Nitrogen Fertilizer Management to Mitigate Greenhouse Gas Emissions

David Burton
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Three myths (*in my opinion*)

We need to apply more nitrogen fertilizer so Canadian agriculture can "feed the world"

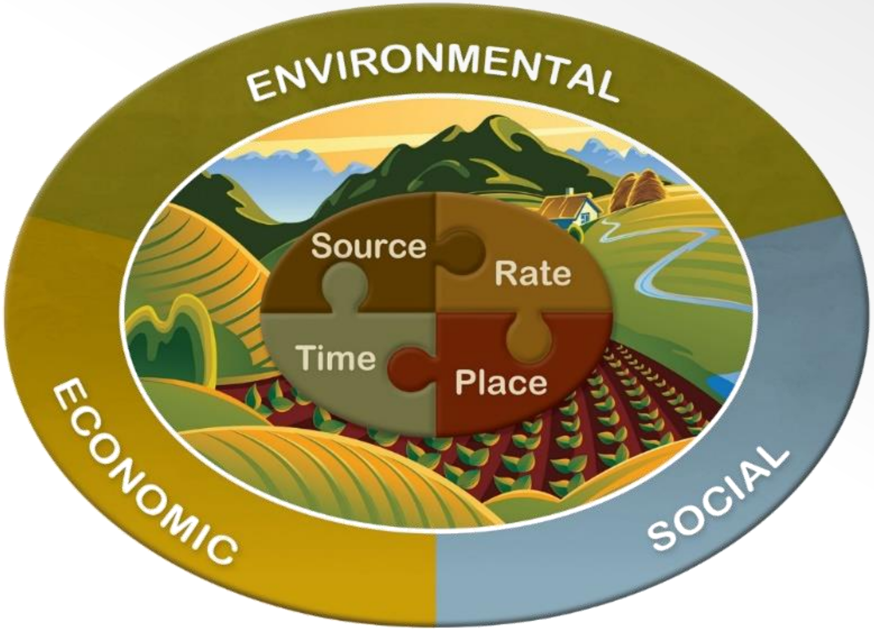
- "Some nitrogen fertilizer is good, more is better"
- "Insurance Nitrogen"
- Fertilizing for "target yields"
- Nitrogen is no longer the primary limitation to crop yield in Canadian agriculture?

We already use nitrogen fertilizer efficiently

- "If I didn't need it, I wouldn't use it"

We cannot reduce N_2O emissions from N fertilizer use without sacrificing yield and <u>profitability</u> in Canadian agriculture.

To improve nutrient management the fertilizer industry has developed the framework of 4R management



IPNI, 2016

What are the 4 "R"s?
Plus one…

+ Right <u>Rotation</u>

But what do we mean by is RIGHT?

- Greater crop diversity, extended rotation
- Inclusion of legumes
- Continuous cover
  - Cover crops
  - Perennial crops

4R Framework builds on science and offers practical solutions

	The Four Rights (4Rs)			
	Source	Rate	Time	Place
Examples of Key Scientific Principles	◆ Ensure balanced supply of nutrients ◆ Suit soil properties	◆ Assess nutrient supply from all sources ◆ Assess plant demand	◆ Assess dynamics of crop uptake and soil supply ◆ Determine timing of loss risk	◆ Recognize crop rooting patterns ◆ Manage spatial variability
Examples of Practical Choices	◆ Commercial fertilizer ◆ Livestock manure ◆ Compost ◆ Crop residue	◆ Test soils for nutrients ◆ Calculate economics ◆ Balance crop removal	◆ Pre-plant ◆ At planting ◆ At flowering ◆ At fruiting	◆ Broadcast ◆ Band/drill/inject ◆ Variable-rate application

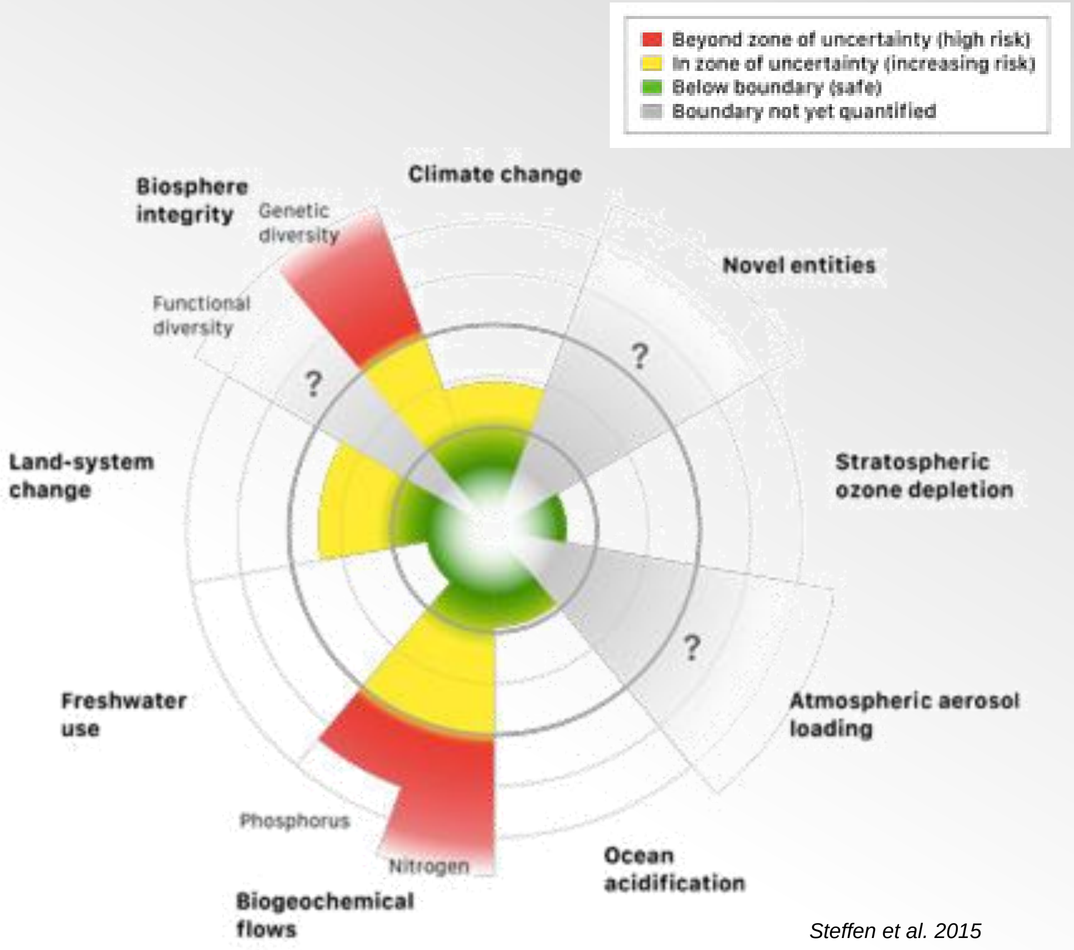
IPNI, 2015

I want to talk about four things…

How much is nitrogen enough?
How well are we quantifying our nitrogen inputs?
How well are we managing our nitrogen losses?
Does 4R work?

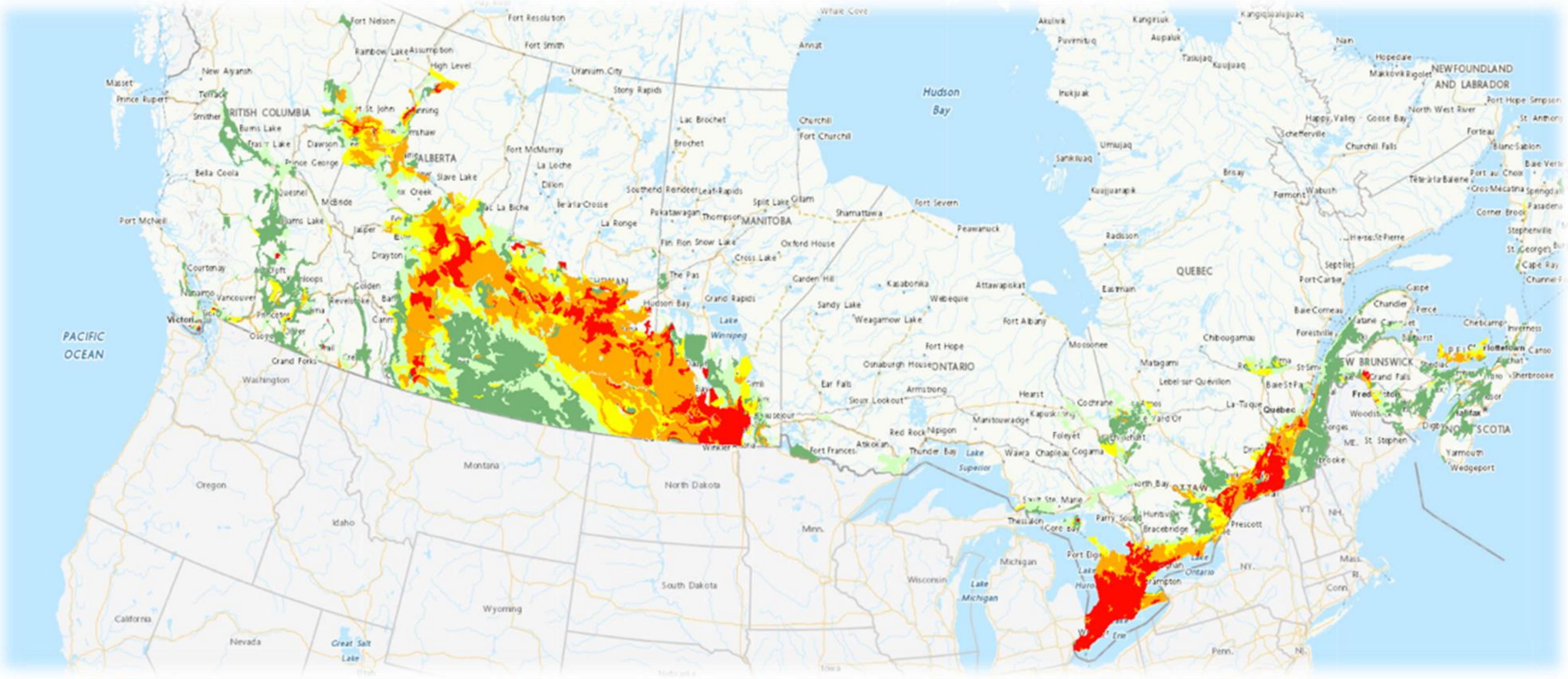
How does the nitrogen cycle impact climate?

- Nitrogen addition to ecosystem one the greatest exceedances of global boundaries
  - Agricultural N inputs have resulted in a doubling of the amount of reactive N in the biosphere.
- This is resulting in significant environmental impact.
- This is not sustainable.



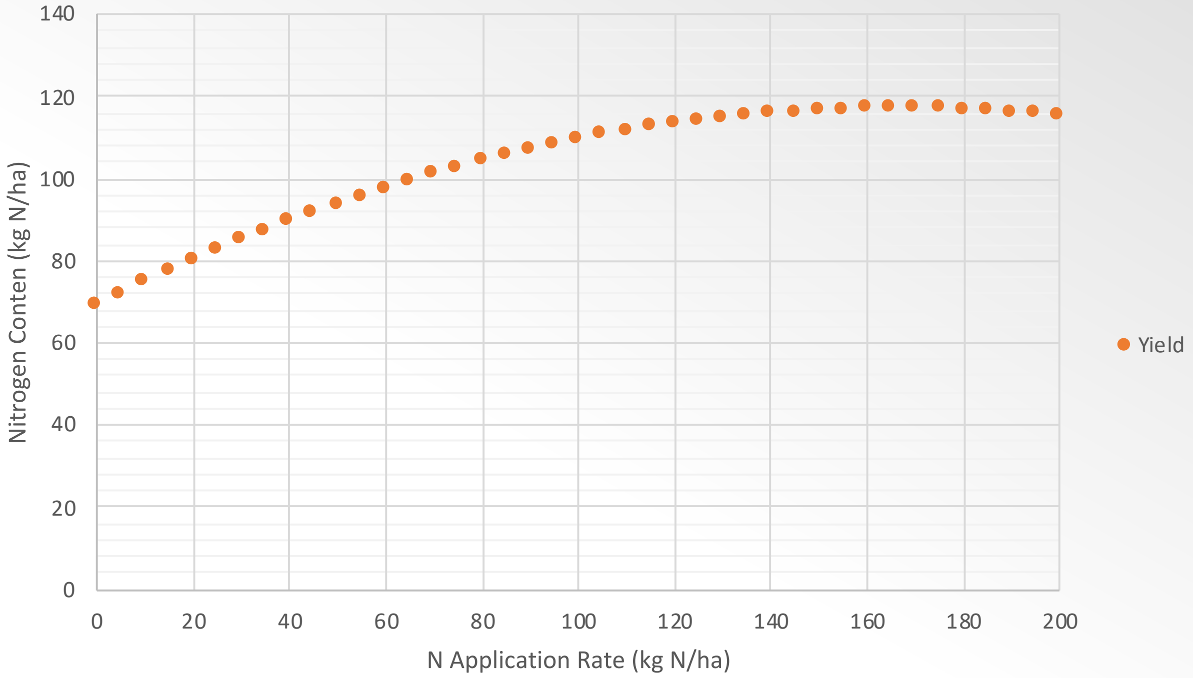
Steffen et al. 2015

Greenhouse Gas Emissions from Fertilizer in Canada



How much is Enough?

