EFFECT OF MANAGEMENT ON NITROGEN BUDGETS AND IMPLICATIONS FOR AIR, SOIL, AND WATER QUALITY

Jorge A. Delgado
Acting Research Leader, USDA-ARS-SMSBRU, Fort Collins, Colorado
jorge.delgado@ars.usda.gov

ABSTRACT

Nitrogen is a key nutrient for both national and global food security, and nitrogen inputs from organic and/or inorganic sources are essential to maintain sustainable and economically viable agricultural systems. The challenge with nitrogen is that it is very dynamic and mobile, and some forms are subject to biogeochemical transformations that contribute to atmospheric, surface and leaching losses. Although nitrogen provides important rural, national and global economic benefits, nitrogen losses can impact the environment and have negative economic impacts at the farm level or on larger scales. Managing nitrogen is key to increasing nitrogen use efficiencies and minimizing nitrogen losses. The scientific literature is full of publications assessing the pathways for nitrogen losses. Understanding the mechanism(s) for these losses is important for the development of management practices that reduce the off-site movement of nitrogen. For example, precipitation events could contribute to the transport of nitrogen out of the root zone, increasing the potential for it to be transported to surface and underground water bodies. There are different approaches that can be used to assess nitrogen budgets and to calculate nitrogen use efficiencies and system use efficiencies. This presentation will cover some of these different approaches and methods to conduct nitrogen budgets to assess management practices, nitrogen use efficiencies and nitrogen losses to the environment. Results from studies conducted using ^{15}N isotopic approaches, non-fertilizer (control) plots, long-term data, and simulation modeling approaches will be presented. Additionally, examples of how best management practices such as cover crops, crop rotations, conservation agriculture, controlled release fertilizers, nitrification inhibitors, and other practices could be used to increase nitrogen use efficiencies to contribute to the conservation of air, soil, and water quality, will also be presented. New information about using long-term nitrogen budget approaches to assess system use efficiencies and nitrogen losses to the environment, as well as new research questions that we need to answer, will also be discussed.

INTRODUCTION

All across the world's agroecosystems, agricultural production is highly dependent on nitrogen inputs to maximize yields to meet the food production demands of a global population that continues to grow, as well to increase economic returns. Nitrogen inputs to agricultural systems are important for food security. This relationship makes nitrogen one of the most important elements in agricultural systems, and is one of the reasons it is widely applied across most cropping systems, from shallow-rooted vegetables, to corn, to small grains such as barley and wheat, to sugar and fruit crops, to grasslands. Nitrogen is used intensively in irrigated systems as well as rainfed systems, and although it is used at lower rates in dryland systems, it is still important for these systems. This element is a key component of essential amino acids of plants and proteins that are needed for plant growth, as well as other molecular plant components such as deoxyribonucleic acid (DNA), ribonucleic acid (RNA), and other compounds that are key for crop physiological functions needed to sustain adequate crop growth during the growing season in order to achieve maximum yields. These are some of reasons this element is so essential for national and global food security.

