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Tom Bruulsema,
Plant Nutrition Canada

Responsible phosphorus management seeks high yields and shows care for the environment

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Outline – responsible phosphorus management

1. Responsible Plant Nutrition – a new paradigm
2. Multiple goals of responsible **phosphorus** management
   - Productivity, water quality, circular economy, biodiversity
3. 4R Nutrient Stewardship
   - Global industry support for science
4. Measuring & reporting performance
   - Soil test levels, nutrient balances and legacies, quantifying risks of yield loss & P loss

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What is the issue?
What can be done?
Who needs to do what?
What will success look like?

https://www.sprpn.org/

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Scientific Panel on Responsible Plant Nutrition

Vision: *Responsible plant nutrition nourishes plants in a sustainable manner that enhances earth's capacity to support healthy life.*

Objectives: *Provide independent science-based knowledge to IFA and other stakeholders involved in food and agriculture on global issues of responsible plant nutrition.*

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ON RESPONSIBLE PLANT NUTRITION

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ON RESPONSIBLE PLANT NUTRITION

https://www.sprpn.org/

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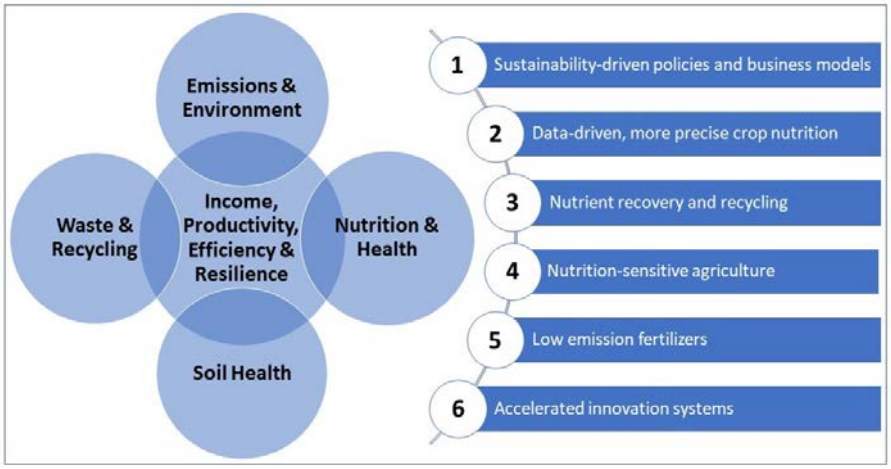
A NEW PARADIGM FOR PLANT NUTRITION



Five interconnected aims, and six key actions

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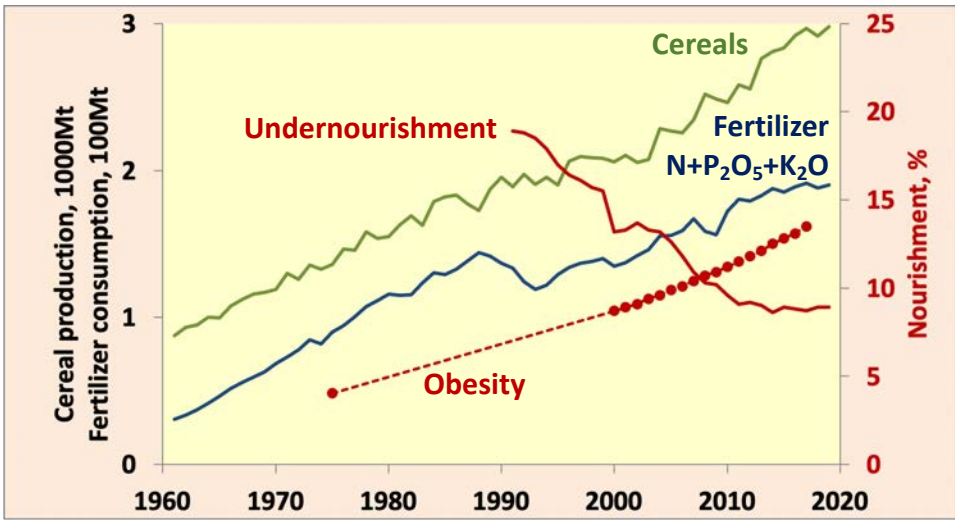
What is the issue?

1 **How can future growth in crop production be decoupled from growth in fertilizer consumption?**



United Nations Food and Agriculture Organization (FAO), 2020

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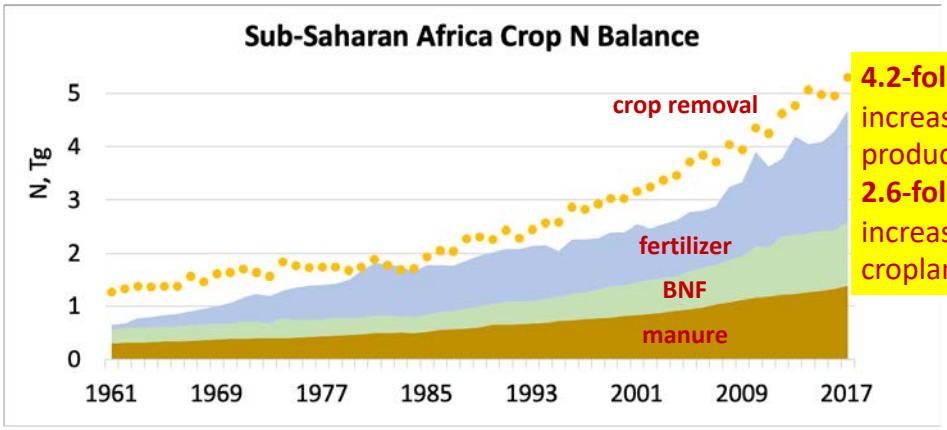
What is the issue?

2 **What are the key measures to double or triple crop yields in Africa with increasing and balanced nutrient inputs?**



4.2-fold increase in production; **2.6-fold** increase in cropland.

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ON RESPONSIBLE PLANT NUTRITION

Crop N removal by far exceeds N inputs from fertilizer, manure and biological fixation (BNF) in sub-Saharan Africa. Source: IFA Nutrient Use Efficiency database, 1961-2017.

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What is the issue?

3. What data-driven technologies, business solutions and policies will accelerate the adoption of more precise nutrient management solutions by farmers?
4. Can nutrient losses and waste along the whole agri-food chain be halved within one generation?
5. How can nutrient cycles in crop and livestock farming be closed?
6. How can we improve soil health?
7. How should we manage nutrition of crops in changing climates?
8. What are options and targets for reducing fertilizer-related GHG emissions?
9. How can cropping systems deliver high quality, more nutritious food?
10. How can we better monitor nutrients and implement high levels of sustainability stewardship?

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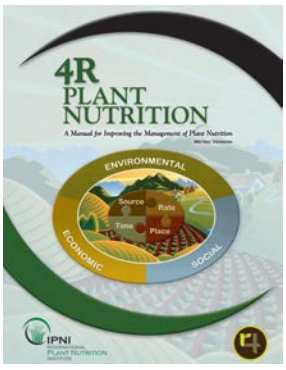
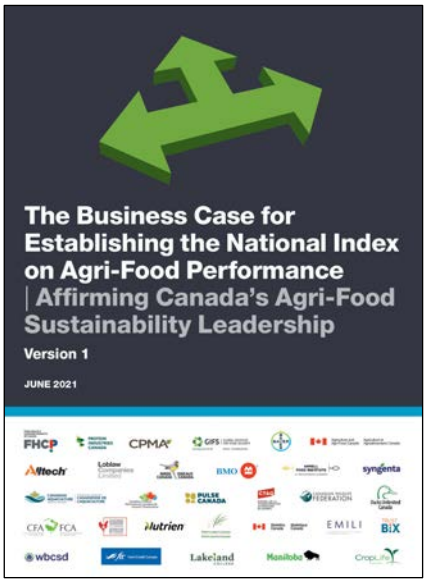
What can be done?





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Action 1: Sustainability-driven policies and business models
Sustainability-driven nutrient policies and business models must be tailored to specific food systems in every country.

"Canada does not have complete data to present a supply chainwide view of emissions, …overlooking 4R Nutrient Stewardship practices used to reduce direct emissions."

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What can be done?

Action 2: data-driven more precise crop nutrition

Knowledge-driven solutions and novel technologies will allow tailoring nutrient formulations and applications to local needs in an increasingly precise manner.

They need to be upscaled to millions of farmers through digitally supported advisory systems and integrated business solutions.

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NUTRIENT EXPERT®

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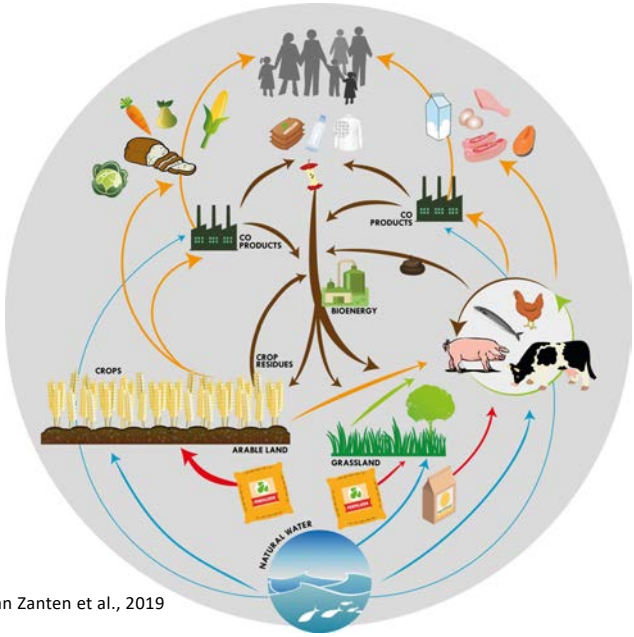
What can be done?