- The response of crop yield to N addition is curvilinear.
- There is a maximum yield that N addition can generate



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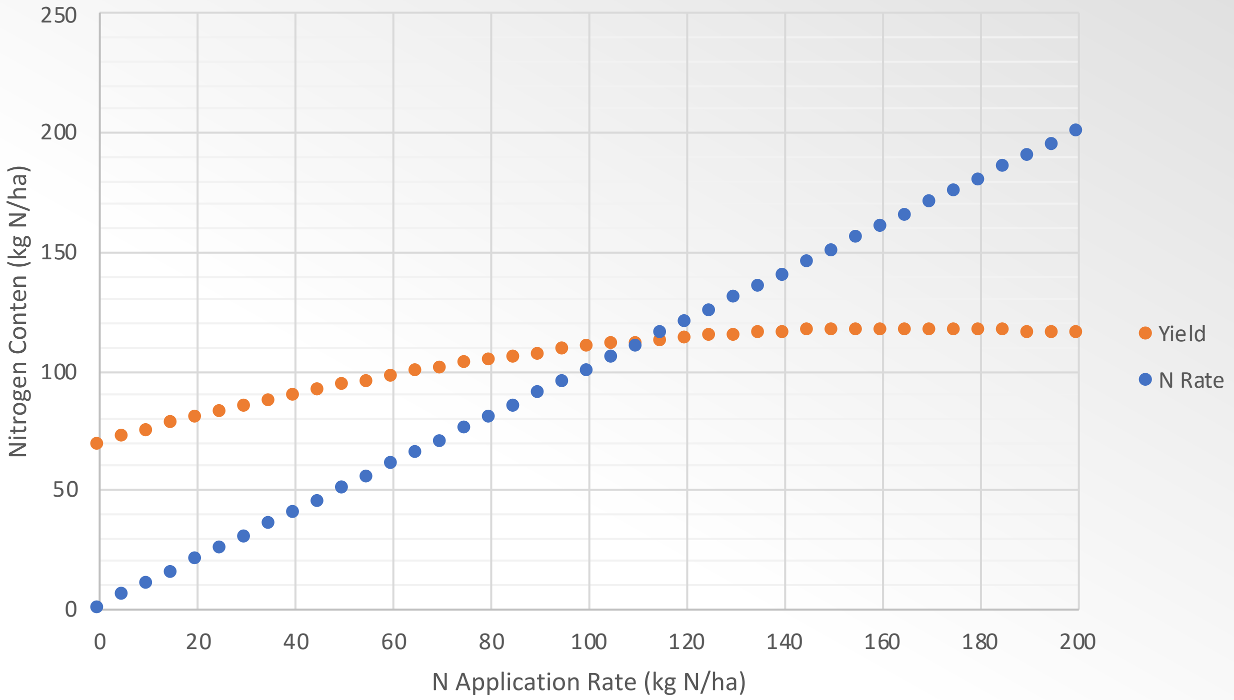
- To achieve maximum yield we are adding more N than we are removing



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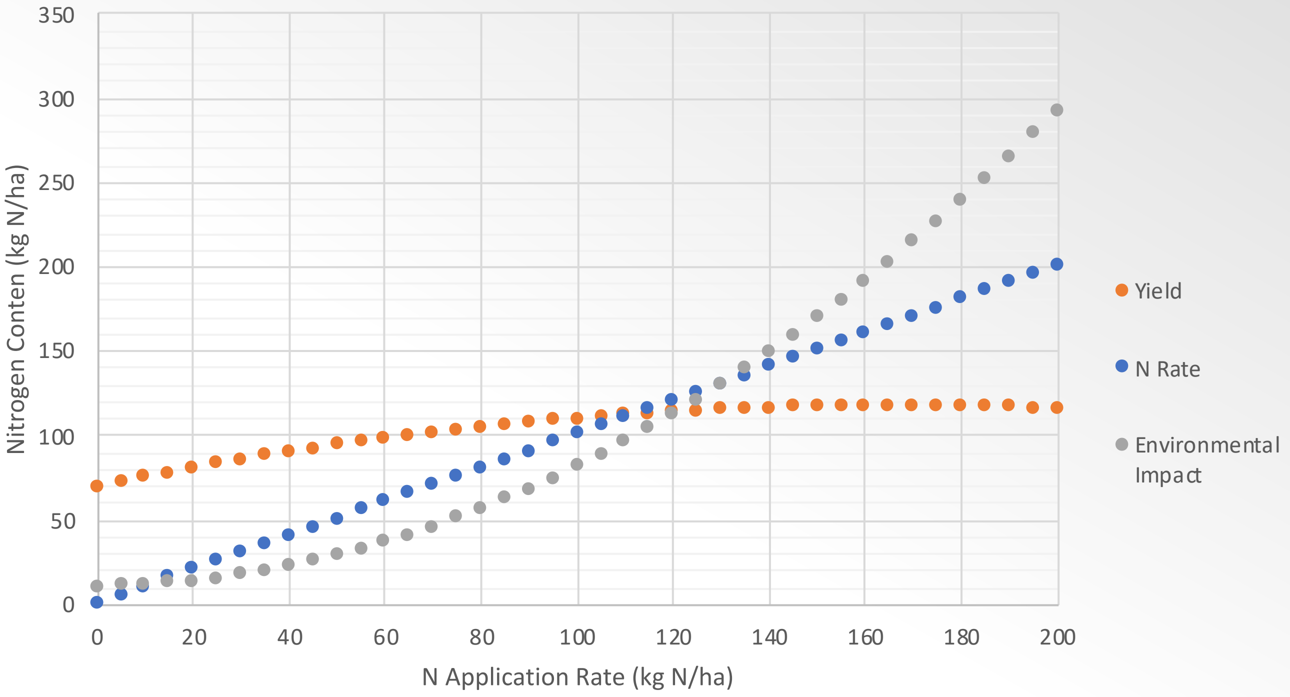
- The potential for environmental impact increases non-linearly with N rate



The evolving Context of Agriculture

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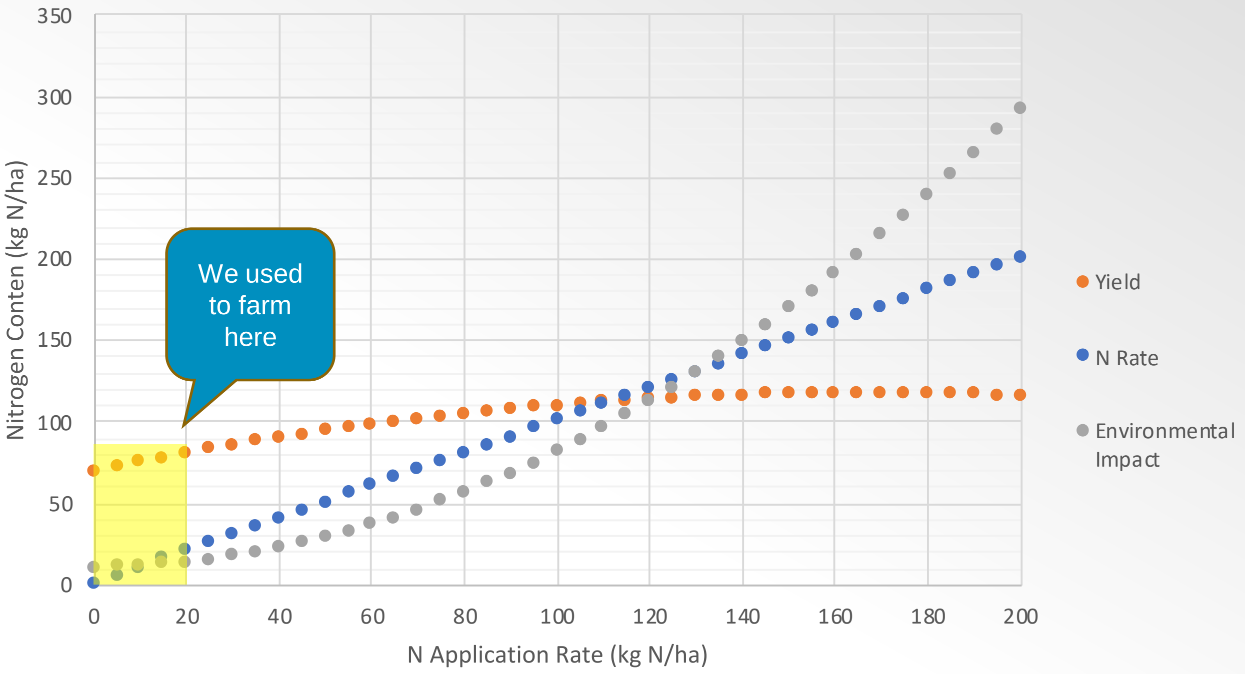

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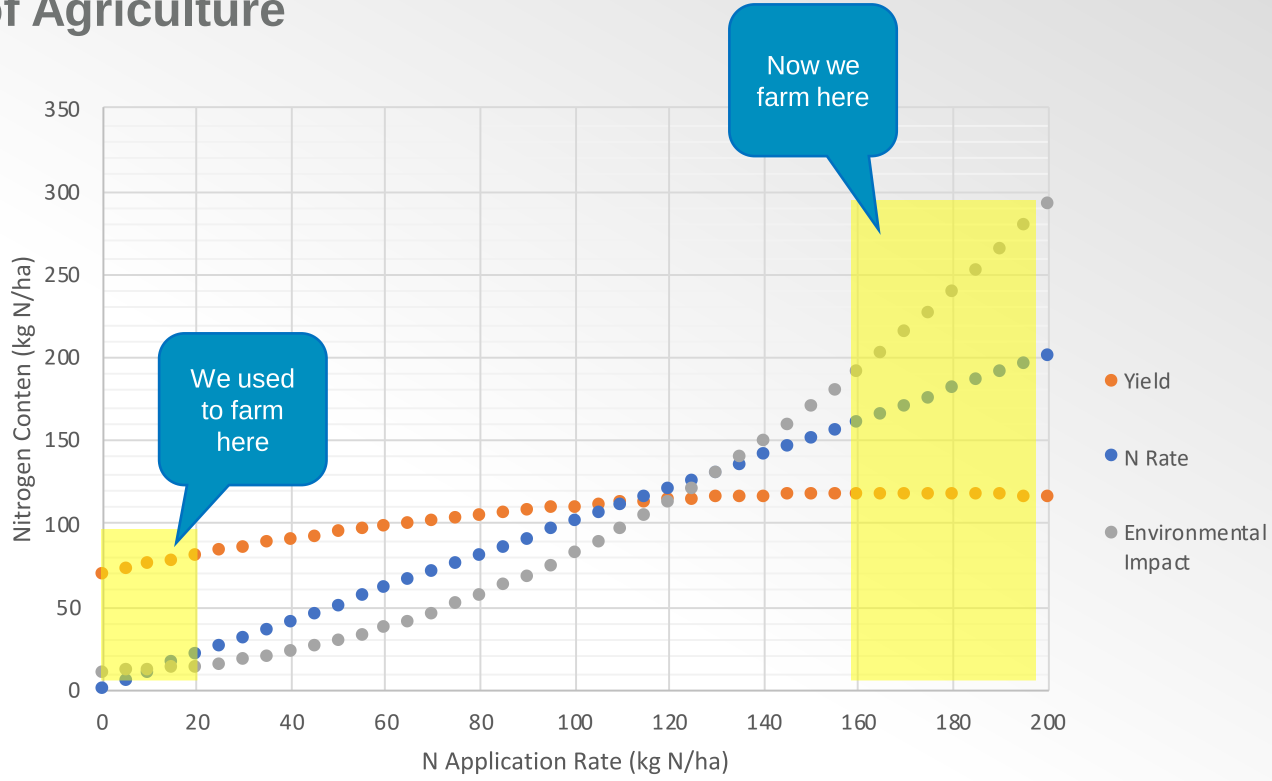

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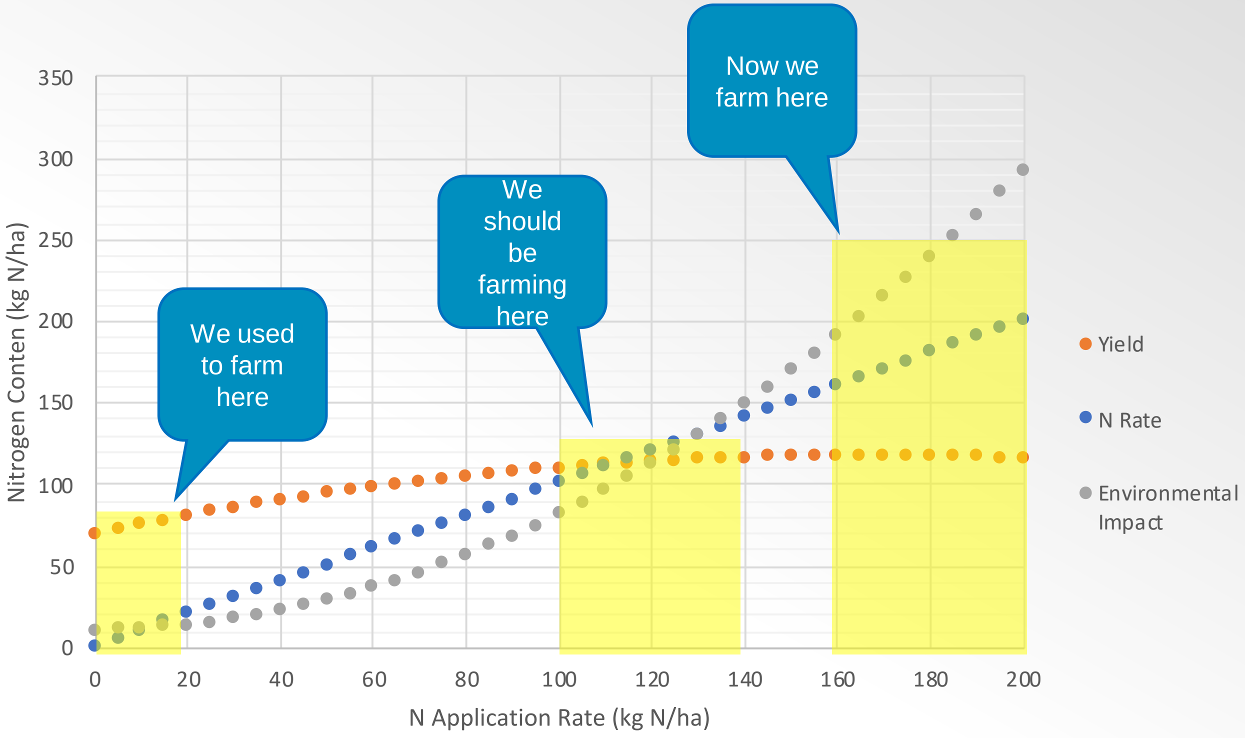

