SCIENCE AND STAKEHOLDER ENGAGEMENT ON 4R NUTRIENT STEWARDSHIP, SUSTAINABILITY AND NUTRIENT PERFORMANCE INDICATORS: A RECENT CENTRAL TO EASTERN U.S. AND GLOBAL PERSPECTIVE

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ABSTRACT

Farmers and society are becoming more aware of the need to better protect water, air and soil resources. The focus of the International Plant Nutrition Institute (IPNI) is on responsible nutrient management and stewardship to support the needs of the growing human family. Since 2007, IPNI has been more actively engaged with university scientists, federal and state agencies, agribusiness associations, crop advisers, and nongovernmental partners to get more of the applied nutrients - especially fertilizer nitrogen (N) and phosphorus (P) - into the standing crop and retained in the soil. By getting more of the applied nutrients into the crop, it is expected that losses to water and air resources will be minimized and soil health will be protected and improved. Leading examples of several IPNI science efforts in key stewardship and sustainability arenas will be shared in this paper, including: 1) greenhouse gas emission, water quality, soil carbon and soil health metrics within the Fieldprint Calculator of the Field to Market Alliance for Sustainable Agriculture; 2) enhanced efficiency fertilizers within the 4R concept to protect crop yields while minimizing global agricultural nitrous oxide emissions; 3) 4R nutrient stewardship and N research to protect local surface water quality, help address state nutrient loss reduction strategies, and lessen downstream loads to major rivers and the Gulf of Mexico; 4) N management research needs and management guidance to protect and increase crop yields, soil health and cropping system resiliency in the face of climate change; 5) state agribusiness and conservation group engagement to cope with local nitrate drainage and drinking water challenges; and 6) integrated N management solutions addressing interests of the Environmental Defense Fund (EDF), the United Nations Environment Program Global Partnership on Nutrient Management (GPNM), the Organization for Economic Cooperation and Development OECD), the International Nitrogen Initiative (INI) and the International Nitrogen Management System (INMS).

INTRODUCTION

While most of the participants in the Western Nutrient Management Conference recognize the vital importance of fertilizer nutrient inputs for the provision of safe, nutritious food and fiber and biofuel for the needs of the human family, too many of those unfamiliar with agriculture continue to perceive that further inputs of those essential nutrients poses unacceptable risks to the environment (e.g. Sutton et al., 2013; Sobota et al., 2015). Unfortunately, too few outside of commercial agriculture and horticulture recognize that a large portion of Earth's population (~40 to 50%) owes its daily existence to the food supply and human nutrition made possible by fertilizer inputs in the U.S. and around the world (Stewart et al., 2015; Erisman, 2008).

Some of the more prominent nutrient loss issues in the eastern and central U.S. are mentioned in this paper, along with brief discussion of related global N and P issues.

SURFACE WATER QUALITY ISSUES AND CHALLENGES

Chesapeake Bay Watershed Example

As a result of low dissolved oxygen in the water column, nuisance algae blooms, and degraded biological integrity – believed to be associated with excessive nutrient (nitrogen (N) and phosphorus (P)) and sediment loads - the nation's largest Total Maximum Daily Load (TMDL) was implemented by the U.S. Environmental Protection Agency (EPA) in December 2010 in the Chesapeake Bay watershed. The TMDL was designed to ensure that all possible pollution abatement measures to restore the Chesapeake Bay were in place by 2025; with an ambitious goal of 60% of the actions completed by 2017. Loading limits from the Chesapeake Bay watershed (64,000 square mile area) were set at 187.4 million lbs of N /year and 12.5 million lbs of P/year; with subdivisions among river sub-basins and jurisdictions. Using 2009 as the baseline, those load limits represent a 25% reduction in N and a 24% reduction in P loads. According to the EPA, those limits were set based on state-of-the-art modeling tools, extensive monitoring data, and peer-reviewed science; covering six states and the District of Columbia. The Chesapeake Bay TMDL actually is a combination of 92 smaller TMDLS for the Bay and many tidal segments. The goal was to include "pollution limits sufficient to meet state water quality standards for dissolved oxygen, water clarity, underwater Bay grasses, and chlorophyll *a* … an indicator of algae levels." It was not until June 16, 2014 that the formal Chesapeake Bay Watershed Agreement (http://www.chesapeakebay.net/documents/FINAL_Ches_Bay_Watershed_Agreement.withsignatures-HIres.pdf) was signed, affecting more than 180,000 miles of creeks, streams, and rivers; with signatories that included representatives from the entire Chesapeake Bay watershed and the Bay's headwater states. The relative contribution of nutrients from different sources in the Chesapeake Bay watershed is contrasted with the Mississippi River Basin and the northern Gulf of Mexico in **Figure 1** below.

