Science Societies

Nutrient stewardship: Taking 4R further

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Sharing data on 4R practices can boost public confidence in farming outcomes.

> It's been 10 years since the *4R Plant Nutrition* manual was published, setting out principles for the stewardship of plant nutrients agreed to by soil fertility scientists and crop nutrition practitioners. Since then, the industry has done a lot to implement the concept, both globally and in North America. What has been learned and accomplished in the process? What needs to be done to take 4R further?

It's been 10 years since the *4R Plant Nutrition* manual was published, setting out principles for the stewardship of plant nutrients agreed to by soil fertility scientists and crop nutrition practitioners. Since then, the industry has done a lot to implement the concept, both globally and in North America. The 4R Nutrient Stewardship concept has grown to become highly recognized within the fertilizer and agri-retail industries and among agri-environmental scientists (Fixen, **2020**). What has been learned and accomplished in the process? What needs to be done to take 4R further?

The intent of 4R was to address every important impact of applying plant nutrients, both the benefits and the risks. Since 1960 to about 10 years ago, we have been fortunate to live in a world where agricultural production has been rising faster than the demand for food. But since around 2010, the world has not been progressing either towards ensuring access to safe, nutritious, and sufficient food or towards eradicating malnutrition, particularly in the past year owing to the COVID-19 pandemic (FAO, 2021).

Most projections agree that food demand will continue to increase until at least 2050, and thus increased research and innovation efforts towards sustainable intensification of crop production are critical needs (Cassman & Grassini, 2020). In addition, there is a need to mitigate greenhouse gas emissions and reduce nutrient losses that impair the quality of water and air and shrink biodiversity. More than ever, there is a strong need for a relevant framework for nutrient stewardship.

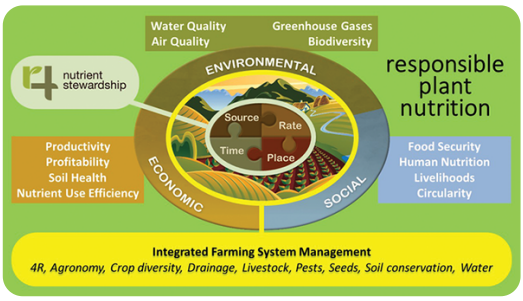


Figure 1, *Furthering 4R Nutrient Stewardship requires integration with farming systems and tracking of outcomes to support the aims of Responsible Plant Nutrition.*

In 2020, the global fertilizer industry established a Scientific Panel for Responsible Plant Nutrition (SPRPN). Its 11 members, recognized scientists from various disciplines and regions around the world, have formulated and described *A New Paradigm for Plant Nutrition* that goes further than 4R Nutrient Stewardship, calling for action from players beyond the fertilizer industry and beyond agriculture to include the whole agricultural supply chain, upstream and downstream from the farm, in the Responsible Plant Nutrition concept (SPRPN, 2020). While 4R can't do it all, it remains at the core of what farmers, agricultural service providers, and the fertilizer industry can do to help solve the sustainability challenges. The principles and practices of 4R need to link to this new paradigm.

From the start, 4R was designed to improve yield, profit to the grower, soil health, and nutrient use efficiency (Figure 1), and it was always emphasized that those economic outcomes depend on integration with the cropping system. In the Responsible Plant Nutrition concept, that dependence expands to include integration with the whole

farming system—including the livestock. The achievement and tracking of progress on environmental and social outcomes depends on integration and collaboration with an even broader range of players in the supply chain to and from the farm (SPRPN, **2020**).

Let's look at some examples of what 4R has achieved, and has potential to achieve, in North America.

Phosphorus and Harmful Algal Blooms

In the Lake Erie watershed, 4R was focused on turning back the trend of rising concentrations and loads of dissolved phosphorus (P) flowing into the western basin of the lake. The industry's support for nutrient balance monitoring tools like NuGIS, and for research that included edge-of-field monitoring, assured everyone of the industry's commitment to effective practice change guided by 4R principles. Not only that, but NuGIS provided strong evidence that rates of application were not in excess of crop removal or crop requirements. In fact, we could demonstrate that the watershed's cropland P deficit—the difference between the amount removed by crop harvests and the amounts applied as fertilizer and manure—was growing larger over the same time period that the loads to the lake and the resulting algae were increasing (Jarvie et al., **2017**). Among the multiple causative factors that remain plausible, subsurface placement of fertilizer and manure was identified as a practice change that could stem the trend, along with opportunities for improving timing of applications as well. Thus 4R was a good fit.

