I'm Tom Bruulsema, chief scientist with IPNI Canada. I provide support for the fertilizer industry's nutrient stewardship programs. For the past 25 years, I've been engaged in making the plant nutrition component of agriculture more sustainable. I'm delighted to have the chance to speak to you today about programs in which we have engaged university scientists and industry leaders to implement new ideas and raise the level of management.

I've phrased the question as what do we know and yet not know. It's often a matter of degree. We often know what direction we need to go, but don't know what or how much we will achieve with the steps we take. So often we need to step together with the stakeholders who seek the changes we aspire to make.

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Why all this effort? We have responded to issues. Issues of algal blooms in Lake Erie (linked to phosphorus losses), greenhouse gas emissions in the form of nitrous oxide from nitrogen fertilizers, and air quality impairments from ammonia emissions from nitrogen fertilizers and manure.

Achim – [yield gaps] – trends, progress, raising yields and NUE at the same time, or increasing yields while reducing fertilizer use
Martin Kropff – CIMMYT – maize and wheat
Matthew Morell – IRRI – rice
Christian Witt – digital farmers services
TWB – nutrient loss, certification, Charlotte's "proper incentives to farmers to promote sustainable plant nutrition", 4R Research Fund

- Define sustainable plant nutrition
- the engagement of agri-retailers, crop advisers, extension workers and research scientists in participatory adaptive management is important, as is peer and community recognition for "doing the right thing."
- Increased nutrient use efficiency helps reduce nutrient losses, but it is not always enough. In some instances, small losses of specific nutrient forms hit the environment hard. Nitrous oxide losses, for example, comprise only a few percent of the nitrogen applied, yet form a large part of its carbon footprint. A "right source" solution—a nitrification inhibitor—could cut that loss by at least a third, even where it improves nutrient use efficiency only a little. In the case of phosphorus, "right time" and "right place" fertilizer applications could cut dissolved phosphorus loss enough to shrink algal blooms in Lake Erie, even where they don't change rates of application or crop yields.
- Information needs to be shared on the basis of trust relationships—developed through on-farm visits, meetings, field tours and demonstrations—among leading farmers and their nutrient service providers.

Sustainable Plant Nutrition

(= Responsible Plant Nutrition)

1. Definition
2. Nutrient use efficiency & nutrient losses
3. Collaborative participatory extension

I plan to discuss three topics under this banner of sustainable plant nutrition. First, while use of the term has picked up, I don't know that an agreed definition exists. In the USA, TFI included the term in its most recent strategic plan. I'll propose a definition, and we can discuss its merits. Second, while it's generally agreed that sustainability demands we need to improve nutrient use efficiency and to reduce nutrient losses, I will argue that these two goals, while complementary, should be kept distinct from each other. Third, I will discuss why sustainability demands collaborative participatory extension and provide some examples from the North American context.
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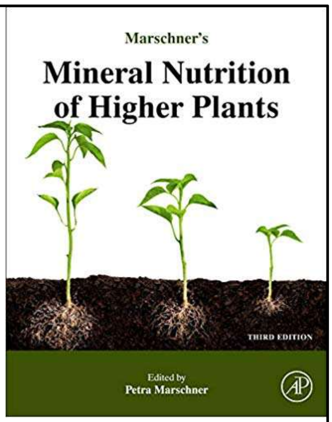
1) an attempt to define "sustainable plant nutrition"
2) explain why optimizing nutrient use efficiency and minimizing nutrient loss, while complementary, should be distinct goals
3) provide examples of collaborative participatory extension in the North American context

Definition…



Plant Nutrition

- "The study of mechanisms by which plants absorb and metabolize nutrients."
- Soil science, plant physiology, biochemistry

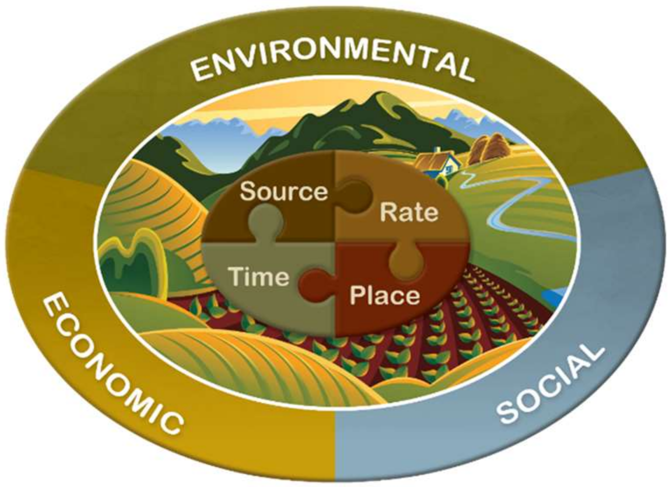
Sustainable Plant Nutrition

- invokes a wider web of connections to global systems;
- Involves economic, environmental and social dimensions.