Action 3: Nutrient recovery/recycling

Crop-livestock integration, less food waste, by-products use and increased nutrient recycling are key measures to optimize nutrient use efficiency across the full food chain.

Political incentives, novel technologies and shifts in behavior will drive greater nutrient recovery from multiple waste streams, as part of circular, bio-based economies.



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Re-drawn and modified from van Zanten et al., 2019

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What can be done?

Action 4: Nutrition-sensitive agriculture includes the targeted enrichment and application of fertilizers to deliver nutrients of importance to crop, animal and human health (e.g., N, Fe, Zn, Se, I).

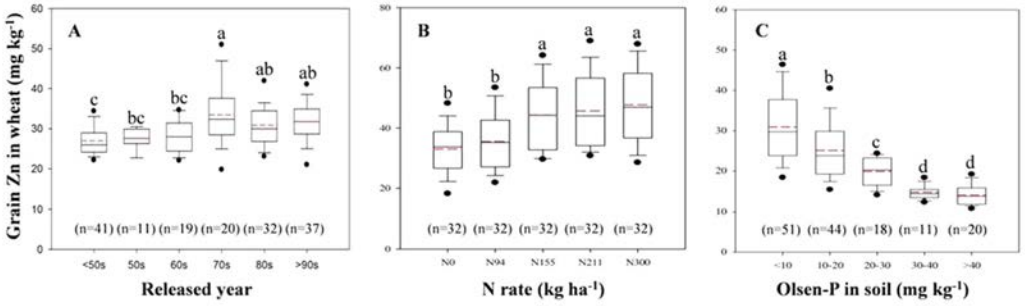

Figure 2. Measures of the "Green Revolution" including historical shift of varieties (**A**), N application rate (**B**) and elevated soil P concentration due to continuous application of P fertilizer (**C**) affect grain Zn in wheat grown in China. These historical varieties were grown in the same field at the North China Plain. And their grain Zn

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Chen, X.-P., Y.-Q. Zhang, Y.-P. Tong, Y.-F. Xue, D.-Y. Liu, et al. 2017. Harvesting more grain zinc of wheat for human health. Sci. Rep. 7(1): 7016. doi: 10.1038/s41598-017-07484-2.

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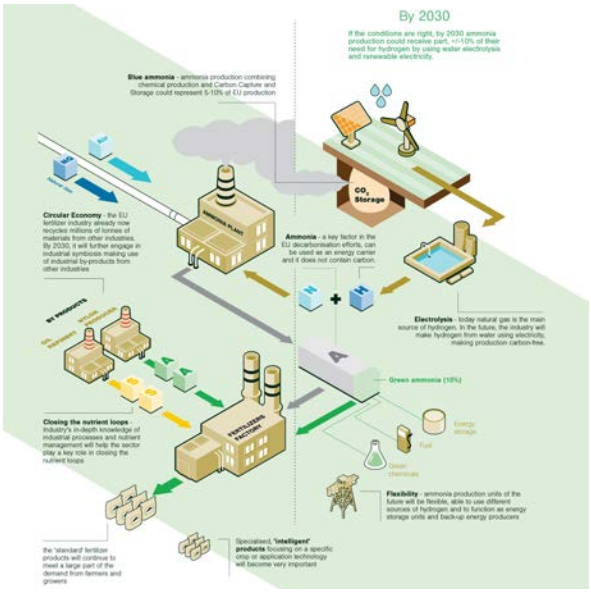
What can be done?

Action 5: Low-emission fertilizers

Fertilizers will increasingly be produced in an environmentally friendly manner and they will embody greater amounts of knowledge to **control the release** of nutrients to the plant.

The "**hydrogen economy**" may lead to abundant **green and blue ammonia**.



Fertilizer FOOTPRINT

Fertilizers Europe

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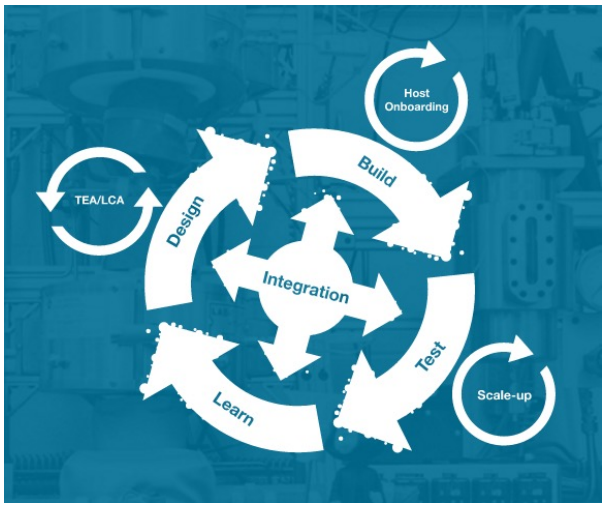
What can be done?

Action 6: Accelerated, more open innovation systems for faster translation of new ideas into practice

This requires more investment, collaboration, risk taking and entrepreneurship by industry, but also a massive culture change in science and science funding.

Science → Technology → Innovation



https://agilebiofoundry.org/

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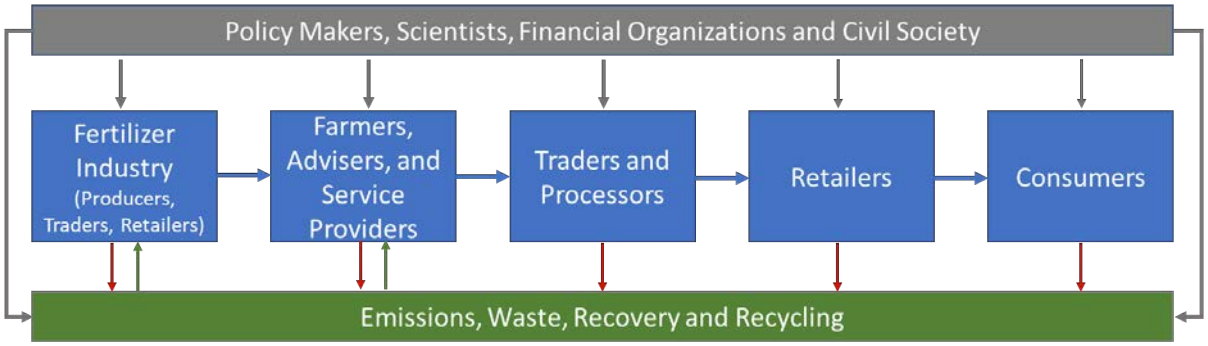
Who needs to do what?



- Many participants in the agricultural value chain play important roles in responsible plant nutrition.
- The **fertilizer industry** has great influence on the **4R**s:
  - making the **right source** available,
  - providing recommendations for applying
    - at the **right rate**,
    - at the **right time**, and
    - in the **right place**.

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What will success look like?

Responsible Plant Nutrition: Societal optimum

by 2040:

1. Accepted **standards and roadmaps** for nutrients along the whole chain.
2. Crop yield growth outpaces growth in fertilizer; **crop NUE ↑ to 70%.**
3. **Nutrient waste halved** to reduce harm; no more hotspots.
4. In sub-Saharan Africa, **fertilizer use has tripled**.
5. Extreme forms of **hunger and malnutrition gone**.
6. Fertilizer **GHG footprint reduced by 30%.**
7. Investments in research & innovation **triple**.
8. **Consumers appreciate** fertilizer's role and footprint.
9. All farmers access **tailored plant nutrition solutions**.

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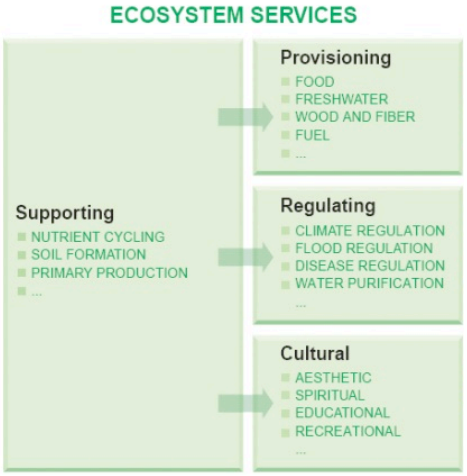
Millennium Ecosystem Assessment

Ecosystem Services: The benefits people obtain from ecosystems



www.millenniumassessment.org | Strengthening Capacity to Manage Ecosystems Sustainably for Human Well-Being

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Trade-offs among multiple ecosystem services: would optimum soil test P increase or decrease?