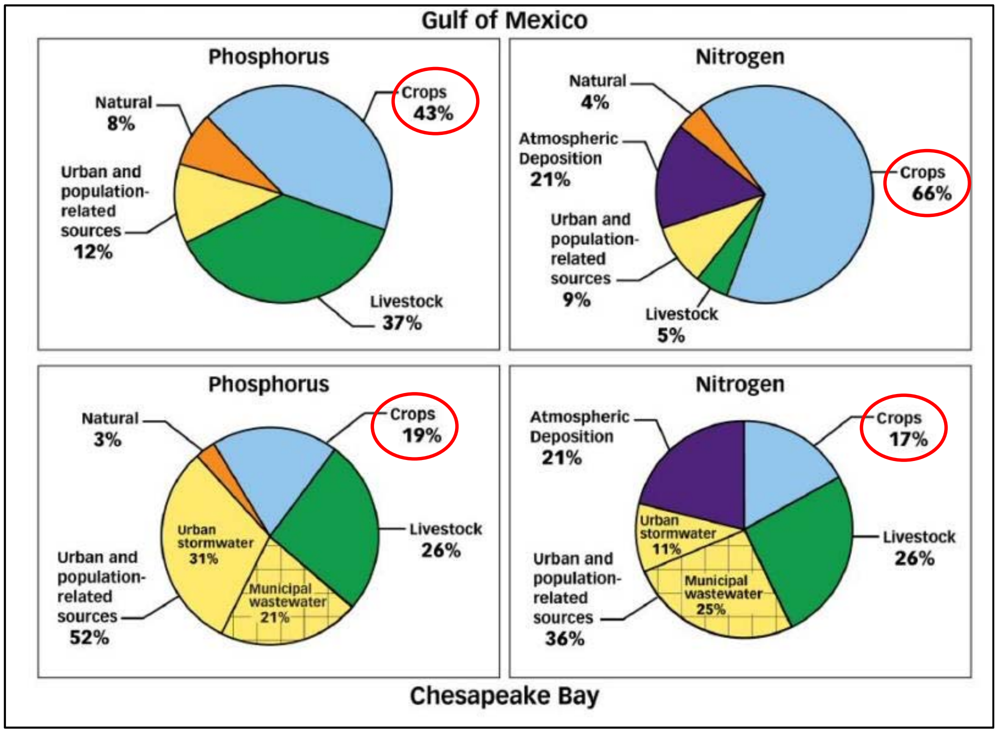

Figure 1 – Relative contributions of crop, livestock, urban, natural and atmospheric sources to nutrient loads in the Chesapeake Bay watershed contrasted with the northern Gulf of Mexico watershed (graph source: Ephraim King, U.S. EPA Office of Science and Technology, 2010.)

The U.S. Geological Survey (USGS) is charged with monitoring and/or modeling nutrient loads to the Chesapeake Bay, and reported the load trends in February 2016, as illustrated in **Figure 2**. Declining long-term trends in N loads were observed for seven out of the nine river monitoring sites. Long-term P load trends showed four of the nine were improving, one was unchanged, and four were degrading.

