to conduct a nitrogen mass balance assessment of two different hydrologic soils. A Bruno silt loam (sandy, mixed, thermic Typic Udifluvents) with a hydrology type A that has a larger leaching potential and a Sharkey clay (very fine, smectitic, thermic Chromic Epiaquerts) with a hydrology type D that has a smaller leaching potential were evaluated.

The rationale for using Bruno silt loam and Sharkey clay soils for the NTT evaluation was to use hydrology types at the two extremes. The higher leaching potential of the hydrology A Bruno silt loam was close to the hydrology of the Beulah fine sandy loam, which has a hydrology type B, whereas the hydrology type D of the Sharkey clay was close to the hydrology type of the Collins silt loam and Dundee silt loam, which have a hydrology type C. For the NTT analysis, we assumed that the farmers would adopt one management scenario and would do the same scenario for the same cropping systems (see Table 1 for description scenarios).

Yields and Nitrogen Inputs Used in NTT Assessment

The state average yield for corn derived from the USDA Census of Agriculture, of 6,711 kg ha^{-1}, was used to conduct the simulation for corn growing under conventional tillage with fertilizer applied at a best recommended nitrogen rate. For the excessive nitrogen fertilizer scenarios, a higher yield for corn of 6,778 kg ha^{-1} was used to conduct the NTT simulation of corn grown under conventional tillage. For the excessive nitrogen application scenarios, we assumed that the increase in yields achieved was only 1%, similar to the response curve from Bock and Hergert (1991). The yield for soybean used for the simulations under conventional tillage was the state average of 1,814 kg ha^{-1}. For no-till systems, the corn yields of 6,040 and 6,100 kg ha^{-1} for best nitrogen management and excessive nitrogen management scenarios, respectively, were used. For the no-till systems' yields, we assumed a yield that was 10% lower than what was simulated with the conventional tillage, in agreement with results from Ma et al. (2007) and Halvorson et al. (2006). The yield for soybean used for the simulations under no-till systems was 1,633 kg ha^{-1}.

The rate of nitrogen application for best management practices for Arkansas developed by Espinoza and Ross (2008) was used to calculate the nitrogen rate for the average yields in the NTT evaluation (Table 1). The Espinoza and Ross (2008) rate of N application for Arkansas was based on yields, so the no-till system received a lower nitrogen rate. In the no-till and conventional

TABLE 1. Nitrogen Fertilizer Application Rates[¶] Used for Corn (C) and Soybeans (S) Grown on a Bruno Silt Loam and a Sharkey Clay

	Bruno	Sharkey			
	N Application Rate				
System[¥]	-------kg Urea-N ha^{-1}--------		Inc	RR	SA
Con-CC-BMP	235	245			
Con-CC-BMP-m	235	245	x		
Con-CC-BMP-r	134	140		x	
Con-CC-BMP-t	235	245			x
Con-CC-BMP-rtm	134	140	x	x	x
Con-CS-BMP	176 (0)	186 (0)			
Con-CS-BMP-m	176 (0)	186 (0)	x		
Con-CS-BMP-r	101 (0)	106 (0)		x	
Con-CS-BMP-t	176 (0)	186 (0)			x
Con-CS-BMP-rtm	101 (0)	106 (0)	x	x	x
NT-CC-BMP	196	206			
NT-CC-BMP-m	196	206	x		
NT-CC-BMP-r	112	118		x	
NT-CC-BMP-t	196	206			x
NT-CC-BMP-rtm	112	118	x	x	x
NT-CS-BMP	137 (0)	147 (0)			
NT-CS-BMP-m	137 (0)	147 (0)	x		
NT-CS-BMP-r	78 (0)	84 (0)		x	
NT-CS-BMP-t	137 (0)	147 (0)			x
NT-CS-BMP-rtm	78 (0)	84 (0)	x	x	x

These values were used to conduct NTT simulations of Arkansas cropping systems.

[¥]Best management practices were incorporation of the applied fertilizer (Inc), using a recommended rate (RR), and application of fertilizer in the spring (SA). The treatments receiving any of these best management practices are indicated in the table with an x under the Inc, RR, and/or SA columns. The fertilizer used for all treatments was urea fertilizer.

[¶]No fertilizer was applied to soybeans. Values in parenthesis are application rates for soybeans.

Con: Conventional tillage; NT: no-till; CC: corn-corn rotation; CS: corn-soybean rotation; BMP-t: application of nitrogen fertilizer in the spring; BMP-m: incorporation of fertilizer N when applied; BMP-r: recommended fertilizer N rate using Espinoza and Ross (2008) approach was used (Table 1); BMP: no best management practice is applied (i.e., it is a fall fertilizer application, surface application without incorporation and an excessively higher rate of fertilizer N applied at 75% higher than best rate); BMP-rtm: all best management practices used [i.e., it is a spring N fertilizer application, incorporation of N fertilizer when applied, with recommended fertilizer N rate using Espinoza and Ross (2008) approach].

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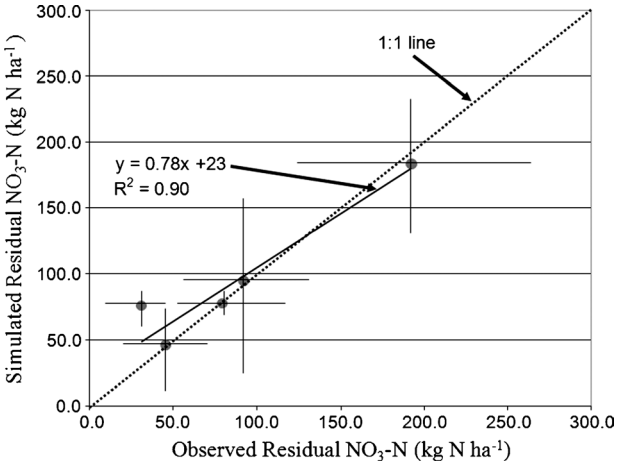

FIG. 1. Simulated versus observed residual soil nitrate after harvesting of Arkansas cropping systems, with S.D.

systems, all the crop residue for corn and soybeans was returned to the system.