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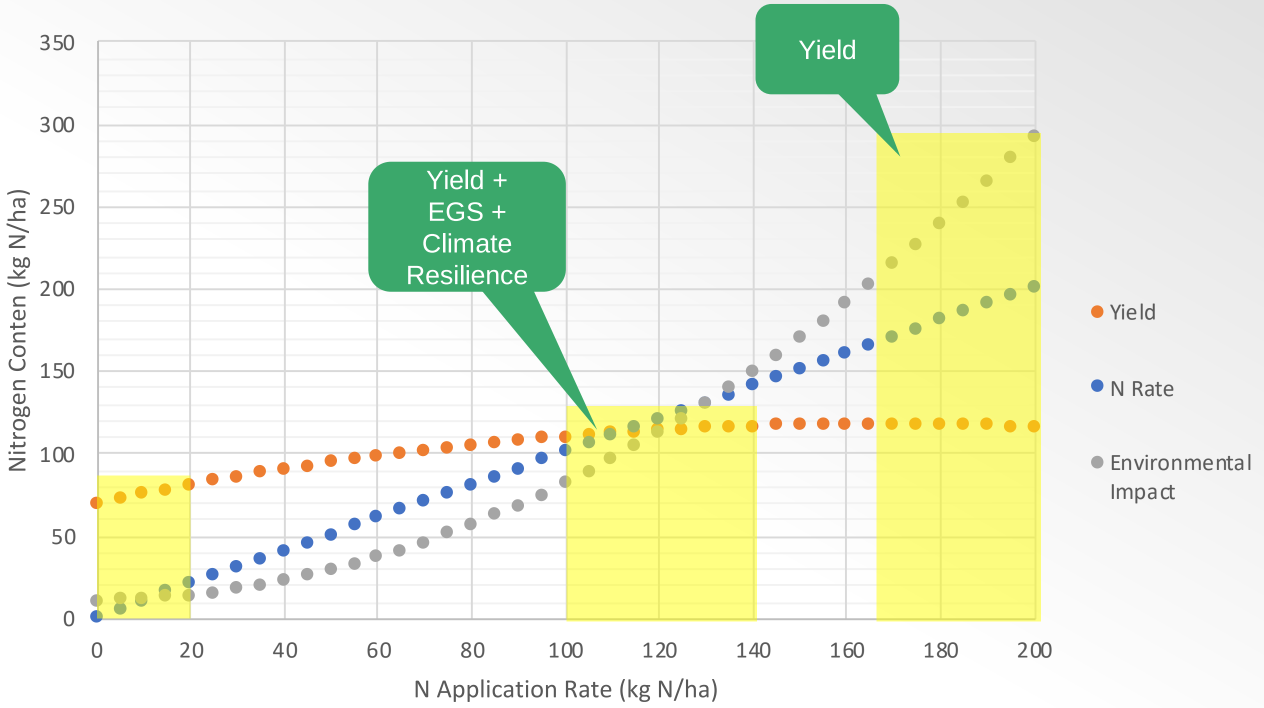
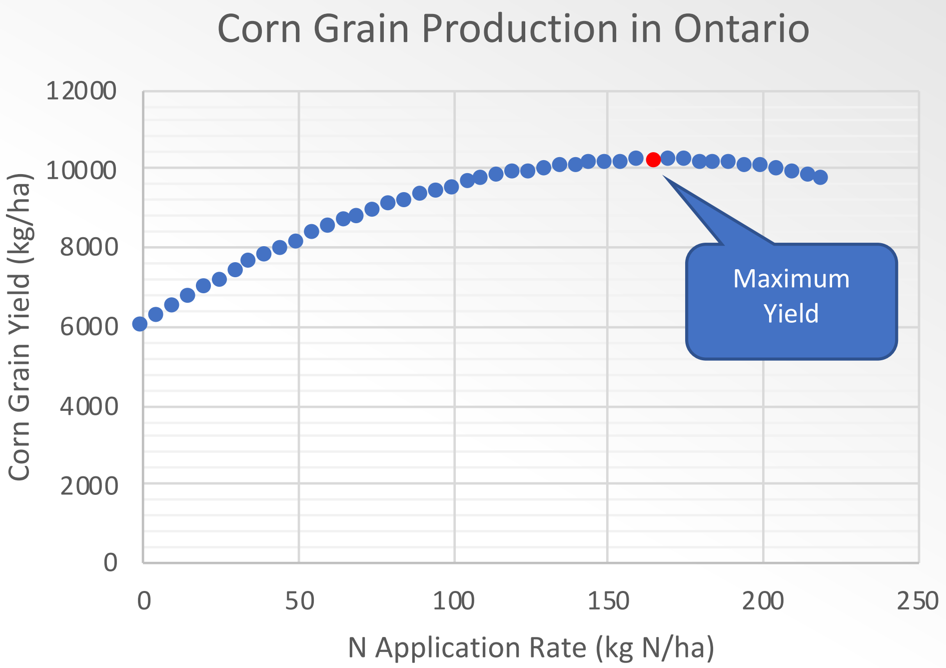


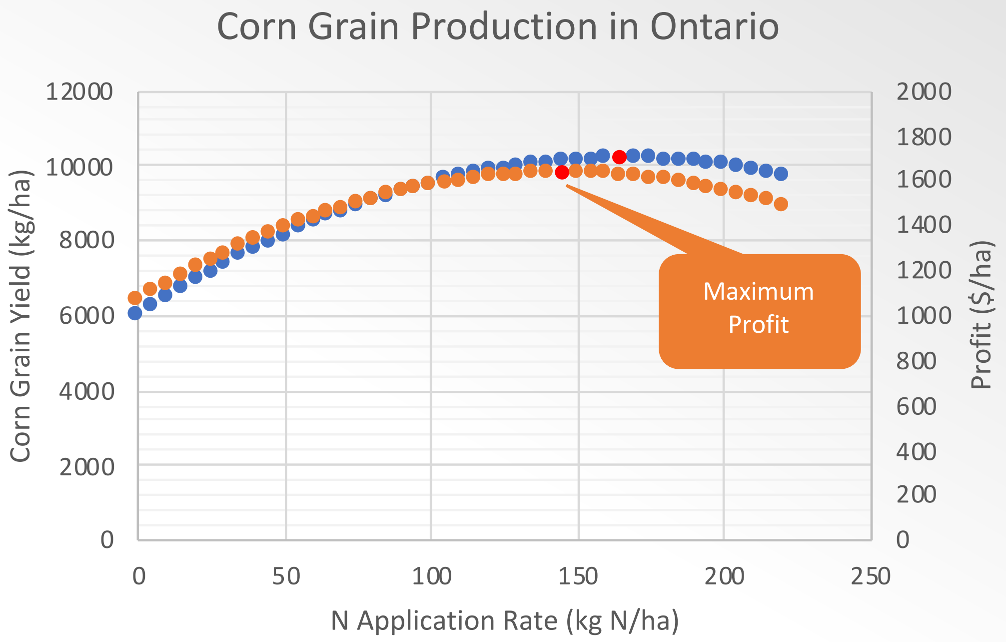
What is the goal… Maximum Yield?

- Often producers talk about fertilizing for maximum yield.
  - “feeding the world”



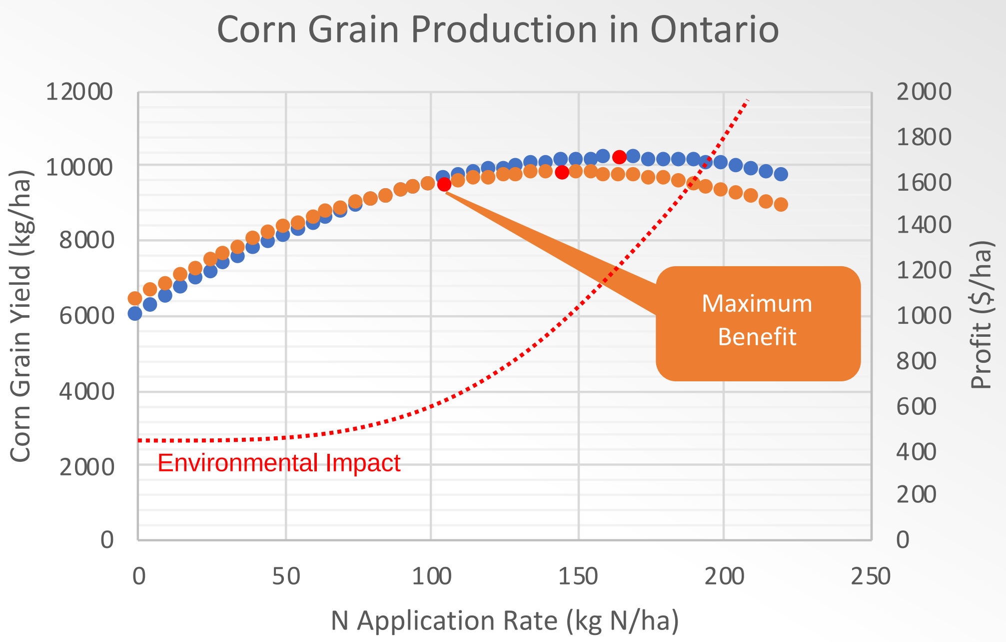
What is the goal… Maximum Yield?

- Often producers talk about fertilizing for maximum yield.
- But maximum yield and maximum profit are not the same
  - The last increment of fertilizer use to achieve maximum yield often does not pay for itself



What is the goal… Maximum Yield?

- The profit curve is often quite flat… the environmental impact curve is not.
- Maximum benefit can be achieved with a modest reduction in profit.
  - In this case 97.5% of maximum profit was obtained despite a 40 kg N/ha N fertilizer reduction.
  - Net cost of $63/ha



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How well are we managing our nitrogen losses?

Does 4R work?

4R Framework requires we assess on nutrient sources

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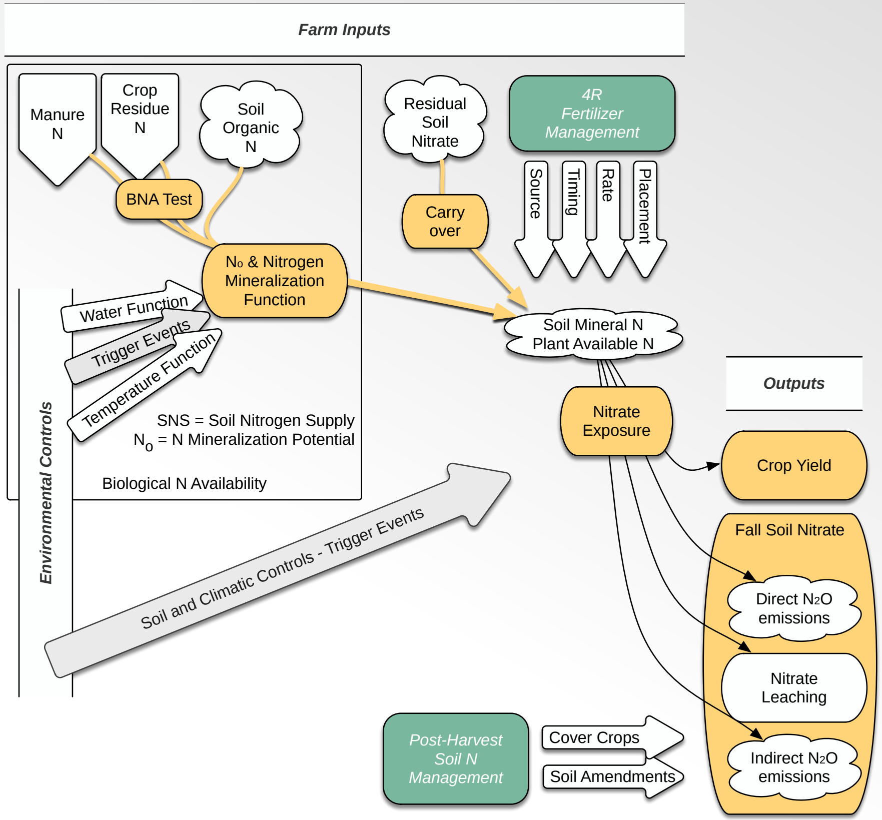
IPNI, 2015

How well are we quantifying inputs?

Need to quantify all sources of N.

Need site-specific information.



How well are we quantifying inputs?

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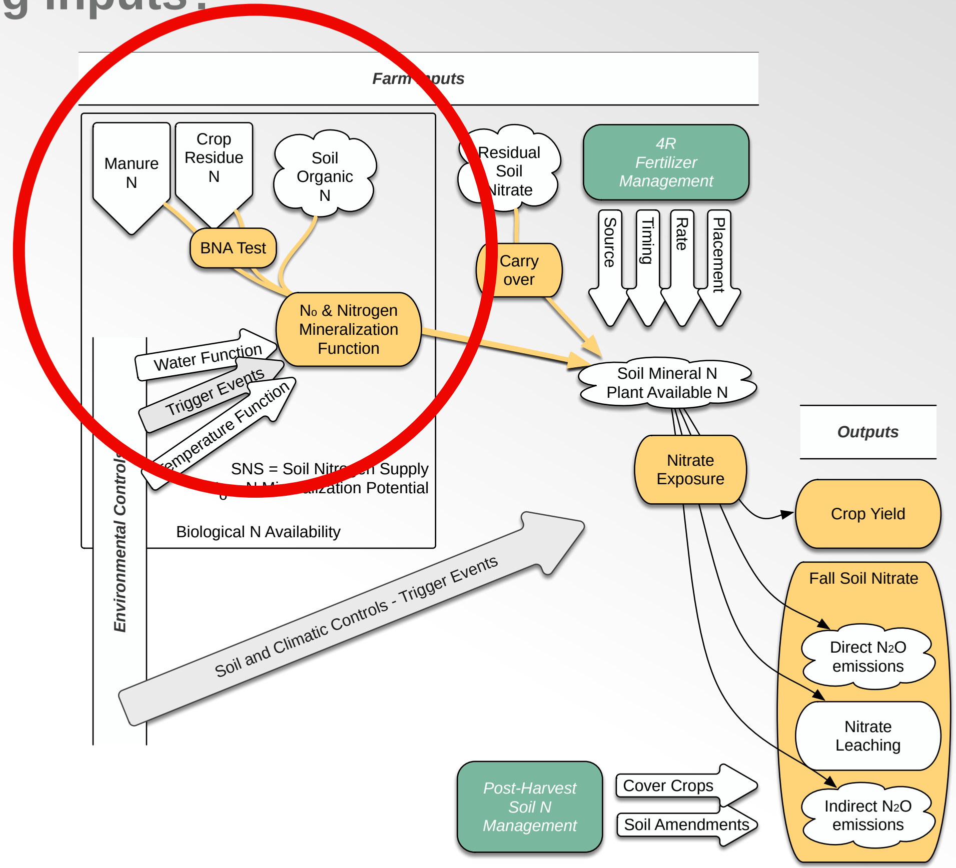
Need site-specific information.

