

Nitrogen and the Upper Mississippi River

Dennis Keeney
Mark Muller

September 2000

Nitrogen and the Upper Mississippi River

Dennis Keeney
Mark Muller

September 2000

Institute for Agriculture and Trade Policy
2105 First Avenue South
Minneapolis, Minnesota 55404 USA

tel: 612-870-0453
fax: 612-870-4846
email: iatp@iatp.org
url: www.iatp.org

©2000 Institute for Agriculture and Trade Policy

Table of Contents

| | | |
|--|----|----|
| Executive Summary | | 2 |
| Introduction | 3 | |
| The Comings and Goings of Nitrogen | | 4 |
| The Midwest Corn-Soybean Cropping System | 5 | |
| Nitrogen Use and Impacts | | 7 |
| Conclusion | 10 | |
| Literature Cited | | 10 |
| About the Authors | 11 | |

Executive Summary

This purpose of this paper is to open debate about the future of the upper Midwest landscape. It addresses options that can truly reinvent the agricultural systems of the Corn Belt, (coinciding with the Upper Mississippi River Basin) moving this area from one dependent on a grain economy with low economic returns and high nutrient and sediment runoff, to a more ecological based landscape containing nutrient sinks, especially for nitrogen, a legume base for supplementing nitrogen fertilizer, and a high level of management that minimizes nitrogen and phosphorus runoff to the rivers while supporting family farms and strong rural communities. This reinvented agriculture will ultimately benefit the Gulf of Mexico through the reduction in the amount of area affected by hypoxia. The paper is not intended to be a comprehensive review of the literature, nor one that offers solutions to the problems facing the watershed and its owners and operators of the land. Rather it is designed to facilitate discussion of the goals of U. S. agriculture.

Introduction

The Mississippi River is part of the great heritage of this country. A highway for the original Americans, for the explorers, French traders, and settlers and now for the bountiful harvests of modern Midwest agriculture, it has given us much and asked little in return. Unfortunately, we have often not given the river an even break, channellizing, damming, polluting and despoiling it and its habitat. This we do at our peril, for we need this river for the future, just as we need the land and other water resources in the drainage basin. Instead, we have rushed headlong into policies that emphasize production of bulk commodities and development of railroad and barge systems to transport these goods (particularly bulk commodities including grain) to other markets.

Our domination of the land for grain production and the increased dominance of concentrated animal feeding operations (Jackson et al, 2000) has come at a price to the river. Increased sediment, greater nutrient loads, and diminished biodiversity are readily apparent (Downing, 1999). Further domination of the river through the lock and dam system for barge navigation has added to the river's woes. Agriculture has moved toward the industrial model and the farmer is increasingly decoupled from the land.

The Gulf of Mexico, like many other estuaries and coastal areas in the world, has seen major ecosystem changes because of low oxygen levels (hypoxia) caused by excessive inputs of sediments and nutrients arising from industrial and agricultural activities in the watershed. While the area affected by hypoxia ebbs and flows with yearly weather cycles and changes in climate and land use, the ultimate fate of the Gulf of Mexico is more dependent on the ability of the agriculture of the upper Midwest to be more efficient in its use of nitrogen for feed and food crops? Or is it? Are there alternatives that can be proposed that will give us a triple win, lower production costs, lower environmental impact, and higher farm incomes without massive government intervention? We wish to develop here the premise that the use and abuse of nitrogen, be it from soils, fertilizers, or wastes and manures is the heart of the issue. We propose that IATP lead a policy discussion, that examines how much external nitrogen is necessary in U.S. agriculture, and whether appropriate controls on nitrogen use would equitably control prices and production while producing environmental and social benefits. This paper represents the thoughts of IATP regarding nitrogen management in the UMRB The Sustainability Institute, in cooperation with IATP, particularly Dick Levins, have developed a dynamic simulations model (Rice et al, 2000) that helps explain the low corn prices that prevail most years in the corn belt. Policies that strive to increase yield, create new demand, support prices through government payments, or remove land from production produce only temporary price relief. The analysis by Rice et al (2000) dramatically shows the "tragedy of the commons" behavior that pervades U. S. farm policy, providing yield/price cycle that continues unbroken. The paper concludes that new policies that provide environmental incentives, diverse crops and products, are needed.