For the NTT simulation, soybean did not receive fertilizer application. For all the corn-soybean rotation simulations, a credit was given for the nitrogen cycled from the soybean crop residue. For the corn-soybean simulations using the nitrogen rates recommended by Espinoza and Ross (2008), the credit given to the soybean residue was 33 kg N ha^{-1} (Table 1). For the corn-soybean scenarios that were simulated with the high nitrogen rates, the credit given to the soybean residue was 59 kg N ha^{-1} (Table 1). The excessive nitrogen fertilizer rate had 75% higher nitrogen input than the recommended rate using the Espinoza and Ross (2008) method. The fertilizer used for all scenarios was urea fertilizer (Table 1).

Soil Type (Physical and Chemical Properties) and Weather Data Used in NTT Assessment

The U.S. Department of Agriculture Natural Resources Conservation Service (USDA-NRCS) soil survey data describing the chemical (e.g., soil organic matter content, pH) and physical (e.g., bulk density; silt, clay, and sand content) characteristics for a Bruno silt loam and a Sharkey clay soil were used. The data from the survey were used to run the simulations and are available at the USDA-NRCS Web site: http://soildatamart.nrcs.usda.gov/. The initial soil NO_3-N content in the soil profile of 45 kg N ha^{-1} was used for all the NTT scenarios. The long-term USDA-NRCS weather databases for each county were used to conduct the 24-year assessment, as described in Delgado et al. (2008, 2010a). All scenarios were evaluated for 24 years, following the Delgado et al. (2008, 2010a) modeling approach that was accepted as an approach allowing sufficient time to run 12 years of sequential model initialization, which will be discarded, followed by 12 years of sequential model evaluation, which will be used to assess the system.

Other Best Management Practices Tested With the NTT

For all the NTT scenarios described above (Table 1), the method of application was evaluated for the management practice: incorporation of nitrogen fertilizer was compared with surface application of nitrogen fertilizer without incorporation. Timing of application (spring application of fertilizer vs. fall application) was also tested. All scenarios were evaluated over 24 years following the Delgado et al. NTT (2008, 2010a) method.

RESULTS AND DISCUSSION

Measured Residual Soil Nitrate Content and Simulated Soil Nitrate Content

The NLEAP-GIS 4.2 simulation values for the residual soil nitrate in the top 1.5 m were significantly correlated with measured soil nitrate values (Fig. 1; $P < 0.01$). The model was able to simulate the average residual soil nitrate after harvest for the corn, cotton, and soybean systems.

At the Judd Hill Plantation, the simulated 48 kg NO_3-N ha^{-1} residual nitrate after cotton harvest was lower than the simulated 77 kg NO_3-N ha^{-1} after corn ($P < 0.08$). At Arkansas State University research farm, the simulated 94 kg NO_3-N ha^{-1} residual nitrate after soybeans was lower than the simulated 183 kg NO_3-N ha^{-1} after corn ($P < 0.14$). The average simulated residual soil nitrate of 76 kg NO_3-N ha^{-1} after cotton and soybean was lower than the simulated average after corn harvest of 130 kg NO_3-N ha^{-1}, suggesting that there is potential to improve nitrogen management to reduce the residual soil nitrate after corn harvesting.

Simulated Nitrogen Losses

There was a correlation between the sum of simulated nitrate leaching and simulated denitrification (kg N ha^{-1}) losses and the sum of two measured nitrogen values, the N fertilizer inputs plus the initial soil nitrate content at planting (Fig. 2; $P < 0.01$).

Randall et al. (2008) analyzed ^{15}N isotopic data from different studies that were conducted across U.S. regions and/or other countries, and they reported that the average nitrogen loss from fertilizer applied to cropping systems was 34% of the applied fertilizer. In other words, 34% of the applied nitrogen fertilizer was lost from the fields and was not recovered in the plants or soil profile. A valid assumption would be that the initial readily available and mobile soil nitrate in the soil profile is at least

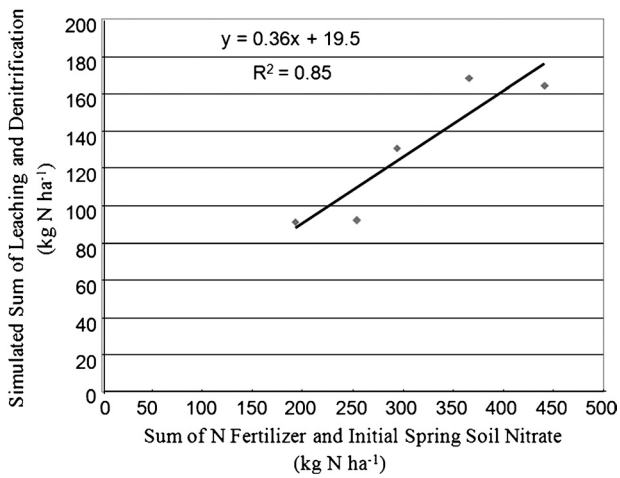

FIG. 2. Simulated sum of nitrate leaching (NO_3-N) and denitrification versus sum of nitrogen fertilizer applied and measured initial residual soil nitrate (NO_3-N) at spring planting for cropping systems in Arkansas.

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as susceptible to nitrogen losses as the readily available nitrogen fertilizer that is added to the system. The sum of the applied nitrogen fertilizer and measured soil nitrate in the profile at planting, shown in Fig. 2, ranged from to 193 to 442 kg N ha^{-1}. Assuming that 34% of the initial soil nitrate and added fertilizer could be lost, the range for estimated nitrogen losses using the published coefficient for nitrogen losses from cropping systems from Randall et al. (2008) is 66 to 150 kg N ha^{-1}.

