Science Societies

Examining environmental sustainability metrics—Nitrogen balance

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Source: Joseph L. Murphy/Iowa Soybean Association.

As companies and farmers seek to show progress towards sustainability goals, they need metrics to assess and document progression. Nitrogen balance—or N-balance—is one frequently used metric to assess the sustainability of nitrogen management.

Sustainability of the food supply chain continues to draw stakeholder attention. Many of the goals set across the food and agriculture industry fall to farmers to make changes and adopt specific practices to achieve sustainability goals. As companies and farmers seek to show progress towards those goals, they need metrics to assess and document progression. Nitrogen balance—or N-balance—is one frequently used metric to assess the sustainability of nitrogen management.

Nitrogen balance can be calculated multiple ways. The method depends on the data available and the overarching question you are trying to assess. The value for N-balance is calculated as the difference between nitrogen inputs and outputs. The most detailed calculation would include ***nitrogen inputs*** from manures and fertilizers; atmospheric depositions, including precipitation and dry deposition; irrigation water; and biological nitrogen fixation and ***nitrogen outputs*** from the removal in crop grain and biomass and nitrogen losses through leaching, denitrification, volatilization, surface runoff, erosion, and gas emissions and during plant senescence (Sainju, **2017**). The easiest way to calculate N-balance is:

N inputs (fertilizer and manure sources) – N outputs (harvested nitrogen) = N-balance

When calculated this way, N-balance can be used as a management tool on any farm or field. It is important to note that calculating N-balance for a system does not quantify losses from the system itself, aside from harvested biomass in this instance. In their simplest form, nutrient balance calculations are indices of agronomic performance.

Calculating N-balance at larger scales for the United States or at a state level can be done using tools like the Nutrient Use Geographic Information System (NuGIS). NuGIS allows stakeholders and advisers to find larger geographic areas where impacts on nitrogen losses can be made from improving nitrogen management practices. The NuGIS platform uses estimations from reported fertilizer sales, animal production data, harvested crop yields, estimations of nitrogen fixation from legumes, and USDA-NASS reported total cropland acres to evaluate partial nutrient balance and other nutrient efficiency metrics (Table 1). The version currently available at **http://nugis.ipni.net/** has information collected through 2014 (IPNI, **2012**). This year, NuGIS is being updated to include the most up-to-date data available for nutrient use and crop production and improved estimations of recoverable nutrients from manure. The updated program will be available fall 2020.

Table 1. Nitrogen fertilizer and manure inputs, removed (harvested) output, and balance for selected states and nationally in the United States**a** for 2014

[a] Data exclude Alaska and Hawaii.

	N Input				N output		N-balance
	Fertilizer N		Manure N		Harvested N		Input – output
State/region	tons	lb/ac	tons	lb/ac	tons	lb/ac	lb/ac

Illinois	1,097,142	92.4	15,955	1.34	1,849,659	155.7	−62.0
Iowa	1,301,988	99.2	75,322	5.74	1,734,304	132.1	−27.2
Minnesota	779,209	72.2	65,782	6.09	1,244,803	115.3	−37.0
Ohio	367,150	68.3	33,379	6.21	740,795	137.8	−63.3
Virginia	81,290	54.4	27,801	18.60	123,494	82.6	−9.63
Unites States	12,959,336	66.6	1,134,968	5.83	18,248,867	97.7	−21.3

Evaluating N-balance at larger geographic scales can introduce uncertainty to the information; therefore, the best practice is to use these numbers to guide where more detailed evaluations at a farm or field level should be pursued. While not a procedure within the NuGIS program, the NuGIS data set has been used to generate N-balances using the equation above for the United States and select states, which has resulted in negative N-balances that don't reflect an accurate nitrogen status in the systems. When only using fertilizer and manure inputs and total crop harvested removal as an output, nitrogen sources, such as symbiotic nitrogen fixation, are ignored. Thus, the calculated N-balance does not accurately depict a true balance assessment. The N-balance numbers in Table 1 show negative values because nitrogen fixation is not accounted for and more nitrogen is recorded as a harvested export due to leguminous crops.

The N-balance approach has been promoted for regional and farm-level environmental assessment (McLellan et al., 2018). However, results in Table 1 show the confusion that can occur when all nitrogen inputs and mineralization and immobilization are not represented.

Evaluating Nitrogen Balance at the Farm and Field Level

Interpreting N-balance gets tricky on the farm because the input and output data in an ideal situation are often not available; therefore, those performing the calculations may pick and choose which are included. When comparing N-balance at different scales or across landscapes, it is important to know what was included in the calculation. Additionally, all crop management information needs to be considered to get the best interpretation and use of N-balance values. Reducing your N-balance or attaining a negative N-balance does not necessarily indicate agronomic performance is optimized. Simply reducing nitrogen inputs through rate reduction may not be the best choice to improve sustainability outcomes. One of the best ways to use N-balance values is to compare a field or farm to other local fields or to the farm itself over time to see how the crop management, weather, and soil conditions impacted N-balance and where further management changes can be implemented. An approach like this can help identify areas that perform differently, and when looking at the complete crop management data, why they perform differently.