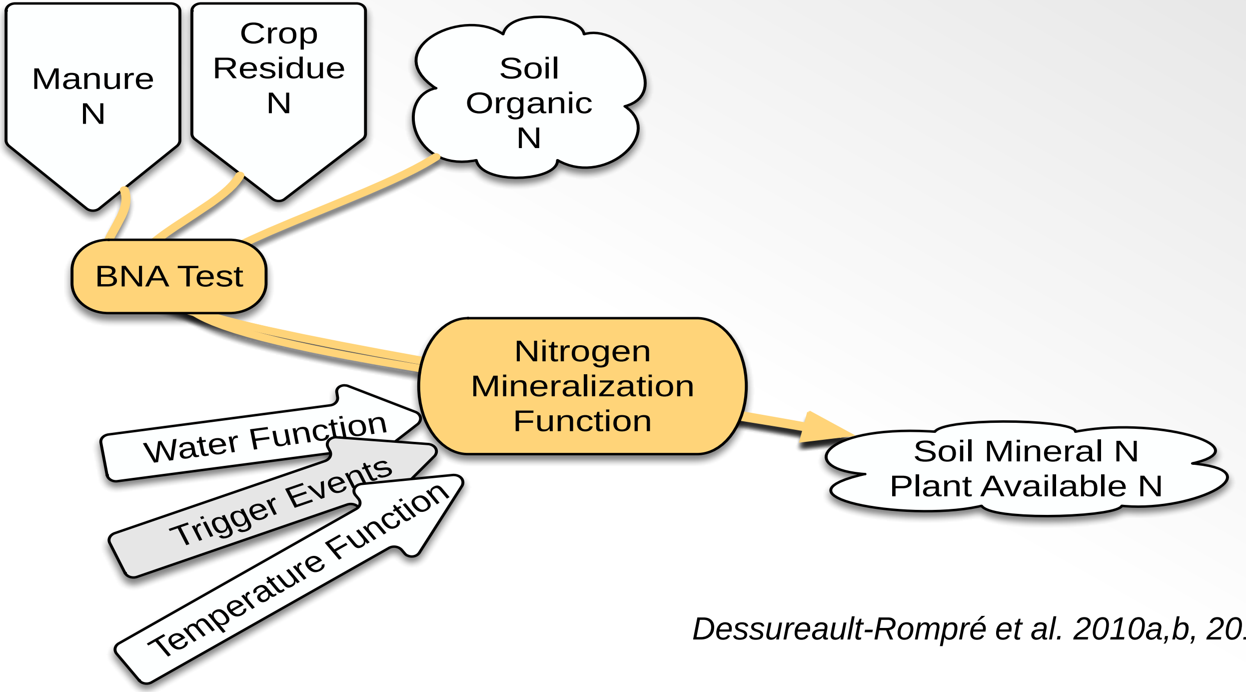
Therefore, we need tools to measure all sources of N:

- Biological N Availability (BNA),
- Estimate growing season N mineralization

Apply 4R principles to supplemental N addition



Soil Properties (Total N and BNA) and climate data (air temperature and precipitation) can be used to predict N mineralization



Dessureault-Rompré et al. 2010a,b, 2011

Leads to a better understanding the impact of <u>soil properties</u> and <u>climate</u> on soil N supply

Atlantic Soil Health Lab

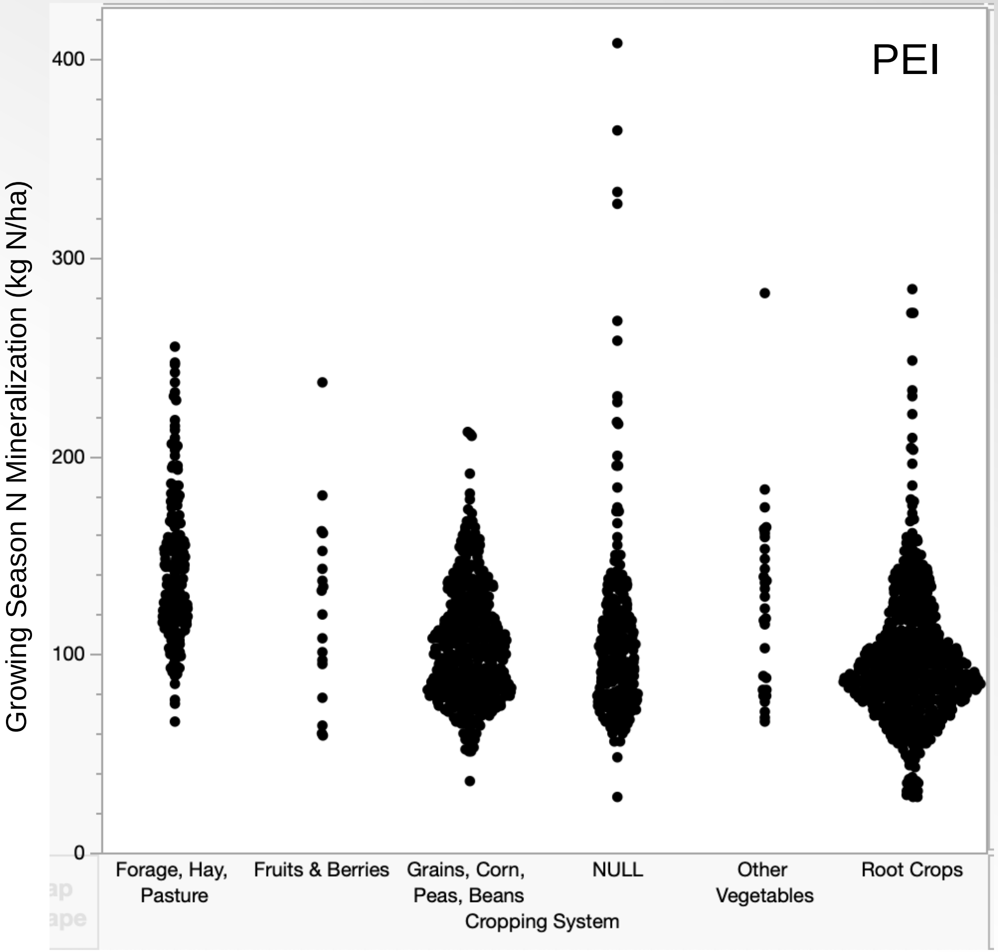
PEI Analytical Laboratories (PEIAL)

PEI Analytical Laboratories (PEIAL) provides chemical and microbiological analysis for water, soil, dairy, animal feed, seed, plant tissue, manure, and compost samples, and disease identification service for crops.

The lab is accredited by the Standards Council of Canada (SCC) to the international standard for the general requirements for competence of testing and calibration laboratories, ISO/IEC 17025:2005. A copy of PEIAL's Scope of Accreditation may found on the Standards Council of Canada website at: https://www.scc.ca/

Growing Season N Mineralization

- This is a summary of estimate of growing season N mineralization derived from the values for ~1300 measurements of BNA made by the PEI Analytical Lab as influenced by cropping system.
- Note the considerable variability between fields.
  - Emphasizes the need to measure



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How does ***Crop Rotation*** influence soil N supply?

Nyiraneza et al. have recently summarized the results of half a dozen studies where a zero N trail was included.

Agriculture and Agri-Food Canada | Agriculture et Agroalimentaire Canada | Canada

Using a plant bioassay approach to estimate soil nitrogen contribution to potato crop

Judith Nyiraneza, Danielle Murnaghan, Aaron Mills, Yefang Jiang, Vernon Rodd, and Mark Grimmett

The price of nitrogen (N) fertilizer keeps rising and applying N fertilizer above the crop N requirement results in economic and environmental losses. Along with N fertilizer, the soil organic matter (SOM) is an important source of N to crop N nutrition.

Prince Edward Island's coarse-textured soil, cold and wet springs, and short growing seasons make it difficult to confidently estimate the N credits from soil organic matter and preceding crops and thus can result in an over-application of N, especially when a legume forage is the preceding crop. This over application enhances soil nitrate leaching risk, increases greenhouse gas emissions, and negatively affects potato yield (Jiang et al. 2019; Nyiraneza et al. 2021; Whittaker et al. 2022). In Prince Edward Island, current N recommendations for potatoes range from 112 kg N ha^{-1} to 207 kg N ha^{-1} depending on the potato variety (Government of PEI 2017).

A research trial located in Harrington, Prince Edward Island, in which half of the potato plots have received recommended nutrients while the other half of the potato plots have received recommended nutrients with the exception of N fertilizer.

How does *Crop Rotation* influence soil N supply?

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What did they find…

- Soil N Supply ~106 kg N/ha
- Legume credit ~ 31 kg N/ha

Crop Sequence	Average soil N contribution to potato using a Plant Bioassay Approach ± Standard Deviation (kg N/ha)	
Three year potato rotation; two cycles of rotation at two sites (2015-2018), soil pH = 6.1, 6.0; SOM = 3.0%, 2.7%		
Barley u/s Red Clover - Red Clover - Potato	83 ± 14	
Grain Corn - Sorghum Sudan Grass - Potato	75± 15	
Soybean - Brown Mustard (double cropping) - Potato	98 ± 26	
Three year potato rotation; one cycle of rotation (2009-2011), soil pH = 5.8; SOM = 3.5%		
Barley - Barley - Potato	82± 28	
Barley u/s Timothy - Timothy - Potato	84± 5	
Barley u/s Red Clover - Red Clover (early fall plowing) - Potato	116 ± 17	
Barley u/s Red Clover - Red Clover (late fall plowing) - Potato	99 ± 29	
Barley u/s Red Clover - Red Clover (spring plowing) - Potato	127± 25	
Three year potato rotation; two cycles of rotation at wo sites (2012-2015), soil pH = 5.3, 5.6; SOM = 3.4%, 3.3%		
Barley u/s Red Clover - Red Clover - Potato	123 ± 34	
Barley u/s Red Clover - Red Clover (mowed before fall plowing) - Potato	121± 41	
Barley u/s Red Clover - Red Clover (sprayed before fall plowing) - Potato	136 ± 29	
Barley u/s Red Clover - Red Clover (spring plowing) - Potato	124 ± 21	
Three year potato rotation; one cycle of rotation (2014-2016), soil pH = 6.5; SOM = 3.1%		
Barley u/s Red Clover - Red Clover (fall plowing) - Potato	113± 32	
Barley u/s Red Clover Red Clover (spring plowing) - Potato	109± 27	
Two year potato rotation; two cycles of rotation at two sites (2012-2014), soil pH = 5.9; SOM = 3.1%		
(sprayed and unsprayed before fall plowing)	**No Spray**	**Spray**
Negative Control (bare soil/weeds) - Potato	59 ± 13	57± 12
Red Clover - Potato	84 ± 20	56± 13
Rye - Potato	95 ± 33	68 ± 21
White Clover - Potato	96 ± 36	84 ± 36
Two year potato rotation; one cycle of rotation (2017-2018), soil pH = 5.9; SOM = 2.6%		
Grasses, legumes, or a mixture of both with and without 20 metric tons/ha (fresh weight) of cow manure	Averaged across all treatments, manure increased soil N contribution by 44% **(Nyiraneza et al. 2021)**	

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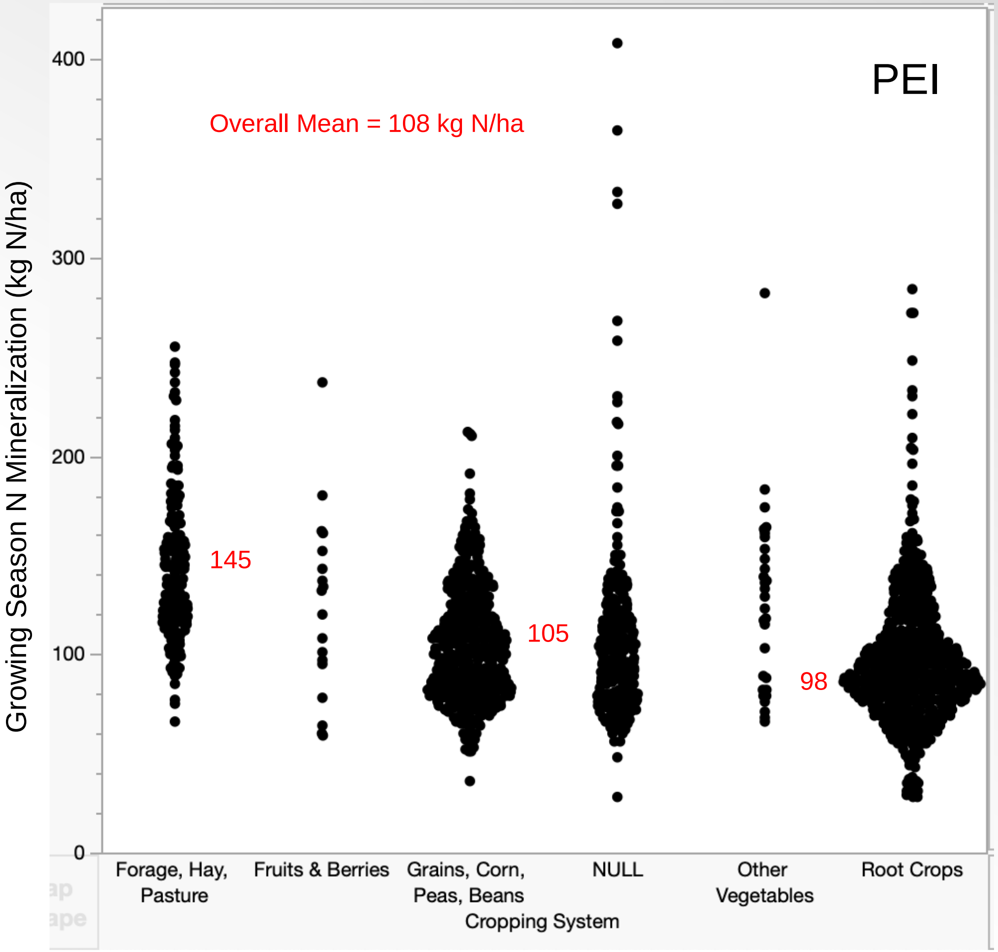