Plant nutrition traditionally has been defined as the study of mechanisms by which plants absorb nutrients, and their functions in plant metabolism. Its close relationship to soil science, plant physiology and biochemistry is here paraphrased from Marschner's classic textbook on the mineral nutrition of higher plants. Amending the term to specify *sustainable* plant nutrition invokes a wider web of connections to global systems. Sustainability implies connection to economic, environmental and social dimensions. Sustainability involves externalities: the impacts associated with inputs before they reach the farm, with losses from the farm, and with the ultimate fate of the farm's products.

Proposing a Definition

Responsible Plant Nutrition nourishes plants in a sustainable manner that enhances earth's capacity to support healthy life.



4R + more.

So here is my proposed definition. Sustainable Plant Nutrition nourishes plants in a manner that enhances earth's capacity to sustain life. The shortcut version is that Sustainable plant nutrition sustains life.

Enhancing the earth's capacity to support life implies that plants are managed to produce quantities and qualities of food, feed, fiber, fuel and more that support humans. It also must be done in a manner that keeps the water clean to drink, the air clear to breathe, and the climate stable enough for ecosystems to flourish. Nutrient losses—be they nitrous oxide linked to climate change, or phosphates linked to algal blooms, or nitrates contaminating drinking water—detract from Earth's capacity. A full appreciation of the impacts on the biosphere is required, balancing benefits to crops with externalities.

Sustainable Plant Nutrition includes the 4Rs—applying the right source at the right rate, right time, and right place—and more, managing whole agro-ecosystems to make optimal use of all resources. Not losing sight of this context, let's now talk about two core aspects of that optimization, improving nutrient use efficiency and reducing nutrient losses.

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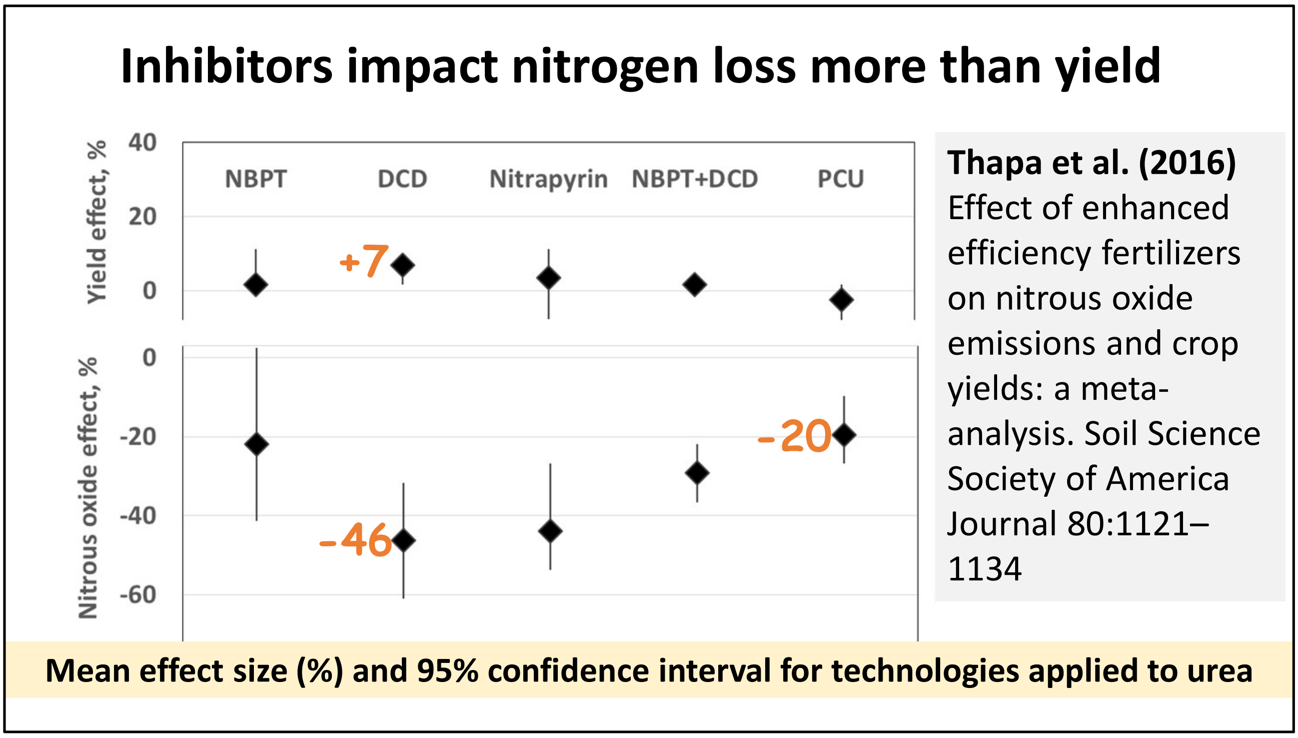
Nutrient use efficiency & nutrient losses