Sharing N-balance data among similar farms and fields along with the associated practices implemented could help farmers and their advisers benchmark performance and learn what is working for others in the same region or raising the same crops (McLellan et al., **2018**). The Fertilizer Institute (TFI) is working on multiple projects to bring these data sets together in ways that are useful to a large group of stakeholders. One of those is through data collection and analysis to generate economic case studies (**www.4rfarming.org**). Working with farmers recognized as 4R Advocates or identified through other stakeholders, data

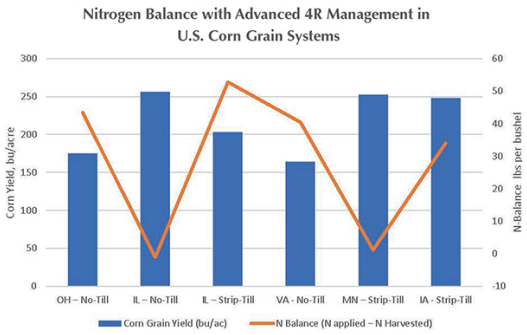

Figure 1, *Average corn grain yield (bushels per acre) and nitrogen balance for corn grain farms in five states in 2018.*

have been collected to calculate the cost of advancing 4R practices, N-balance, and nitrogen use efficiency.

While N-balance can be calculated for any crop, interpretation of the value has been focused on corn grain production. Among the currently published case studies at 4RFarming.org, six focus on corn grain production in different states. These six case studies cover 13,580 ac and have a yield range of 164 to 256 bu/ac of corn grain (Figure 1). The differences in yield and management practices selected by the growers resulted in a range of (–1.14) to 52.8 lb N/bu corn grain (Figure 1). Additionally, costs associated with 4R practice changes resulted in an average reduced cost of $37.90/ac and ranged from $10.89 to $101.11/ac. Reductions in cost across all case studies were linked to reduced fertilizer product cost, reduced equipment time and cost, and reduced fuel costs.

Because no farm is the same and many factors influence nitrogen uptake and loss, N-balance should not be used as a stand-alone metric for nitrogen management. Comparing N-balances across farms and understanding the variation in results means understanding practice specifics (Table 2). All six of the farms use nitrogen stabilizer products, urease or nitrification inhibitors, with one or more of the nitrogen applications to corn for grain; all six use either grid- or zone-based soil samples for variable-rate applications of nutrients and seeding; and all are placing nitrogen applications closest to where the plant can intercept. However, most of these farms are splitting their nitrogen applications from two to four different application timings, a few are using or testing cover crops, and a few are working with other stakeholders to test new nitrogen management practices.

Table 2. Detailed 4R nitrogen management practice changes made by farm with N-balances calculated

Farm	4R nitrogen management practices implemented
OH – no-till	• Eliminated fall ammonia sulfate applications • Variable-rate seeding and starter application • Early post-emergence nitrogen application with herbicides • Sidedress nitrogen using variable-rate application zones established for variable-rate application of phosphorus and potassium • Sidedress nitrogen is placed below the surface by knifing it in the soil
IL – no-till	• All nitrogen applied in season • All nitrogen applied with a urease or nitrification inhibitor • Nitrogen applied as a component of a liquid starter • Early post-emergence nitrogen applied with herbicide application • Sidedress nitrogen is injected anhydrous ammonia with an inhibitor • Additional V-10 application of nitrogen as needed
IL- strip-till	• Fall application of nitrogen with nitrogen stabilizer and injected in strips • Cover crops • 2.5-acre grid soil sampling for variable-rate applications
VA – no-till	• Cover crops • No out-of-season nitrogen • Starter nitrogen with seed • Nitrogen broadcast at planting that contains protected urea • In-season nitrogen is applied as a mix UAN with protected urea • Nitrogen rates are based on crop needs and crop removal history

Farm	4R nitrogen management practices implemented
MN – strip-till	• Cover crops applied with sidedress fertilizer • Urease inhibitor for sidedress nitrogen applications • Works with local university to test nitrogen management practices around rate and timing of application
IA – strip-till	• Strip-till placement of nitrogen • Variable-rate applications based on soil samples and crop removal • Use of in-season tools to evaluate nitrogen needs for additional nitrogen applications • Participates in nitrogen field trials

Conclusions

Tracking progress of sustainability efforts for farmers and across the food supply chain is a large undertaking that is increasing in demand today. Nitrogen balance is a metric that can be simple to calculate with farm- and field-level available data, including fertilizer and manure nitrogen inputs and crop yield and nitrogen concentration, and it should be a datapoint that you keep in your toolbox. But, in its simplicity, don't give into the temptation to use it as the sole measure to assess improvement. Without other metrics, cropping system outcomes and documentation of practices to achieve the calculated N-balance, continuous improvement and comparisons between other farmers or across regional or state geographies can be misinterpreted.

4 nutrient stewardship

This article is part of a series from The Fertilizer Institute highlighting some of the latest 4R research.



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