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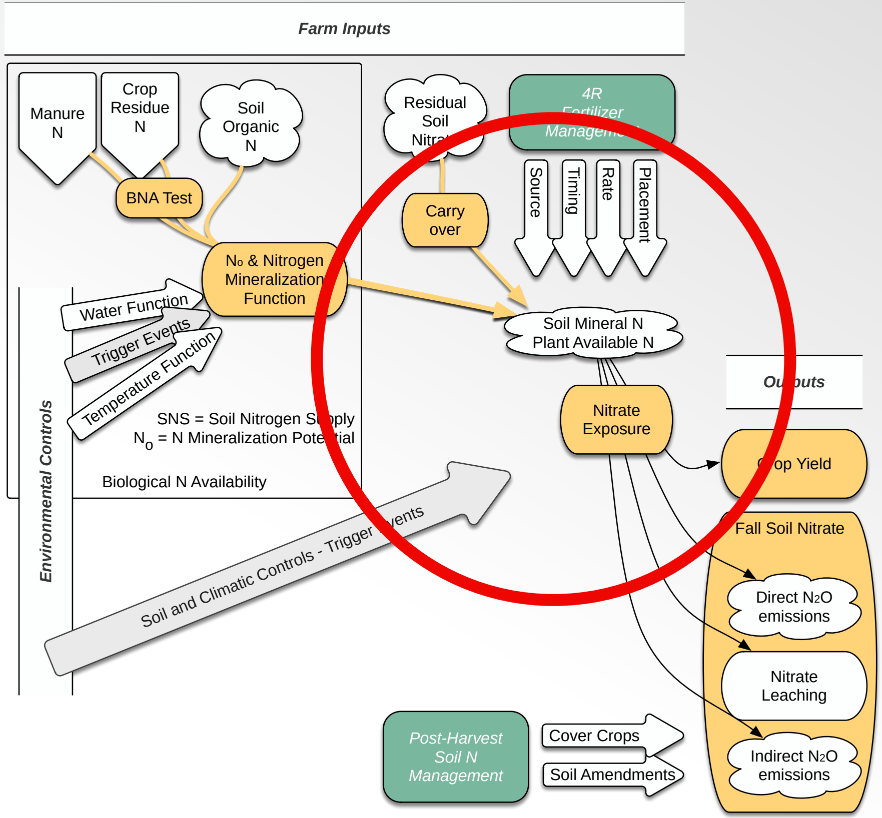
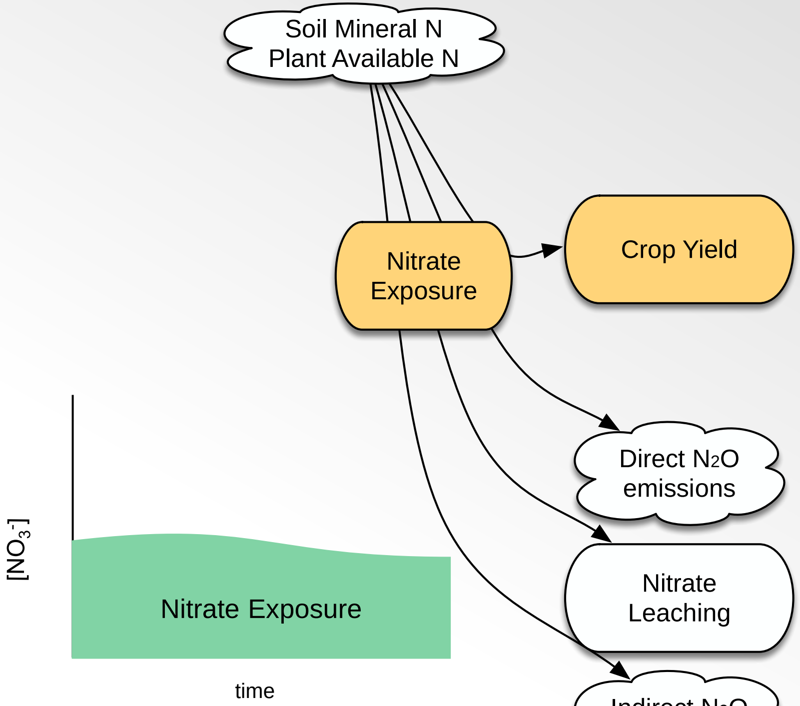


Nitrate Exposure is a means of evaluating the synchrony of N supply and plant N demand

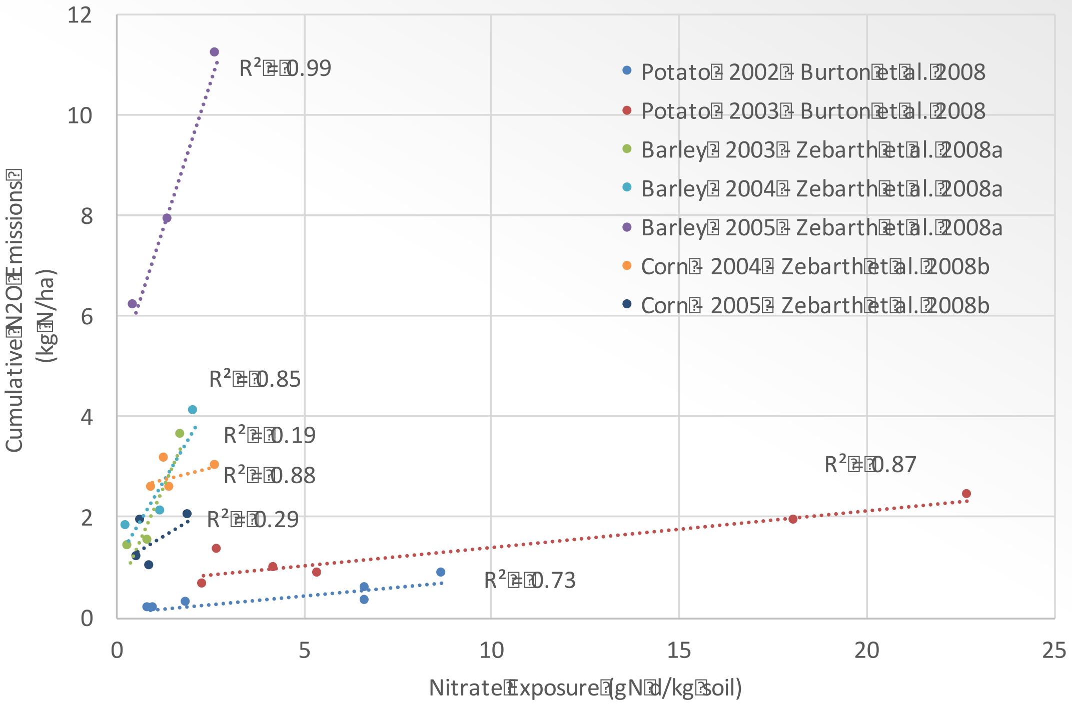
- Nitrate exposure is the amount of nitrate days over the growing season
- Nitrate is the major pool from which N losses occur
- Greatest N use efficiency occurs when soil N supply is in synchrony with plant N uptake and therefore little nitrate accumulates (low nitrate exposure)
- Nitrate exposure is therefore a measure of the potential for loss during the growing season



$$NE = \sum_{i=1}^{n} [NO_3^-]_i * \left(\frac{d_{i+1} - d_{i-1}}{2} \right)$$

Nitrate Exposure and Cumulative N_2O Emissions

Atlantic Canadian Cropping Systems



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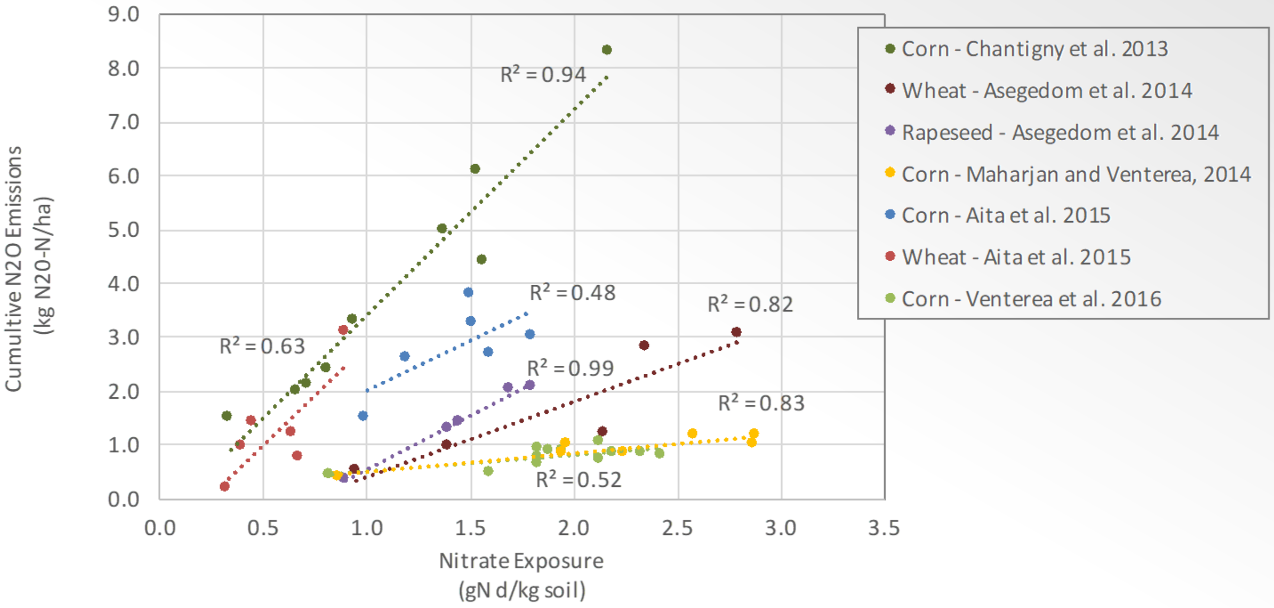
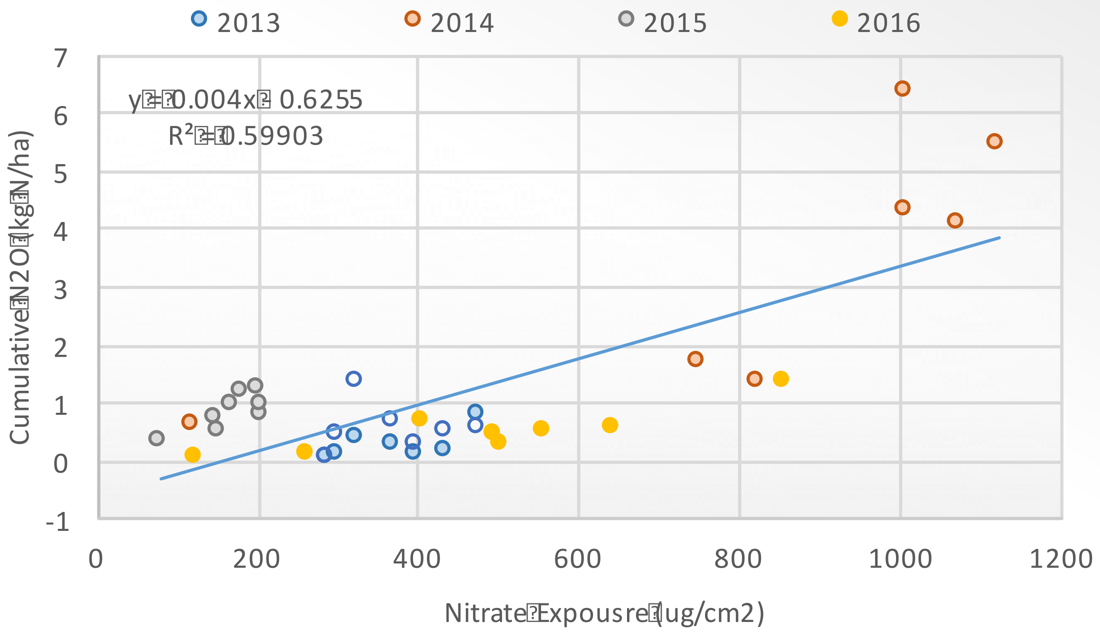
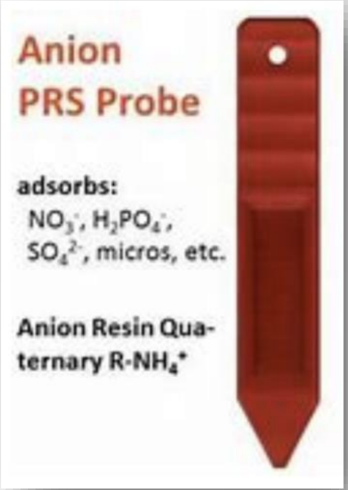
North American Cropping Systems



N_2O Emissions vs. Nitrate Exposure (IEM NO_3^-)

