Using RZWQM-DSSAT to Simulate Drainage Water Management Across the United States Corn Belt

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Introduction

Drainage water management (DWM) has potential to reduce the amount of nitrate leaving tile-drained agricultural systems in the midwestern United States. Increases in crop yield are also possible with improved management of water in the agricultural system. To practice DWM, a control structure near the outlet of the tile drain is used to adjust the water table depth within the field throughout the season (fig. 1). Environmental and economic benefits may arise from the way in which these adjustments alter the hydrology and nitrogen dynamics within the agricultural system. In this study, the RZWQM-DSSAT hybrid model was used to quantify how DWM altered the cycling of water and nitrogen within tile-drained agricultural fields at 48 locations across the Midwestern United States. The model was calibrated and validated using ten years of data collected at a site in Iowa, and the calibrated model was then used to simulate the performance of both conventional drainage (CVD) and DWM over a 25-year sequence of historical weather information at each of the 48 locations.

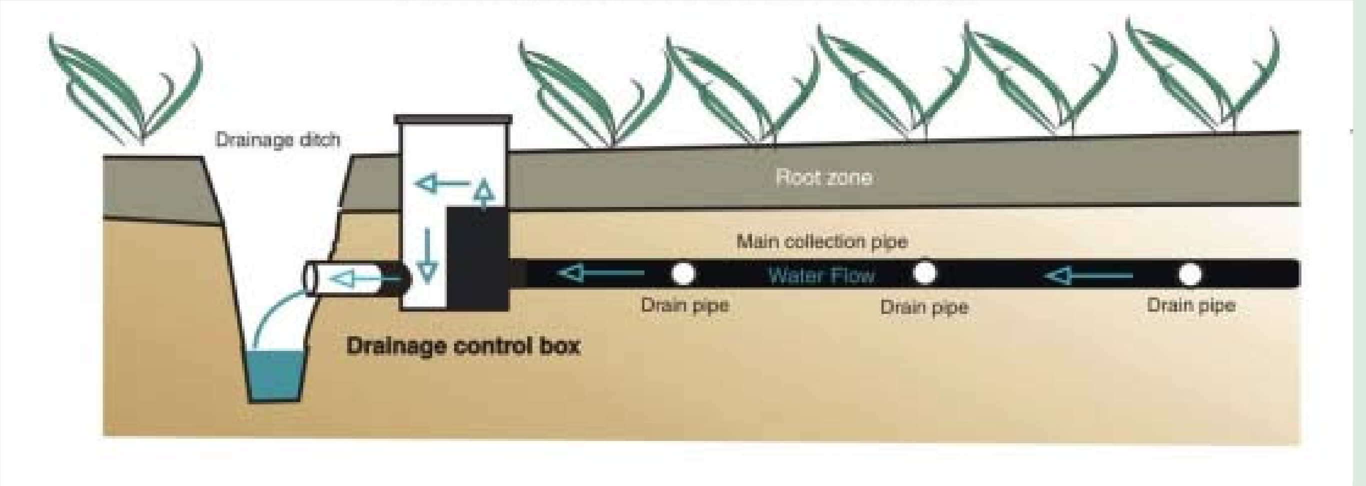

Figure 1. A drainage water management system

Materials and Methods

Developers of the RZWQM agricultural systems model and the DSSAT family of crop growth models have recently collaborated to replace the generic plant growth component of RZWQM with the CERES-Maize and CROPGRO-Soybean crop growth models (Ma et al., 2005; Ma et al., 2006). This model was calibrated using ten years of measured information for a tile-drained agricultural field near Story City, Iowa.

After calibrating the model for the site in Iowa, the site was "relocated" to 48 other locations across the midwestern United States (fig. 2), and simulations of CVD and DWM were run over 25 years of historical climate information for these locations. Climate data for each site was obtained from the National Solar Radiation Data Base also known as the Solar and Meteorological Observation Network (SAMSON) database. Crop planting dates, harvest dates, and cultivar coefficients were adjusted for local site conditions using data from the National Agricultural Statistics Service (NASS), and control gates for DWM were adjusted relative to the planting and harvest dates at each site. Simulated data was then used to compare the cycling of water and nitrogen under 25 years of CVD versus DWM at each location.

