Increasing Nitrogen Use Efficiency Correlates with Lower Nitrate Concentrations in the Illinois River

By Clifford S. Snyder, Gregory F. McIsaac, and Mark B. David

This article summarizes watershed N balances that were related by McIsaac et al. (2016) to NO_3-N concentrations and loads in the Illinois River in the U.S. from 1976 to 2014.

The watershed residual N balance was helped by higher crop harvest N removal associated with higher crop yields and relatively modest increases in N inputs in more recent years, and this was correlated with lower flow-weighted NO_3-N concentrations in the river.

Increased crop yields, improved cropping system N use efficiency, and depletion of legacy N stored in the soil over time, may help many farmers and governments reach their N loss reduction goals.

Krakozawr/iStock

Aerial view of the Illinois RIver surrounded by a mosaic of farm land.

Loss of NO_3-N via subsurface (tile) drainage in corn-soybean systems in the Midwest U.S. can pose serious eutrophication and related water quality concerns; especially where such water resources are used for drinking water supplies and have concentrations approaching the public health protection standard of 10 mg NO_3-N/L (Ward et al., 2015). Loss of nutrients from soils supporting major cropping and livestock systems within the large Mississippi-Atchafalaya River Basin (MARB) has been estimated to account for up to 60% of the N and 49% of the P entering the Gulf of Mexico (Robertson and Saad, 2013). Those nutrient losses combine with water stratification and coastal currents that favor blooms of algae (or phytoplankton), which die and then contribute to low dissolved oxygen (< 2 ppm) in the relatively shallow waters of the northern Gulf.

In addition to MARB nutrient loss reduction goals reinforced in 2013 by the federal and state agency Hypoxia Task Force, twelve states along the Mississippi River corridor, including Illinois, have developed state-specific nutrient loss reduction strategies aimed at improved local and downstream water quality (EPA, 2015). The Illinois River watershed covers about 40% of Illinois (69,264 km² within the 3.2 million km² MARB), drains parts of northwestern Indiana and southeastern Wisconsin, includes over 90% of the Illinois population, connects the Mississippi River to Chicago and the Great Lakes, and receives sizeable N and P contributions from nonpoint sources and point sources; including loads from the Chicago metropolitan area wastewater treatment discharges (MWRDGC - Metropolitan Water Reclamation District of Greater Chicago). Illinois is estimated to be the largest N-contributing state to N loads reaching the Gulf (Alexander et al., 2008), averaging > 17 kg N/ha/yr, with subsurface tile-drained corn and soybean systems believed to account for the largest agricultural N losses (i.e., 11% of the NO_3-N load and 3.5% of the water delivered annually to the Gulf from 1980 to 2014).

Previous research in tile-drained watersheds has shown that NO_3-N in streams and rivers may be correlated with stream flow, N input amounts and timing, and crop yields. The work reported here addressed the annual residual agricultural N, which was estimated from USDA crop and livestock production statistics, as well as fertilizer N inputs that were estimated for each county in the Illinois River watershed, using Illinois Commercial Fertilizer Sales reports; assuming the same level of fertilizer N consumption as the rest of the state.

Abbreviations and notes: N = nitrogen; P = phosphorus; NO_3-N = nitrate-nitrogen; ppm = parts per million.

Annual residual agricultural N (RAN) was calculated as:

RAN = [fertilizer N + legume N fixation – harvested N adjusted for manure N applied]

Multiple-year cumulative residual agricultural N (CRAN) balances were also calculated using current year and prior year(s) RANs minus river NO_3-N losses. Annual loads and flow-weighted NO_3-N concentrations in the Illinois River were statistically compared with river flow, RAN lagged one year, and CRAN for two to seven years.

Residual Agricultural Nitrogen

During the 1980s to early 1990s, the RAN averaged 22 kg N/ha, with a peak of 43 kg N/ha in the drought year of 1988. From 1998 to 2010, the RAN was consistently below 20 kg N/ha, and declined to a minimum value of 7.7 kg N/ha in 2008 (**Figure 1**).