- Increasing nutrient use efficiency reduces losses.
- BUT some big issues arise from small losses.
  - Nitrous oxide – greenhouse gas and ozone depletion
  - Dissolved phosphorus – harmful algal blooms
- Improving NUE is an important first step.
- More can be done with source, timing and placement.

In general increasing nutrient use efficiency reduces losses, since the risk of nutrient loss decreases as nutrient surpluses shrink. But there are examples of large impacts that arise from small losses. One example is nitrous oxide – losses of merely one or a few percent of the nitrogen applied contribute substantially to the greenhouse gas footprint of agriculture. Another is the loss of the dissolved form of phosphate: losses of less than a kilogram per hectare can stimulate harmful algal blooms. Where feasible, improving nutrient use efficiency is an important first step. But source, timing and placement can do much more than just improve efficiency. I will show a few examples.

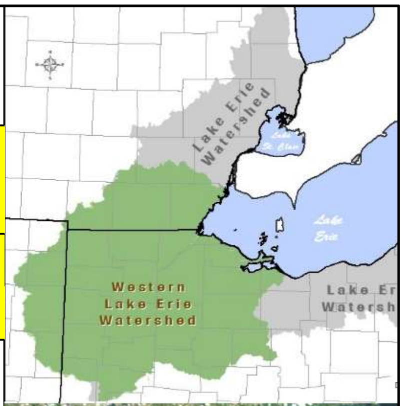


The first example deals with nitrogen. This meta-analysis summarizes effects of nitrogen source on yield and nitrous oxide emission. Different technologies can be applied to urea, using urease inhibitors, nitrification inhibitors, and polymer coatings. These inhibitors improve yield, and thereby nutrient use efficiency, but only modestly, the largest average effect of 7%. Even if the efficiency increase is larger, the benefit hardly covers the cost. Reductions to nitrous oxide emissions, however, are much larger. These are average reductions, ranging from 20 to 46 percent! The difficulty is that so far, farmers are generally not paid for this benefit. Adoption would increase dramatically if they were. Current we are relying on the nutrient use efficiency benefit to drive adoption of the much larger but less tangible benefit of nitrous oxide emission reduction. The question of how we will realize this value is a socio-economic question. Where nitrous oxide emission factors are high – on clay soils, in wet climates – alternative strategies to recognize, value and drive adoption of inhibitors is needed.

Western Lake Erie Watershed

Year	Outputs, kt P_2O_5 crop removal	Inputs, kt P_2O_5 fertilizer	manure	PUE
1987	69	85	11	72%
2014	112	71	12	135%

- Cropland PUE almost doubled.
- Loss of dissolved P to the lake also doubled.
- ***Unintended consequence of conservation tillage with broadcast application of P fertilizer.***