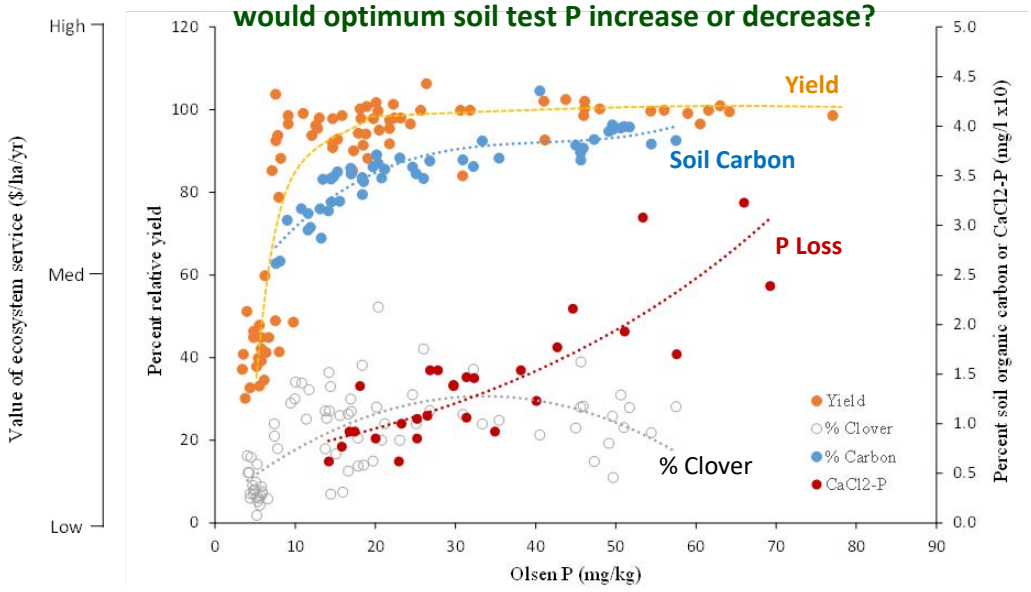

Figure from Macintosh, et al. (2018). Data from New Zealand irrigated pastures (McDowell and Condron 2012; Condron et al. 2012; Rickard and McBride 1986)

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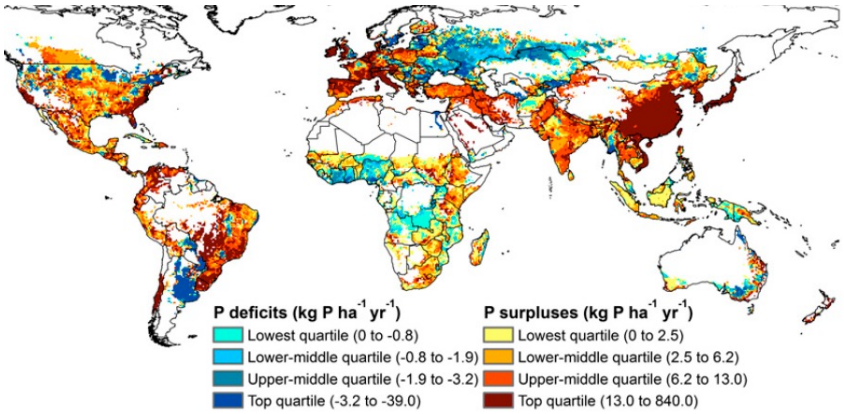
What is the issue?



Global map of agronomic P imbalances for the year 2000 expressed per unit of cropland area.

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MacDonald et al., 2011. PNAS 108(7)3086-3091. https://doi.org/10.1073/pnas.1010808108

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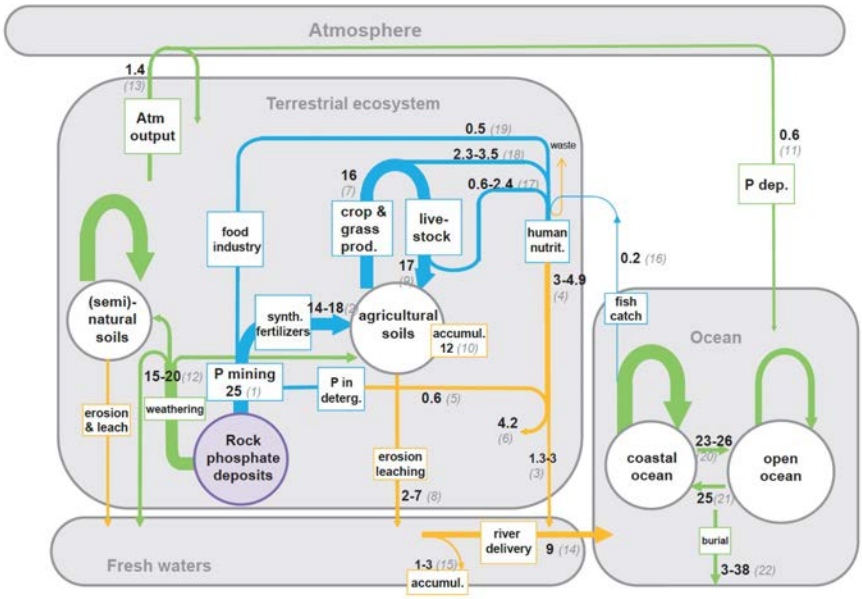

Global P cycle, around 2000-2010. Numbers indicate flows in million tonnes per year

Global P Cycle

Less than one-fifth of fertilizer P shows up in the food we eat

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Lake Erie & P

- Eutrophication
- Hypoxia
- Harmful Algal Blooms

Photo credit: Carrie Vollmer-Sanders, The Nature Conservancy

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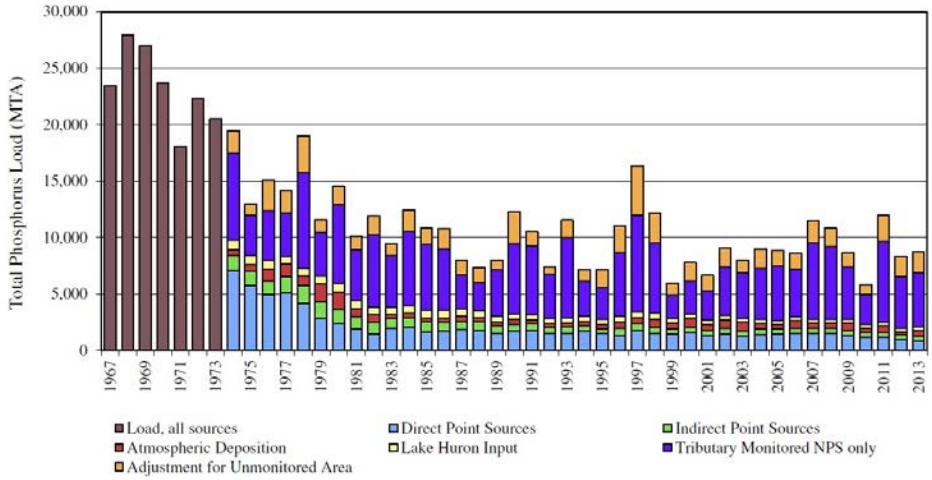
Lake Erie total P loads 1967-2013



Total P load does not explain the increase in algal blooms since ~1995

Maccoux MJ et al J Great Lakes Res (2016), http://dx.doi.org/10.1016/j.jglr.2016.08.005

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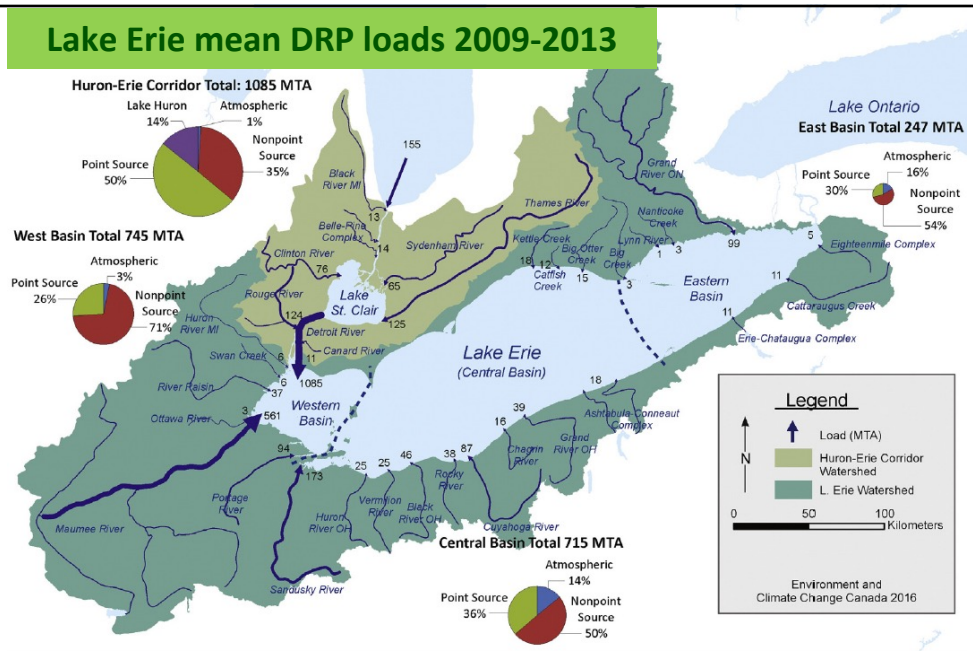
Lake Erie mean DRP loads 2009-2013



Maccoux MJ et al J Great Lakes Res (2016), http://dx.doi.org/10.1016/j.jglr.2016.08.005

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Lake Erie – both dissolved and particulate P loads are important.