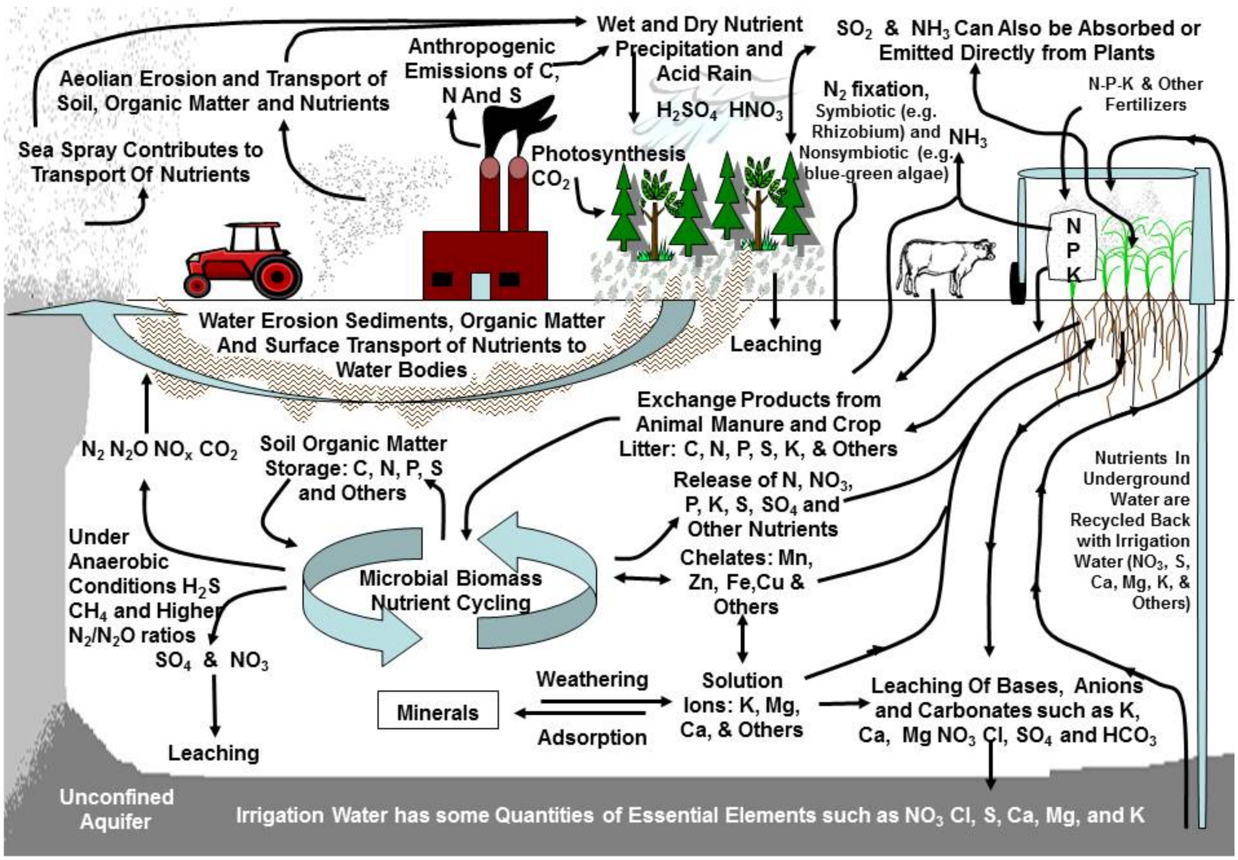

Figure 1. Nutrient cycles of essential elements for crop production, showing their fate and transport in the environment (from Delgado and Follett, 2002).

Nitrogen is a very mobile and dynamic element, and it moves across natural and agricultural systems from the soil to the air to water bodies as part of the nitrogen and other nutrient cycles (Figure 1). Most agricultural systems respond to nitrogen inputs with higher yields and economic returns. Because of the importance of nitrogen for crop growth and the response to nitrogen applications across agricultural systems, nitrogen tends to be applied in high quantities. When the amount of nitrogen applied exceeds the crop's needs, it can start accumulating in the soil and/or move through the environment via different pathways of the nitrogen cycle, and at higher rates than background losses from non-fertilized systems (e.g., higher rate of nitrate leaching, ammonia volatilization, surface runoff). In fact, these higher-than-needed application rates can increase the rate of nitrogen losses significantly. Nitrogen is important for farmers because it increases their economic returns, which results from the higher yields accompanying nitrogen application. However, losses of reactive nitrogen are also financially costly for farmers since nitrogen that is lost to the environment will not be available for the following crop.

ENVIRONMENTAL IMPACTS

All across worldwide agroecosystems, nitrogen use efficiencies can be low if there are excessive applications of nitrogen to agricultural systems (Randall et al, 2008; De Paz et al. 2009; Li. et al. 2007; Figueroa-Viramontes, 2011). Over-application of nitrogen can contribute to significant impacts to air and water resources. In the USA agriculture is the largest contributor of direct and indirect emissions of N_2O (EPA, 2010). Agriculture also contributes greatly to emissions of ammonia in the USA (EPA, 2010). Additionally, losses of N in the USA are also impacting water quality. These losses are impacting large water bodies and contributing to the hypoxia problem in the Gulf of Mexico and underground water contamination (Antweiler et al., 1996; Follett and Walker, 1989; Follett et al., 1991; Mitsch and Day, 2006; Dubrovsksy et al., 2010; Rabalais et al., 2002; Galloway et al., 2008). Ribaudo et al. (2011) reported that the removal of nitrate from drinking water costs 4.8 billion dollars per year, and that removal of nitrate lost to the environment from agricultural systems was about $1.7 billion of that cost.