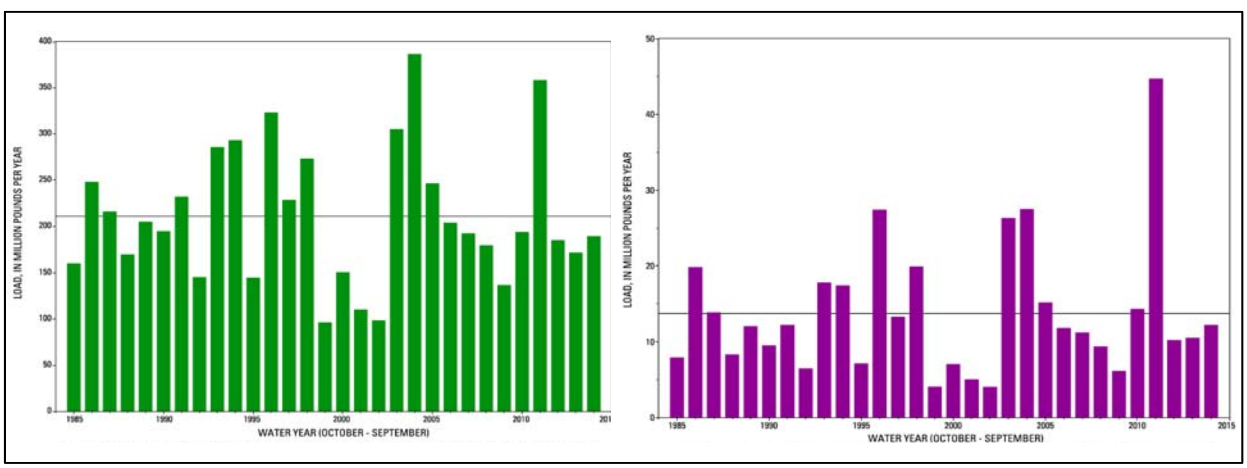

Figure 2 – Combined annual total N and P loads delivered from nine river monitoring stations to the Chesapeake Bay from 1985 to 2014 (Source: USGS, 2016). Horizontal line represents the average annual loads across years, based on September to October water years.

The Chesapeake Bay Program has posted information on different point source and nonpoint source best management practice (BMP) verification resources and timelines at its webpages (http://www.chesapeakebay.net/about/programs/bmp/additional_resources), including the following statements:

> *"To address the challenge of providing verification guidance for this diverse collection of BMPs in a simple format, agricultural BMPs are organized into three categories: a) Visual Assessment BMPs- Single-Year; b) Visual Assessment BMPs- Multi-Year; c) Non-Visual Assessment BMPs. The three BMP categories are primarily based on the assessment method for their physical presence, as well as on the respective life spans or permanence on the landscape."*

However, to the best of our knowledge, the extent of specific N and/or P BMP adoption or implementation is not known across the Chesapeake Bay watershed, or has not been publicly disclosed. Of course, the lack of systematic 4R BMP documentation and tracking is not unique to the Chesapeake Bay watershed.

The regulatory processes in the Chesapeake Bay watershed were well underway between 1983 and 1987. IPNI (and predecessor PPI) directors later became more engaged with sectors of the agribusiness community, nutrient management specialists with certain Land Grant Universities, and representatives of some state and federal agencies, on the N and P loss management and challenges in the Bay watershed. The nutrient losses and loads in the Chesapeake Bay watershed were perceived to be due more to the manure resources associated with confined animals (e.g. predominantly poultry), as illustrated in **Figure 1**. IPNI has relied on its Nutrient Use Geographic Information System (NuGIS) software tool (IPNI, 2017; Fixen, 2012) to estimate cropland net N balance in the Chesapeake Bay watershed, compared to the net N balances for the entire U.S. and the entire Mississippi-Atchafalaya River Basin (MARB- watershed of the northern Gulf of Mexico), as illustrated in **Figure 3**. The cropland net N balance per acre is estimated as: (farm fertilizer N + recoverable manure N + crop symbiotic N fixation) – crop harvest removal. Since about 1992, the net N balance for the Chesapeake Bay watershed appears to be declining.