Implementation of 4R Nutrient Stewardship has been a large component of the agricultural community's response to the issue. Within two years of its launch in 2014, the first 4R Nutrient Stewardship Certification Program grew to influence nutrient applications on nearly 40% of the western Lake Erie watershed's cropland (Vollmer-Sanders et al., **2016**). By early 2020, it extended to more than two million acres through

58 certified agri-retail locations, and additional programs were started in Ontario, New York, and other states. Voluntary 4R certification programs, and the 4R concept in general, were also recognized in federal, state, and provincial government action plans to address goals for P loading reductions to Lake Erie (Canada–United States Collaboration for Great Lakes Water Quality, **2019**).

Opportunity remains, however, to better integrate subsurface placement into conservation tillage programs. Additional evidence of a connection of fertilizer to P load emerged in 2019 when an incredibly wet spring limited not only fertilizer application but even crop planting—followed by a sharp reduction in dissolved P in the Maumee river (Guo et al., **2020**). Would we have seen this effect if in the years prior to and after 2019, more of the P fertilizer had been applied subsurface rather than broadcast? We don't know for sure, but a lot of evidence points to broadcast application constituting a substantial risk (Williams et al., **2018**; Carver et al., **2022**; King et al., **2015**). Subsurface placement costs more, and doesn't necessarily increase yield or profit to the farmer, and thus more cost share may be needed to motivate greater adoption of this practice change. When we ask who will pay for the cost share, it becomes evident that we need to involve players beyond the farming system—consumers, environmental protection agencies, food companies, etc. Stakeholder engagement was key to getting the 4R program started, but taking it further will require yet more.

Nitrous Oxide Emission

The importance of 4R nitrogen (N) practices to mitigate nitrous oxide emissions has been recognized by the Field to Market sustainability organization (Field to Market, 2017) and by the province of Alberta (Alberta Government, 2014). An assessment of natural climate solutions for Canada concluded that increased adoption of 4R

practices could reduce greenhouse gas emissions in Canada by an additional 6.9 million short tons of carbon dioxide equivalents annually by 2030, contributing 3% of Canada's commitment to the Paris Accord (Drever et al., **2021**).

In Canada, the federal government's emissions reduction initiative calls for a 30% reduction in greenhouse gas emissions from fertilizer use by 2030. The main source of such emissions is the nitrous oxide emitted from nitrogen fertilizers in the soil. But only one of the 4Rs—rate—is currently reflected in the nation's greenhouse gas inventory. Nitrogen fertilizer use increased from 2.1 to 3.2 million short tons between 2010 and 2020. A 30% rate reduction implies going almost all the way back to the levels of N fertilizer use 10 years ago, potentially reversing the growth trend in production of canola, wheat, and corn. A "right source" technology—the use of nitrification inhibitors or controlled-release forms—has strong scientific backing for a 20 to 40% reduction in nitrous oxide emissions per unit of N applied (Thapa et al., **2016**; Eagle et al., **2017**; Maaz et al., **2021**). The challenge is that currently, the government statistical agency does not collect data on the use of these sources. Industry collaboration with government or other carbon-accounting initiatives to share data on 4R practices could go a long way toward gaining recognition of this benefit to the adoption of available 4R technology.

Nitrogen Use Efficiency

Another pathway to achieving the emissions reduction target would be to improve nutrient use efficiency; specifically, fertilizer N use efficiency. The use of 4R practices can contribute to this pathway in several ways.

Sourcing more N recycled from manures and other forms of biowaste can contribute to the improvement of aggregate N use efficiency. For those already using manure, can it be applied in a manner to improve the capture of its N? For those not using it, what are the options for capturing manure N in a more transportable form?

Considerable opportunity exists to improve fertilizer N use efficiency by responding more dynamically to weather during the growing season. The “right time” may be multiple times, with the last application later in the season, to allow the crop to communicate its N needs. Sensors, field observations, tissue tests, and weather-based computer crop growth models can all contribute information for setting the rate of the last application to match as closely as possible the final crop demand (Tremblay et al., **2012**; Banger et al., **2020**). A modeling study for corn in Ontario, Canada found that split N application with rate adjustments may increase profit between 15 and 19% in dry conditions and between 1 and 15% in wet conditions while lowering nitrate leaching, nitrous oxide emissions, and ammonia volatilization losses in most weather (Kabir et al., **2021**).