We could develop and use best management practices to reduce the emissions of reactive nitrogen and conserve air, soil and water quality (Delgado and Follett, 2010; Randall et al 2008; Meisinger and Delgado, 2002). We could significantly reduce emission of NH_3 by applying best management practices that incorporate the applied inorganic and/or organic nitrogen below the soil surface (Fox et al.,1996; Freney et al., 1981; Peoples et al., 1995). It has been reported that incorporation of nitrogen inputs is a best management practice to reduce atmospheric NH_3 losses (Fox et al.,1996; Freney et al., 1981; Peoples et al., 1995). Atmospheric losses or other pathways of nitrogen loss could also be reduced with best management practices. For example, reduced emissions of N_2O could be achieved by using controlled release fertilizers, nitrification inhibitors, and/or enhanced fertilizers (Delgado and Mosier 1996; Bronson and Mosier 1993; Snyder et al 2007; 2009; Snyder and Fixen 2012; Shoji et al 2001; Halvorson et al, 2009; 2010). Best nitrogen management practices that increase nitrogen use efficiencies and reduce the rate of applied nitrogen will contribute to reducing reactive nitrogen losses (Ribaudo et al 2011).

Additionally, best management practices can be used to protect water quality (Delgado and Follett, 2010). Meisinger and Delgado (2002) reported on the basic management principles that contribute to conservation of water quality such as: 1) knowing the soil-crop-hydrologic cycle at the site; 2) applying the proper rate of nitrogen; 3) applying nitrogen in sync with crop demand; 4) adding a legume to a cereal-grain rotation; 5) expanding the use of the soil resource by adding a scavenger crop to a cropping system (e.g., a cover crop); 6) managing adjacent ecosystems, tillage, equipment, and nitrification inhibitors; 7) using irrigation scheduling; 8) using other water management tools; 9) using in-season nitrogen monitoring tools (e.g., chlorophyll meter); 10) using real-time monitoring tools (e.g., remote sensing); 11) using crop simulation models; and using site-specific management. Use of cover crops is very advantageous, and a good tool to conserve water quality (Delgado 2001).

As described above, nitrogen is a key element, but when applied at a greater-than-needed rate, the losses of nitrogen can impact the environment. Best management practices are usually developed by using a nitrogen application budget approach, such as using control or zero-fertilizer plots and/or ^{15}N isotopic techniques. Sometimes a best management practice is developed that targets the losses of reactive nitrogen from only one pathway. Incorporation as a management practice reduces the losses of NH_3 for the applied nitrogen but could potentially increase nitrate leaching (Delgado et al. 2008). To assess the impact of the best management practice we could quantify the nitrogen use efficiency of the applied nitrogen by using an approach with control or zero-nitrogen-applied plots while assessing how we could increase agricultural productivity. We could also use ^{15}N to trace the nitrogen uptake and determine how much nitrogen was still remaining in the soil and/or lost from the cropping system, and to assess how much of the applied nitrogen is taken up by the plant versus leaving the system. We could also use computer models that have been calibrated and validated to assess the cycling of nitrogen and the nitrogen use efficiencies. One of the challenges in assessing effects of management practices is that nitrogen cycles in the environment and the effects of one year could affect the rate of nitrogen uptake of the following year (e.g., nitrogen cycling from the previous leguminous crop planted at the site; use of a cover crop that could contribute nitrogen to the following crop; mineralization of nitrogen from organic matter).Tracing the long-term nitrogen balances is also another approach that could be used to assess nitrogen budgets and the long-term implications for air, soil and water quality. Monitoring long-term ^{15}N balances (Delgado et al 1996); using long-term nitrogen budgets (Delgado et al 2016), and long-term modeling approaches (Delgado et al 2008; Delgado et al 2010a) are methods that could help in the assessment of these balances and the effects on the environment.