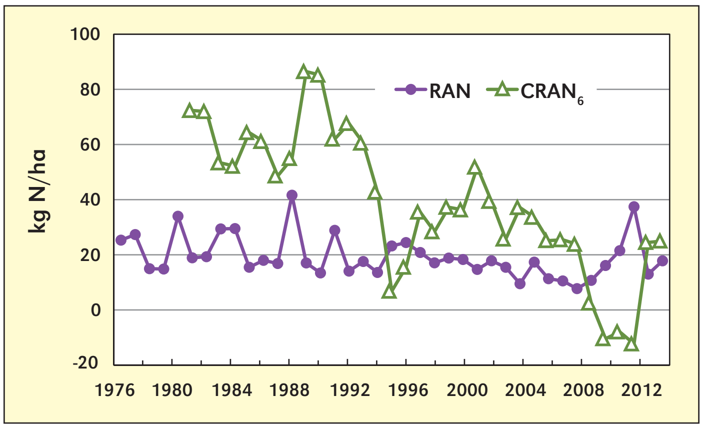

Figure 1. Residual agricultural nitrogen (RAN) and cumulative residual agricultural N over the previous six years ($CRAN_6$) in the Illinois River basin.

River NO_3-N Loads and Concentrations

There was no significant linear trend in Illinois River NO_3-N loads from 1976 to 2014 (**Figure 2**), but declining trends were detected from 1982 to 1989, and from 1993 to 2006, and an increasing trend from 2006 to 2010. The load trends coincide closely with trends in river flow (data not shown). Annual average and November river flow, $CRAN_6$ (previous 6-year cumulative RAN minus 5-year cumulative river N loads), and the MRWRDGC NO_3-N discharge combined to explain 86% of the variation in annual NO_3-N loads.

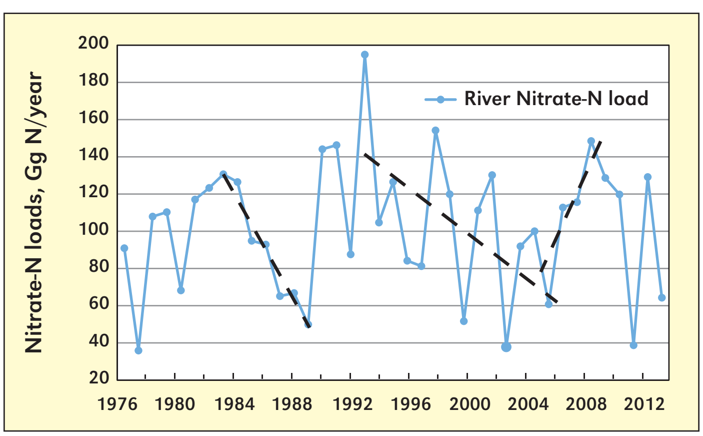

Figure 2. Annual NO_3-N loads in the Illinois River at Valley City, estimated by interpolation. Dashed lines illustrate statistically significant trends for the noted time intervals. Note: 1 Gg = 1,102 short tons.

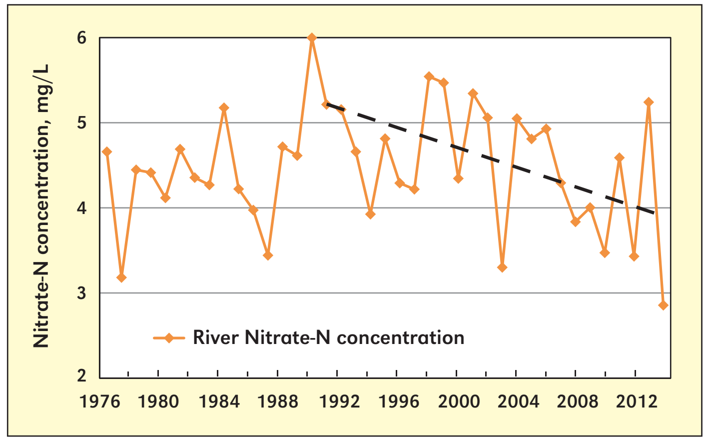

Figure 3. Annual flow-weighted NO_3-N concentrations for the Illinois River at Valley City. Dashed line illustrates statistically significant trend for the noted time interval. Note: 1 mg/L = 1 ppm.