NASA Earth Observatory, late Sept 2017 (National Geographic)

Terra MODIS Direct Broadcast Image 7 May 2017

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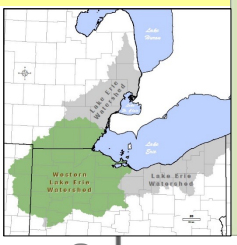
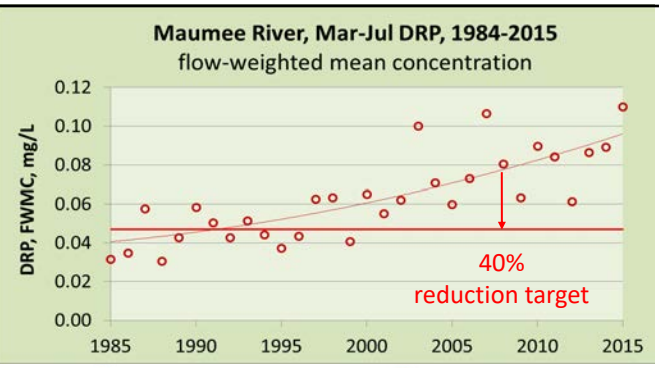
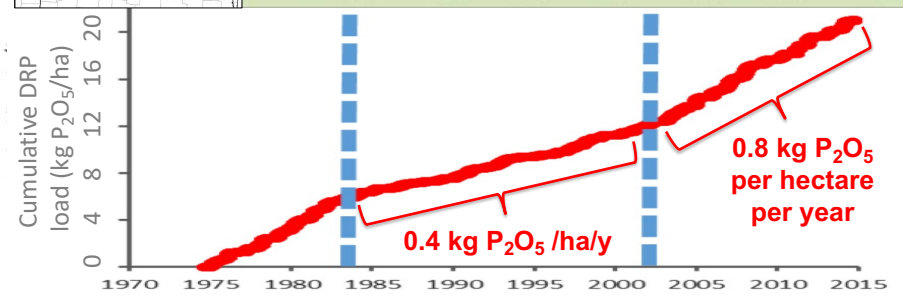
Western Lake Erie: dissolved P trends increasing since 2002







1. David Baker & Laura Johnson, National Center for Water Quality Research, Tiffin, OH
2. Jarvie et al., 2016, J Environ. Qual. 46(1):123-132

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Western Lake Erie Watershed

Cropland PUE almost doubled.
Loss of dissolved P to the lake also doubled.

Year	P outputs, kt	P inputs, kt		PUE
	crop removal	fertilizer	manure	
1987	30	37	5	72%
2014	49	31	5	135%

Increased DRP loss an "unintended consequence" of conservation tillage with **broadcast application** of P fertilizer. ***"Right place" = subsurface.***

NuGIS Nutrient Use Geographic Information System

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

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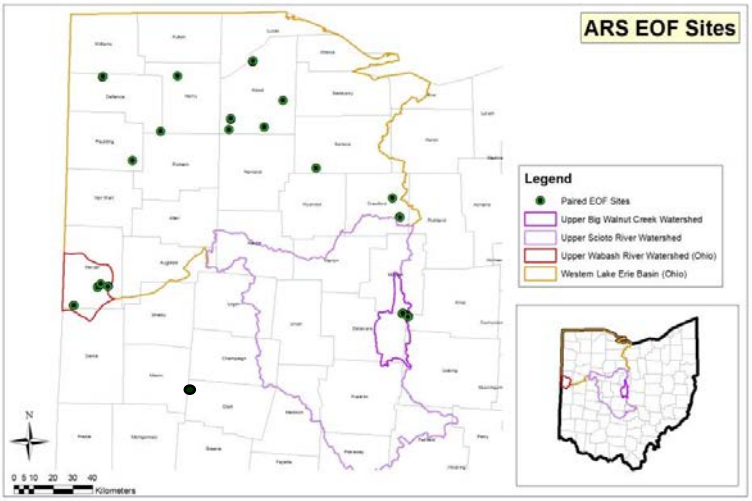
Ohio
P loss monitoring at edge of field



Funding Sources:

4R Research Fund
USDA-ARS: USDA-Agriculture Research Service
CEAP: Conservation Effects Assessment Project
EPA: DW-12-92342501-0
Ohio Agri-Businesses
Ohio Corn and Wheat Growers
CIG: 69-3A75-12-231 (OSU)
CIG: 69-3A75-13-216 (Heidelberg University)
MRBI: Mississippi River Basin Initiative
The Nature Conservancy
Becks Hybrids/Ohio State University
Ohio Soybean Association

USDA ARS
Soil Drainage Research Unit

Kevin King, USDA-ARS, Columbus, Ohio

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Our Vision

We envision a food system that manages phosphorus more sustainably to provide abundant, nutritious food while protecting the health of rivers, lakes, and oceans.

Sustainable Phosphorus Alliance

Allies Addressing a Complex Problem

The Sustainable Phosphorus Alliance is a membership organization addressing the complex problem of phosphorus sustainability. We are North America's central forum and advocate for the sustainable use, recovery, and recycling of phosphorus in the food system. We collaborate with our members and supporters to innovate and implement evidence-based solutions to the phosphorus sustainability challenge, to be shared and accessible to the community.

The Sustainable Phosphorus Alliance is a unit of the Julie Ann Wrigley Global Institute of Sustainability at Arizona State University. Our activities to advance phosphorus sustainability and benefit our members are funded by membership dues and contributions.

OCP · FEECO INTERNATIONAL · Biochar Now · OSTARA · GreenEdge GreenTechnologies, LLC · CTB · RENEWABLE NUTRIENTS · e2metrix · NACWA · The Water Research Foundation · The Sustainability Consortium

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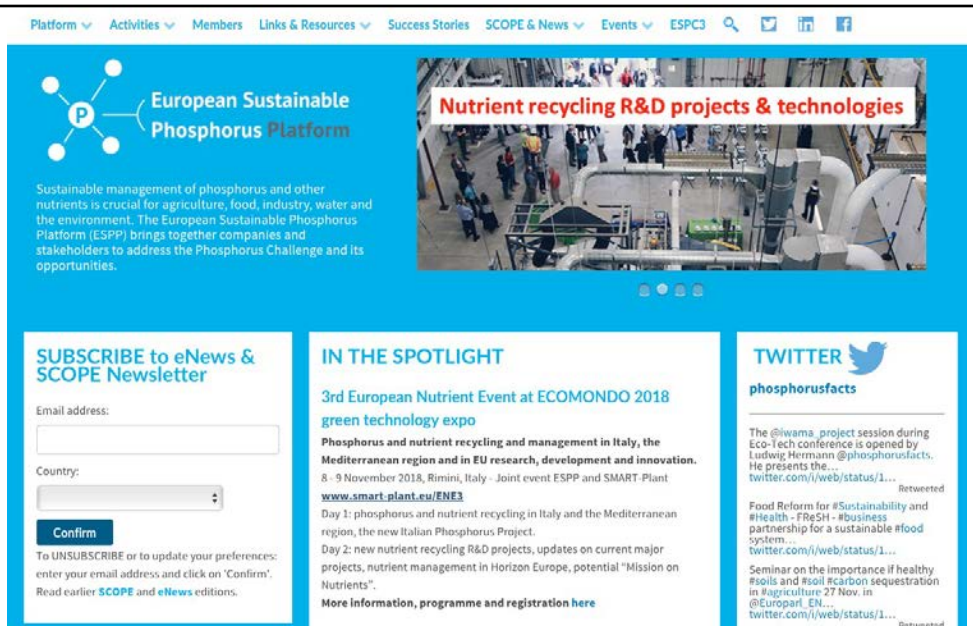

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Outline – responsible phosphorus management

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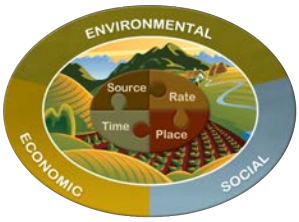
Indicators of Sustainable Crop Nutrition

Enablers (process)

- Extension & professionals
- Infrastructure
- Research & innovation
- Stakeholder engagement



Actions (adoption)

- **Cropland area under 4R [Requires regional definition of 4R]**

Outcomes (impact on ecological services)

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

4R nutrient stewardship

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4R Adaptive Management for MES

Policy Level – Regulatory, Infrastructure, Product Development

Regional Level
Agronomic scientists, Agri-service providers

Farm Level
Producers, Crop advisers

DECISION SUPPORT based on scientific principles

Recommendation of **right source, rate, time, and place** (BMPs)

DECISION
Accept, revise, or reject

ACTION
Change in **practice**

EVALUATION of OUTCOME
Cropping System Sustainability Performance (ecological services)

LOCAL SITE FACTORS

- Climate
- Policies
- Land tenure
- Technologies
- Financing
- Prices
- Logistics
- Management
- Weather
- Soil
- Crop demand
- Potential losses
- Ecosystem vulnerability