Our range of simulated nitrogen losses of 90 to 168 kg N ha^{-1} due to denitrification and nitrate leaching across these fields (Fig. 2) is in agreement with the expected average nitrogen losses from fertilizer added to cropping systems, estimated to be 34% by Randall et al. (2008), or 66 to 150 kg N ha^{-1}. Close to 77% of the simulated range of 90 to 168 kg N ha^{-1} of losses due to denitrification and nitrate leaching (Fig. 2) overlaps with the estimated range of nitrogen losses using the Randall et al. (2008) 34% coefficient. We propose that the agreement between the simulated and measured residual soil nitrate and the 77% of agreement of the range of simulated nitrogen losses with the estimated nitrogen losses using the Randall et al. (2008) 34% coefficient supports the proposal that the NTT tool/approach can be used to assess the effects of management on residual nitrate and on nitrogen losses from these systems.

Simulated Nitrate Leaching Losses and Water Inputs

Simulated nitrate leaching was also correlated with the sum of the irrigation and precipitation at the sites (Fig. 3; $P < 0.05$). These results are in agreement with Meisinger and Delgado (2002), who reported that lower water inputs will contribute to a lower nitrate leaching potential. Figure 3 shows that the model is sensitive to water inputs and that in wetter years (e.g., higher water inputs), there is potential for higher nitrate leaching losses.

Simulated Nitrate Leaching Losses and Nitrogen Inputs

At Judd Hill (2009) and Arkansas State University (2008), the corn was fertilized with 269 and 209 kg N ha^{-1}, respectively. The cotton and soybean at Judd Hill (2008) and Arkansas State University (2008) were fertilized with 123 and 44 kg N ha^{-1}, respectively, much lower than the amount applied to corn. At the commercial field (2009), the fertilizer applied to corn was 269 kg N ha^{-1}.

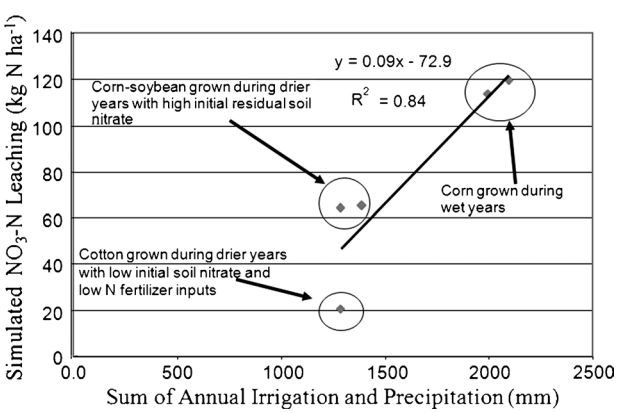

FIG. 3. Simulated nitrate leaching versus sum of annual irrigation and precipitation for fertilized corn, cotton, and soybean systems in Arkansas.

The measured initial soil nitrate content during the spring of 2008 at the soybean and corn plots was about 224 kg NO_3-N ha^{-1}, more than double the measured 96 and 69 kg NO_3-N ha^{-1} initial soil nitrate at planting for corn and cotton, respectively, at Judd Hill. At the commercial field (2009), the measured initial soil nitrate at planting was 97 kg NO_3-N ha^{-1}.

The average simulated nitrate leaching for corn and soybean at the Arkansas State University site was very similar and averaged 65 kg NO_3-N ha^{-1}. It seems that the high initial measured residual soil nitrate of 224 kg NO_3-N ha^{-1} contributed to the simulated leaching in both systems, even though soybeans received only a small application of a starter fertilizer (44 kg N ha^{-1}). The simulated nitrate leaching during the wet 2009 growing season when corn was grown at Judd Hill and that at the commercial field were very similar and averaged 117 kg NO_3-N ha^{-1}. This simulated nitrate leaching for corn was much higher than the simulated nitrate leaching for cotton, soybean, and corn in 2008, a drier year ($P < 0.05$, Fig. 3). The simulated nitrate leaching for cotton was 22 kg NO_3-N ha^{-1} during 2008, which was much lower than the simulated 67 kg NO_3-N ha^{-1} leaching for corn at Arkansas State University in 2008 or the simulated 117 kg NO_3-N ha^{-1} for corn at Judd Hill during the wet 2009 growing season ($P < 0.05$).

NTT Simulation Assessment (General)

We conducted simulations and analysis for corn-corn and corn-soybean rotations grown under no-till and conventional-tillage systems over a long period (24 years) following the approach presented in Delgado et al. (2008, 2010a). We also tested the following best management practices: the application of nitrogen fertilizer in the spring (BMP-t), incorporation of N when applied (BMP-m), and recommended N rate using the Espinoza and Ross (2008) approach (BMP-r). A scenario without any best management practices was also simulated [fall surface application of nitrogen fertilizer without incorporation, with a high rate of N, 75% higher than with Espinoza and Ross (2008) approach] (BMP). A scenario with all best management practices used was also simulated (spring, incorporation of N, with best nitrogen application rate) (BMP-rtm) (Table 1).

NTT Simulation Assessment of Time of Application

The time of application had an effect on nitrate leaching, with fall applications showing a higher nitrate leaching potential (Tables 2 and 3), in agreement with other reports of higher nitrate leaching for management practices that apply fertilizer in the fall (Meisinger and Delgado, 2002; Randall et al., 2008; Williams and Kissel, 1991). However, ammonia volatilization losses were higher in the spring, when warmer conditions were observed, in agreement with several studies that have reported this observation (Hutchinson et al., 1982; Fox et al., 1996; Freney et al., 1981; Sharpe and Harper, 1995; Peoples et al., 1995). Spring applications also increased N_2O emissions, in agreement with several studies that have found higher N_2O emissions from spring-applied nitrogen inputs under warm conditions (Delgado et al., 1996; Rochette et al., 2004; Hernandez-Ramirez et al., 2009). In contrast, Hao et. al (2001) reported a daily flux of 15.6 g N_2O-N ha^{-1} d^{-1} for plots fertilized in the fall with 100 kg N ha^{-1} d^{-1} and plowed in the fall versus 9.5 g N_2O-N ha^{-1} d^{-1} for plots that were plowed in the fall and fertilized in the spring with 100 kg N ha^{-1}.