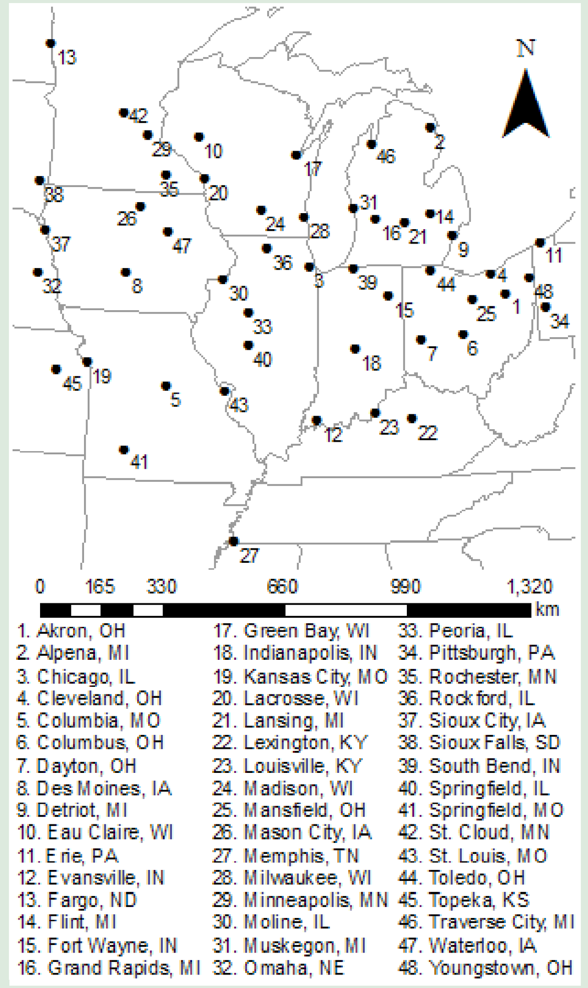

Figure 2. Simulations of CVD and DWM were run at 48 locations over 25 years of historical weather

Results and Discussion

Hydrology

Simulations of the hydrologic balance demonstrated that DWM had the greatest effect on subsurface drainage (fig. 3), followed by surface runoff and evapotranspiration (ET). Drainage water management reduced subsurface drainage by an average of 151 mm yr^{-1} across the region, which corresponded to a 53% reduction over 25 years. Drainage reduction percentages in response to DWM ranged from a 35% reduction (Omaha, NE) to a 68% reduction (Memphis, TN). Under CVD and DWM, subsurface drainage was 32% and 15% of precipitation plus storage losses, respectively (fig. 5). Both the volume of the drain flow reduction (fig. 3a) and the percent reduction of drain flow (fig. 3b) tended to decrease when moving from the southeast to the northwest across the region. Thus, DWM was most effective at reducing drain flow across the southern portions of Missouri, Illinois, Indiana, and Ohio. It was moderately effective in southern Michigan and across the northern portions Missouri, Illinois, Indiana, and Ohio, and it was least effective in Iowa, Minnesota, and Wisconsin.

Decreases in subsurface drainage were offset mainly by increases in surface runoff and ET. The average annual increase in surface runoff across the region was 85 mm yr^{-1}, which corresponded to a 327% increase over 25 years. The percent increase in runoff was large, but the volume of the runoff increase was not excessive due to low simulated runoff values (fig. 5). The average annual increase in ET was 51 mm across the region, which corresponded to an 11% increase over 25 years. Use of DWM did not increase average annual deep seepage by more than 22 mm at any site, and long-term changes in soil water storage were similar between CVD and DWM simulations.