In conjunction with the oversupply paper by Muller et al, (1999) that questions the assumptions used that the grain moving through the Mississippi River Lock and Dam

system is needed to feed the world, we have developed the hypothesis that increased grain production will exacerbate nitrogen use and losses. The current paper accepts the assumption that nitrogen flows, particularly to the surface waters in the Midwest, is directly linked to the nearly universal corn-soybean rotation. It asks the question: can Midwest agriculture meet the demand for corn while protecting and enhancing natural resources?

The Comings and Goings of Nitrogen

Nitrogen, an innocuous molecule and 79% of the air we breathe, is one of the elements most threatening the global environment (Vitousek et al., 1997, Moffat, 1998). Nitrogen cycles by biological and chemical processes from organic forms to ammonia, may be volatilized to the atmosphere as ammonia or be oxidized by soil bacteria to nitrate, the most water soluble and mobile form of inorganic nitrogen. Nitrate may be taken up by plants, leached, or be converted by biological processes to nitrous oxide and elemental dinitrogen gas, a process called denitrification or. This collection of reactions where nitrogen weaves in and out of various forms and moves through various parts of the environment is known as the “nitrogen cycle”.

The carbon and nitrogen cycles are intimately linked (Asner et al., 1997) and therefore nitrogen is an issue in soil quality, carbon sequestration, water quality and virtually all components of the ecosystem. In its reduced form as ammonia and amides, it is a critical component of life’s building blocks, the amino acids and proteins. Plants need nitrogen for growth: a typical cornfield might tie up 150 to 200 pounds of nitrogen an acre in the fodder and harvested grain. This is more nitrogen than most soils can supply in an available form during the short growing season of a corn crop, even though a fertile soil might have 3,000 pounds or more of nitrogen per acre incorporated in the organic matter. Some of the nitrogen in the corn comes from the soil but fertilizer or other external sources must make up the difference. The need for nitrogen fertilizer often is not one of total supply but of providing adequate nitrogen during the rapid period of corn growth (June to August).

Before human dominance of the world’s ecosystems, the primary source of nitrogen in plants, soils and waters was biological nitrogen fixation (conversion of atmospheric nitrogen, by legumes and free living bacteria to ammonia and organic nitrogen) and from lightning. The ecosystems of the world had adapted to the efficient recycling of nitrogen and little free (available) nitrogen existed. This changed when *homo sapiens* changed from a hunter-gather to an agricultural society.

Dietary changes and population increases expanded the need for cereals and thus more plant available nitrogen. Initially most of this nitrogen came from mining of native organic matter and from domestication of legumes, which were cycled through animals or plowed under to provide nitrogen for crop growth. As demand for food and feed grew, nitrogen fertilizers became essential. We now have reached the point where scientists estimate that the known human sources of nitrogen (fertilizers, legumes and the nitrogen

emitted by internal combustion engines and power plants), is equal to the nitrogen that is produced by natural sources before civilization (Jordan and Weller, 1996; Keeney, 1997; Vitousek et al., 1997).

The doubling of available nitrogen in the active cycles of water, soil and atmosphere has a profound effect on the world's ecosystems. Excess nitrogen in rivers, lakes and groundwater can be toxic to humans, and causes water quality problems in natural water systems (Hallberg and Keeney, 1993). Excess nitrogen in the estuaries of the oceans enhances growth of aquatic organisms to the point that they affect water quality and lower dissolved oxygen levels (Rabalais et al., 1996; Downing, 1999, Howarth, 2000). This affects the metabolism and growth of oxygen requiring species, causing a condition referred to as hypoxia (Rabalais et al., 1996; Downing, 1999). Nitrogen in the atmosphere comes from emission of ammonia from human activities such as feedlots (Jackson et al., 2000) and from combustion sources. This nitrogen contributes, as nitric acid, to acid rain, damaging lakes, rivers and forests. In land ecosystems, excess atmospheric nitrogen may enhance growth of exotic species or accelerate growth of trees, causing disruption of ecosystem functions (Vitousek et al., 1997; Jordan and Weller, 1996) such as over-fertilizing natural grasslands and lakes (Keeney, 1997; Moffat, 1998)