Management practices beyond 4R can also contribute to the improvement of N use efficiency. Legumes provide N with less nitrous oxide emission than fertilizer. Legume cover crops like red clover in crop rotations that include winter wheat provide N credits that can be used to reduce fertilizer rates without losing yield. In fact, the dominance of soybeans and alfalfa in North American crop rotations (Figure **2**) contributes to a relatively high aggregate N use efficiency (Figure **3**). Genetic improvement in corn hybrids accounts for a considerable portion of corn’s N use efficiency gains (Mueller et al., **2019**). While it’s difficult to decipher how much of the credit goes to improved 4R practices, it’s worth taking a look at some of the data we have on trends in crop N use efficiency across North America.

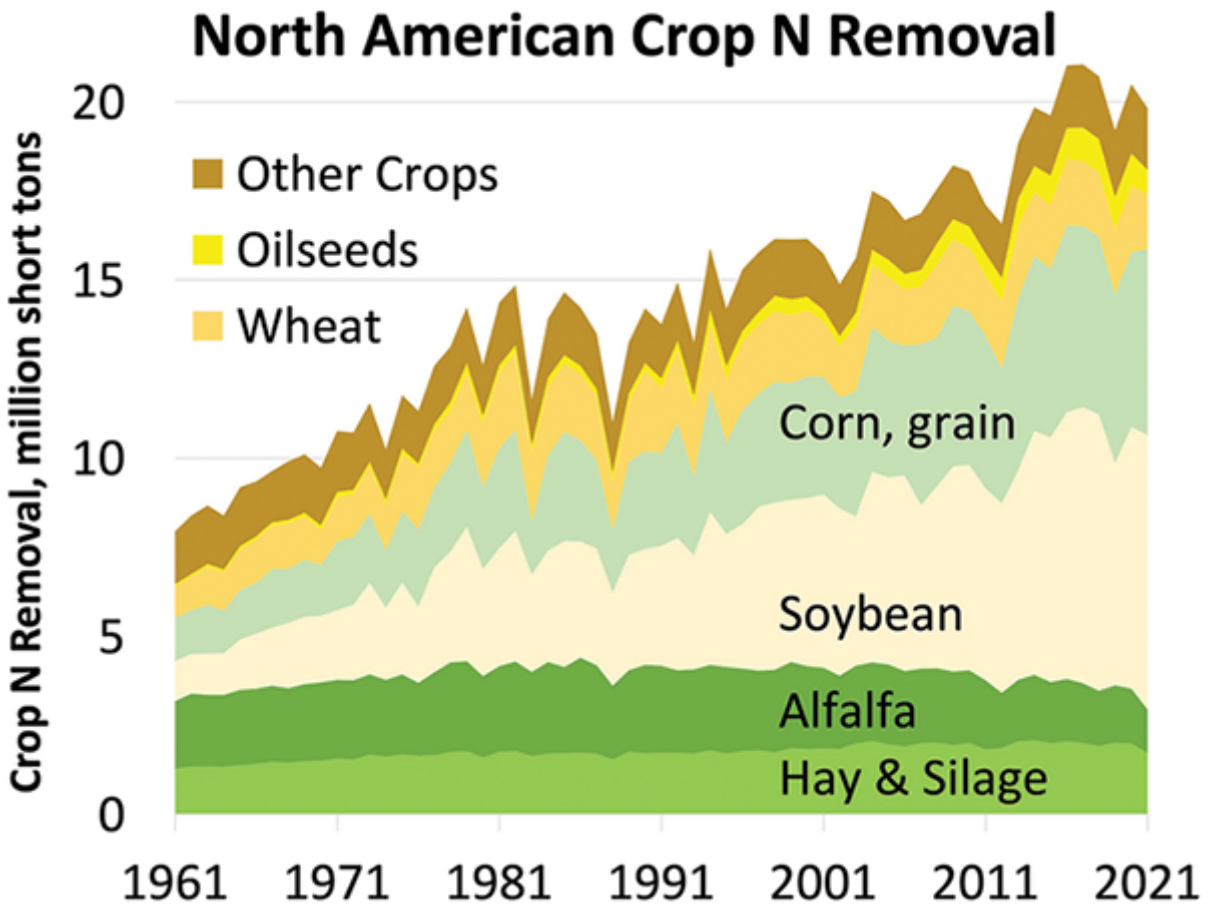


Figure 2, *Removal of N by crop harvest in North America (United States and Canada). Data sources: Zhang et al., **2021**; USDA-NASS & Statistics Canada with NuGIS coefficients.*