NuGIS Nutrient Use Geographic Information System

Jarvie et al., 2017, J Environ. Qual. 46(1):123-132

In a second example, with phosphorus in the Lake Erie watershed, we have a similar story. Over the past twenty years, algal blooms have again become common in the western basin of the lake. Its watershed comprises over 2 million hectares of productive cropland. The dominant crop rotation includes soybeans and maize. Compare the two years, 1987 and 2014. Owing to rising crop yields, phosphorus removal in crop harvest increased from 69 kilotons to 112 kilotons annually. The amount of phosphorus applied in the form of fertilizer and manure now falls short of replacing crop removal. While phosphorus use efficiency almost doubled, the algae problem worsened. Monitoring of the watershed indicates that losses of the dissolved form of phosphate are increasing, and in fact, doubled. Many causes have been proposed and discussed, but one fact stands out. In 2014, over half the fertilizer phosphate applied was broadcast on the soil surface, and not incorporated. Combine that practice with widespread adoption of conservation and no-tillage systems, and there is a plausible link to losses arising directly from fertilizer application. Those losses could be curtailed by changing placement. But changing placement is not going to be driven by increased use efficiency. Yield loss arising from those losses is negligible, and broadcasting helps prevent yield loss from delayed planting. So from an agronomic point of view, broadcasting is the preferred placement, even if not the "right place." To solve this problem, a focus is needed on loss reduction, not efficiency improvement.

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Jarvie, H. P., Johnson, L. T., Sharpley, A. N., Smith, D. R., Baker, D. B., Bruulsema, T. W., & Confesor, R. (2017). Increased soluble phosphorus loads to lake erie: Unintended consequences of conservation practices? *Journal of Environmental Quality*, *46*(1). https://doi.org/10.2134/jeq2016.07.0248

Nutrient use efficiency & nutrient losses

- The economic benefits of improved nutrient use efficiency may not be enough to drive adoption of the technologies needed for loss mitigation.
- In such situations, need ways to derive value from the loss reduction.

The previous two large-scale examples showed important differences between nutrient use efficiency and nutrient loss. This does not apply to all issues. Improving NUE can play a big role in reducing larger volume losses, like volatilization of ammonia from urea application, or nitrate losses to groundwater. The point is that improving NUE is not always enough. Choosing the focus depends on regional priorities. Choosing those priorities, and making them real, demands stakeholder engagement in the process, and this is why I’d like to talk next about collaborative participatory extension.

I will draw on my experiences in the Lake Erie watershed. Agri-retailers there were convinced that they needed to do something to deal , largely through the efforts of David Baker, a scientist at Heidelberg University who had been monitoring Lake Erie tributaries since 1975.

- Program initiated by four agri-retailers (not shown) centered in the Lake Erie watershed, in response to science data supplied by the National Center for Water Quality Research at Heidelberg University in Tiffin, Ohio.
- The critical slogan for success was “We all play a Role.” In adopting this attitude, a lot of finger-pointing among sectors was avoided.

- The implementation of principles of 4R Nutrient Stewardship using a collaborative approach is helping to guide producers to adopt practices that benefit both their profitability and the health of Lake Erie.
- By 2010, Ohio researchers from Heidelberg University had been reporting increases in loads and concentration of phosphate in the Sandusky and Maumee rivers, two of the major tributaries monitored in their water quality sampling program. The Andersons, a large agricultural retail business headquartered in Maumee, Ohio, began discussions with these scientists to

better understand the issues. Recognizing that a large part of their business was located in the watershed, they became engaged, even to the extent of financially supporting the program monitoring the river P loads. Around the same time, the North American fertilizer industry was developing the concept of 4R Nutrient Stewardship—the application of the right source of nutrients at the right rate, right time, and right place. Working with the Nature Conservancy, The Andersons invited other local agricultural retailers, fertilizer industry associations, government agencies and environmental organizations to come together, with the aim of developing a specific implementation of 4R Nutrient Stewardship to change and document nutrient application practices toward reducing P losses. Following multiple engagement sessions, the stakehold- ers developed and agreed to support a voluntary program which became known as the Western Lake Erie Basin 4R Nutrient Stewardship Certification Program

- The value of the program was demonstrated during a widely publicized "do not drink" advisory issued for the City of Toledo's water supply in August of 2014. While the program was not yet at a stage to have impacted P losses or algal blooms, the many stakeholders involved were able to provide consistent messages about the efforts being made to address the issue.
- One remaining issue of uncertainty surrounds conservation tillage and its impact on P loading within the watershed. Incorporation or sub-surface injection of applied P is known to reduce loss risks for dissolved P, but the associated increase in soil disturbance may increase losses of particulate P through erosion. Additionally, owing to the large influence of weather on annual loads of P in the tributaries, many years may be required to detect the effect of this and other programs being implemented to reduce P loading from nonpoint sources.