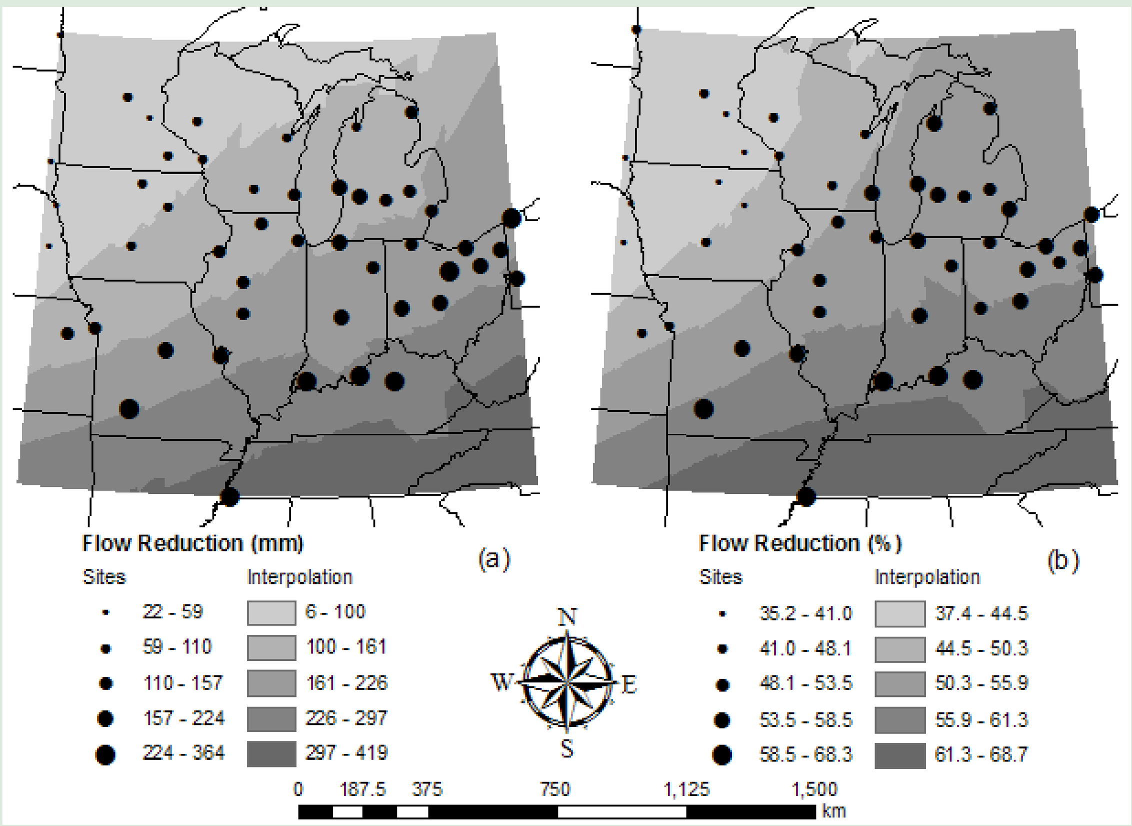

Figure 3. (a) Average annual subsurface drain flow reduction and (b) long-term percent reduction of subsurface drain flow when using DWM instead of CVD

Nitrogen

Simulations of the nitrogen balance demonstrated that DWM had the greatest effect on nitrate in subsurface drainage, followed by soil N storage changes, plant N uptake, N lost in seepage, and denitrification. Drainage water management reduced nitrate in subsurface drainage by an annual average of 19.4 kg N ha^{-1} across the region, which corresponded to a 49% reduction over 25 years. Reduction percentages for nitrate mass in drainage ranged from a 33% reduction (Omaha, NE) to a 56% reduction (Memphis, TN). Under CVD and DWM, subsurface drainage was 13% and 7% of N inputs plus storage losses, respectively (fig. 5). Similar to the patterns of drain flow reduction, both the amount of the nitrate mass

Results and Discussion (cont.)

reduction in subsurface drainage (fig. 4a) and the percent reduction of nitrate loss over the long-term (fig. 4b) tended to decrease when moving from the southeast to the northwestern portions of the region, and DWM was more effective at reducing nitrate losses from subsurface drains in Missouri, Illinois, Indiana, Ohio, and Michigan than in Iowa Minnesota, and Wisconsin.

