#### Table 5

Mean and its standard error of annual crop yield for conventional drainage (CNV) and drainage water management (DWM) for 2006 to 2009 and the two year averaged yields for each crop.

Yield (Mg ha⁻¹)	2006 corn	2007 soybean	2008 corn	2009 soybean	Average corn	Average soybean
CNV	11.17 ± 0.18	<b>3.90</b> ± 0.04	14.16 ± 0.21	3.80 ± 0.08	12.66 ± 0.47	<b>3.85</b> ± 0.04
DWM	11.52 ± 0.34	<b>4.21</b> ± 0.05	13.98 ± 0.14	4.11 ± 0.06	12.75 ± 0.57	<b>4.16</b> ± 0.07
Note: Bolded numbe	ers in the same colum	n are significantly diffe	erent at <i>p</i> = 0.05.			

ferences by drainage treatment significant, increasing by about 8% averaged over the two soybean years. In 2008, DWM actually resulted in a 0.18 Mg ha<sup>-1</sup> (2.9 bu ac<sup>-1</sup>) lower yield than CNV. This may have been due to the relatively wet weather throughout the growing season in 2008, negating any advantage DWM would have for storing water to use when ET exceeded rainfall and soil water storage. There was no significant difference in yields for corn in either 2006 or 2008 or for the corn years combined.

The lack of corn yield response to DWM found here is similar to that found for corn by Fausey et al. (2004) in Ohio and Grigg et al. (2004) in Louisiana. Fausey et al. (2004) also found no yield response for soybean, while in this study, soybean yields were significantly greater for DWM in 2007 and for 2007 and 2009 combined. Greater yields for DWM compared to CNV were also observed for small grains in two of three years in southern Sweden (Wesström and Messing 2007) with yield increases ranging from 9% to 18%, whereas CNV resulted in 14.5% greater corn yields than DWM in small plots in Nova Scotia, Canada (Smith and Kellman 2011).

The lack of consistent yield responses for DWM may be because DWM holds the water table higher within the soil only when there is excess precipitation. The inability to hold a consistently higher water table may limit DWM compared to systems where a consistently higher water table is maintained through a combination of DWM and subirrigation and in which yield increases of 10% to 64% have been reported for corn and soybean (Fisher et al. 1999; Barnett et al. 1997). However, corn and soybean yields appear to be sensitive to the depth to which a constant water table is held with the greatest yields observed when the water table is at least 0.9 m (3 ft) below the soil surface (Kalita and Kanwar 1993; Busscher et al. 1992). The modest to absent yield benefits observed here for DWM are consistent with modeling studies of DWM across the Midwest that show only about a 3% to 4% yield increase

# Figure 4

Residual soil nitrate concentrations after harvest by soil depth in (a) 2006, (b) 2007, (c) 2008, and (d) 2009, averaged for conventional tile drainage (CNV) and for drainage water management (DWM). The \* indicates depths where the differences are significant (p = 0.05).



with DWM over CNV for corn and soybean with considerable variability across years and locations (Thorp et al. 2008; Ale et al. 2009).

**Soil Nitrogen.** Residual soil NO<sub>3</sub> content after harvest was greater in the CNV treatments than the DWM for most depths and

years (figure 4). For most depths in 2006 and 2009, the differences were significant (p = 0.05), but differences were significant for only two depths in 2007 and no depths in 2008. Residual soil NO<sub>3</sub> contents tended to decrease with depth, perhaps reflecting the

## Table 6

Mean (kg N ha<sup>-1</sup>) and its standard error for residual soil nitrate (NO<sub>2</sub>), ammonium (NH<sub>2</sub>), and mineral N (NO<sub>2</sub> + NH<sub>2</sub>) remaining in the top 1.2 m of the soil profile after harvest for 2006 to 2009 and averaged over all four years.