Annual flow-weighted NO_3-N concentrations in the Illinois River varied between 2.9 and 6.0 mg NO_3-N/L, with significant declining concentrations observed from 1990 to 2014 (**Figure 3**). The $CRAN_6$ and MRWRDGC NO_3-N discharge explained 34% of the variation in annual flow-weighted Illinois River NO_3-N concentrations.

These regression results, while not proving cause and effect, suggest that Illinois River NO_3-N loads and concentrations are strongly affected by hydrology, multiple year RAN levels, and NO_3-N discharges from the MWRDGC. Declines in river NO_3-N concentrations after 1990 occurred while fertilizer and manure N use and management in corn production were

Beginning in Chicago, the Illinois River connects the Great Lakes to the Mississippi River.

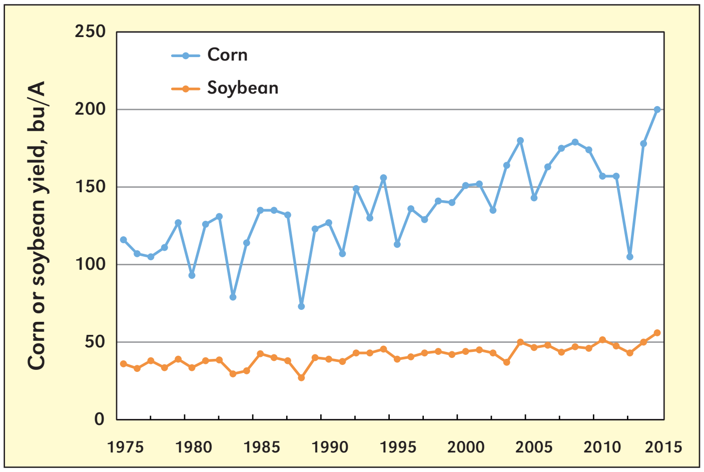

Figure 4. Corn and soybean yields in Illinois, 1975 to 2014. Source: USDA National Agricultural Statistics Service.

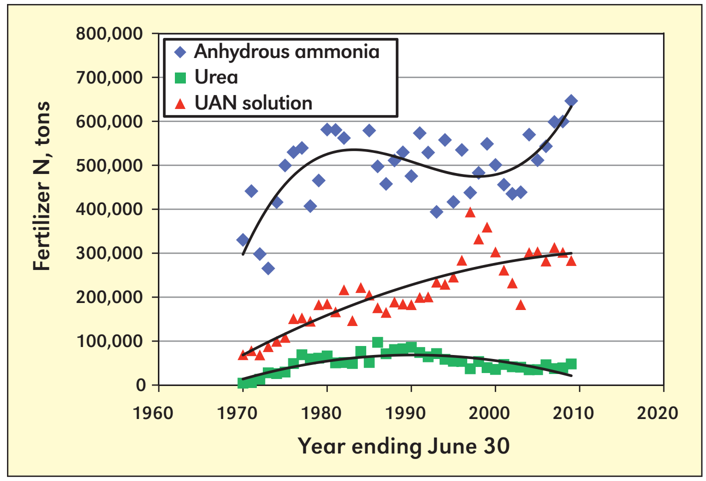

Figure 6. Trends in anhydrous ammonia, urea, and urea ammonium nitrate fertilizer N consumed in Illinois, 1970 to 2009. Note: fertilizer N source data available only through 2009.

becoming more efficient, as indicated by reductions in RAN and $CRAN_6$ since 1990. Higher crop yields (**Figure 4**), and greater crop harvest N removal, in combination with less N application in excess of crop needs, are a plausible explanation for reduced N losses to aquatic resources in the Illinois River watershed.