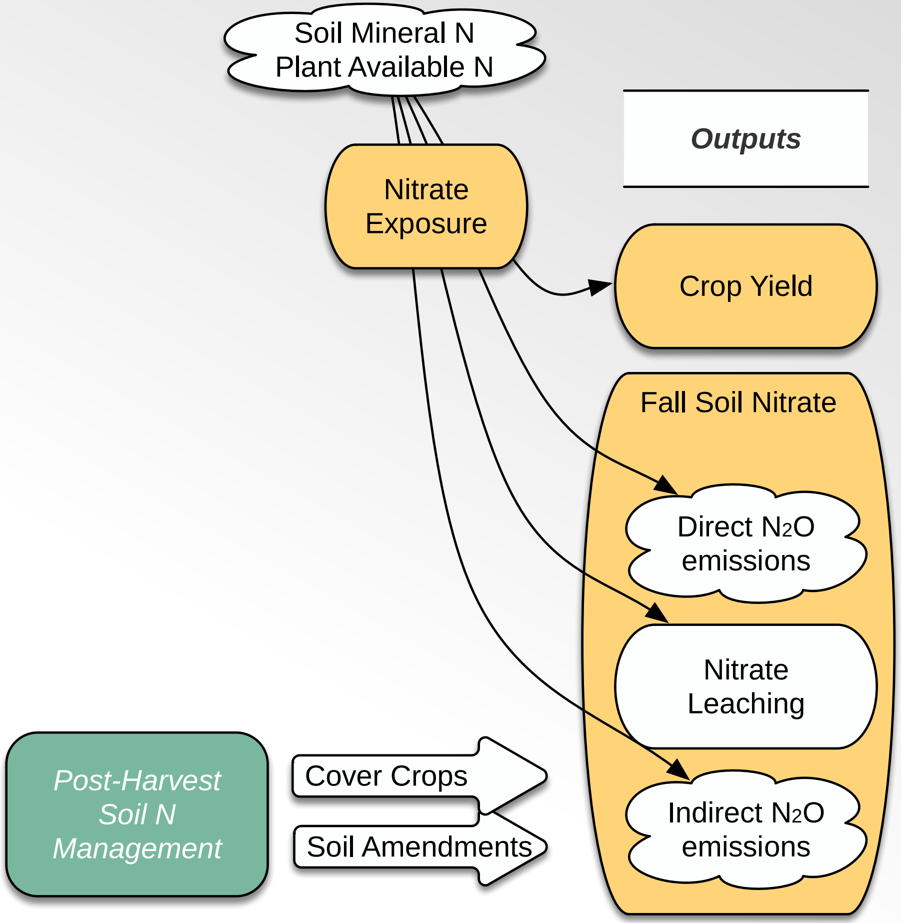




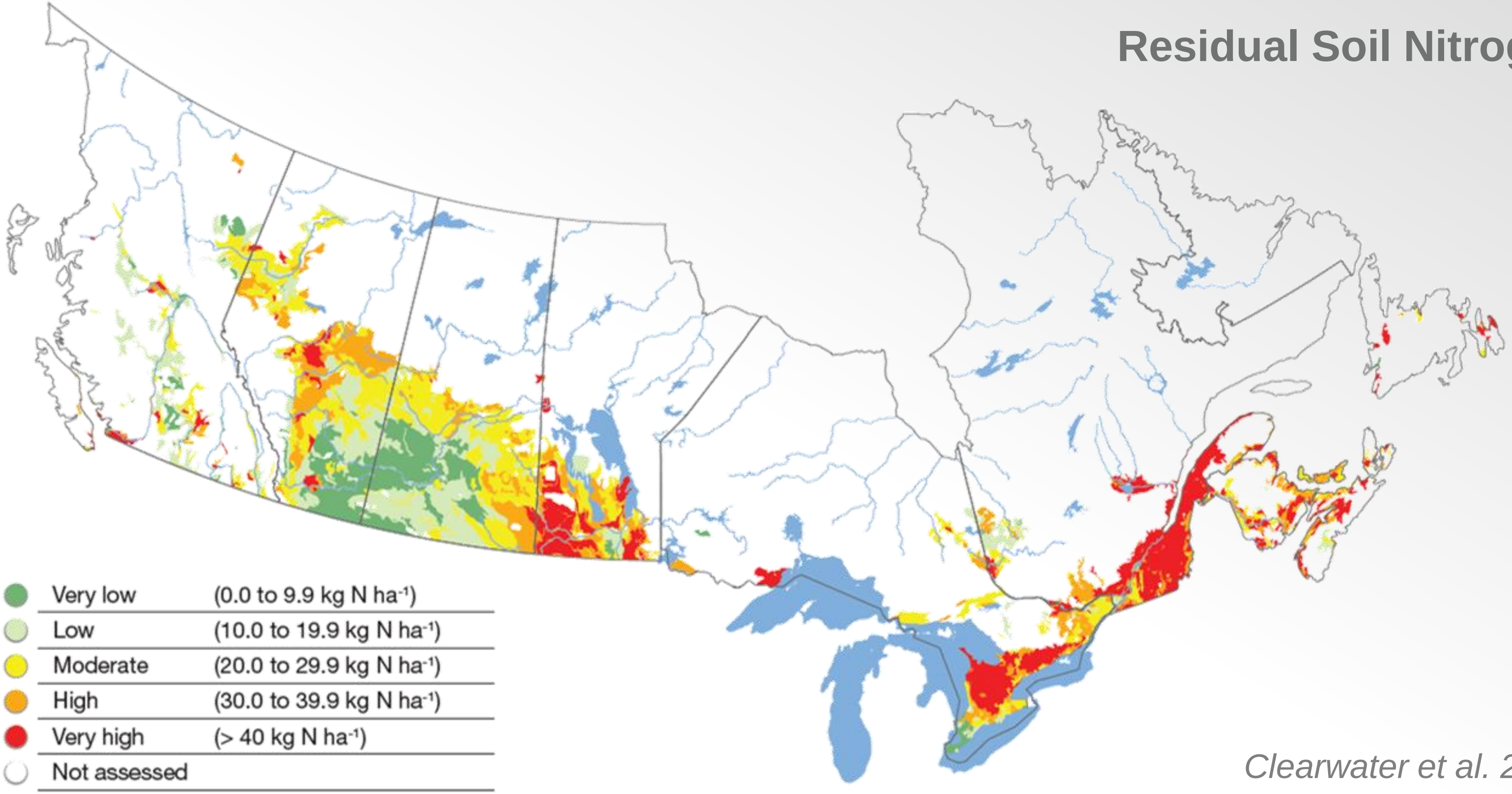
Monitoring the Potential for N Loss

- Need a means of practically measuring the potential for N loss
  - N_2O emissions
  - Nitrate leaching

- Can assess how well management is doing in reducing nitrate accumulation
  - Feedback to producer
  - Documentation of success of mitigation strategies

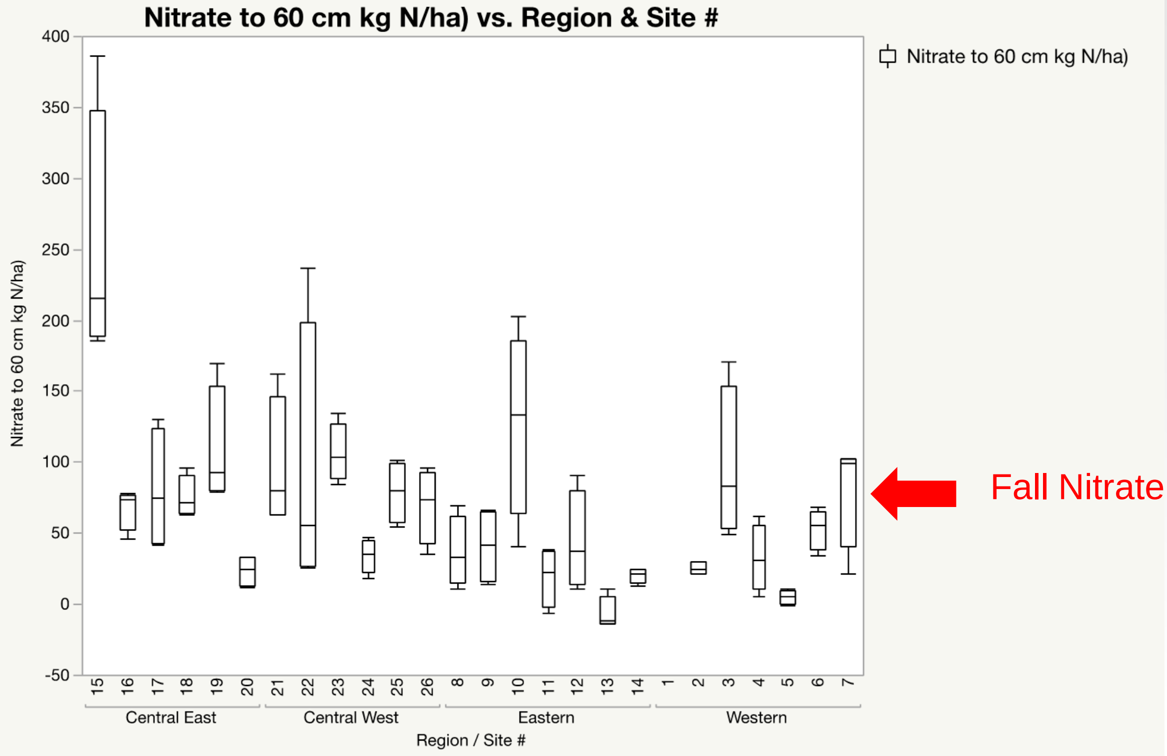


Residual Soil Nitrogen



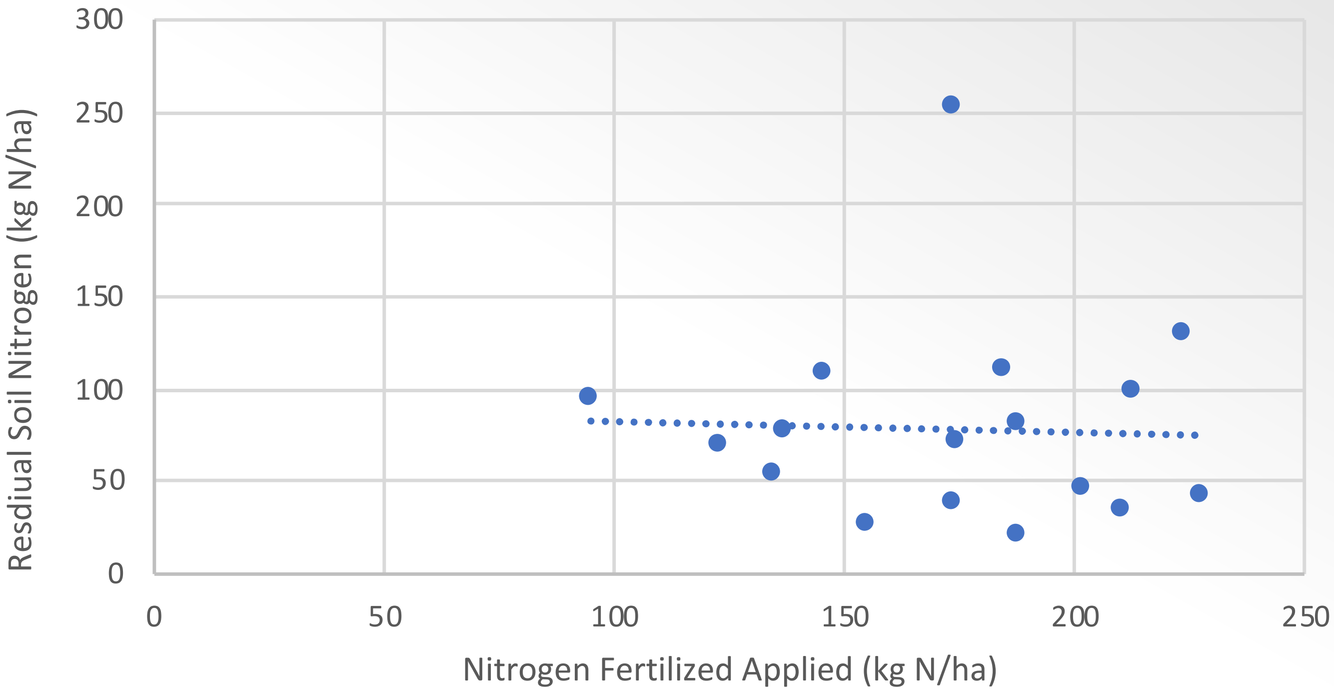
Clearwater et al. 2016

Measured Soil Nitrate Remaining after Harvest (Fall 2015)

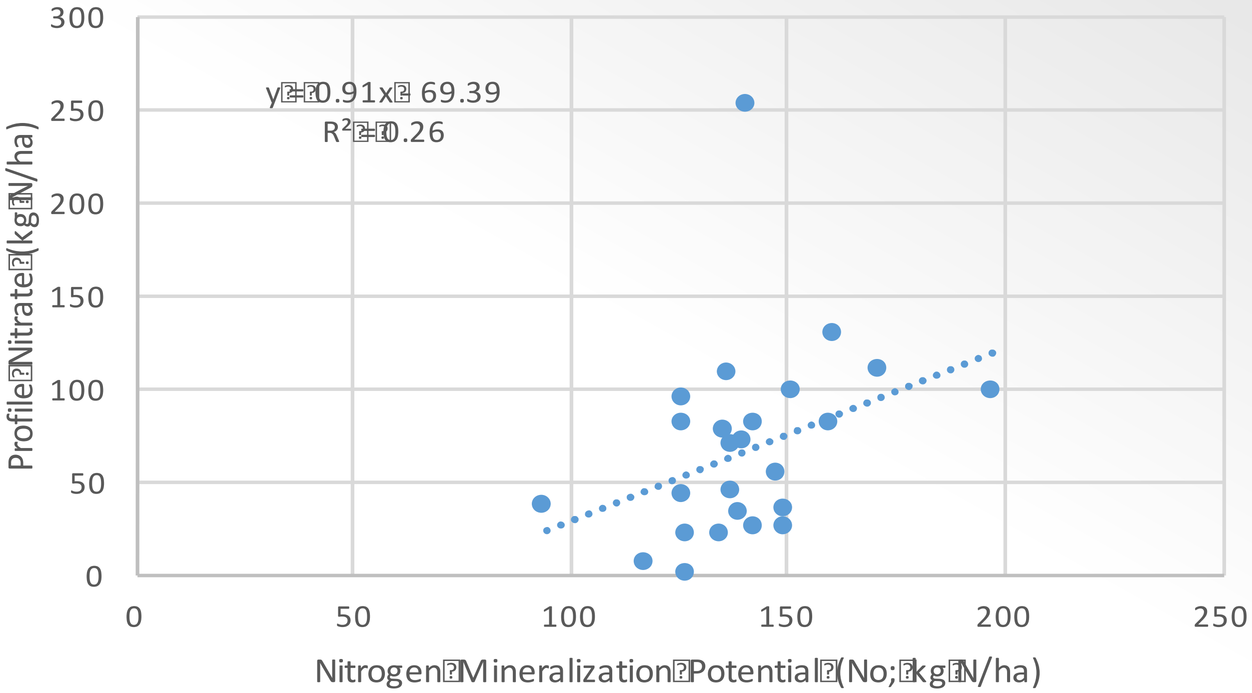


Fall Nitrate ~ 70 kg N/ha

Residual Soil Nitrogen was not a function of fertilizer N application…



Residual Soil Nitrogen was a function of soil N mineralization potential



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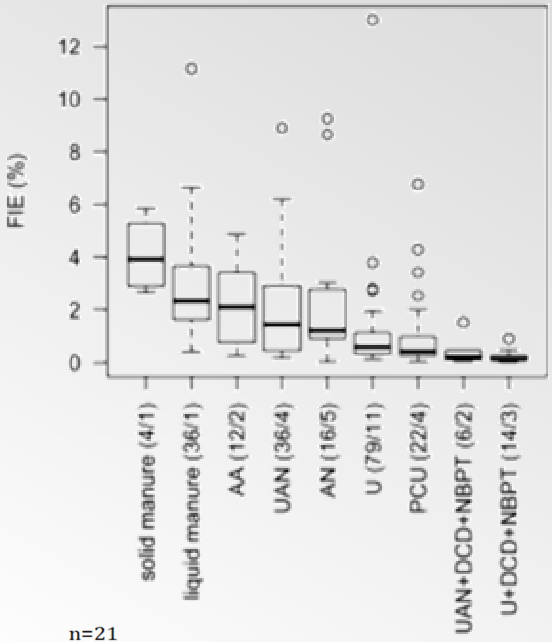
IPNI, 2015

Right Source

- Ammonium (NH_4^+) based sources are less likely to be lost than nitrate (NO_3^-)
  - In what situation do we use nitrate-based fertilizers
- Use of enhanced efficiency fertilizer products
  - Urease and nitrification inhibitors
  - Coated N sources
- Foliar nitrogen
- Organic N sources



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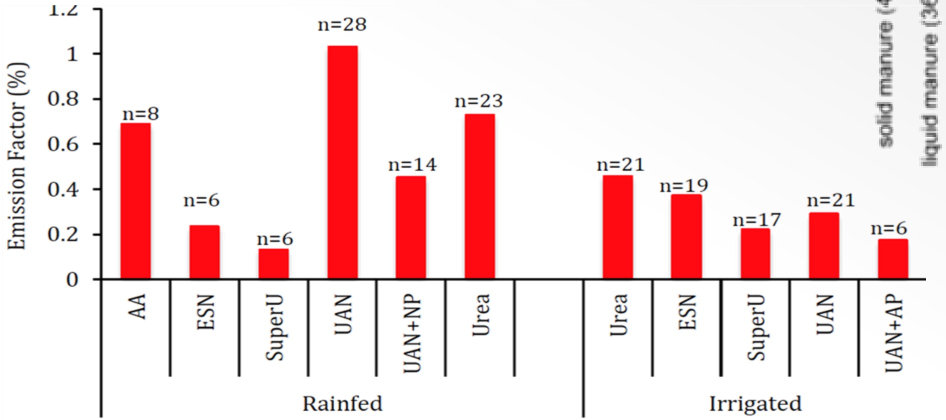


Vyn et al. 2016

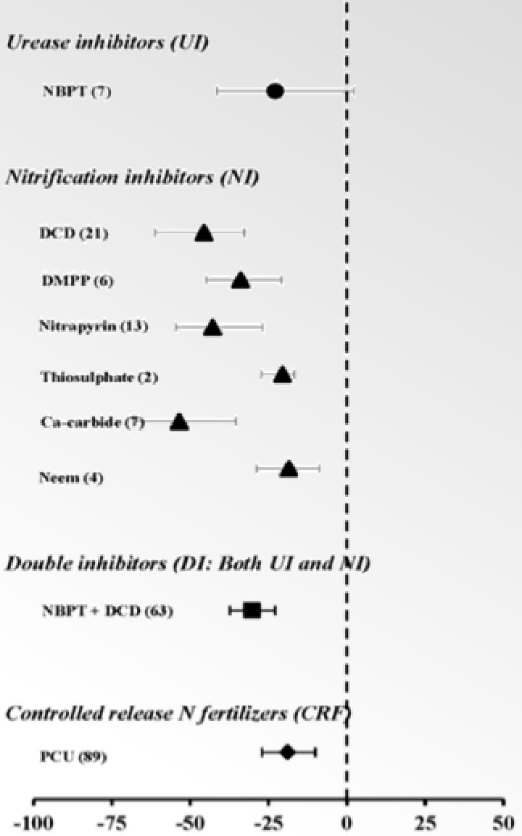
Right Source: The use of enhanced efficiency fertilizers

The use of an enhanced efficiency fertilizer results in a reduction in N_2O emissions relative to the uninhibited N source.