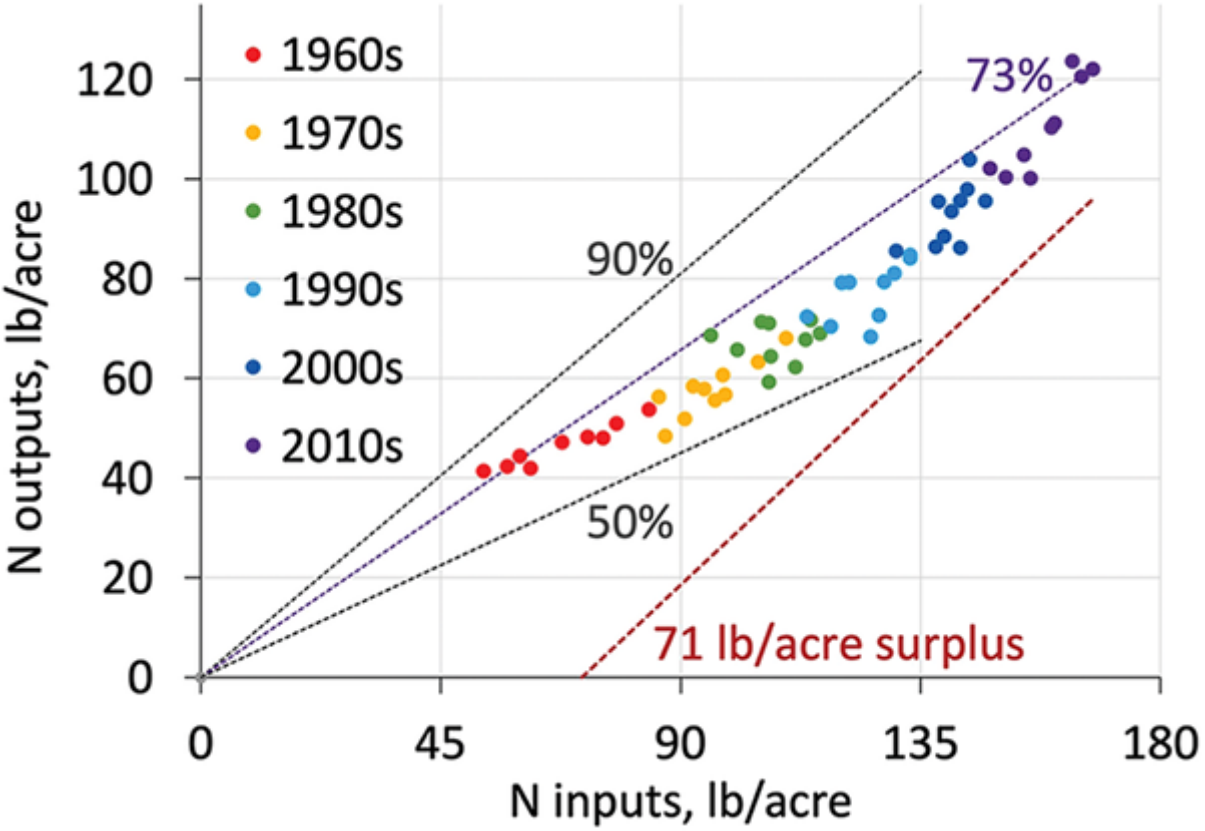


Figure 3, *Trends in N outputs and inputs for harvested crops in North America from 1961 to 2018. Outputs do not include forage crops. Inputs include fertilizer, manure, legume fixation, and atmospheric deposition. The slope of a line from any point to the origin indicates N use efficiency. Data sources: Zhang et al., **2021**, with extrapolation from 2015 to 2018 using (FAO, **2020**).*

According to the European Expert Panel on Nitrogen (EUNEP, **2016**), N use efficiency should be considered in the context of N output and N surplus, and a format similar to that in Figure **3** is recommended, with optimum values between 50 and 90%. The aggregate performance shown for North American crop production has encouraging trends. For the past few decades, both N use efficiency and N output per acre are increasing. But some important caveats need to be kept in mind.