The Midwest Corn-Soybean Cropping System

Many papers and opinion pieces have discussed the current state of agriculture in the Upper Mississippi River Basin (drainage above Cairo, IL-refer to Brezonik et al, 1999 for a more complete description). Mollisols (soils formed under prairie in till and loess and high in organic matter and clay but with poor internal drainage) dominate but there are also Alfisols (soils formed under mixed prairie and forest) that have high clay subhorizons and lower amounts of organic matter and clay in the surface horizons. These soils are highly productive but have poor internal drainage. Subsurface tile drainage of soils in this region is necessary for crop production. Corn and soybean require a well-drained warm soil for optimum growth. But water moves so slowly downward to the water table that soils in the spring are often too wet and cold to be planted to corn or soybean in a timely manner. If a porous tile (farmers now use perforated plastic pipe) is placed below the seasonal water table, water flows to the tile by the force of gravity. Tiles are placed so that water flows to larger collector tile and finally to open ditches. Tile drainage short circuits the natural drainage pattern, and effectively flushes nitrate out of the soil before it is either denitrified or leached to the water table. The tile drainage systems thus become a major source of nitrate to surface water (Randall and Mulla, 1998). Before habitation, this nitrate would have been denitrified in wetlands and ponds, or taken up by prairie grasses. Effectively, human intervention has allowed the agricultural nitrogen cycle to change markedly from its natural state.

Five states (Illinois, Indiana, Iowa, Ohio and Minnesota) comprise the heart of the Corn Belt, and will be referred to as the Upper Mississippi River Basin (UMRB). They have the greatest amount of artificially drained soil, the highest percentage of total land in agriculture (corn and soybean) and the highest use of nitrogen fertilizers in the nation.

The region has abundant precipitation most years for crop growth and only rarely suffers from major yield declines because of drought.

Data analyzed by Goolsby et al (1999) showed that the UMRB generates about 19% of the flow but 43% of the nitrate load to the Mississippi River basin. Two states, Iowa and Illinois, provide 16 and 19% of the nitrate, respectively. These two states have the most intensive corn-soybean cropping systems, the most productive soils, and the highest total nitrogen fertilizer use

The UMRB basin is the most productive agricultural region in the world. Total nitrogen output to the Gulf of Mexico has increased 3 to 7-fold compared to outputs before settlement (Downing 1999). The tributary rivers have been straightened, and dams have been installed on the Mississippi River and many of its major tributaries. Industrialization at the mouth of the river has diminished wetlands and added to the pollutant load.

The apparent result of the dramatic increase in nitrogen input to the Gulf of Mexico has been a major change in the ecology of the Gulf (Rabalais et al., 1996, Downing, 1999). Higher productivity of phytoplankton because of increased nutrient input has provided more organic residue from dead cells. This has led to increased oxygen consumption during decomposition of the material. The result has been the development of an extensive region of oxygen deficiency (less than 2 mg/liter of dissolved oxygen, commonly referred to as hypoxia). This level of dissolved oxygen is below the threshold for survival of most aquatic organisms, hence the popular term, "dead zone." The zone runs roughly directly west from Louisiana to Texas and is the third largest hypoxia zone in the world. (Downing, 1999). The area varies between 12,000 to 18,000 square kilometers in mid-summer during normal to high rainfall years, but is smaller during drought years. (Downing, 1999). For example it was only about 5,000 square kilometers in June of 2000 because of low rainfall in the basin.

Goolsby et al., (1999) recently examined the nitrate loads to the Gulf of Mexico from the Mississippi and Atchafalaya Rivers. Their results indicated that since 1985, the amount of nitrogen released to the Gulf has been more or less constant, varying directly in proportion to the streamflow. Streamflow is related to land drainage. In normal and wet years, much of the excess nitrate (that is nitrate that has not been denitrified or used by plants) is flushed from the soil system. In dry years, it is retained, but in wet years profile drainage flushes the nitrate to the tile systems before it can be used by the corn crop (Randall and Mulla, 1998; Brezonik et al., 1999).

Nitrogen fertilizer use has been approximately constant in the basin over the past 15 years. The increasing yields of corn and soybean without additional fertilizer N implies a more efficient nitrogen using cropping system. Frequently the soil system is sufficiently high in available nitrogen that nitrogen-fixing legumes are not active. Nitrogen cycling at the basin level is not a simple balance sheet process, and other factors may be influencing nitrate output.