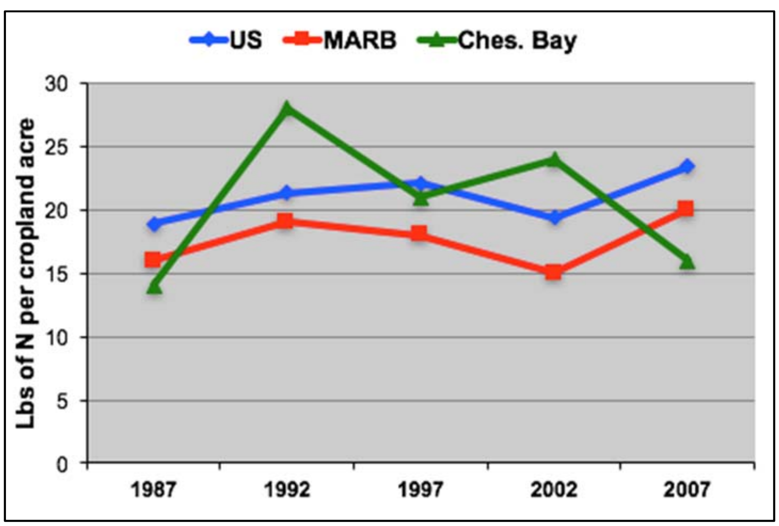

Figure 3 - Cropland net N balance for the Chesapeake Bay watershed in comparison with the Mississippi-Atchafalaya watershed and the entire U.S., based on the IPNI NuGIS software tool and available data for USDA census years 1987 to 2007.

Western Lake Erie Basin (WLEB) Example

In the summer of 2011, national and international news attention was given to beach closures and water use restrictions near Toledo, OH, as a result of elevated microcystin concentrations, associated with harmful algal blooms in Western Lake Erie. Elevated nutrient loads (both N and P), in conjunction with other factors, may contribute to nuisance algal blooms. Such algal blooms and phytoplankton growth are known to reduce dissolved oxygen in water columns, may cause fish kills, and interfere with the mobility and life cycles of bottom dwelling organisms. Water quality, cyanobacteria, and environmental factors associated with elevated microcystin concentrations at Ohio Lake Erie sites have been reviewed by Francy et al. (2015), who stated: "*The toxins produced by cyanobacteria are a diverse group of compounds and include neurotoxins (such as anatoxin and saxitoxin) and hepatotoxins (such as cylindrospermopsin and microcystin)*." The cyanobacertial harmful algal blooms (often referred to as cyanoHABs) have been associated with incidents of human and animal death and disease; especially where monitoring and additional preventative water treatment measures have not been taken. Those same authors found that microcystin concentrations were significantly correlated with total N at Buckeye Onion Island, ammonia and nitrate plus nitrite (both negatively correlated) at Harsha Main and Maumee Bay State Park (MBSP); and with total P at MBSP Lake Erie.

In the WLEB, the HABs are thought to perhaps be most related to increased dissolved reactive P loads, as opposed to other forms of P or other nutrients. Dr. Tom Bruulsema, IPNI P Program Director, has been working closely with both Canada and U.S. industry members, universities, and agricultural stakeholders to understand the issue, the nutrient management challenges, and optimized fertilizer and manure P management actions that may help to lessen the water quality impairment risks. **Figure 4** is from one of Dr. Bruulsema's informative presentations (http://phosphorus.ipni.net/topic/presentations) on Western Lake Erie P, water quality, and harmful algal blooms. Based on IPNI's NuGIS tool, the crop harvest removal of P in recent years has been trending greater than fertilizer and manure P inputs; resulting in negative P balances.

A voluntary Western Lake Erie Basin (WLEB) 4R Nutrient Stewardship Certification Program has been developed (*which may be adapted to other areas, including Ontario*), to address the water quality problems. According to Vollmer-Sanders et al. (2016), the certification program requires that "*a third-party auditor objectively evaluates the nutrient service providers' implementation of the 41 criteria of the program that encompass education, recordkeeping, nutrient recommendations, and applications*". The program was initiated through collaborative leadership that included the Ohio Agribusiness Association, The Andersen's, The Nature Conservancy, and others. Vollmer-Sanders et al. (2016) also reported: *"In two years, the 4R Certification Program has influenced nearly 40% of WLEB's farmland through the 30 4R certified providers. While any single organization could have created a nutrient management program, it would not have been as robust, as practical, or as accepted as the one created by the broad group of stakeholders involved with the WLEB 4R Advisory Committee. The rigor, structure, governance, and credibility of the 4R Certification Program make it a top candidate to act in other regions with wicked problems related to nutrient management*." As of November 2016, Bruulsema (**Figure 5**) noted that more than 2.7 million acres in Ohio, Indiana, and Michigan were being serviced under the voluntary Certification Program.