- Bruulsema, TW. 2017. A Certification Program for 4R Nutrient Stewardship. Better Crops/Vol. 101(1):7-9

Supporting the efforts in

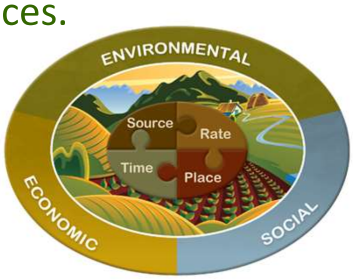
So what do we know and yet not know?

Responsible Plant Nutrition nourishes plants in a sustainable manner that enhances earth's capacity to support healthy life.

Improving nutrient use efficiency reduces losses, but is not always enough.

A collaborative participatory form of extension and research is needed to effect adoption of the "right" practices.

nutrient stewardship



1 – we know this definition is right. We don't know to whom it means anything!
2 – we know NUE is a good start. We don't know how much to invest in it. Nor what is enough!
3 – the form does not have to be third party certification. Different approaches may be needed for different regions with different issues.

4R Nutrient Stewardship Certification Program

- Requirements for Nutrient Service Providers in the Lake Erie Watershed and all of Ohio
- 45 Standards for training & education, monitoring of implementation, and nutrient recommendations & application
- Example – Standard 3.5.8: “applications are neither made nor recommended to be made on frozen or snow covered ground.”
- **Recognition**

NUTRIENT STEWARDSHIP CERTIFICATION

- agri-retailers and service providers decided they needed third party certification. Without it, they would not be empowered to deny a customer who requested application on frozen or snow-covered ground.
- The right to bear the logo is all the value the program provides. It has value, because the importance of the issue is so widely recognized among farmers, among agri-business people, and by the rural population. In other watersheds without a focused issue, ag retailers might not see as much value.

Contents lists available at ScienceDirect

Journal of Great Lakes Research

journal homepage: www.elsevier.com/locate/jglr

Building partnerships to scale up conservation: 4R Nutrient Stewardship Certification Program in the Lake Erie watershed

Carrie Vollmer-Sanders [a,*], Andrew Allman [b], Doug Busdeker [c], Lara Beal Moody [d], William G. Stanley [e]

"…implementing the 4Rs has been identified as a key step to improving water quality.

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**."

The importance of this collaboration is documented in the Journal of Great Lake Research

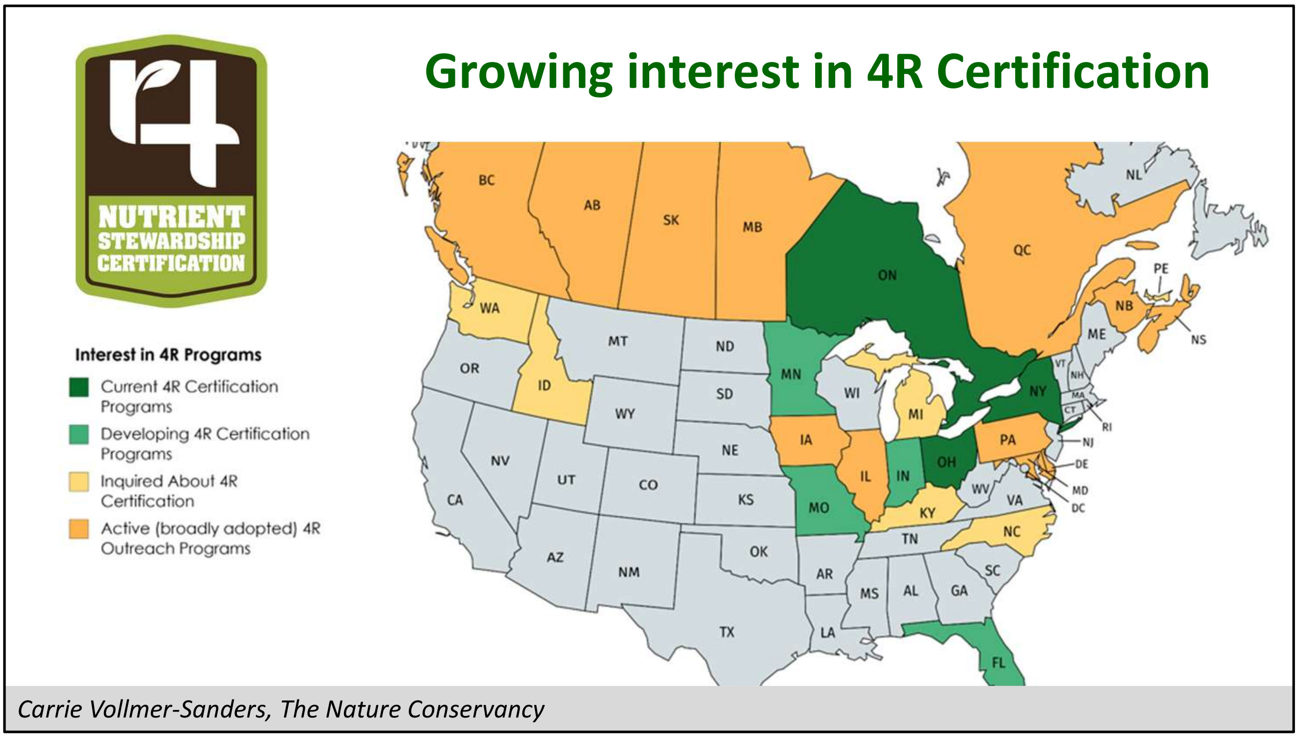
Support for research underscores industry commitment to linking 4R practice to outcomes