Although the data are not shown in Tables 2 and 3, when system nitrogen use efficiency was compared for nitrogen incorporated in the fall versus nitrogen incorporated in the spring,

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TABLE 2. Nitrogen Losses (kg N ha^{-1}) for Nitrate (NO_3-N) Leaching (NL), Denitrification (Den), Emissions of Nitrous Oxide (N_2O-N) Trace Gas (TG), Surface Runoff (Runoff), Ammonia Volatilization (NH_3-N), Total N Losses (TNL), Reactive Nitrogen Losses (RNL), and Residual Soil Nitrate (NO_3-N) (RSN) in the Soil Profile of a Hydrology A Bruno Soil in Arkansas

Management Scenario[¥+]	NL	Den	TG	Runoff	NH_3-N	TNL	RNL	RSN	Inc	RR	SA
	kg N ha^{-1}										
Con-CC-BMP	94	15	4	0	54	167	152	64			
Con-CC-BMP-m	148	20	3	0	1	172	152	109	x		
Con-CC-BMP-r	48	10	3	0	31	93	83	20		x	
Con-CC-BMP-t	47	22	9	0	99	177	155	61			x
Con-CC-BMP-rtm	38	21	3	0	1	64	43	48	x	x	x
Con-CS-BMP	36	12	2	0	24	75	63	38			
Con-CS-BMP-m	57	14	2	0	1	75	61	54	x		
Con-CS-BMP-r	26	9	2	0	14	52	43	38		x	
Con-CS-BMP-t	23	12	4	0	45	84	72	38			x
Con-CS-BMP-rtm	20	13	2	0	1	37	24	38	x	x	x
NT-CC-BMP	88	15	4	0	47	154	139	18			
NT-CC-BMP-m	125	18	4	0	3	151	133	31	x		
NT-CC-BMP-r	58	10	3	0	29	100	90	17		x	
NT-CC-BMP-t	40	20	8	0	85	59	39	40			x
NT-CC-BMP-rtm	31	20	5	0	3	153	133	28	x	x	x
NT-CS-BMP	44	12	3	0	20	80	68	34			
NT-CS-BMP-m	55	14	3	0	3	75	61	34	x		
NT-CS-BMP-r	36	10	3	0	13	62	52	34		x	
NT-CS-BMP-t	27	13	5	0	37	81	68	34			x
NT-CS-BMP-rtm	26	13	3	0	3	46	33	34	x	x	x

The values presented for each category in the table represent the total amount of nitrogen loss for that category (e.g., RNL values are *total* reactive nitrogen losses).

[¥]Best management practices were incorporation of the applied fertilizer (Inc), using a recommended rate (RR), and application of fertilizer in the spring (SA). The treatments receiving any of these best management practices are indicated in the table with an x under the Inc, RR and/or SA columns. The fertilizer used for all treatments was urea fertilizer. Treatments that received an application of fertilizer that was incorporated (Inc) are indicated with an x under the Inc column of the table. Treatments without an x under the Inc column were surface broadcasted. Treatments that received a recommended rate based in corn crop production yield goals (RR) were marked with an x for that column; treatments without an x for the RR column received an application 75% higher than the recommended rate. Treatments with fertilizer applied in spring (SA) were marked with an x in the SA column; for treatments without an x in this column, the fertilizer was applied in the fall.

[+]All scenarios were evaluated for 24 years following the Delgado et al. (2008,2010a) modeling approach to evaluate the effects of management scenarios. A period that consists of 12 years of sequential model initialization was followed by 12 years of sequential model evaluation. The above averages represent the averages from years 13 to 24.

Con: conventional tillage; NT: no-till; CC: corn-corn rotation; CS: corn-soybean rotation; BMP-t: application of nitrogen fertilizer in the spring; BMP-m: incorporation of fertilizer N when applied, BMP-r: recommended fertilizer N rate using Espinoza and Ross (2008) approach was used (Table 1); BMP: no best management practice is applied (i.e., it is a fall fertilizer application, surface application without incorporation, and an excessively higher rate of fertilizer N applied at 75% higher than best rate); BMP-rtm: all best management practices used [i.e., it is a spring N fertilizer application, incorporation of N fertilizer when applied, with recommended fertilizer N rate using Espinoza and Ross (2008) approach]. TNL = NL + Den + TG + runoff + NH_3-N. The difference between the TNL and RNL is that the RNL does not account for the losses due to denitrification: RNL: TNL − Den.

the system nitrogen use efficiency was higher for the spring application. This finding is supported by ^{15}N studies conducted by Delgado et al. (1996), which reported overall lower N losses, yet higher N_2O emissions for the spring-incorporated (with irrigation) ^{15}N fertilizer. The model simulations found that when fertilizers are applied in the spring, they have a higher system nitrogen use efficiency (in other words, lower losses of reactive nitrogen), even if the emissions of N_2O are slightly higher (Delgado et al., 1996).