SELECTED METHODS TO ASSESS NITROGEN BUDGETS

Over-application of nitrogen reduces nitrogen use efficiencies significantly, in some cases to less than 30% (De Paz et al, 2009; Li et al 2007; Figueroa-Viramontes et al. 2011). ***Nitrogen Use Efficiency:*** Bock and Hergert (1991) reported on the use of the nitrogen use efficiency (NUE) index, using control or zero-fertilizer plots to conduct an indirect mass balance of the applied nitrogen to assess the N absorbed by the crop. Although indirectly the NUE index can be used to assess the potential for nitrogen losses, this index approach cannot provide a direct assessment of the nitrogen losses to the environment. However, it provides a good indirect assessment of the potential impact, and, for example, how the potential nitrogen available to leach could be increased. Jenkinson et al. (1985) reported that one of the deficiencies of this approach is that non-fertilizer plots have a smaller rooting system and are thus exposed to less available nitrogen from the soil profile. This approach also does not assess the effects of a rotation that includes deeper-rooted crops that could serve as scavenger crops and recover nitrate that may be lost from the surface profile during the shallower-rooted crop phase, when shallower-rooted crops are in a rotation with deeper-rooted crops (Delgado 2001). ***Shifts in nitrogen dynamics:*** Legg and Meisinger (1982) reported that shifts in land use and management have significant effects on nitrogen dynamics that will impact the dynamics of a system for many years before it reaches steady state. ***^{15}N isotopic approach:*** A ^{15}N isotopic approach could be used to assess the nitrogen use efficiency of the applied nitrogen and to determine the fate of the applied nitrogen in crops, soil and the environment outside the system (Porter and Mosier 1992; Hauck and Bremner 1976; Hauck 1982). We could label fertilizers and crop residue with ^{15}N and assess the fate of nitrogen in crops, soils, and the environment outside the system using these ^{15}N isotopic techniques when conducting a mass balance of the applied nitrogen (Randall et al. 2008; Delgado et al 2010b).

SELECTED POSITIVE IMPACTS OF BEST MANAGEMENT PRACTICES - CASE SCENARIOS

There are examples of specific studies conducting nitrogen balances showing that improved management practices are reducing the net losses of reactive nitrogen to the environment. Rupert (2008) reported that the network of groundwater wells in northeastern Colorado shows that the concentrations of nitrate in groundwater increased from 1988 to 2004. This is in agreement with assessments using NLEAP modeling techniques and studies that calibrated and validated NLEAP for this region. These studies using NLEAP conducted nitrogen mass balances showing that nitrate leaching from agricultural systems potentially contributed to these increases in nitrate groundwater concentrations (Wylie et al 1994, 1995; Delgado and Bausch 2005; Hall et al. 2001).

Rupert (2008) also reported that for south-central Colorado the nitrate concentrations in groundwater did not increase from 1988 to 2004. This is also in agreement with nitrogen mass balance simulations in the Delgado (2001) and Delgado et al. (2010c) (Figure 2) studies that calibrated and validated NLEAP for this region and found that best management practices such as use of cover crops, and rotations of deeper-rooted crops (e.g., barley, winter wheat) with shallower-rooted crops (e.g., lettuce and potato), were significantly contributing to minimizing net nitrate leaching from agricultural systems in this region, and were even resulting in the mining of nitrate from groundwater. These net increases in groundwater nitrate concentrations are also in agreement with studies by Al Sheik et al. (2005) that studied the changes in soil nitrogen levels in these irrigated and cultivated vegetable-small grain systems. Al-Sheik et al (2005) found that best management practices used for these systems were contributing to soil nitrogen sequestration and increasing the carbon and nitrogen content in the soil organic matter of these irrigated course sandy soils.

Most recently, Delgado et al. (2016) presented data about nitrogen budgets and balances and the potential implications of losses of reactive nitrogen from irrigated no-till corn-corn systems in northeastern Colorado that were contrary to what was expected. Delgado et al (2016) reported that the data suggest that although no-till is resulting in accumulation of carbon in the top 7 cm, the system is losing organic carbon in a 120 cm soil depth. Although the system is accumulating inorganic nitrogen (NH_4 and NO_3), the data strongly suggest that this no-till system is a leaky system and is losing a large amount of nitrogen to the environment. The data suggest that the no-till system is losing a large amount of soil organic nitrogen. The data suggests that the particulate soil organic nitrogen pool (surface 30 cm) is the pool losing nitrogen.