- The large role of soybean in the N balance obscures the lower efficiency of other crops. As a legume, soybean N use efficiency is quite high.

- Values lower and higher than the current 73% shown have been published (Lassaletta et al., **2014**; TFI, **2021**). Differences arise owing to assumptions on N removal per unit of yield, the amount of N fixed by legumes, the fraction of manure N excreted that reaches cropland, whether atmospheric deposition is included, and which crops are included. In the output, NuGIS includes the harvested forages like alfalfa, hay, and silage but does not include atmospheric deposition; the FAO outputs do not include forages, but inputs include atmospheric deposition and larger amounts of manure N.
- The amount of N removed per unit of yield likely changes over time for many crops but is not accounted for in most N budgets. In particular, corn grain is lower in N today compared with decades ago (Mueller et al., **2019**).
- As N output increases, higher levels of N use efficiency will be needed to avoid increasing the N surplus (Figure **3**).
- While the aggregate N surplus has not exceeded the 71 lb/ac maximum suggested by the EUNEP, regional variation means that exceedances are likely in some areas (Figure **4**).

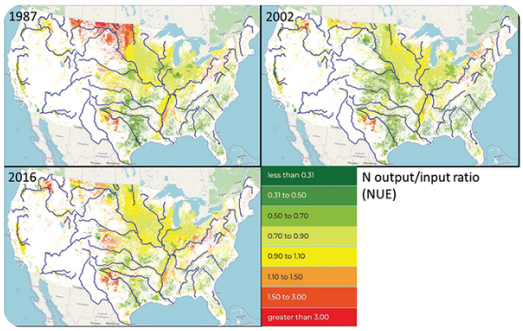


Figure 4, *Changes over time in the spatial distribution of cropland N use efficiency as calculated in NuGIS (crop N removal divided by the sum of N from fertilizer, recovered manure, and crop legume N fixation)*

*(TFI, **2021**). Green areas represent surpluses; red, deficits.*

How much of the improvement in N use efficiency in the past decade or two can we attribute to 4R? That's a hard question to answer because there is little data available on the specific source–rate–time–place practice changes over time. There is opportunity for the fertilizer industry to further 4R by working together with farmers to share aggregated data on actual 4R practice trends in the field. The emerging carbon programs may play a great role in this regard.

Further into the Future

A stewardship system seeks to optimize production, balancing it against the multiple forms of nutrient loss that cause issues of concern to society, as shown in Figure **1**. Water quality and greenhouse gas emissions are examples of environmental issues that have recently come to the forefront for crop producers, but others lurk in the background.

Such environmental issues include biodiversity and air quality. Nutrient losses to air and water enrich natural ecosystems to the point where the organisms that do well with low nutrient inputs are competed out by other species more responsive to added nutrients. Losses of ammonia can interact with other air pollutants to increase smog, and that can be directly related to human health.

Another set of issues can be considered social. They include global food security, already discussed in the introduction, and the nutritional quality of the crops being grown. As nutrient use efficiency has increased, and as carbon dioxide levels rise, crops contain less protein and less of several minerals important to the health of animals and people. Responsible plant nutrition concerns itself not only with the quantity of crop produced, but also its quality. Livelihoods are also important, especially for hundreds of millions of smallholder farmers, in the development of more

sustainable farming. Sustainability also demands that nutrient cycling become more circular as part of the growing trend toward circular economies.

Many of the issues have grown larger over the past 10 years. Action on climate change to make greenhouse gas emissions "net zero" drives action to establish "carbon farming"—management of farming systems to store more carbon in the soil while reducing emissions of carbon dioxide, nitrous oxide, and methane. The emission reductions include those from the supply chains upstream and downstream from the farm. Global concern about biodiversity increases pressure for sustainable intensification—producing more on less land, saving space for nature—and building soil health. As a result, the principles and practices of 4R need to evolve to ensure linkage to the emerging sustainability platforms.

Industry's efforts and support for 4R Nutrient Stewardship have built a solid base for sustainable crop nutrition. There is excellent opportunity to build on this base and broaden its reach. Look for more information on this topic from the Scientific Panel on Responsible Plant Nutrition—**www.sprpn.org**.

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