Variable	2006 corn	2007 soybean	2008 corn	2009 soybean	Average all years
Residual soil NO <sub>3</sub>					
CNV	<b>54.0</b> ± 4.0	<b>46.1</b> ± 2.1	28.4 ± 2.8	<b>27.2</b> ± 1.2	<b>38.9</b> ± 1.7
DWM	<b>33.4</b> ± 2.7	<b>38.2</b> ± 2.8	22.2 ± 1.7	<b>22.9</b> ± 1.6	<b>29.2</b> ± 1.4
Residual soil NH <sub>4</sub>					
CNV	<b>11.2</b> ± 1.1	$11.4 \pm 1.6$	8.2 ± 1.1	9.6 ± 0.8	<b>10.1</b> ± 0.6
DWM	<b>15.4</b> ± 2.2	16.4 ± 2.6	11.5 ± 1.0	$10.4 \pm 0.6$	<b>13.4</b> ± 0.9
Residual mineral N					
CNV	<b>65.2</b> ± 4.2	57.5 ± 2.3	36.6 ± 3.2	<b>36.7</b> ± 1.5	<b>49.0</b> ± 1.8
DWM	<b>48.8</b> ± 3.3	54.6 ± 3.5	33.6 ± 1.6	<b>33.3</b> ± 1.5	<b>42.6</b> ± 1.7

greater soil organic carbon content of the surface and greater amount of decomposing plant residues. Differences in residual soil NO<sub>2</sub> were much more pronounced in 2006 than in the other years. There were greater differences in the drainage treatments in the soybean years of 2007 and 2009 than found by Jaynes and Colvin (2006) for differences by treatment in an N rate and timing experiment conducted earlier on this field. When summed over the top 1.2 m (4 ft) of the soil, the residual soil NO, was significantly less for DWM than for CNV in every year except for 2008 and for all years combined (table 6). Conversely, residual soil NH, was significantly greater in the DWM plots than in the CNV plots in 2006 and for all years combined (table 6). Lower NO, and higher NH<sub>4</sub> concentrations may indicate that the soil environment in the DWM plots was more reducing than in the CNV plots thus favoring the reduced form of N. Less well oxygenated soil would be expected in the soils of the DWM plots due to the generally higher water tables.

Overall, there was less residual mineral N  $(NO_2 + NH_4)$  in the soil of DWM plots than the CNV plots. This is in contrast to Lalonde et al. (1996) who measured no significant difference in either NO<sub>2</sub> or NH<sub>4</sub> concentrations at three depths within the soil. The differences observed here may have been due to greater uptake of N by the crops in the DWM plots. However, there was no significant difference in grain N content between the drainage treatments for any year (data not shown). Grain N content averaged 12.2, 55, 10.5, and 53 g kg<sup>-1</sup> (6.1, 27.5, 5.3, 26.5 lb tn<sup>-1</sup>) or 1.22%, 5.5%, 1.05%, and 5.3% for 2006 to 2009, respectively. The residual soil NO<sub>3</sub> differences may have been due to differences in yield, but yield was only significantly greater for DWM than for CNV in the 2007 soybean year and for the soybean years combined (table 5) and not in the corn years, such as 2006, when the greatest difference in residual soil NO<sub>3</sub> was found. Conversely, more N may have been lost from the soil in the DWM treatment because of increased denitrification (Kliewer and Gilliam 1995). Wesström and Messing (2007) also observed less mineral N in the soil profile at harvest for DWM than for CNV and attributed much of the difference to higher N uptake by the crop.

## **Summary and Conclusions**

During four years (2006 to 2009) of monitoring tile flow from a production field in central Iowa, there was a statistically significant 21% decrease in average tile flow, no significant decrease in average FWANC, and a significant 29% reduction in average NO<sub>3</sub> leaching for DWM compared to CNV. No yield benefits were observed for two years of corn (2006 and 2008), but a significant increase of 8% was observed for the two year (2007 and 2009) average soybean yield. The operation of the DWM systems in this study was based on the scenario described in Skaggs and Gilliam (1981). Modifications of the outlet heights within the control structures and the timing of the raising and lowering of the set heights may have affected the performance for DWM at this site (Ale et al. 2009). However, we are unaware of any research for optimizing the operation of DWM for the soils, climate, and crops in central Iowa.