The improved N use efficiency and reduced NO_3-N concentrations observed in the Illinois River since 1990 occurred even while fertilizer N consumption was trending slightly upward in Illinois after 2001 (**Figure 5**). Beginning in the early 1990s,

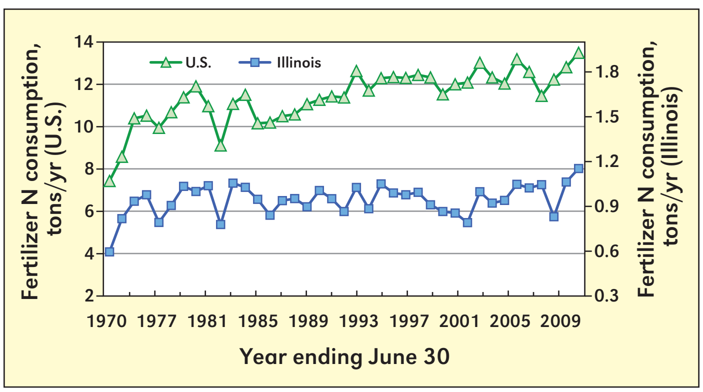

Figure 5. Fertilizer N consumption in Illinois and the U.S., 1970 to 2012.

the consumption of urea ammonium nitrate solutions in Illinois began to grow, compared to the consumption of anhydrous ammonia; then peaked around 2000 and has become more static since. Those fertilizer N consumption changes in Illinois (**Figure 6**) may possibly reflect some shifts in the timing of application; including greater implementation of site-specific tools and technologies (data available only through 2009). In addition, some industry initiatives such as those led by the Illinois Fertilizer and Chemical Association (Payne and Nafziger, 2015) beginning in 2009, may also be having some positive impacts on the more recent declining trends in river NO_3-N concentrations.

Summary

It is difficult to quantify the cropping system, N management, and conservation practices that contributed to lower RAN and $CRAN_6$ values, and improvement in N use efficiency. Straight-forward N budgets used in this study, and other similar studies, can help explain a large proportion of the variations in river NO_3-N loads and concentrations. Meeting nutrient loss reduction goals in the face of more intense precipitation events (that are difficult to predict), drainage, and river flows - associated with a more uncertain climate future - will require greater nutrient stewardship and conservation practice implementation by farmers, their input providers, soil and water conservation professionals, and other watershed stakeholders. Reductions in N and P discharges by municipal point sources should also be given due attention. Such dedicated cooperation and collaboration can help sustain cropping system and environmental improvements in Illinois and elsewhere. BC

Acknowledgement

Fertilizer N source consumption data were provided by Dr. Harry Vroomen with The Fertilizer Institute, Washington, DC.

Dr. Snyder (e-mail: csnyder@ipni.net) was the IPNI Nitrogen Program Director (retired) and also is Adjunct Professor in the Crop, Soil, and Environmental Sciences Department, Division of Agriculture, University of Arkansas. Dr. McIsaac (e-mail: gmcisaac@illinois.edu) and Dr. David (e-mail: mbdavid@illinois.edu) are Professors Emeriti in the Department of Natural Resources and Environmental Sciences at the University of Illinois. Snyder is located in Conway, Arkansas and McIsaac and David are located in Urbana, Illinois

References

Alexander, R.B. et al. 2008. Environ. Sci. Technol. 42:822-830.

EPA. 2015. Hypoxia Task Force Nutrient Reduction Strategies. Mississippi River/Gulf of Mexico Hypoxia Task Force. https://www.epa.gov/ms-htf/hypoxia-task-force-nutrient-reduction-strategies and also Appendix: https://www.epa.gov/sites/production/files/2015-03/documents/hypoxia_annual_federal_strategy_appendix-508.pdf. U.S. EPA.

McIsaac, G.F., M.B. David, and G.Z. Gertner. 2016. J. Environ. Qual. 45:1268-1275.

Payne, J. and E. Nafziger. 2015. Better Crops 99(3):4-6.

Robertson, D.M. and D.A. Saad. 2013. J. Environ. Qual. 42:1422-1440.

Ward, M.H. et al. 2005. Environ. Health Perspect. 113:1607-1614.