Decreases in subsurface drainage were offset mainly by increases in stored soil N, plant N uptake, N lost in deep seepage, and denitrification. An interesting result was that, second to nitrate loss in subsurface drainage, DWM had a considerable effect on the amount of N stored in the soil over the long-term. The average annual increase in stored N was 8.5 kg N ha^{-1} across region, mainly due to decreases in N mineralization under DWM. As compared to CVD, DWM increased the average annual plant uptake by 5.9 kg N ha^{-1} across the region, which corresponded to a 3% increase over 25 years. Nitrogen loss in deep seepage increased by 3.2 kg N ha^{-1}, which corresponded to a 20% increase. Since nitrate lost to deep seepage increased under DWM but water loss did not, DWM tended to increase the concentration of N in the lower soil layers. Our results showed only a marginal change in denitrification between CVD and DWM simulations. DWM increased average annual denitrification by 2.9 kg N ha^{-1} across the region; however, that did correspond to a 48% increase. Although the percentage increase was relatively high, the mass of N lost through denitrification is low relative to other pathways. Low denitrification rates may be related to the model calibration (Thorp et al., 2007), in which the denitrification rate coefficient was adjusted to reduce denitrification and close the N mass balance for conditions in Iowa.

The remaining components of the N balance were affected even less greatly under DWM. On average across the region, DWM increased soybean N fixation by 39 kg N ha^{-1} over the entire 25-year simulation, which is only a 3 kg N ha^{-1} increase during each of the 14 soybean years. Volatilization of N did not increase by more than 2.2 kg N ha^{-1} under DWM at any site over the entire 25-year simulation period. Finally, even though DWM greatly increased the volume of surface runoff, the average increase in the amount of N lost in surface runoff across the region was only 15.3 kg N ha^{-1} over the entire 25-year simulation, and no site had an annual average runoff increase greater than 2.6 kg N ha^{-1}. This can be attributed to the method of N fertilizer applications, which were simulated as injections of anhydrous ammonia. Very little nitrate was available for mixing with runoff water on the soil surface.