From the limited four year dataset of this study, it is unclear if the yield increase for soybean versus no increase for corn was due to weather patterns during 2006 to 2009 or because corn and soybean responded differently to the raised water table. Using the 2010 average price for soybean (~\$385 Mg<sup>-1</sup> [\$349 tn<sup>-1</sup>]), the soybean yield increase from DWM would return on average \$65 y<sup>-1</sup> for the 1.1 ha (2.7 ac) area under the influence of the three control structures installed in this study. Given that the cost of the structures and installation is on the order of \$3,000 (Jaynes et al. 2010), the modest vield increase for soybean in this study would not be sufficient to encourage the farmer to adopt DWM just for the yield benefits. Thus, if DWM is to be widely implemented for the water quality benefits it provides, either locations where a greater area of the field is under the influence of the control structures need to be identified (fields with < 0.8% slope studied here), or incentive programs that share the cost of installation and management of the control structures need to be developed to increase the adoption rate.

## Acknowledgements

The author thanks K. Heikens, B. Knutson, J. Cook, and R. Hartwig, technicians at the USDA Agricultural Research Service National Laboratory for Agriculture and the Environment, Ames, Iowa, who conducted most of the field activities for this project, A. Morrow, laboratory supervisor at the USDA Agricultural Research Service National Laboratory for Agriculture and the Environment, Ames, Iowa, who supervised the chemical analyses, and B. Larson and his family, farmers in Story City, Iowa, for collaborating in this research. This research was supported in part by Conservation Innovation Grant #68-3A75-6-116.

## Disclaimer

Names are necessary to report factually on available data; however, the USDA neither guarantees nor warrants the standard of the product, and the use of the name by USDA

implies no approval of the product to the exclusion of others that may also be suitable.

#### References

- Ale, S., L.C. Bowling, S.M. Brouder, J.R. Frankenberger, M.A. Youssef. 2009. Simulated effect of drainage water management operational strategy on hydrology and crop yield for Drummer soil in the Midwestern United States. Agricultural Water Management 96(2009):653-665.
- Bakhsh, A., T.S. Colvin, D.B. Jaynes, R.S. Kanwar, and U.S. Tim. 2000. Using soil attributes and GIS for interpretation of spatial variability in yield. Transactions of the American Society of Agricultural Engineers 43(4):819–828.
- Barnett, N.B., C.A. Madramootoo, and M.N. Mejia. 1997. Economic feasibility of subsurface irrigation in southeastern Ontario. Canadian Agricultural Engineering 39(3):177-186.
- Brevé, M.A., R.W. Skaggs, J.W. Gilliam, J.E. Parsons, A.T. Mohammad, G.M. Chescheir, and R.O. Evans. 1997. Field testing of DRAINMOD-N. Transactions of the American Society of Agricultural Engineers 40(4):1077-1085.
- Brevik, E.C., T.E. Fenton, and D.B. Jaynes. 2000. Evaluation of the accuracy of a central Iowa soil survey and implications for precision soil management. *In* Proceedings of the 5th International Conference on Precision Farming, ed. P.C. Robert et al. Bloomington, Minnesota. 16–19 July 2000. Madison, WI: American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America.
- Busscher, W.J., E.J. Sadler, and ES.Wright. 1992. Soil and crop management aspects of water table control practices. Journal of Soil and Water Conservation 47(1):71-74.
- Colvin, T.S. 1990. Automated weighing and moisture sampling for a field-plot combine. Applied Engineering in Agriculture 6(6):713–714.
- CENR (Committee on Environment and Natural Resources). 2010. Scientific Assessment of Hypoxia in US Coastal Waters. Interagency Working Group on Harmful Algal Blooms, Hypoxia, and Human Health of the Joint Subcommittee on Ocean Science and Technology. Washington, DC: Committee on Environment and Natural Resources.
- David, M.B., L.E. Drinkwater, and G.F. McIsaac. 2010 Sources of nitrate yield in the Mississippi River basin. Journal of Environmental Quality 39:1657-1667.
- Dinnes, D.L., D.L. Karlen, D.B. Jaynes, T.C. Kaspar, J.L. Hatfield, T.S. Colvin, and C.A. Cambardella. 2002. Nitrogen management strategies to reduce NO<sub>3</sub> leaching in tile-drained Midwestern soils. Agronomy Journal 94(1):153-171.
- Evans, R.O., R.W. Skaggs, and J.W. Gilliam. 1995. Controlled versus conventional drainage effects on water quality. Journal of Irrigation and Drainage Engineering 121(4):271-276.