Nitrate leaching was higher for the soil of hydrology type A than the soil of hydrology type D. This is in agreement with principles of hydrology established by several scientists (Williams and Kissel, 1991; Meisinger and Delgado, 2002) (Tables 2 and 3). These principles can be used to apply precision conservation approaches such as management zones to manage hot spots of the field to increase the system nitrogen use efficiency (Delgado, 2001; Khosla et al., 2002; Delgado et al., 2005; Delgado and Bausch, 2005). Precision conservation approaches can be used to reduce the higher potential for nitrate leaching from hot spot areas (Delgado et al., 2005; Delgado and Bausch, 2005), and the NTT has the capability to quickly assess how soil hydrology type may affect reactive N losses via nitrate leaching.

Denitrification and N_2O emissions were much higher in the finer-textured soil, in agreement with previous studies and simulations (Mosier et al., 1996; Delgado et al., 2008; Tables 2 and 3). The losses of reactive nitrogen are higher from a soil with hydrology type A, which can contribute to nitrate leaching losses at a higher rate (Tables 2 and 3); however, total nitrogen losses can be higher in a soil of hydrology type D if the denitrification potential is high, and management of nitrogen (e.g., lower N rate) is important for reducing denitrification

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TABLE 3. Nitrogen Losses (kg N ha^{-1}) for Nitrate (NO_3-N) Leaching (NL), Denitrification (Den), Emissions of Nitrous Oxide (N_2O-N) Trace Gas (TG), Surface Runoff (Runoff), Ammonia Volatilization (NH_3-N), Total N Losses (TNL), Reactive Nitrogen Losses (RNL), and Residual Soil Nitrate (NO_3-N) (RSN) in the Soil Profile of a Hydrology D Sharkey Clay in Arkansas

Management Scenario	NL	Den	TG	Runoff	NH_3-N	TNL	RNL	RSN	Inc	RR	SA
	kg N ha^{-1}										
Con-CC-BMP	74	90	7	1	2	174	84	120			
Con-CC-BMP-m	77	91	6	1	0	174	83	121	x		
Con-CC-BMP-r	25	48	4	1	1	79	31	17		x	
Con-CC-BMP-t	29	128	18	1	5	181	53	67			x
Con-CC-BMP-rtm	6	64	5	1	0	76	12	14	x	x	x
Con-CS-BMP	18	52	4	1	1	77	25	34			
Con-CS-BMP-m	12	36	3	1	1	53	17	34	x		
Con-CS-BMP-r	19	52	4	1	0	76	24	34		x	
Con-CS-BMP-t	10	58	9	1	3	81	23	34			x
Con-CS-BMP-rtm	7	39	4	1	0	50	11	34	x	x	x
NT-CC-BMP	49	39	5	1	54	147	108	29			
NT-CC-BMP-m	84	54	5	1	4	147	93	57	x		
NT-CC-BMP-r	36	23	4	1	32	96	73	15		x	
NT-CC-BMP-t	16	40	9	1	93	158	118	25			x
NT-CC-BMP-rtm	13	39	4	1	4	61	22	16	x	x	x
NT-CS-BMP	27	25	4	1	23	79	54	31			
NT-CS-BMP-m	34	31	4	1	3	72	41	31	x		
NT-CS-BMP-r	23	20	3	1	15	61	41	31		x	
NT-CS-BMP-t	16	24	5	1	40	85	61	3			x
NT-CS-BMP-rtm	16	25	3	1	4	49	77	31	x	x	x

The values presented for each category in the table represent the total amount of nitrogen loss for that category (e.g., RNL values are total reactive nitrogen losses).

[¥]Best management practices were incorporation of the applied fertilizer (Inc), using a recommended rate (RR), and application of fertilizer in the spring (SA). The treatments receiving any of these best management practices are indicated in the table with an x under the Inc, RR, and/or SA columns. The fertilizer used for all treatments was urea fertilizer. Treatments that received an application of fertilizer that was incorporated (Inc) are indicated with an x under the Inc column of the table. Treatments without an x under the Inc column were surface broadcasted. Treatments that received a recommended rate based in corn crop production yield goals (RR) were marked with an x for that column; treatments without an x for the RR column received an application 75% higher than the recommended rate. Treatments with fertilizer applied in spring (SA) were marked with an x in the SA column; for treatments without an x in this column, the fertilizer was applied in the fall.

[+]All scenarios were evaluated for 24 years following the Delgado et al. (2008, 2010a) modeling approach to evaluate the effects of management scenarios. A period that consists of 12 years of sequential model initialization was followed by 12 years of sequential model evaluation. The above averages represent the averages from years 13 to 24.

Con: conventional tillage; NT: no-till; CC: corn-corn rotation; CS: corn-soybean rotation; BMP-t: application of nitrogen fertilizer in the spring; BMP-m: incorporation of fertilizer N when applied, BMP-r: recommended fertilizer N rate using Espinoza and Ross (2008) approach was used (Table 1); BMP: no best management practice is applied (i.e., it is a fall fertilizer application, surface application without incorporation and an excessively higher rate of fertilizer N applied at 75% higher than best rate); BMP-rtm: all best management practices used [i.e., it is a spring N fertilizer application, incorporation of N fertilizer when applied, with recommended fertilizer N rate using Espinoza and Ross (2008) approach]. TNL = NL + Den + TG + Runoff + NH_3-N. The difference between the TNL and RNL is that the RNL does not account for the losses due to denitrification: RNL = TNL − Den.

losses from hydrology type D soils, in agreement with Mosier et al. (2002). From an atmospheric standpoint, emissions of N_2O can also be higher from a finer-textured soil (Mosier et al., 1996; Tables 2 and 3).

NTT Simulated Assessment of Method of Application

Incorporation of the nitrogen fertilizer minimized the nitrogen losses from ammonia volatilization (Tables 2 and 3). However, although incorporation of nitrogen fertilizer reduces atmospheric nitrogen losses, it could contribute to higher nitrogen losses via other pathways such as nitrate leaching and denitrification (Tables 2 and 3). Several studies have reported that incorporation increases N_2O emissions (Flessa and Beese, 2000; Wulf et al., 2002). The NTT (Table 2) showed that N_2O emissions from surface-applied fertilizer applied without incorporation were higher than when the nitrogen inputs were incorporated, contrary to results reported in earlier studies (Flessa and Beese, 2000; Wulf et al., 2002). This suggests that N_2O emissions due to surface application of nitrogen fertilizers without incorporation may be overestimated by the model.