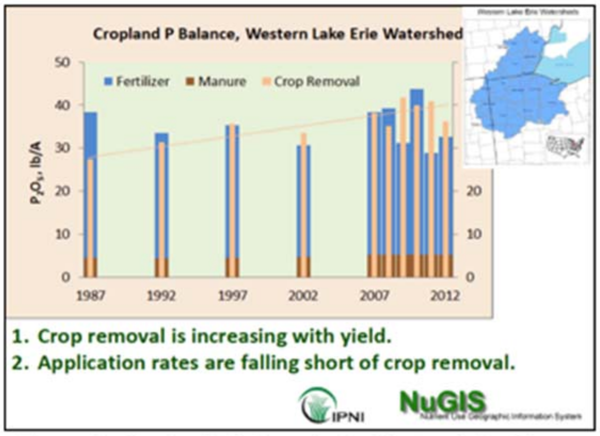

Figure 4 – Cropland P balance in the Western Lake Erie Basin (WLEB) (Source: T. Bruulsema, IPNI)

Figure 5– Voluntary 4R Nutrient Stewardship Certification in the WLEB(Source: T. Bruulsema, IPNI; Nov. 2016).

Gulf of Mexico Hypoxia, Iowa Raccoon River and Des Moines Water Works Challenges

Since 1985, annual summertime hypoxia (<2 mg/L dissolved oxygen) has been an ecological concern in the northern Gulf of Mexico; associated primarily with spring N and P losses from the 31 MARB states. State N and P loss reduction strategies (https://www.epa.gov/ms-htf/hypoxia-task-force-nutrient-reduction-strategies) and goals have been developed to cope with the MARB N and P load reductions to the Gulf; both reductions are aspirationally set at 45% of the 1980 to 1996 average loads (https://www.epa.gov/sites/production/files/2015-03/documents/2008_8_28_msbasin_ghap2008_update082608.pdf). Since about 2014, the federal and state agency Hypoxia Task Force (https://www.epa.gov/ms-htf) has expanded its interactions with Land Grant Universities in states bordering the Mississippi River (https://www.epa.gov/ms-htf/hypoxia-task-force-partnerships) to address N and P losses. Sadly, annual fluxes of nitrate-N and total N have not significantly declined, and it appears that total P and orthophosphate-P loads may actually be increasing; (https://toxics.usgs.gov/hypoxia/mississippi/flux_ests/delivery/index.html). Total annual loads delivered to the Gulf of Mexico from the MARB watershed in the 2014 water year were: 1.27 million short tons of N and 179,000 short tons of P. Those collective N and P losses from the MARB to the Gulf represent a retail fertilizer value loss of >$1.5 billion per year, and $55 billion since 1980. Added to those N and P loss challenges in America's heartlands, are the pressing subsurface drainage system contributions to nitrate-N delivery in streams like the Raccoon River in Iowa, and the pending litigation initiated by the Des Moines Waterworks (rescheduled for June 26, 2017; http://www.desmoinesregister.com/story/money/2016/05/13/des-moines-water-works-trial-delayed-until-next-year/84322342/)). Preemptive 4R N stewardship outreach and education within the fertilizer industry has recently intensified in Iowa (http://www.agprofessional.com/topics/4r-plus) - with coordination led by The Nature Conservancy, CF Industries and others - to stir greater farmer action to address those nitrate-N losses to streams, that may serve as drinking water resources. Novel industry-led outreach began in Illinois (Payne and Nafziger, 2015) several years earlier, that also included soil sampling and development of a soil nitrate-N monitoring network.

GROUNDWATER NITRATE-N ISSUES

Many states (e.g. California, Minnesota, Nebraska, etc.) have regions that are experiencing elevated groundwater nitrate-N concentrations (Nolan et al., 2002; Dubrovsky et al., 2010; Nolan et al., 2012) (https://water.usgs.gov/edu/nitrogen.html), which have developed over decades, and which may take many decades to remedy. Intensive research, education, outreach, and conservation district oversight have helped lower shallow groundwater nitrate-N concentrations in parts of the Platte River Basin in Nebraska, over several decades (Ferguson, 2015).