- *nitrification inhibitors result in reductions of ~35%,*
- *a urease inhibitors result in reductions of ~20%*
- *the use of both urease and nitrification inhibitors ~25%.*
- *The use of polymer-coated urea results in a ~20% reduction in N_2O emissions.*

For consistent results other N sources must be quantified

Increased efficiency should be reflected in reduced rate



Thapa et al. 2016

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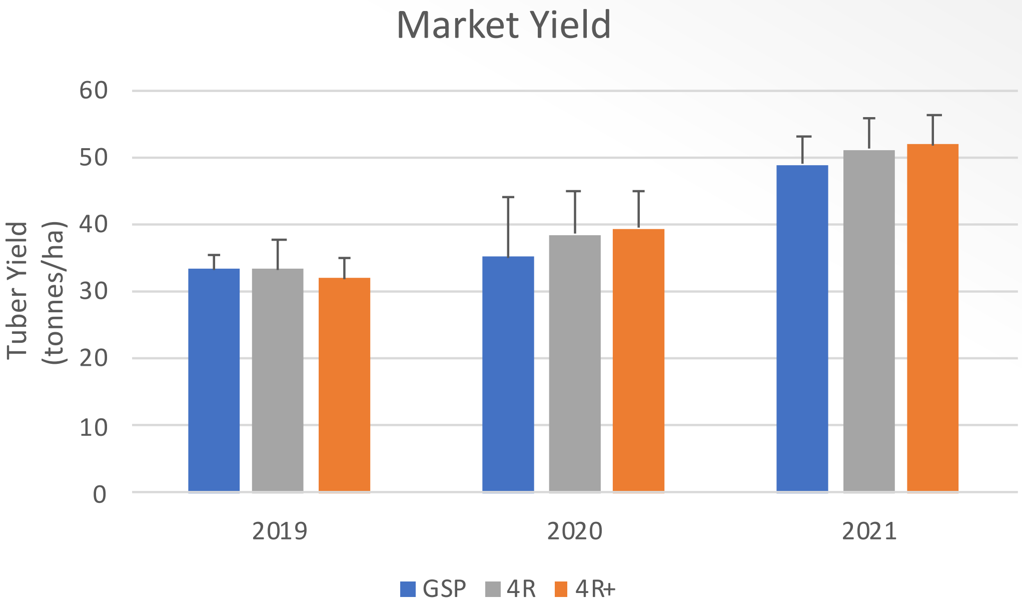
Does 4R work?

Living Labs
Side-by-Side Trials



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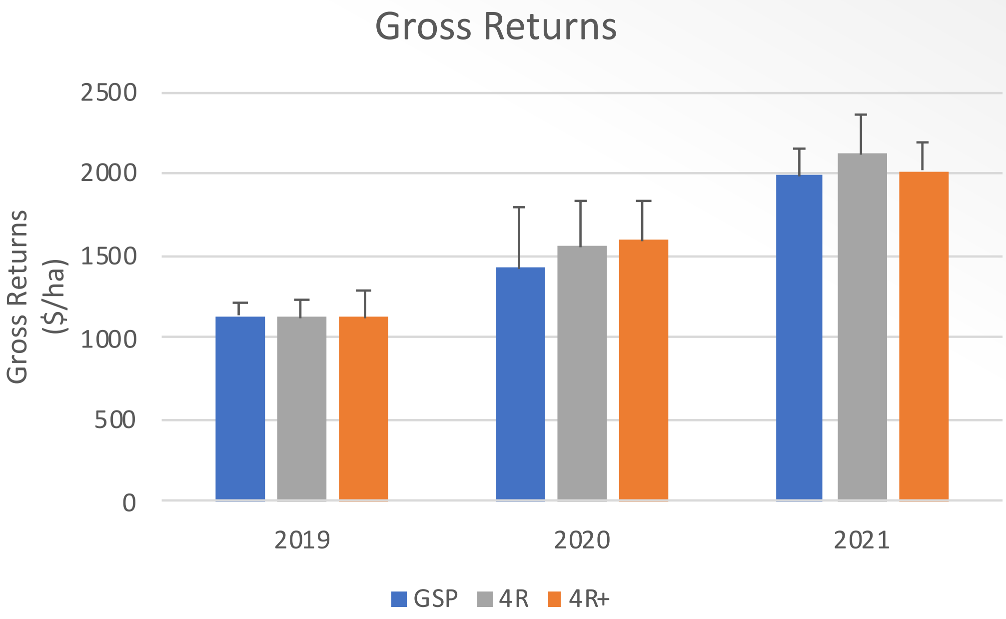

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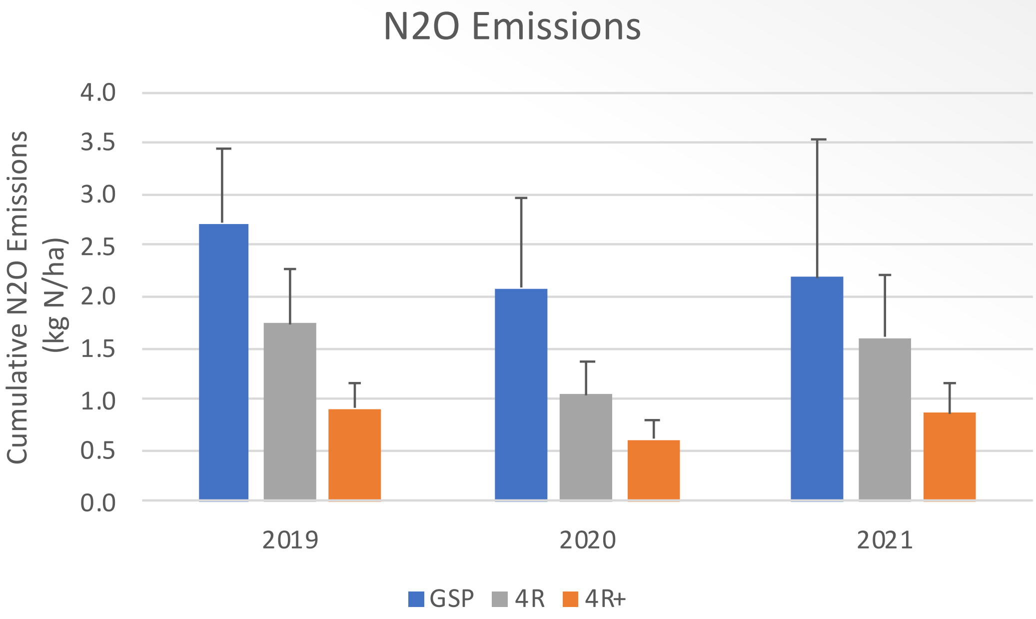
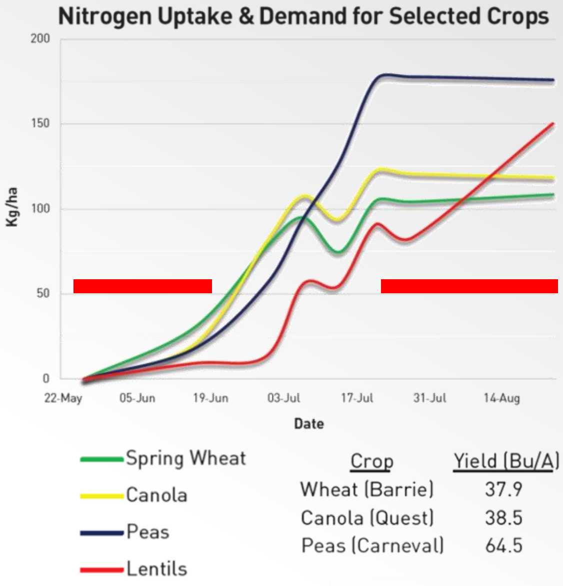


Right Time

- Attempt to synchronize N availability with plant N demand
- Applying all at or before planting increases risk of N loss
- Can improve synchrony of N supply by
  - Delaying application
    - Split applications of N
    - Side-dress applications
    - Foliar applications & fertigation
  - Delaying nitrification – NH_4^+ less likely to be lost than NO_3^-
    - Using urease or nitrification inhibitors
    - Banding of N fertilizer to inhibit nitrification
    - Coated products
    - Application of N to cold soils delays nitrification



Source: IPNI, 1998

Right Time

Prairie Canada

- *Delaying of fall application of N until the soil has cooled to below 5 ºC or the use of an inhibitor will result in N being retained in the NH_4^+ form and a reduction of N_2O emissions of ~30% relative to spring pre-plant application (Tenuta et al., 2016).*

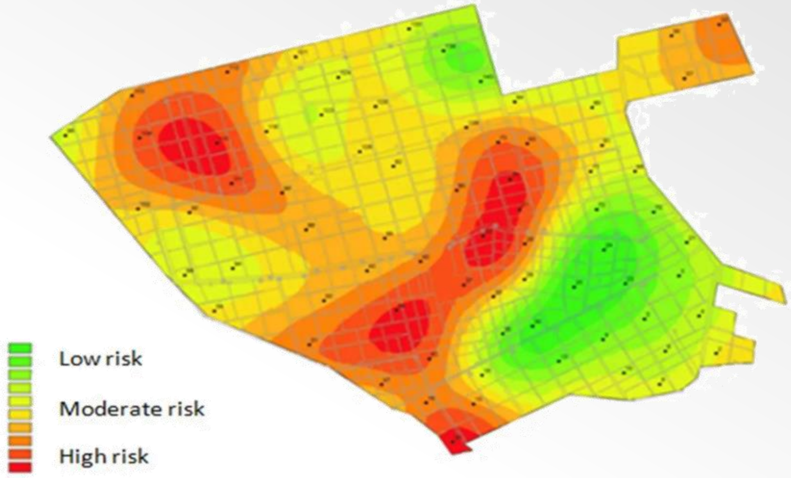
- *Spring application of N will result in a reduction of N_2O emissions of ~20% relative to an early fall application with no inhibitor (Kryzanowski 2018).*

More humid regions of Canada

- *Split applications of N can result in reductions of N_2O emissions of ~30% in years where there is a risk of N_2O emissions early in the growing season (the period over which the split occurs).*

Right Place

- Right place often refers to placement of fertilizer with respect to the seed
  - Sub-surface placement to reduce NH_3 losses
  - Sub-surface placement to reduce N_2O loss (does not always work)
  - Banding urea to reduce nitrification and delay NO_3^- production to reduce leaching and N_2O loss
- Also placement within the landscape
  - Precision farming – place the N according to landscape-specific yield potential
  - Avoid areas of high risk of NO_3^- loss and/or N_2O emissions… often they are poorer yielding as well

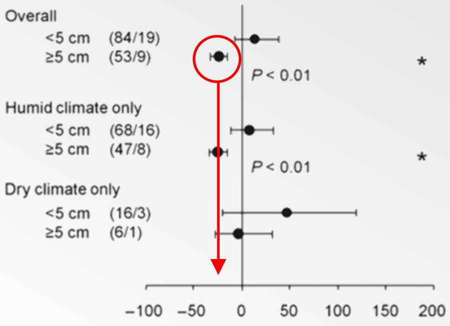


Right Place

Increased N_2O emissions as a result of banding compared to broadcast applications (Venterea et al., 2010; Engel et al., 2010; Fujinuma et al., 2011)

Gao et al. (2017) observed that *banding of ESN, but not urea, reduced N_2O emissions compared to broadcast-incorporation placement.*

- *In semi-arid regions, deep sub-surface banding of N results in a 30% reduction in N_2O emissions.*
- *Does surface banding of urea or UAN with an inhibitor results in a reduction in N_2O emissions.*
- *Surface dribble banding of UAN should be avoided?*
- *Sub-surface banding of ESN results in a 10% reduction in N_2O emissions.*



Van Kessel et al. 2013

Right Rate

Current language is to fertilizer for “target yields”

- How often are those target yields achieved?
- Are we fertilizing for crops we do not get?

Rate should reflect the efficiencies of other measures

Rate should reflect all N sources

Rate should be based on a calculation of nitrogen use efficiency.