NTT Simulated Assessment of Nitrogen Rate

The best management practice that resulted in a decrease in nitrogen losses for all loss pathways was reduction of nitrogen fertilizer rate (Tables 2 and 3). Matching nitrogen inputs with nitrogen sinks (uptake) is the most effective method for reducing nitrogen losses to the environment along all pathways (Delgado, 2002; Meisinger and Delgado, 2002; Randall et al., 2008; Mosier et al., 2002). Emissions of N_2O increased with excessive nitrogen inputs, which has also been reported in studies by McSwiney and Robertson (2005), Jarecki et al. (2009), and Bouwman et al. (2002). The finding is also in agreement with Mosier et al. (2002), who reported that the best strategy for reducing N_2O emissions

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is to increase system nitrogen use efficiency with lower nitrogen application rates.

NTT Simulated Assessment of Use of a Leguminous Crop in the Rotation

Results presented in Tables 2 and 3 are in agreement with Meisinger and Delgado (2002), who reported that when a leguminous crop is added to the rotation, nitrate leaching losses decrease. Emissions of N_2O and losses of reactive nitrogen to the environment are also reduced, in agreement with results from Delgado et al. (2008). Adding a leguminous crop in the rotation could therefore contribute to increases in the system's nitrogen use efficiency and reduce the losses of reactive nitrogen to the environment (Tables 4 and 5).

NTT Simulated Assessment of Tillage Effects

The effect of tillage on N_2O emissions will be influenced by carbon management, water budgets, and many other factors that will affect hydrology and microbial activities. For example, several studies have reported higher N_2O emissions for conventional-tillage than no-till systems (Almaraz et al., 2009; Ussiri et al., 2009), whereas others have reported that there are no differences

TABLE 4. Nitrogen Trading Tool (NTT) Assessment of the Effects of Different Management Scenarios on Delta Nitrogen Values for Different Loss Pathways and Residual Soil Nitrate of Cropping Systems Grown on a Hydrology A Bruno Soil in Arkansas

Management Scenario[¥]	NL[†]	Den	TG	Runoff	NH_3-N	TNL	RNL	RSN	Inc	RR	SA
	kg N ha^{-1}										
Con-CC-BMP-m	−54	−4	1	0	53	−5	−1	−45	x		
Con-CC-BMP-r	46	5	1	0	23	75	70	44		x	
Con-CC-BMP-t	47	−7	−5	0	−45	−10	−3	2			x
Con-CC-BMP-rtm	56	−6	0	0	53	103	109	16	x	x	x
Con-CS-BMP	58	4	1	0	30	93	97	26			
Con-CS-BMP-m	37	1	2	0	53	93	94	10	x		
Con-CS-BMP-r	68	6	2	0	40	115	109	26		x	
Con-CS-BMP-t	71	2	3	0	9	83	81	26			x
Con-CS-BMP-rtm	74	3	2	0	53	130	133	26	x	x	x
NT-CC-BMP	6	1	0	0	7	13	14	46			
NT-CC-BMP-m	31	−3	0	0	51	17	20	33	x		
NT-CC-BMP-r	36	5	0	0	25	67	62	46		x	
NT-CC-BMP-t	54	−5	5	0	−31	14	19	23			x
NT-CC-BMP-rtm	63	−5	−1	0	51	108	113	36	x	x	x
NT-CS-BMP	50	3	0	0	34	87	84	30			
NT-CS-BMP-m	39	1	1	0	51	92	91	30	x		
NT-CS-BMP-r	58	5	1	0	41	105	100	30		x	
NT-CS-BMP-t	67	3	3	0	18	86	83	30			x
NT-CS-BMP-rtm	68	2	2	0	51	121	119	30	x	x	x

[¥]It is important to note that the values presented in this table are delta nitrogen values (e.g., NL is the change in nitrate leaching). NTT assessment of the effects of management scenarios on long-term changes in N loss. To calculate the change in N loss for a given nitrogen loss pathway, the total N losses from a given management scenario were subtracted from the total losses from the baseline scenario (the baseline scenario used was a corn-corn, conventional tillage rotation with no best management practices used, i.e., excess N applied, fall application, surface application: Con-CC-BMP). A positive value for change in N loss means that the management scenario is reducing the losses via that pathway, and there is potential to trade. A negative value for change in N loss means that the scenario is increasing losses via that pathway. NTT analysis was done on changes in N losses for nitrate (NO_3-N) leaching (NL), denitrification (N_2-N) (Den), emissions of nitrous oxide (N_2O-N) trace gas (TG), surface runoff (runoff), ammonia volatilization (NH_3-N), total N losses (TNL), reactive nitrogen losses (RNL), and changes in residual soil nitrate (NO_3-N) (RSN). Best management practices were incorporation of the applied fertilizer (Inc), using a recommended rate (RR), and application of fertilizer in the spring (SA). The treatments receiving any of these best management practices are indicated in the table with an x under the Inc, RR, and/or SA columns. The fertilizer used for all treatments was urea fertilizer.

[†]Example for NL: change in nitrate leaching loss = [Con-CC-BMP from Table 2 − NL for Con-CC-BMP-m from Table 2] = [94 − 148] = −54.

[+]All scenarios were evaluated for 24 years following the Delgado et al. (2008, 2010a) modeling approach to evaluate the effects of management scenarios. A period that consists of 12 years of sequential model initialization was followed by 12 years of sequential model evaluation. The above averages represent the averages from years 13 to 24.