The paradox that the UMRB faces is complex and has no simple solutions. Nitrate outputs to the Gulf, largely from the UMRB, are degrading the water quality and aquatic habitat. Nitrogen use efficiency can be increased somewhat by better management and more education but the efficiency gain will be modest. Increases in grain production, forecast by those who desire a competitive environment with other exporting nations, will require more nitrogen fertilizer (for example, a recent yield contest won by a northeast Iowa farmer, used nearly 400 lbs of nitrogen fertilizer per acre to achieve a yield of 397 bushels per acre). While this might be about the same nitrogen efficiency as achieved with a 200 bushels per acre yield, twice as much nitrogen per acre will be lost to the environment if yields were pushed to extremely high levels. If the area currently under corn-soybean is pushed to the upper yield levels that might be forthcoming, not only will a grain glut be almost certain (Muller, 2000), but also prices will decline rapidly (Rice et al, 2000). Under a free market system, massive export increases would be needed to take care of the surplus. Hence the basis for pressure to enlarge the MSR lock and dam system.

Without changes in the agriculture and land use in the basin, it is unlikely that row crop agriculture will decline, and hence that nitrate loads to the Gulf will decrease. The problem is simple: small incremental improvements in nitrogen use efficiency will make little difference. Large reductions in N output, on the order of 30% are needed to affect the Gulf ecosystem (Brezonik et al., 1999). Large changes in the agriculture and nitrogen use in the basin will be required. Let us examine the feasibility of this scenario.

Nitrogen Use and Impacts

Nitrogen is at the root of the UMRB problems. The availability of cheap nitrogen fertilizer – and the complete freedom farmers and farm businesses have to use that nitrogen, leads to buildup of nitrate in the environment. Two rivers in Iowa, the Raccoon River and the Iowa River, are among the highest in the United States for nitrate loss (Goolsby et al, 1999). The associated watersheds of these rivers suffer from eroded soils, clogged rivers and lakes, and declining biodiversity and water quality. It is not a farmer problem we face, but a **system** problem. Can the system be changed enough to “save” the river and the Gulf, or are programs and processes in place that cannot be stopped?

Jules Pretty uses the phrases “Efficiency, Substitution, and Reinvention,” to describe the various phases that agriculture must pass through before it is sustainable. (Vorley and Keeney, 1998). In almost all cases, proposals to reduce the Mississippi River watershed nitrogen load stop at the efficiency phase. Improved nitrogen management including soil and plant testing, more timely applications, precision agriculture, all are efficiency messages (best management practices) that echo the management that got the ecosystem in trouble in the first place (a student of soil fertility history would see little new in the efficiency proposals from those of the past). Incorporation of improved management practices will help address the problem of high nitrate in the Mississippi River, but it is apparent that nitrogen outputs can not be reduced sufficiently with even improved management practices to meet the 30% reduced nitrogen load target. The concept of substitution, that works at least in theory for pest control, is

not easily carried out for nitrogen. The only substitution in fact is nitrogen-fixing legumes in place of fertilizers, an age-old practice that was finely honed in the first half of the last century, but abandoned quickly when nitrogen fertilizers came on the scene. And few would argue that agriculture based on nitrogen-fixing legumes would be sufficiently productive to meet feed and food needs for the next decade. Too much land would be required for the legumes; the amount of nitrogen fixed is variable depending on weather and disease and insect infestation. But there are ways that issue can be addressed for the good of all.

But many advantages would accrue with a system that relied principally on nitrogen fixation, with fertilizers as the “topping off” agent. Rotations including several years of legumes (the pre-1950 model) would greatly lessen weed pressures, break insect and soil borne pathogen cycles and provide a diverse agriculture much more suited to smaller land holdings and “family farming.” Importantly, soil erosion would be markedly reduced because of the high soil quality resulting from forage growth, and the long times for soils to be under perennial cover. Carbon would be sequestered in the soils, lowering the carbon dioxide level in the atmosphere. Further, nitrous oxide, another powerful greenhouse gas largely derived from oxidation of ammonium would be reduced, providing a win-win for the climate change issues facing the world.

Reinvention of agriculture will have its strong critics. Most would first bring up the issue that a lower productive agriculture would not feed the world, would not save land for wildlife, would impoverish the farm sector, and most importantly, would not serve their corporate interests. These criticisms can be addressed.