- Fausey, N.R., K.W. King, B.J. Baker, and R.L. Cooper. 2004. Controlled drainage performance on Hoytville soil in Ohio. In Drainage VII Proceedings of the Eighth International Symposium, ed. R. Cooke, Sacramento, California, March 21-24, 2004. St. Joseph, MI: American Society of Agricultural Engineers.
- Fisher, M.J., N.R. Fausey, S.E. Subler, L.C. Brown, and P.M. Bierman.1999. Water table management, nitrogen dynamics, and yields of corn and soybean. Soil Science Society of America Journal 63(6):1786–1795.
- Foth, H.D., and L.M. Turk. 1972. Fundamentals of Soil Science. New York: John Wiley & Sons.
- Gilliam, J.W., R.W. Skaggs, and S.B. Weed. 1979. Drainage control to diminish nitrate loss from agricultural fields. Journal of Environmental Quality 8(1):137-142.
- Goolsby, D.A., W.A. Battaglin, B.T. Aulenbach, and R.P. Hooper. 2001. Nitrogen input to the Gulf of Mexico. Journal of Environmental Quality 30:329-336.
- Grigg, B.C., L.M. Southwick, J.L. Fouss, and T.S. Kornecki. 2004. Climate impacts on nitrate loss in drainage waters from a southern alluvial soil. Transactions of the American Society of Agricultural Engineers 47(2):445-451.
- Helmers, M.J., P. Lawlor, J.L. Baker, S. Melvin, and D. Lemke. 2005. Temporal subsurface flow patterns from fifteen years in North-Central Iowa. ASAE Paper No. 052234. St. Joseph, MI: American Society of Agricultural Engineers.
- Herzmann, D. 2011. Iowa State University Iowa Ag Climate Network [Online]. Iowa Environmental Mesonet. Ames, IA: Iowa State University, Department of Agronomy. http://mesonet.agron.iastate.edu/agclimate/index.phtml.
- Hewes, L., and P.E. Frandson. 1952. Occupying the wet prairie: The role of artificial drainage in Story County, Iowa. Annals of the Association of American Geographers 42(1):24–50.
- High Plains Regional Climate Center. 2011. Automated Weather Data Network. http://www.hprcc.unl.edu/ awdn/et/.
- Jaynes, D.B., and T.S. Colvin. 2006. Corn yield and nitrate loss in subsurface drainage from midseason nitrogen fertilizer application. Agronomy Journal 98(6):1479–1487.
- Jaynes, D.B., T.S. Colvin, D.L. Karlen, C.A. Cambardella, and D.W. Meek. 2001. Nitrate loss in subsurface drainage as affected by nitrogen fertilizer rate. Journal of Environmental Quality 30(4):1305–1314.
- Jaynes, D.B., J.L. Hatfield, and D.W. Meek. 1999. Water quality in Walnut Creek watershed: Herbicides and nitrate in surface waters. Journal of Environmental Quality 28:45-59.
- Jaynes, D.B., T.C. Kaspar, T.B. Moorman, and T.B. Parkin. 2008. *In* situ bioreactors and deep drain-pipe installation to reduce nitrate losses in artificially drained fields. Journal of Environmental Quality 37(2):429-436.
- Jaynes, D.B., K.R. Thorp, and D.E. James. 2010. Potential water quality impact of drainage water management in the Midwest USA. In XVIIth World Congress of the

International Commission of Agricultural Engineering, Québec City, Canada, June 13-17, 2010.