[++]Treatments that received an application of fertilizer that was incorporated (Inc) are indicated with an x under the Inc column of the table. Treatments without an x under the Inc column were surface broadcasted. Treatments that received a recommended rate based in corn crop production yield goals (RR) were marked with an x for that column; treatments without an x for the RR column received an application 75% higher than the recommended rate. Treatments with fertilizer applied in spring (SA) were marked with an x in the SA column; for treatments without an x in this column, the fertilizer was applied in the fall.

Con: conventional tillage; NT: no-till; CC: corn-corn rotation; CS: corn-soybean rotation; BMP-t: application of nitrogen fertilizer in the spring; BMP-m: incorporation of fertilizer N when applied, BMP-r: recommended fertilizer N rate using Espinoza and Ross (2008) approach was used (Table 1); BMP: no best management practice is applied (i.e., it is a fall fertilizer application, surface application without incorporation and an excessively higher rate of fertilizer N applied at 75% higher than best rate); BMP-rtm: all best management practices used [i.e., it is a spring N fertilizer application, incorporation of N fertilizer when applied, with recommended fertilizer N rate using Espinoza and Ross (2008) approach]. TNL = NL + Den + TG + runoff + NH_3-N. The difference between the TNL and RNL is that the RNL does not account for the losses due to denitrification: RNL = TNL − Den.

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TABLE 5. Nitrogen Trading Tool (NTT) Assessment of the Effects of Different Management Scenarios on Delta Nitrogen Values for Different Loss Pathways and Residual Soil Nitrate of Cropping Systems Grown on a Hydrology D Sharkey Clay in Arkansas

Management Scenario[¥]	NL[†]	Den	TG	Runoff	NH_3-N	TNL	RNL	RSN	Inc	RR	SA
	kg N ha^{-1}										
Con-CC-BMP-m	2	0	1	0	2	1	1	−1	x		
Con-CC-BMP-r	50	42	3	0	1	95	53	103		x	
Con-CC-BMP-t	45	−38	−11	8	−3	−7	31	52			x
Con-CC-BMP-rtm	68	27	2	0	2	99	72	105	x	x	x
Con-CS-BMP	56	38	3	0	1	98	60	86			
Con-CS-BMP-m	62	55	4	0	2	122	67	85	x		
Con-CS-BMP-r	55	38	3	0	0	98	60	86		x	
Con-CS-BMP-t	64	33	−2	0	−1	94	61	85			x
Con-CS-BMP-rtm	67	51	4	0	2	124	73	86	x	x	x
NT-CC-BMP	25	52	2	0	−52	27	−25	91			
NT-CC-BMP-m	−10	37	2	0	−2	28	−9	61	x		
NT-CC-BMP-r	39	67	3	0	−30	79	12	104		x	
NT-CC-BMP-t	59	50	−2	0	−52	16	−34	95			x
NT-CC-BMP-rtm	61	52	3	0	−2	113	61	104	x	x	x
NT-CS-BMP	48	65	3	0	−21	95	30	89			
NT-CS-BMP-m	41	59	3	0	−1	102	43	89	x		
NT-CS-BMP-r	52	70	4	0	−13	113	43	89		x	
NT-CS-BMP-t	59	67	2	0	−39	89	22	89			x
NT-CS-BMP-rtm	59	65	4	0	−1	126	61	89	x	x	x

[¥]It is important to note that the values presented in this table are delta nitrogen values (e.g., NL is the change in nitrate leaching). NTT assessment of the effects of management scenarios on long-term changes in N loss. To calculate the change in N loss for a given nitrogen loss pathway, the total N losses from a given management scenario below were subtracted from the total losses from the baseline scenario (the baseline scenario used was a corn-corn, conventional tillage rotation with no best management practices used, i.e., excess N applied, fall application, surface application: Con-CC-BMP). A positive value for change in N loss means that the management scenario is reducing the losses via that pathway and there is potential to trade. A negative value for change in N loss means that the scenario is increasing losses via that pathway. NTT analysis was done on changes in N losses for nitrate (NO_3-N) leaching (NL), denitrification (N_2-N) (Den), emissions of nitrous oxide (N_2O-N) trace gas (TG), surface runoff (runoff), ammonia volatilization (NH_3-N), total N losses (TNL), reactive nitrogen losses (RNL), and the change in residual soil nitrate (NO_3-N) (RSN) in the soil profile. Best management practices were incorporation of the applied fertilizer (Inc), using a recommended rate (RR), and application of fertilizer in the spring (SA). The treatments receiving any of these best management practices are indicated in the table with an x under the Inc, RR, and/or SA columns. The fertilizer used for all treatments was urea fertilizer.

[†]Example for NL: change in nitrate leaching loss = [Con-CC-BMP from Table 2 − NL for Con-CC-BMP-m from Table 2] = [94 − 148] = −54

[+]All scenarios were evaluated for 24 years following the Delgado et al. (2008, 2010a) modeling approach to evaluate the effects of management scenarios. A period that consists of 12 years of sequential model initialization was followed by 12 years of sequential model evaluation. The above averages represent the averages from years 13 to 24.

[++]Treatments that received an application of fertilizer that was incorporated (Inc) are indicated with an x under the Inc column of the table. Treatments without an x under the Inc column were surface broadcasted. Treatments that received a recommended rate based in corn crop production yield goals (RR) were marked with an x for that column; treatments without an x for the RR column received an application 75% higher than the recommended rate. Treatments with fertilizer applied in spring (SA) were marked with an x in the SA column; for treatments without an x in this column, the fertilizer was applied in the fall.