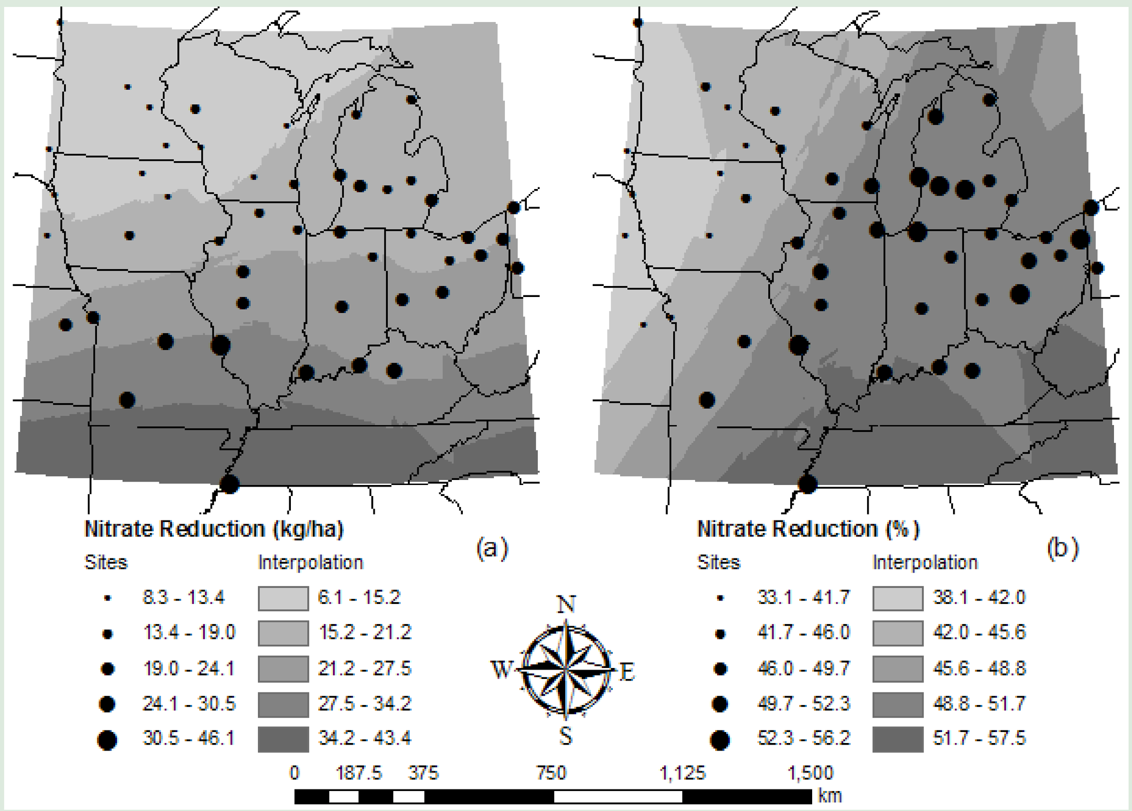

Figure 4. (a) Average annual reduction in nitrate loss through subsurface drains and (b) long-term percent reduction of nitrate loss through subsurface drains when using DWM instead of CVD across the midwestern United States

Results and Discussion (cont.)

For CVD, the percentages of N inputs plus storage losses that moved through air, water, and plant pathways were 2.1%, 19.0%, and 79.0%, respectively (fig. 5). For DWM, the percentages of N inputs minus storage gains that moved through these three pathways were 3.2%, 14.1%, and 82.8%, respectively. Thus, in addition to increasing the amount of stored soil N, simulated DWM also tended to increase the percentage of N flowing through airborne and plant uptake pathways while reducing the percentage of N flowing through waterborne pathways. With a reduction in waterborne N from 56.6 to 41.1 kg N ha^{-1} when using DWM instead of CVD, our simulations showed that, overall across the region, DWM was capable of reducing the amount of N moving through undesirable waterborne pathways by 27.4%.

	CVD			DWM	
	Value	% I+SL[a]		Value	% I+SL[a]
Hydrology					
	mm	%		mm	%
Precipitation	892.9	99.9		892.9	99.9
Runoff	25.9	2.9		111.1	12.4
Evapotranspiration	467.5	52.3		518.8	58.0
Drainage	283.8	31.8		132.7	14.9
Seepage	111.6	12.5		125.3	14.0
Δ Storage	-0.9	0.1		-0.2	0.0
I+SL[b]	893.8	100.0		893.1	100.0
Nitrogen					
	kg ha^{-1}	%		kg ha^{-1}	%
N Fertilizer	93.6	31.4		93.6	32.1
N in Precipitation	7.6	2.6		7.6	2.6
N Fixation	90.3	30.3		91.9	31.5
N in Residue	98.8	33.1		99.2	34.0
Denitrification	6.1	2.1		9.0	3.1
Volatilization	0.3	0.1		0.3	0.1
N in Runoff	0.2	0.1		0.8	0.3
N Uptake	235.7	79.0		241.6	82.8
N in Drainage	40.0	13.4		20.6	7.1
N in Seepage	16.4	5.5		19.6	6.7
Δ Storage	-8.1	2.7		0.5	0.2
I+SL[c]	298.5	100.0		291.8	100.0
Airborne N	6.4	2.1		9.3	3.2
Waterborne N	56.6	19.0		41.1	14.1

[a] % I+SL = Values are expressed as a percentage of I+SL
[b] I+SL = Inputs plus storage losses (Precipitation – Δ Storage)
[c] I+SL = Inputs plus storage losses (Fert+Precip+Fix+Res – ΔS)

Fig. 5. Average annual mass balance for water and nitrogen across the region for CVD and DWM

Conclusions

RZWQM-DSSAT simulations across the climates of the midwestern United States demonstrated that DWM has great potential to reduce losses of nitrate to surface waters. Reduction of nitrate losses in subsurface drainage under DWM ranged from 33% to 56% across the region. When considering the effects of DWM on all undesirable waterborne output pathways for N, including surface runoff, deep seepage, and subsurface drainage, large-scale adoption of DWM across the midwestern United States would reduce nitrate loss by a more conservative 27%. Whereas this has potential to substantially improve water quality in the Mississippi River Basin and reduce hypoxia in the Gulf of Mexico, these results indicate that DWM cannot be the lone solution for solving problems associated with release of agricultural N to the environment. Rather, a more holistic approach involving several different techniques for managing the N imports to and exports from the agricultural system as well as controlling N processes within the system will be required.

References

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