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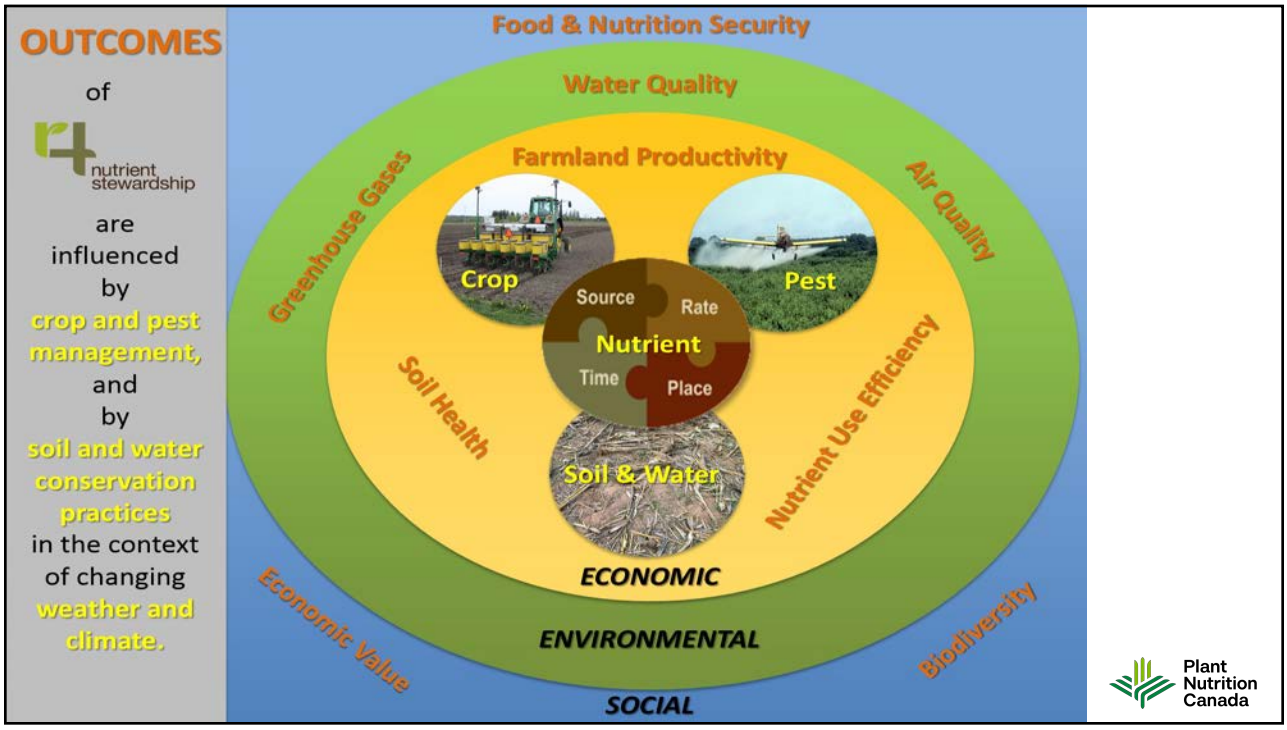

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Approaches to recognition of crop nutrition impact on ecosystem services

- 4R certification
- Counting 4R acres
- Aggregate data on 4R practices
- Models of nutrient loss
  - Incentive programs
  - Water quality trading
  - Carbon trading

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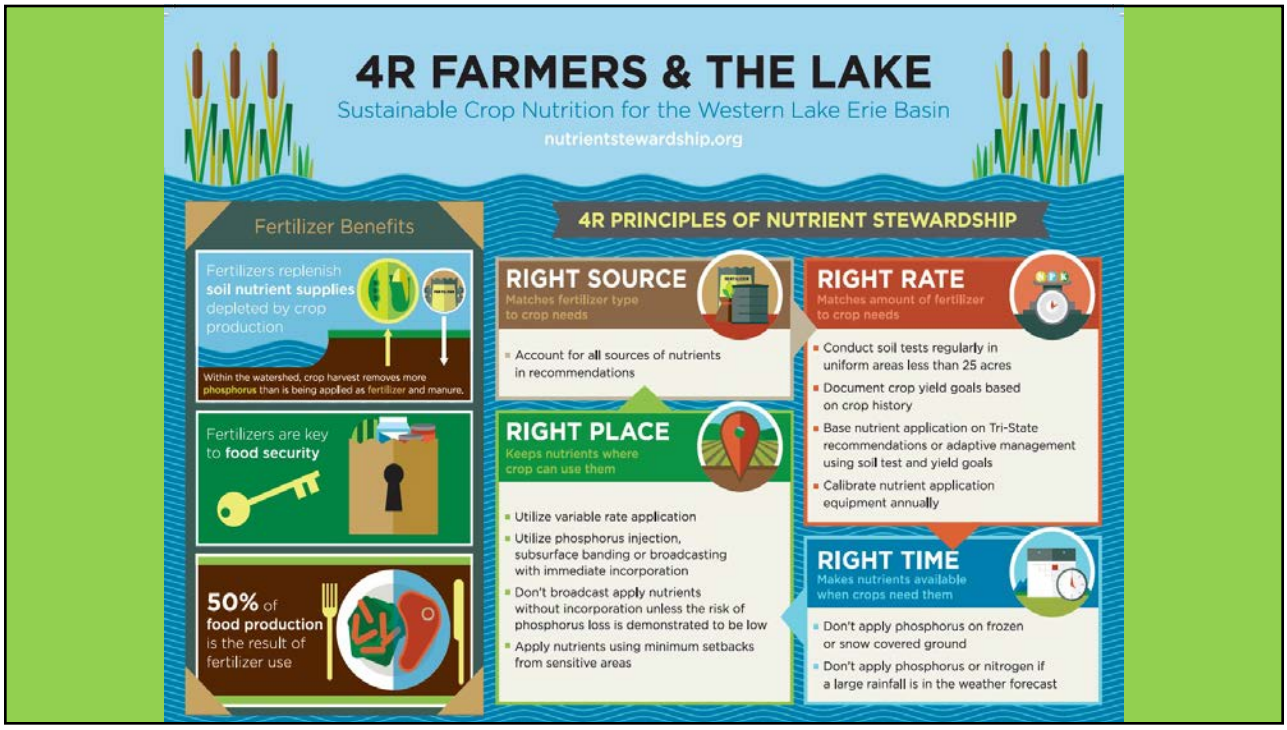

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4R Certification in Western Lake Erie Basin (WLEB)

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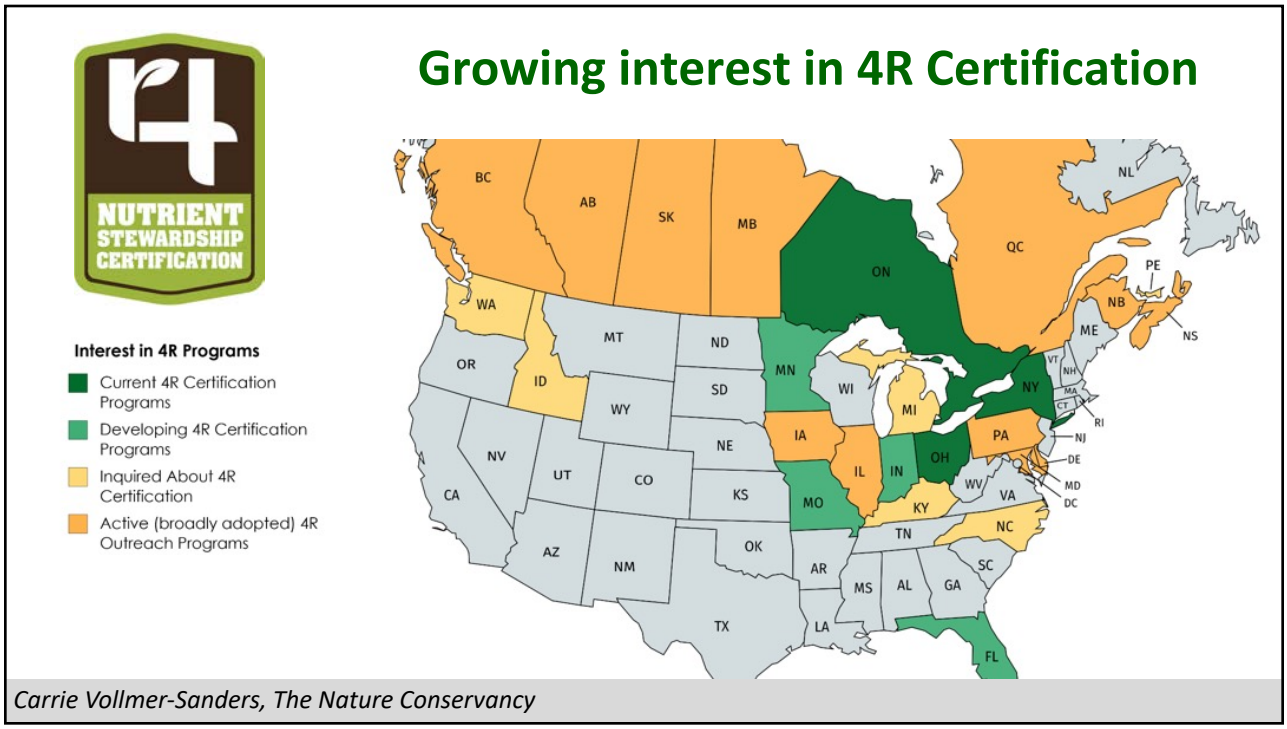
Growing interest in 4R Certification