Con: conventional tillage; NT: no-till; CC: corn-corn rotation; CS: corn-soybean rotation; BMP-t: application of nitrogen fertilizer in the spring; BMP-m: incorporation of N when applied, BMP-r: recommended fertilizer N rate using Espinoza and Ross (2008) approach was used (Table 1); BMP: no best management practice is applied (i.e., it is a fall, surface application with a rate of N application 75% higher than best rate); BMP-rtm: all best management practices used (i.e., it is a spring N fertilizer application, incorporation of N fertilizer when applied, with recommended fertilizer N rate using Espinoza and Ross (2008) approach). TNL = NL + Den + TG + runoff + NH_3-N. The difference between the TNL and RNL is that the RNL does not account for the losses due to denitrification: RNL = TNL − Den.

in N_2O emissions between no-till and conventional-till systems (Abdalla et al., 2010). Some studies have reported that the N_2O emissions are initially higher in the conventional systems, later becoming higher in the no-till systems (Mosier et al., 2006). In general, there is the perception that N_2O emissions are higher in the no-till system (Almaraz et al., 2009; Tan et al., 2009). Six et al. (2004) reported that although initially the N_2O emissions are higher in the no-till system, after 10 years these differences are minimized, and by year 20, the no-till system has lower N_2O emissions.

Similarly, there have been different results reported for the relationship between nitrate leaching and no-till and conventional systems. Cameron and Wild (1984) reported higher nitrate leaching from conventional systems, whereas Bakhsh et al. (2002) reported that a 6-year corn-soybean rotation had higher nitrate leaching in the no-till system compared with the conventional system.

Tables 2 and 3 show that for both soil hydrology types, the nitrate leaching, on average, was higher in the highly intensive corn-corn conventional system with higher nitrogen inputs than

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the corn-corn no-till system, which received less nitrogen fertilizer. However, for the highly intensive conventional corn-soybean rotation with higher nitrogen inputs, there was more nitrate leaching in the no-till system than the conventional system, even though the no-till system received less nitrogen fertilizer.

The N_2O emissions in corn-corn and corn-soybean rotations tended to be higher with the no-till system than the conventional system for the hydrology type A soil, whereas for the hydrology type D soil, N_2O emissions were higher in the conventional system (Tables 2 and 3).

This NTT analysis shows that the adoption of best management practices presents great potential for nitrogen trading (in other words, for increased system nitrogen use efficiency) (Tables 4 and 5). For example, the potential reduction in nitrate leaching that can be traded ranges from -54 to 74 kg N ha^{-1} (Tables 4 and 5). In addition, the potential reduction in N_2O emissions that can be traded ranges from -5 to 9 kg N ha^{-1} (Tables 4 and 5). Delgado et al. (2010a) reported that the NTT approach can even be used to calculate the potential to trade carbon sequestration equivalents generated by implementation of best management practices that directly reduce emissions of N_2O, as well as best management practices that indirectly reduce N_2O emissions by reducing the leaching of nitrate.

The evaluation with the NTT shows that depending on the management scenario, losses of reactive nitrogen could increase or decrease relative to the baseline scenario. Tables 4 and 5 used a conventional corn-corn rotation, with high rates of nitrogen being surface applied without incorporation in the fall, as the baseline scenario. This approach shows that there is potential to evaluate several management practices and to identify the pathways and magnitudes of losses at the field level. If emission markets for air or water quality are developed in the future, the NTT can serve as a tool to assess the trading potential that may be generated from different management decisions and help guide management decisions that can reduce the losses of reactive nitrogen to the environment (Delgado et al., 2008, 2010a). This could prove valuable for the Mississippi Delta region, which has been identified as a contributor to the nitrogen flux that is believed to be contributing to the hypoxia issue in the Gulf.

How this trading will be realized in air and water quality markets is still unknown; however, an NTT analysis of the Mississippi Delta region clearly shows that there are potential benefits to water and air quality if we implement best management practices that reduce the losses of nitrogen across these direct and indirect pathways (Table 2).

This first evaluation of this new model for the region of the Mississippi River basin suggests that the model can be used to assess nitrogen management practices in this region, which has been identified as a critical source of nitrate to the Mississippi River basin and fluxes of nitrogen to the Gulf.

CONCLUSIONS

This study demonstrated that the NLEAP-GIS 4.2 NTT model is capable of assessing different cropping systems during different years and simulating the effects of management on residual soil nitrate in the Arkansas Delta region ($P < 0.01$). The evaluations show that there is a need to account for high initial residual nitrate in the soil when determining optimal fertilizer rates. The results show that there is potential to use soybeans and cotton to lower the nitrate leaching potential during winter, because the measured residual soil nitrate, which will be available to leach after the soybean and cotton harvest, was lower than the measured residual soil nitrate after corn harvest. In addition, the NTT simulations of the soybean-corn rotation suggested lower leaching potential for this rotation than the corn-corn rotation. The addition of cotton and/or soybean into the rotation can potentially reduce the flux of nitrogen out of these systems if they are incorporated into a corn rotation.

Because of the aforementioned environmental concern of nitrogen from this region being transported to the Gulf of Mexico, reducing the flux of nitrogen starting at the field level, and increasing system nitrogen use efficiency to reduce the losses of reactive nitrogen are both desirable from an environmental policy standpoint.

In this article, we evaluated the potential use of the Delgado et al. (2008, 2010a) NTT approach to assess what trading benefits farmers in the Arkansas Delta might potentially gain by improving management practices to increase system nitrogen use efficiency and reduce the potential losses of reactive nitrogen to the environment. Any tools that can help us identify areas where system nitrogen use efficiency can be increased will contribute to minimizing the flux of nitrate to the hypoxic zone in the Gulf. The NTT evaluations show that by implementing best management practices, reductions in nitrogen losses can be achieved in the Arkansas Delta. Reducing nitrogen application rates to match nitrogen uptake rates and accounting for initial soil nitrate levels could help decrease direct and indirect emissions of N_2O, increasing the potential to trade direct and indirect carbon sequestration equivalents. How these potential savings at a field level could be traded remains to be seen, but the potential benefits for this region are significant.

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