Initiated 2013.

Delivering ~$1M per year to research projects linking 4R practices to metrics of impact.

2019: $2.7M for new projects in AZ, AR, CA, UT, VA.

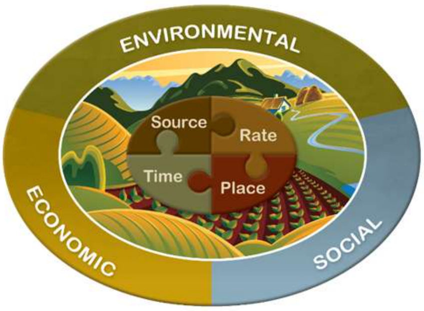
The people supporting 4R Certification recognize the need for more practice data to support metrics of 4R impact.



Nevertheless, interest is spreading. Success in Ohio has led many other jurisdictions to show interest in 4R certification. Ontario Canada is also driven by the Lake Erie phosphorus issue. But places as far away as Minnesota and Florida are also showing interest in this approach.

As the program expands to other regions, different regional priorities will need to be addressed. In Canada, for example, the emphasis on greenhouse gas emissions is likely to increase. In the recent federal election, two-thirds of Canadians voted for parties supporting a carbon tax.

Metrics of Sustainable Plant Nutrition



nutrient stewardship

1. **Farmland productivity**
2. **Soil health**
3. **Nutrient use efficiency**
4. **Water quality**
5. **Air quality**
6. **Greenhouse gases**
7. **Biodiversity**
8. **Macroeconomic value**
9. **Food security**

Regional Prioritization

At the farm scale, nutrient use efficiency is one of three measurable and actionable outcomes of sustainable nutrient practices. It needs to be balanced against farmland productivity and soil health. These three form the focus at the farm level. It's hard to imagine anything more being measured on the farm. But if we are to achieve larger regional goals, we may need to pick from among priority goals associated with larger scale outcomes ranging from water quality to biodiversity.

Nutrient use efficiency is one metric. Performance is many. We are managing a system for multiple outcomes. To capture the value of enhanced efficiency technologies, we need systems that reward progress on multiple outcomes. It's not just productivity. It's as many of these nine outcome metrics as we can possibly capture.

While sustainability implies multiple outcomes, not every outcome is material on any one specific farm. The farm on clay soil in the humid climate of eastern Canada can reduce nitrous oxide emissions, but has little impact on groundwater nitrate. The farm in southeastern Alberta in an arid climate has little to contribute to reducing nitrous oxide emissions, because its emissions are small. The farm importing grain to feed its livestock has a nutrient surplus problem, that will not be fixed by timing and placement of manure application.

REGIONAL PRIORITIZATION of farm-specific nutrient management goals, and of regional research themes. Both among and within these metrics.

The USEPA is proposing a nitrogen challenge, and has met with USDA and TFI. One part of the challenge would be testing the efficacy of enhanced efficiency fertilizers for the full range of impacts, including productivity and at least something from each of the first 6 categories listed here. Ironically, today, new fertilizer products are not even tested for agronomic efficacy. The cost of testing for all impacts would be far higher.