Carrie Vollmer-Sanders, The Nature Conservancy

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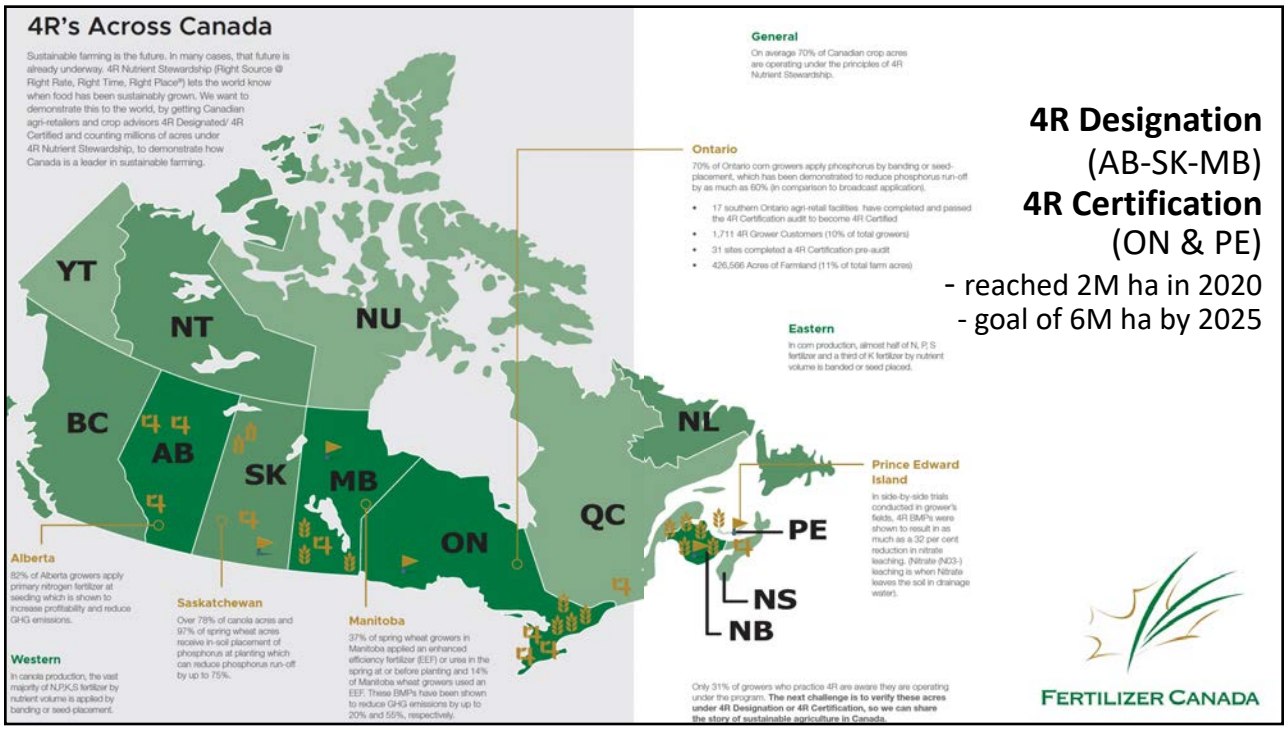

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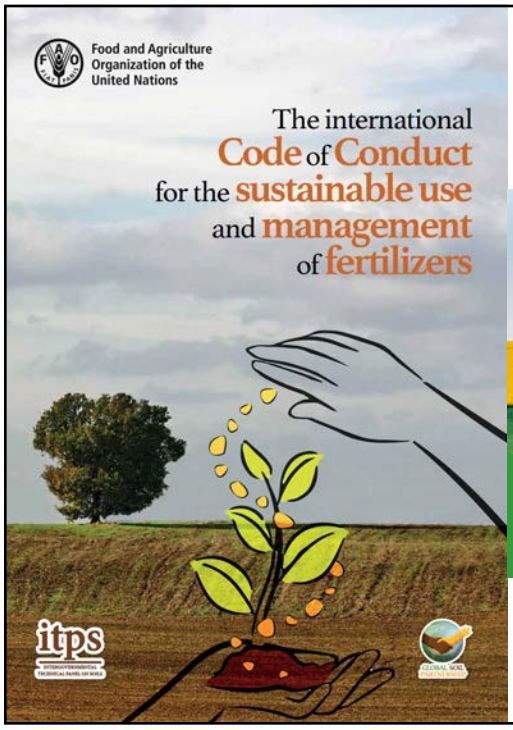

Principles of 4R Nutrient Stewardship are embedded in the FAO Code of Conduct, and in other Codes of Practice.

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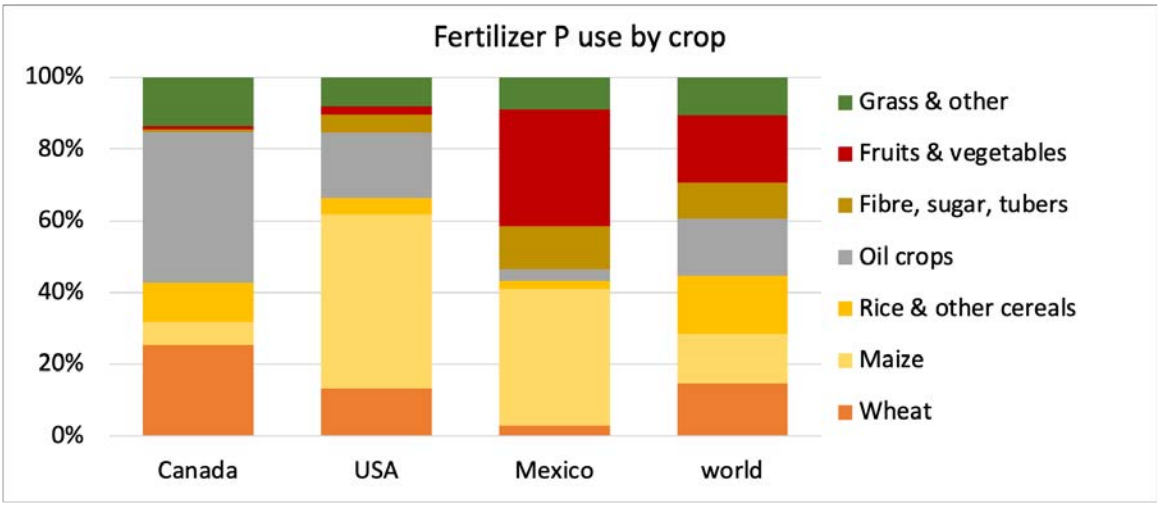

IFA. 2017. Assessment of Fertilizer Use by Crop at the Global Level 2014-2014/15. International Fertilizer Association, Paris, France.

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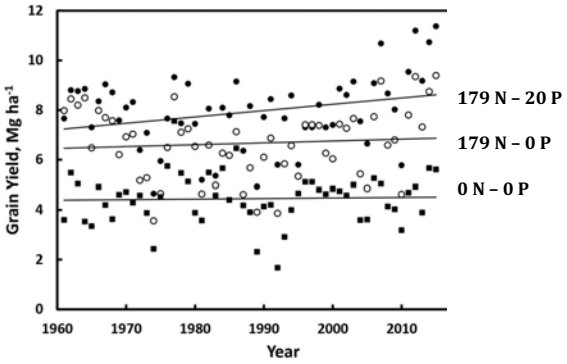
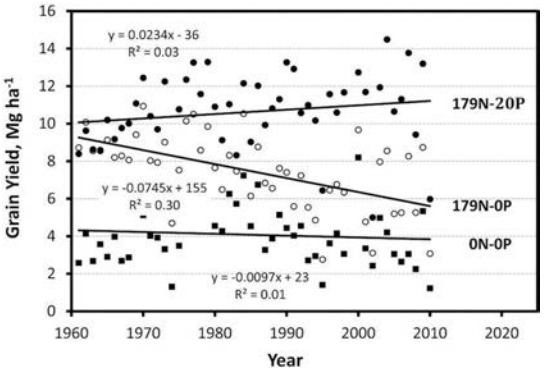
Long term benefit of P fertility



Annual rain yields from 1961 to 2015 for **irrigated continuous sorghum** grown near Tribune, KS
N and P rates in kg/ha



Annual grain yields from 1961 to 2010 for **irrigated continuous corn** grown near Tribune, KS.

Schlegel, A.J., and J.L. Havlin. 2020. Irrigated grain sorghum response to 55 years of nitrogen, phosphorus, and potassium fertilization. Agron. J. https://doi.org/10.1002/agj2.20453

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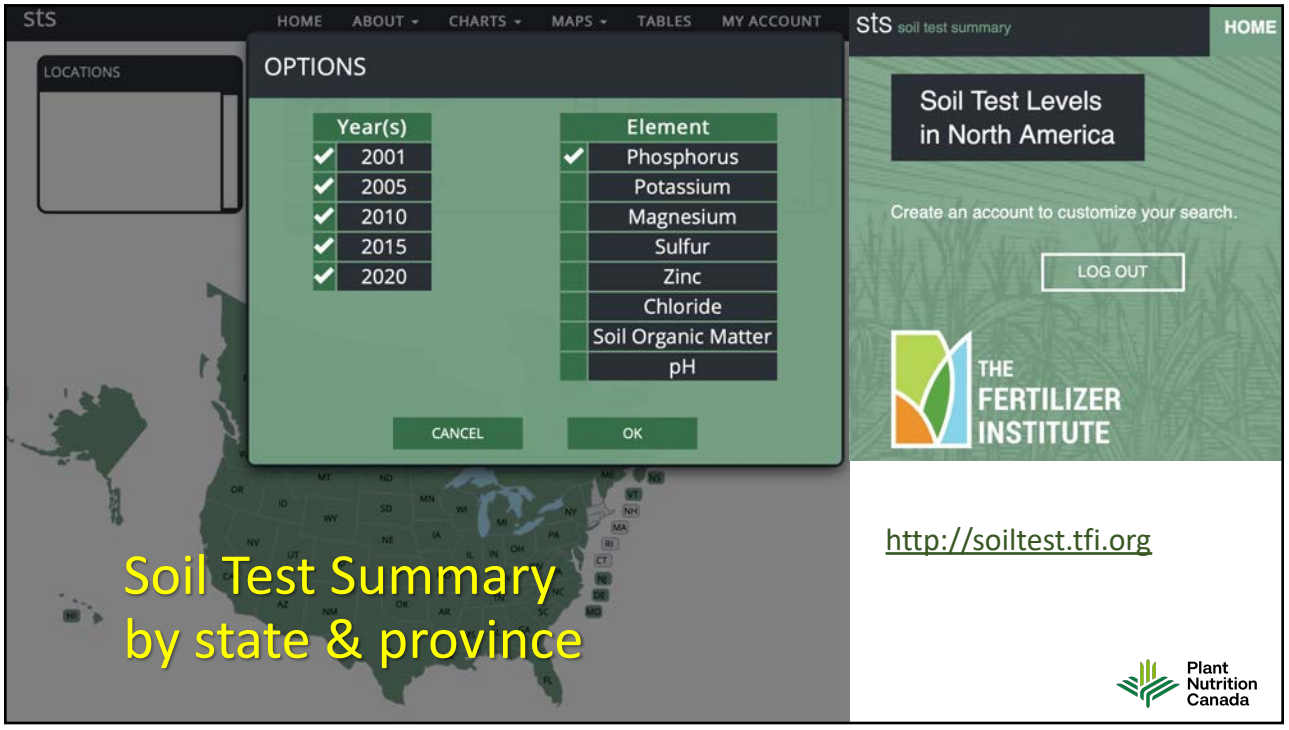