NITROUS OXIDE EMISSION ISSUES AND CLIMATE CHANGE

Changes in weather patterns, increased storm intensities and enduring droughts, are causing farmers (and the entire food supply chain) to ask what can be done in the vein of Climate Smart Agriculture to achieve more resilience and crop yield stability. Among the most politically contentious N management issues is the challenge of reducing our global and U.S. greenhouse gas (GHG) emissions; especially the seemingly inordinate focus on reduced nitrous oxide (N_2O) emissions. That focus may largely be due to the ~300x carbon dioxide-equivalent (CO_2-e radiative forcing value) of N_2O vs. CO_2. These GHG and N_2O issues are discussed in the following papers, and cannot be addressed here because of space constraints (Snyder et al., 2009; Cavigelli et al., 2013; Snyder et al., 2014). IPNI has been involved with the Field to Market Alliance for Sustainable Agriculture to improve the science foundation of its Fieldprint Calculator and several other sustainability metrics. Our efforts have most recently engaged leading university and government N management and N_2O scientists with a focus on the Fieldprint Calculator N_2O estimator, to better align it with USDA quantification methods (Eve et al., 2014) and suites of 4R N stewardship practices (Snyder, 2015; Snyder, 2016a). Besides these efforts, we have also worked with U.S. scientists involved in Climate Smart Agriculture; university and government scientists in the U.S. and Canada who conduct GHG research and who also help develop and submit annual agricultural sector GHG emissions data and information to national inventory reports; as well as international bodies like UNEP who are monitoring the global direct and indirect N_2O emissions and considering intervention policies (UNEP, 2013).

SUMMARY

Numerous challenges persist in addressing crop yield gaps, soil fertility improvements, plant nutrition deficiencies, fertilizer management profitability; and environmental impacts of N and P losses. IPNI has intensified work with industry leaders to ramp up their initiatives and outreach; to get more agribusiness members, professional crop advisers and their farmer clients to expand implementation of optimized 4R plant nutrition and stewardship principles. Those principles are outlined in IPNI's 4R Plant Nutrition Manual (IPNI, 2012) and were introduced to the larger agronomic science and practitioner community through a series of articles in Crops and Soils magazine in 2009 (**Figure 6**), and also to a broader international audience (IFA, 2009). A series of 4R articles was also developed and published in HortTechnology in 2011(http://horttech.ashspublications.org/content/21/6.toc), through the leadership of Dr. Rob Mikkelsen, to help also extend the science and principles to the American Society for Horticultural Science and horticultural practitioners.

Figure 6 – Four 4R Nutrient Stewardship articles were collaboratively developed by IPNI with university and government scientists and published in Crops and Soils in 2009.

IPNI has strived to work closely with university, government and not-for-profit conservation and environmental groups in developing science-based educational resources. We have encouraged the use of, and provided guidance on, indicators of nutrient performance that can be used from the field to the national and to the global scale (Snyder and Bruulsema, 2007; IPNI Scientists, 2014; Norton, 2015). We have also interacted more closely with leaders of the United Nations Environment Program Global Partnership on Nutrient Management (GPNM), the Organization for Economic Cooperation and Development (OECD - *through interactions with the International Fertilizer Association (IFA)*), the International Nitrogen Initiative (INI), and leaders of the International Nitrogen Management System (INMS). Quite recently, IPNI was a major sponsor of the 7th International Nitrogen Conference in Melbourne, Australia (http://www.ini2016.com/); and three IPNI scientists reported on their intensive regional N management research and education programs, and an invited plenary paper was presented by the IPNI Nitrogen Program Director (Snyder, 2016b).

The success of these local to global collaborative efforts - to accomplish increased farmer implementation of optimized 4R cropping system nutrient management - also depends on wise implementation of other sustainable soil and water conservation practices by farmers. Hopefully, by working together with various stakeholders and scientists, on key cropping systems in key geographies, we will all be able to look back in a few years and be pleased with results.

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