- Johanns, A. 2011. Iowa corn and soybean county yields File A1-14. Iowa State University Extension File A1-14. Ames, IA: Iowa State University Extension. http:// www.extension.iastate.edu/agdm/crops/pdf/a1-14.pdf.
- Kalita, P.K., and R.S. Kanwar. 1993. Effect of water-table management practices on the transport of nitrate-N to shallow groundwater. Transactions of the American Society of Agricultural Engineers 36(2):413-422.
- Kliewer, B.A., and J.W. Gilliam. 1995. Water table management effects on denitrification and nitrous oxide evolution. Soil Science Society of America Journal 59(6):1694–1701.
- Lalonde, V., C.A. Madramootoo, L. Trenholm, and R.S. Broughton. 1996. Effects of controlled drainage on nitrate concentrations in subsurface drain flow. Agricultural Water Management 29(1996):187-199.
- Littell, R.C., J. Pendergast, and R. Natarajan. 2000. Modelling covariance structure in the analysis of repeated measures data. Statistics in Medicine 19(13):1793–1819.
- Rabalais, N.N., W.J. Wiseman, R.E. Turner, D. Justic, B.K. Sen Gupta, and Q. Dortch. 1996. Nutrient changes in the Mississippi River and system responses on the adjacent continental shelf. Estuaries 19(2):386–407.
- Ritchie, S.W., J.J. Hanway, and G.O. Benson. 1989. How a corn plant develops. Special Report No. 48. Ames, IA: Iowa State University of Science and Technology Cooperative Extension Service.
- Robertson, D.M., G.E. Schwarz, D.A. Saad, and R.B. Alexander. 2009. Incorporating uncertainty into the ranking of SPARROW model nutrient yields from Mississippi/Atchafalaya River basin watersheds. Journal of the American Water Resources Association 45(2):534-549.
- Royer, T.V., M.B. David, and L.E. Gentry. 2006. Timing of riverine export of nitrate and phosphorus from agricultural watersheds in Illinois: Implications for reducing nutrient loading to the Mississippi River. Environmental Science and Technology. 40:4126–4131.
- SAS Institute Inc. 1999. SAS On line Doc, version 8. Cary, NC: SAS Institute Inc. http://v8doc.sas.com/sashtml/.
- Skaggs, R.W., and J.W. Gilliam. 1981. Effect of drainage system design and operation on nitrate transport. Transactions of the American Society of Agricultural Engineers 24(4):929-934.
- Smith, E.L., and L.M. Kellman. 2011. Nitrate loading and isotopic signatures in subsurface agricultural drainage systems. Journal of Environmental Quality 40(4):1257-1265.
- Sprague, L.A., R.M. Hirsch, and B.T. Aulenbach. 2011. Nitrate in the Mississippi River and its tributaries, 1980 to 2008: Are we making progress? Environmental Science and Technology 45(17):7209–7216.
- Tan, C.S., C.F. Drury, M. Soultani, I.J. van Wesenbeeck, H.Y.F. Ng, J.D. Gaynor, and T.W. Welacky. 1998. Effect of controlled drainage and tillage on soil structure and tile

drainage nitrate loss at the field scale. Water Science and Technology 38(4-5):103-110.

- Thomas, D.L., P.G. Hunt, and J.W. Gilliam. 1992. Water table management for water quality improvement. Journal of Soil and Water Conservation 47(1):65-70.
- Thorp, K.R., D.B. Jaynes, and R.W. Malone. 2008. Simulating the long-term performance of drainage water management across the Midwestern United States. Transactions of the American Society of Agricultural and Biological Engineers 51(3):961-976.
- Turner, R.E., Rabalais, N.N., and Justić, D. 2006.Predicting summer hypoxia in the northern Gulf of Mexico: Riverine N, P, and Si loading. Marine Pollution Bulletin 52(2):139–148.
- USDA NRCS (Natural Resources Conservation Service). 2010. Assessment of the effects of conservation practices on cultivated cropland in the upper Mississippi River basin. http://www.nrcs.usda.gov/Internet/FSE\_ DOCUMENTS/stelprdb1042093.pdf.
- USEPA-SAB (US Environmental Protection Agency Science Advisory Board) 2007. Hypoxia in the Northern Gulf of Mexico: An Update by the EPA Science Advisory Board. EPA-SAB-08-003. Washington, DC: USEPA-SAB. http://water.epa.gov/type/watersheds/ named/msbasin/upload/2008\_1\_31\_msbasin\_sab\_ report\_2007.pdf.
- Wesström, I., and I. Messing. 2007. Effects of controlled drainage on N and P losses and N dynamics in a loamy sand with spring crops. Agricultural Water Management 87(2007):229-240.
- Wesström, I., I. Messing, H. Linnér, and J. Lindström. 2001. Controlled drainage—Effects on drain outflow and water quality. Agricultural Water Management 47(2001):85-100.
- Zucker, L.A., and L.C. Brown (ed.). 1998. Agricultural drainage: Water quality impacts and subsurface drainage studies in the Midwest. Ohio State University Extension Bulletin 871 Columbus, OH: The Ohio State University.