Let’s start at the basics: nitrogen. It is needed for corn and at relatively low levels for wheat. Wheat has a low impact on the environment because its nitrogen demands are not great and it is grown in the western part of the MSRB where leaching is far less than in the humid east, consequently wheat and other small grains are not included in this analysis. Nitrogen also is not needed on soybean, although today’s high yielding varieties normally remove more soil nitrogen than they fix, thereby depleting the soil organic matter. Soybean would be included as a part of the rotation, just as is the case now, following probably two years of corn preceded by 3-4 years of a legume. Soil rebuilding would occur during the legume phase. Other crops would include sunflower and canola. No new crops or infrastructure would be needed for this system. All erosive land would be relegated to longer-term rotations or to more permanent forage systems such as rotational grazing systems that greatly improve returns from dairy and beef. This is a tried and true technology that adapts well to family farming.

Rates of land application of swine, dairy and beef manures would be based on phosphorus-needs. This will create problems for the concentrated animal feeding operations that now dispose of manure on legumes in addition to corn (Jackson et al, 2000). We call this disposal, because putting manure on legumes is putting a resource in the wrong place just to get rid of it. Concentrated animal feeding operations that do not have sufficient land available would be required to adopt secondary treatment including N removal. Very likely methane capture could be included in secondary waste treatment,

increasing returns from waste handling and lessening global impact of methane. Pasture and hoop-house raised swine provide an environmentally friendly alternative to large operations. The concepts could be applied to poultry and beef operations.

Instead of solely being dedicated to feed grains, fragile lands could be converted to perennial energy crops such as switchgrass and coupled with locally owned and operated ethanol and electricity plants. The grassland systems would need to be integrated with a nitrogen-fixing legume, eliminating the need for nitrogen fertilizers. (Nitrogen fertilizer production, transport and application releases considerable carbon dioxide and thus biomass systems for energy and carbon sequestration cannot be based on systems requiring nitrogen fertilizer if they hope to alleviate global climate change).

Alfalfa is a source of high quality protein, but it has the disadvantage of high processing costs. These can be overcome by the use of improved plant varieties and new technologies. The University of Wisconsin conducted considerable research on the use of alfalfa for food protein a number of years ago, and there is data to build from. This concept is now being considered in Europe as a substitute for soy protein. Transferring much of the intellectual input and marketing currently going into corn to alfalfa would lead to breakthroughs that would cause us to regard alfalfa as the miracle plant of the future.

Along with the extensive cropping system reinvention would come enhanced efforts on value added (adding value to crops in the local economy, not padding the profits of a large corporation), and growing foods locally. Because large tracts of corn-soybean land would not be the norm, more opportunities would exist for local foods and for community supported value added programs. The smaller family farmers will be the main beneficiaries of this new agriculture.

Pesticide use would be greatly reduced because of the breaking of pest cycles with the extended rotations. Ways would be needed to provide an acceptable seed bed for grains following alfalfa without use of the moldboard plow. The concept of using fertilizer nitrogen as a policy tool is not new. It was discussed by Levins and Schmitt (1995) in the form of green payments. Smith et al (2000) also considered nitrogen fertilizer reductions as a lowest cost way to achieve nitrogen control.

Conclusion

We need to reassess agricultural priorities in the Midwest. Hypoxia in Gulf of Mexico, high nitrogen concentration in surface and ground waters, high levels of erosion and siltation and global climate change are symptoms that the systems are out of control.

Expanding locks and dams and increasing feed grain production will only exacerbate these local, regional and global problems. Our first priorities should be to foster an agriculture that creates healthy food systems, protects natural resources and revitalizes rural communities and family farms. We propose that a reinvented agriculture based on defining options that replace or greatly reduce the need for nitrogen in row crops is a key component of policies that would achieve these objectives.

Literature Cited

Asner, G. P., T. R. Seastedt, and A. R. Townsend. 1997. The decoupling of terrestrial carbon and nitrogen cycles. *BioScience* 47:226-234.

Brezonik, P. L. et al. 1999. Effects of reducing nutrient loads to surface waters within the Mississippi River Basin and Gulf of Mexico. (D. R. Keeney is one of the authors). NOAA Coastal Ocean Program Analysis Series.

Downing, J. A. (chair) et al. 1999. Gulf of Mexico Hypoxia: Land and Sea Interactions. CAST Task Force Report 134.