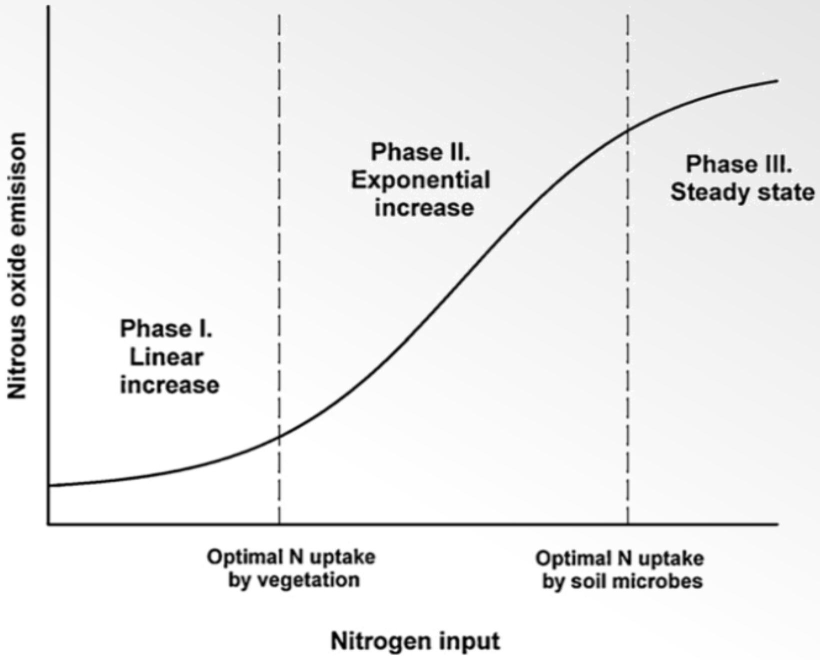
Rate should be based on site-specific measures of soil N supply and yield responses

- Opportunities of in-field calibration – N response test strips

Maximum Yield

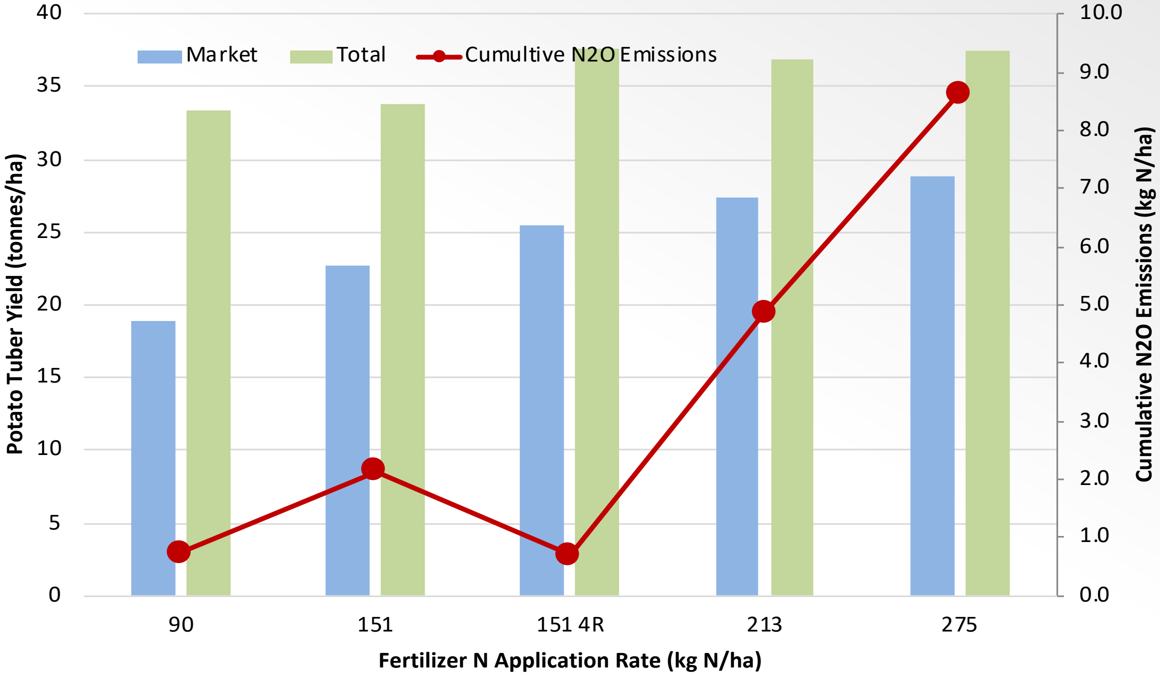
Maximum Profit

Maximum Benefit



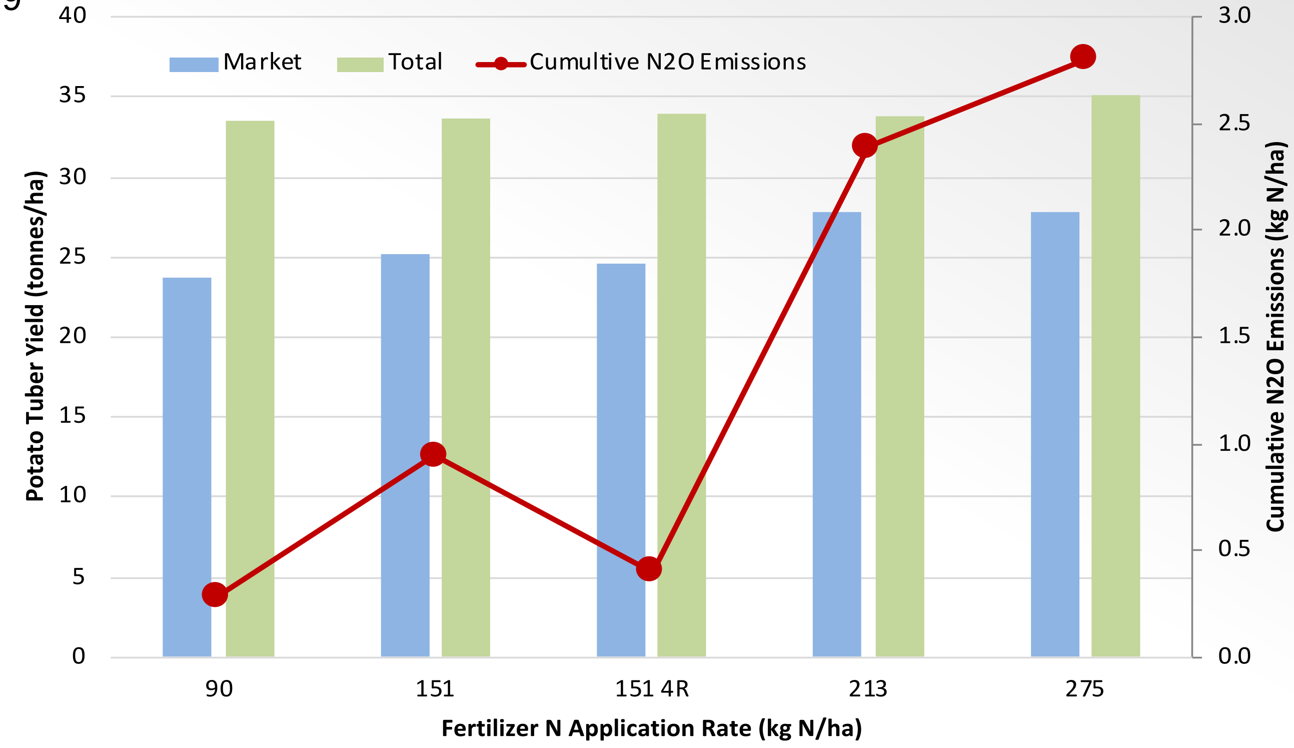
Does 4R work?

2018



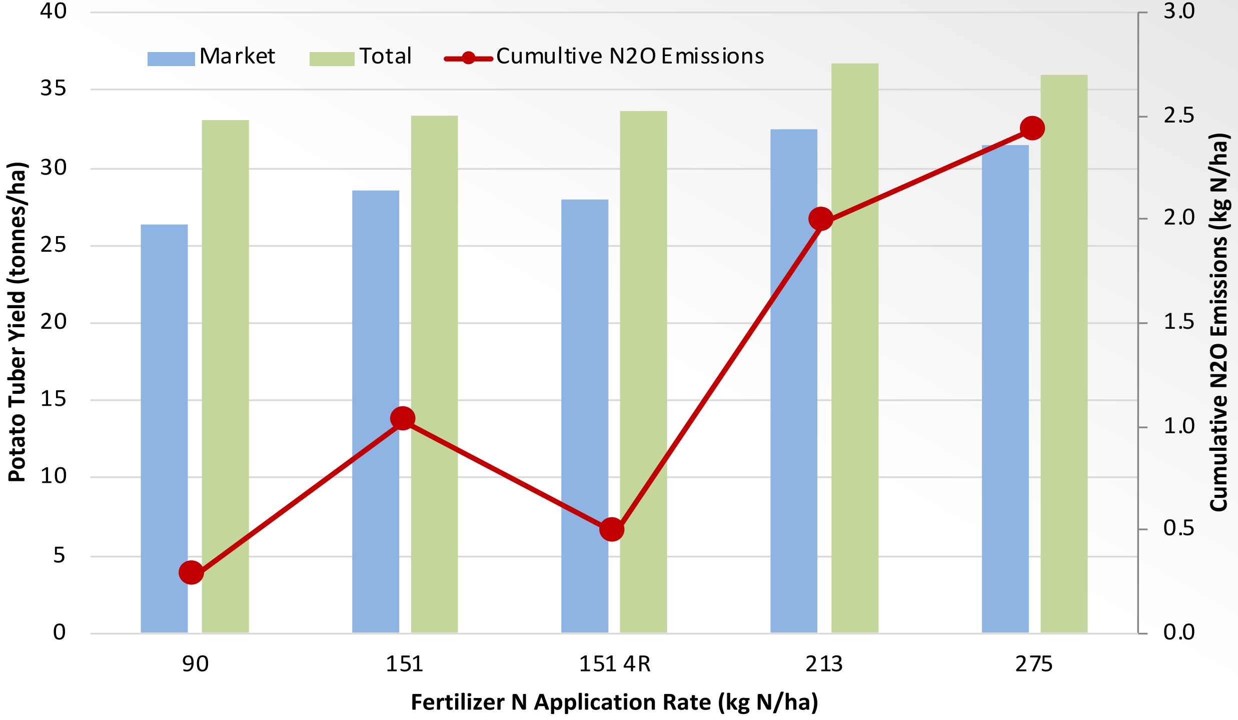
Does 4R work?

2019



Does 4R work?

2020



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Right Rotation

- Including legumes in rotation
  - Fertilizer N replacement
  - N credits – fertilizer N reduction
- Building soil organic matter
  - Increased N mineralization
    - fertilizer N reduction
  - More resilient – more consistent crop yields
    - Increase climate resiliency – improved water holding capacity
    - Decreased pest pressures

Implement site specific N management tools

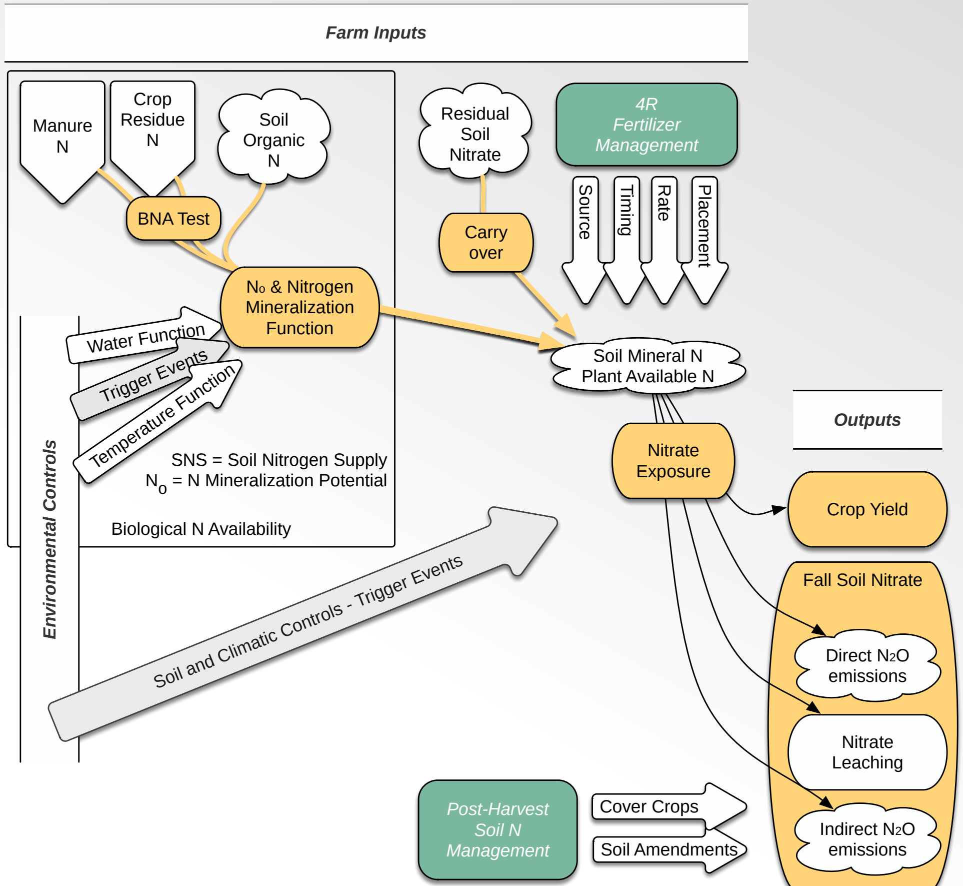
Measure Biological Nitrogen Availability (BNA)

Predict climate impacts on N mineralization

Measure potential for N losses

- Nitrate exposure
- Fall Soil Nitrate

Recognize and value increased Nitrogen Use Efficiency



I want to talk about four things…

How much is nitrogen enough?

How well are we quantifying our nitrogen inputs?

How well are we managing our nitrogen losses?

Does 4R work?

Can nitrogen management result in a 30% reduction in N_2O emissions? ***Absolutely…*** and we can do it with out impacting profitability

But “the devil is in the details”… we have to use our knowledge of the system to provide integratedsite-specific solutions

Need to update National Inventory Report

- NIR does not provide an accurate picture of current emissions
  - It fails to account for on farm management impacts on emissions

- Improved N management, including 4R has the potential to reduce N_2O emissions
  - Not clear how robust the implementation of 4R is
  - Actual yields not “target yields”… fertilize for the crop you are getting
  - Improved efficiency should be reflected in reduced rates
    - Cover the cost of efficiency practices
    - Avoid excess N at the end of the season

Karen Klassen (left) and Scott Beaton (right) at Faspa Farm in Manitou, MB. Photo credit: Geralyn Wichers for Manitoba Co-Operator

2023 Annual Meeting of the Canadian Society of Soil Science

Soils go Digital

June 25 – 29, 2023
Truro, Nova Scotia
Centre for Sustainable Soil Management

csss2023.ca

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These concepts are the product of many…

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- East Prince, Kensington North and Souris Watershed groups
- NSERC CREATE Climate Smart Soils Group
- Farmers for Climate Solutions