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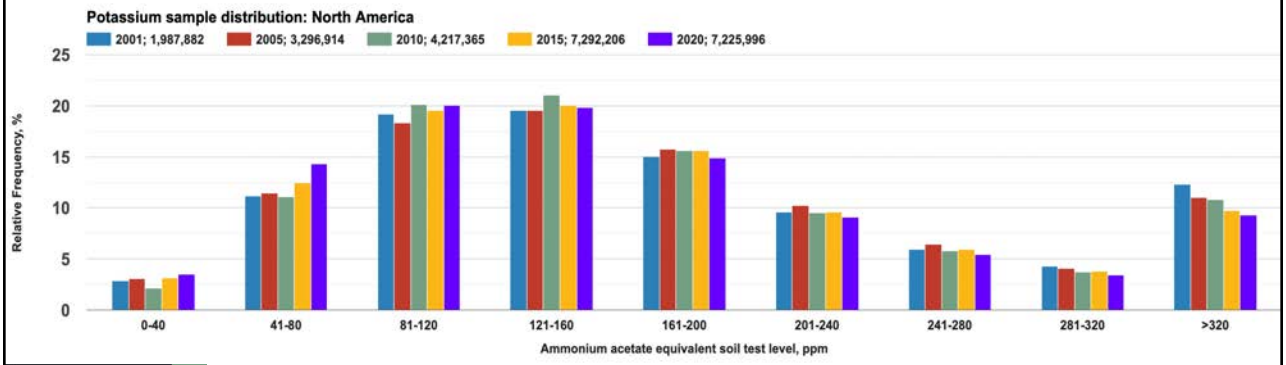
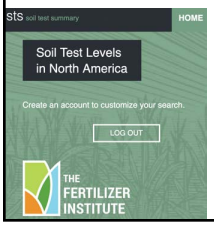
Soil Test Levels in North America





https://soiltest.tfi.org/

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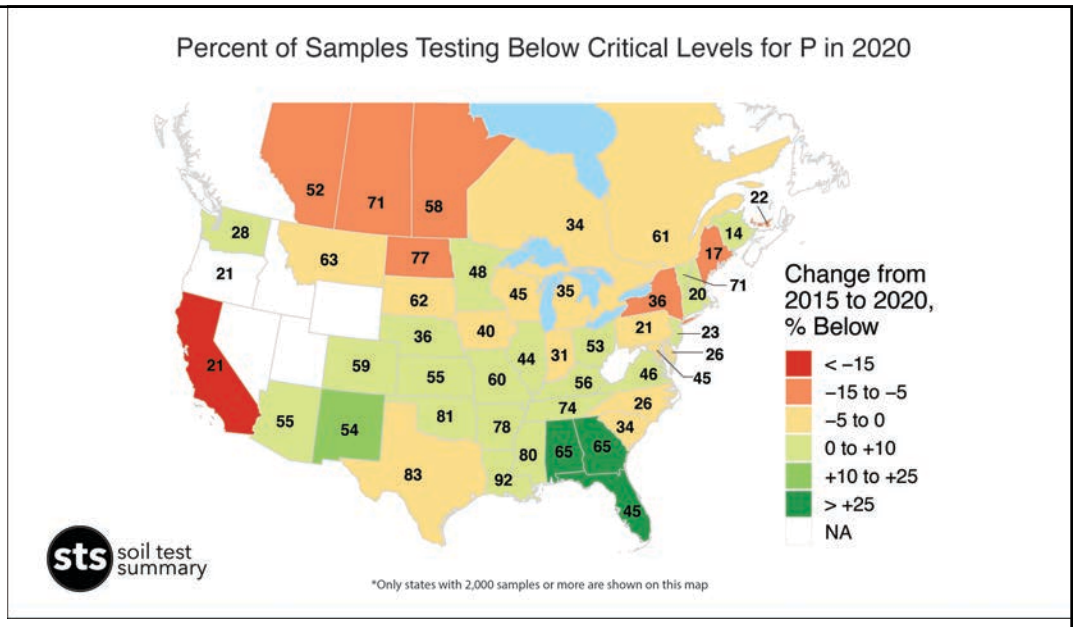

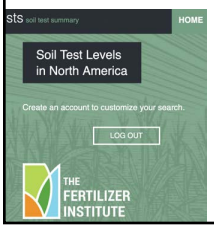

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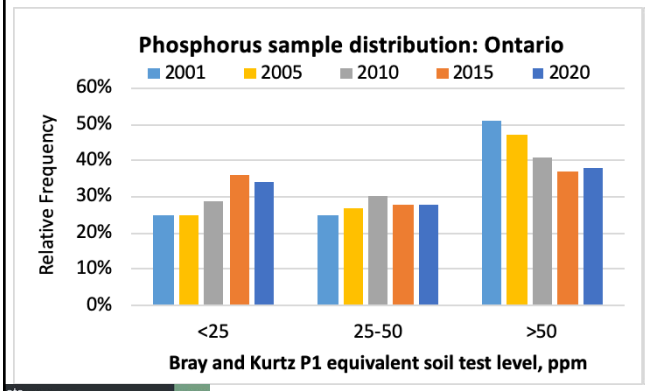
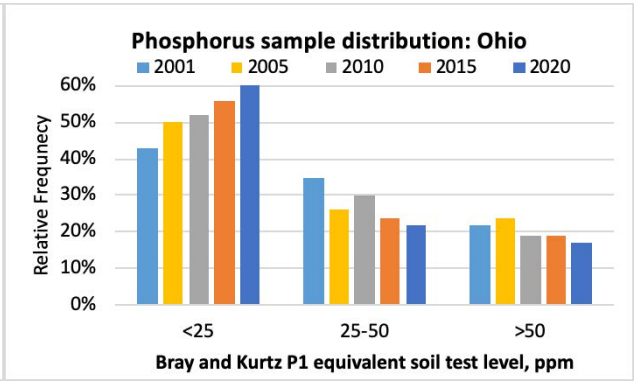
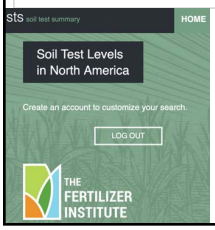
Ontario and Ohio – differ in soil P distribution







To mitigate P loads to Lake Erie, soil P drawdown is more relevant in Ontario. Applying at "right time" and in "right place" is more relevant in Ohio.

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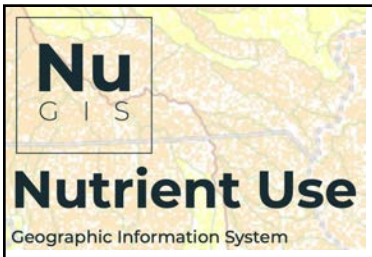
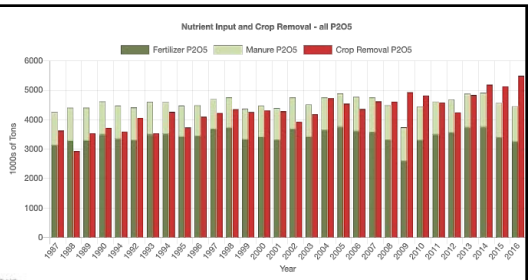
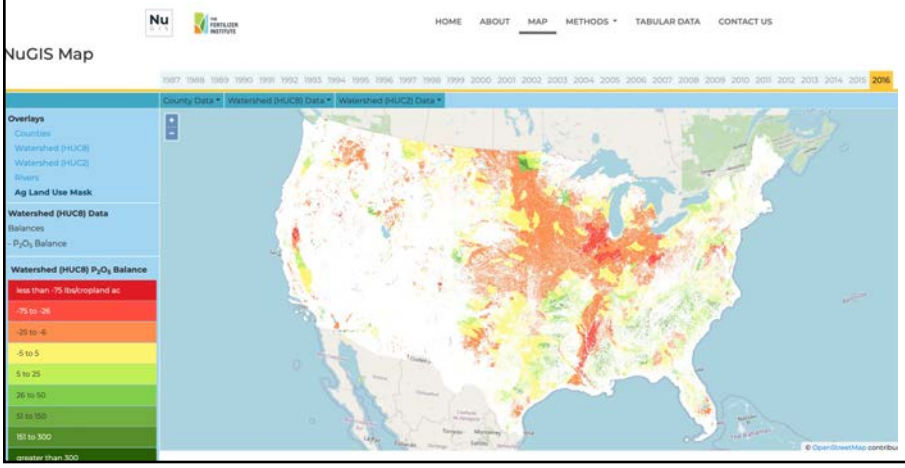
Deficits and surpluses in the US cropland P balance