Goolsby, D. A. et al., 1999. Fluxes and sources of nutrients in the Mississippi-Atchafalaya River Basin. (D. R. Keeney is one of the authors). NOAA Coastal Ocean Program Decision Analysis Series.

Hallberg, G. R. and D. R. Keeney. 1993. Nitrate. Pp 297-332. In *Regional Ground-water quality*. W. M. Alley, ed. Van Nostrand Reinhold, N. Y.

Howarth, R. W. 2000. *Clean Coastal Waters: Understanding and reducing the effects of nutrient pollution*. National Academy of Sciences Washington, DC.

Jackson, L. L., D. R. Keeney and E. M. Gilbert. 2000. Swine manure management plans in north-Central Iowa: Nutrient loading and policy implications. *J. Spoil Water Conserv.* 55:205-212.

Jordan, T. E. and D. E. Weller. 1996. Human contributions to terrestrial nitrogen flux. *Bioscience* 46:655-664.

Keeney, D. R. 1997. What goes around comes around-the nitrogen issues cycle. Dahlia Greidinger Symposium on fertilizer and the environment, Technion0Israel Institute of Technology, Haifa, Israel. March, 1997.

Levins, R. A. and M. A. Schmitt. 1995. Green programs. A Corn Belt example of one way to reduce nitrogen use. CHOICES. Second Quarter 1995. Pp. 24-26.

Moffat, A. S. 1998. Global nitrogen overload problem grows critical. Science 279:988-999.

Muller, M, R. Levins and B. Vorley. 1999. An assessment of the assumptions and assertions used in the Mississippi River navigation debate and the project's impact on family farms and the river Institute for Agriculture and Trade Policy Report to the McKnight Foundation.

Rabalias, N. N., R. E. Turner, G. Dortch, W. J. Wiseman, J. R., and B. K. Sen Gupta. 1996. Nutrient Changes in the Mississippi River Basin and system responses on the adjacent continental shelf. Estuaries 19:396-407.

Randall, G. W., and D. J. Mulla. 1998. Nitrate-N in surface waters as influenced by climatic conditions and agricultural practices. In Hypoxia around the world: Causes and solutions. Soil Sci Soc. Amer. (in press).

Rice, P, E. Sawin and D. Meadows. 2000. The corn systems project: Defining an economically and ecologically sustainable commodity corn system. Sustainability Institute. Hartland Four Corners, VT.

Smith, M. E., M. A. Peters, J. P. Sullivan, U. Vsavada, and T. M. Worth. 2000. Curbing nitrogen runoff: effects on production & trade. Agricultural Outlook. May 2000. P. 19-21.

Vitousek, P. M., J. D. Aber, R. M. Howarth, G. E. Likens, P. A. Watson, D. W. Schindler, W. H. Schlesinger, and D. W. Tilman. 1997. Human alterations of the global nitrogen cycle: sources and consequences. Ecological Applications 7:737-750.

Vorley, W. and Keeney, D (ed). 1998. Bugs in the System: Redesigning the pesticide industry for sustainable agriculture. Earthscan Publications Ltd. London. 222 p.

About the Authors

This report was prepared by Dennis Keeney and Mark Muller. Dr. Keeney is a Senior Fellow at the Institute for Agriculture and Trade Policy and former Director of the Leopold Center for Sustainable Agriculture at Iowa State University. Mark Muller is a Senior Associate at the Institute for Agriculture and Trade Policy.

About the Institute for Agriculture and Trade Policy

The Institute for Agriculture and Trade Policy (IATP) was established in 1986 as an independent non-profit and tax-exempt research, education and advocacy organization. The Institute for Agriculture and Trade Policy promotes resilient family farms, rural communities and ecosystems around the world through research and education, science and technology, and advocacy.

Institute for Agriculture and Trade Policy
2105 First Avenue South
Minneapolis, MN 55404

Tel: 612-870-0453
Fax: 612-870-4846
e-mail: iatp@iatp.org
url: <http://www.iatp.org>

Comments or questions on this paper can be directed to Mark Muller at (612) 870-3420, or mmuller@iatp.org

This project has received generous financial support from the McKnight Foundation. We also thank Dr. Gyles Randall and Dr. Patrick Brezonik for their reviews of this report.