SUMMARY

There are different approaches that can be used to assess nitrogen budgets and to calculate nitrogen use efficiencies and system use efficiencies. This proceedings paper covers some of these different approaches and methods to conduct nitrogen budgets to assess management practices, nitrogen use efficiencies and nitrogen losses to the environment. New information about using long-term nitrogen budget approaches to assess system use efficiencies and nitrogen losses to the environment, as well as new research questions that we need to answer, will also be discussed. Preliminary results suggest that the method of using linear regressions to conduct C and N balances (modeled in SAS using PROC MIXED with a first-order autoregressive covariance structure for repeated measures over years on the subject plot, together with lack-of-fit analysis [LOF] and adjusted p-values with using PROC MULTTEST with the false discovery rate [FDR] method) is a strong approach to assess changes of nitrogen with time and nitrogen balance. These preliminary results suggest that the cycling of N from added fertilizer is larger than expected and net N losses from the system are larger, with potential global and regional implications. Additional assessment of the pathways is critical to determine the pathway(s) for losses (denitrification [N_2]; leaching [NO_3]; ammonia volatilization [NH_3], etc.). However, other studies have found the potential for nitrogen sequestration and minimization of nitrogen losses to the environment. Nitrogen is key for agricultural production and to increase yields, economic returns and food security. There is the potential to use best management practices to minimize the losses of nitrogen to the environment. Additional research is needed to better understand the long-term effects of best management practices and to identify site-specific management practices that could contribute to sustaining yields while minimizing losses of nitrogen to the environment.

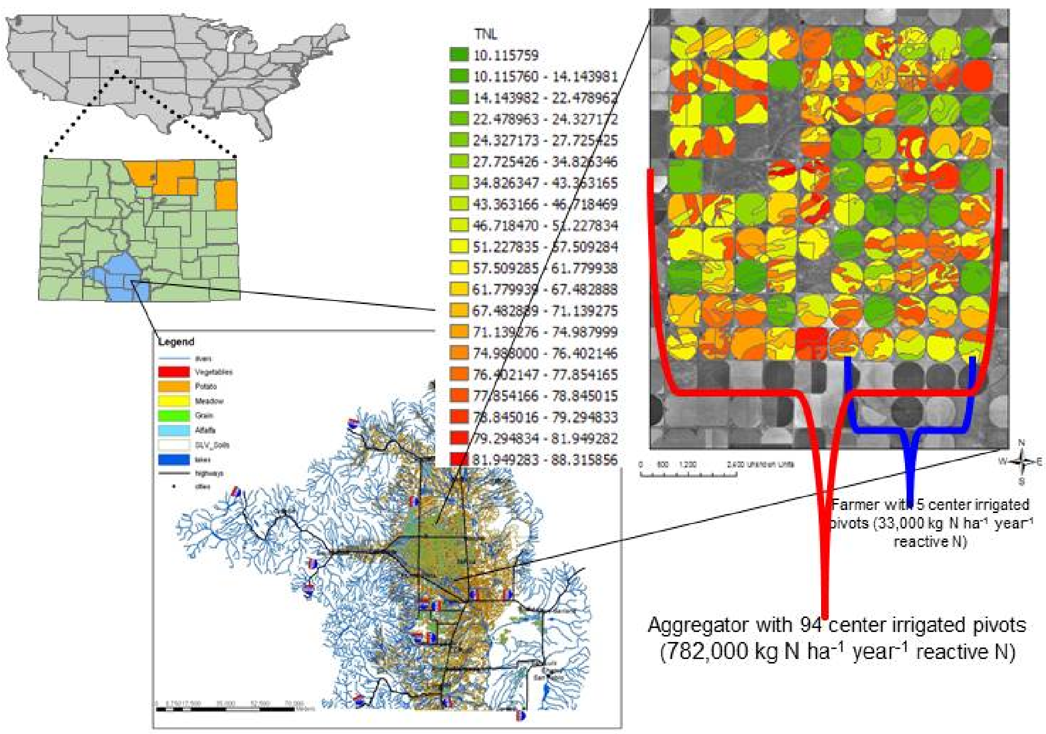

Figure 2. A stand-alone NTT-GIS prototype can be used to quickly evaluate the effects of management practices on total reactive N losses and the resultant potential to trade across regions (hypothetical example) (From Delgado et al. 2010c).

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