Nu GIS

THE FERTILIZER INSTITUTE

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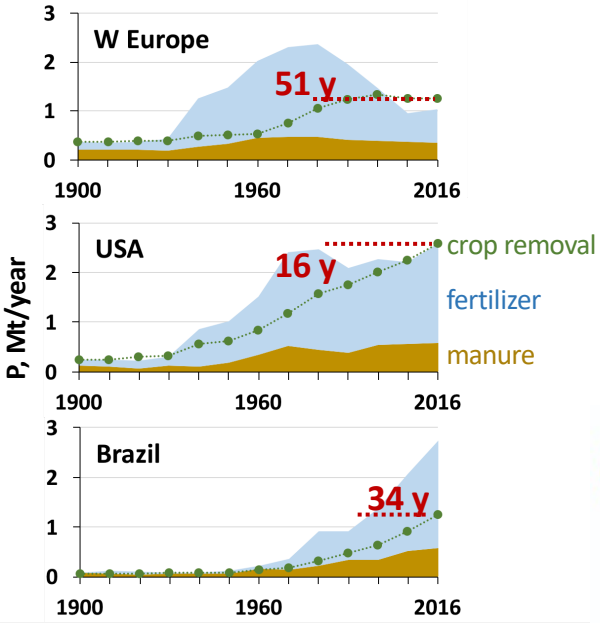
Crop P balances 1900-2016

In years of current annual crop removal, Brazil's **cumulative P surplus** falls between that of W Europe and USA.



Adapted from Mogollón et al., 2018. Global Environmental Change 50:149 and Zhang et al., 2017, Biogeosciences 14:2055-2068. Published in Bruulsema et al., 2019. J. Environ. Qual. 48(5). doi: 10.2134/jeq2019.02.0065.

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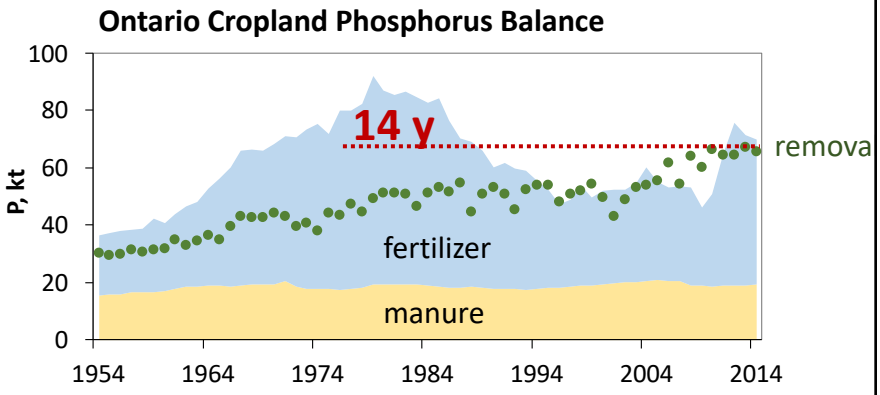
In years of current annual crop removal, Ontario's **cumulative P surplus** is similar to that of the USA.



See Bruulsema et al. (2019) J Environ Qual (for USA, Europe, and Brazil)

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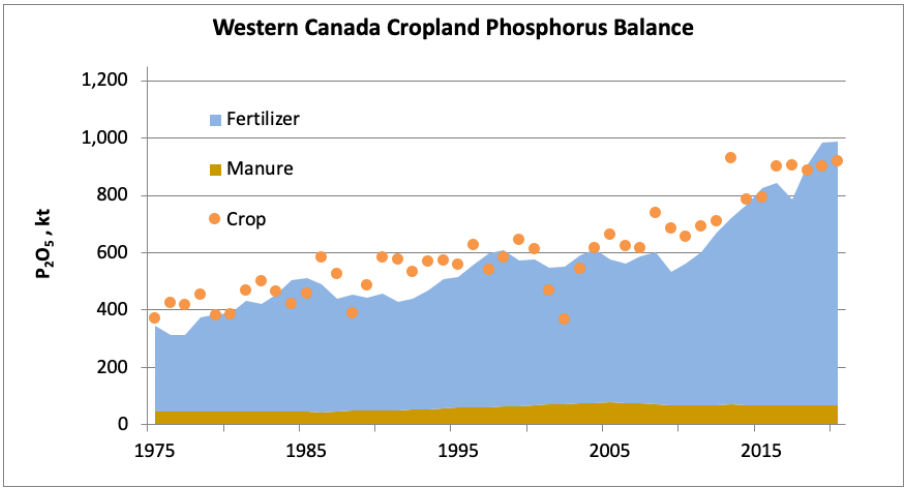

Canadian prairie provinces show no cumulative surplus P

Calculated from Statistics Canada data for crops, livestock, and fertilizer using methods of NuGIS *(assumes no change in manure P since 2013)*

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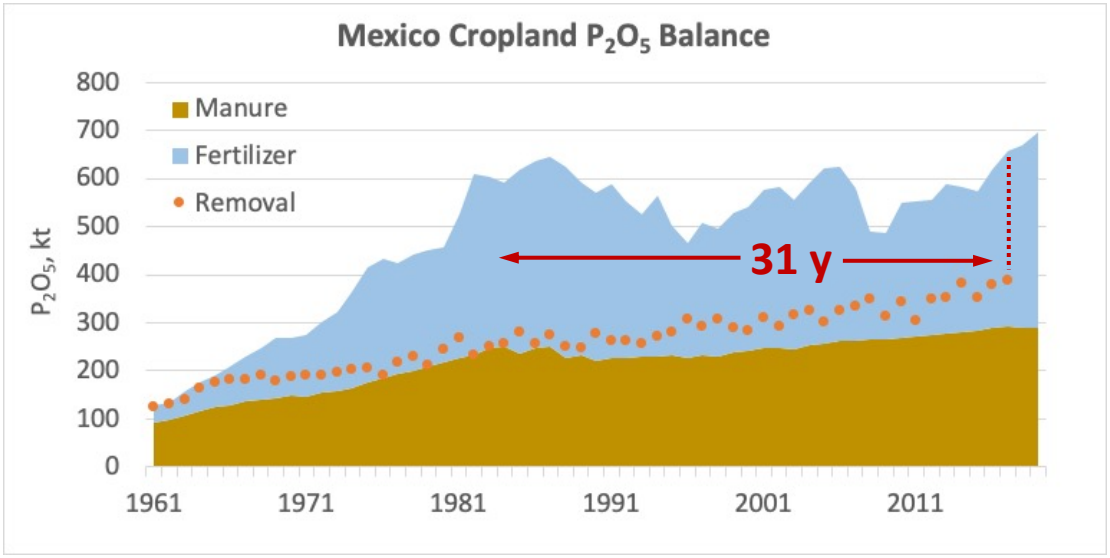

Mexico's **cumulative P surplus** is equivalent to 31 years current crop removal

Data source: IFA 2020 – International Fertilizer Association

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Legacies across Latitudes

Agricultural P legacies differ among countries and regions.

Europe's surplus larger owing to: assumptions about P fixation, soils longer depleted, socioeconomic policy, different crop mix

Moving to responsible phosphorus management depends on **continued research** to develop better assessment of soil P status, and to develop technologies that help crops exploit legacy P in soils.

For Brazil: "Combined use of no-till, cover crops, and 4R enables a transition to align P inputs more closely to crop offtake." (Withers et al., 2018)

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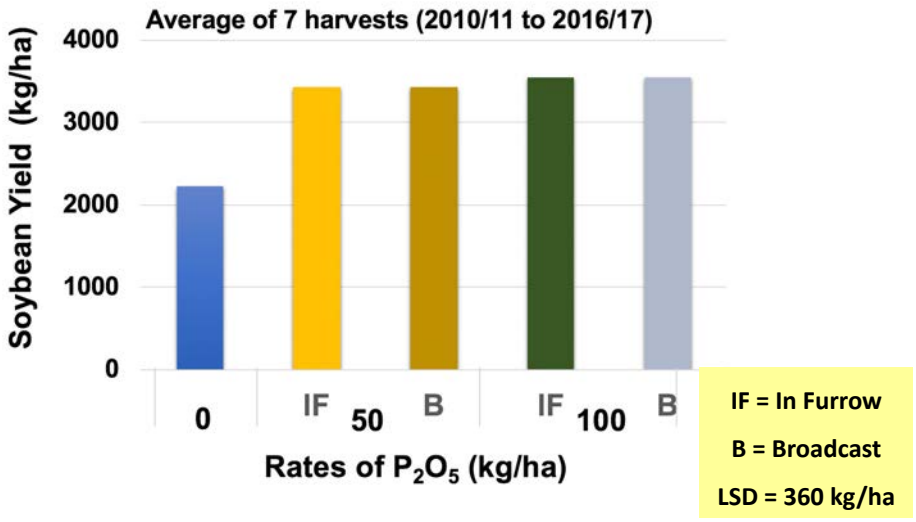
Soybeans – crop removal rates sufficient



Source: Long-term experiment, MT Research Foundation, Itiquira, Mato Grosso, Brazil.

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Summary

1. The new paradigm for plant nutrition recognizes its multiple responsibilities in sustainably enhancing earth's capacity to support life.
2. Responsible phosphorus management addresses multiple goals: Productivity, water quality, circular economy, biodiversity
3. Focusing on 4R Nutrient Stewardship is the fertilizer industry's most efficient contribution to responsible plant nutrition.
4. To further 4R, the industry needs to support science and report performance – soil tests, nutrient balances, & more

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