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Nitrogen Use Efficiency in Responsible Plant Nutrition

Tom Bruulsema, Chief Scientist, Plant Nutrition Canada

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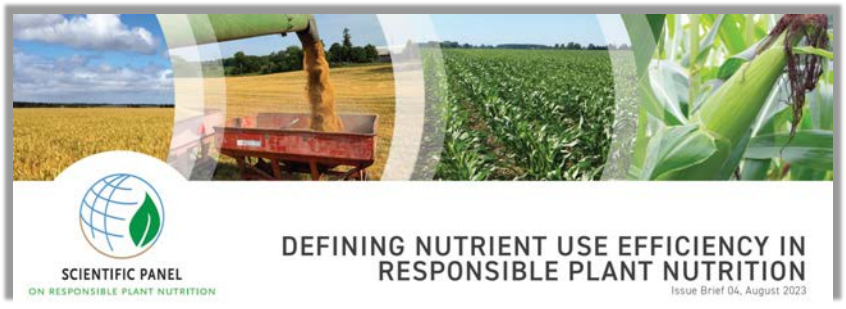
Outline

Nitrogen Use Efficiency in Responsible Plant Nutrition

1. Responsible plant nutrition and 4R nutrient stewardship
2. Definitions and formulations of nitrogen use efficiency indicators
3. NUE indicators for the five aims of responsible plant nutrition
4. Assessing 4R nutrient stewardship programs



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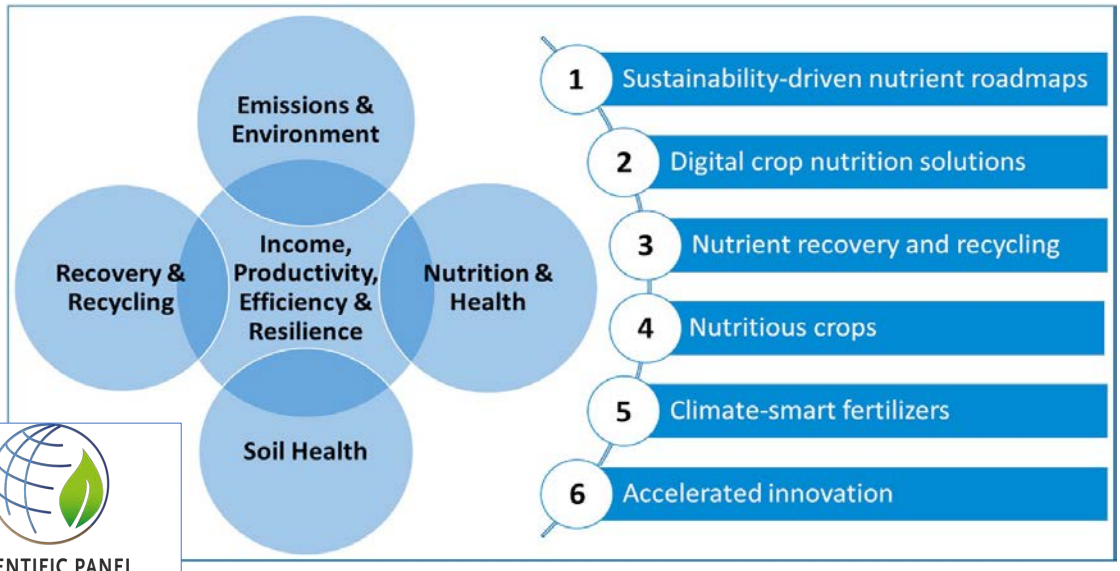
Responsible Plant Nutrition – 5 aims, 6 actions



SCIENTIFIC PANEL
ON RESPONSIBLE PLANT NUTRITION

Dobermann, et al., 2022. Global Food Security 100636.

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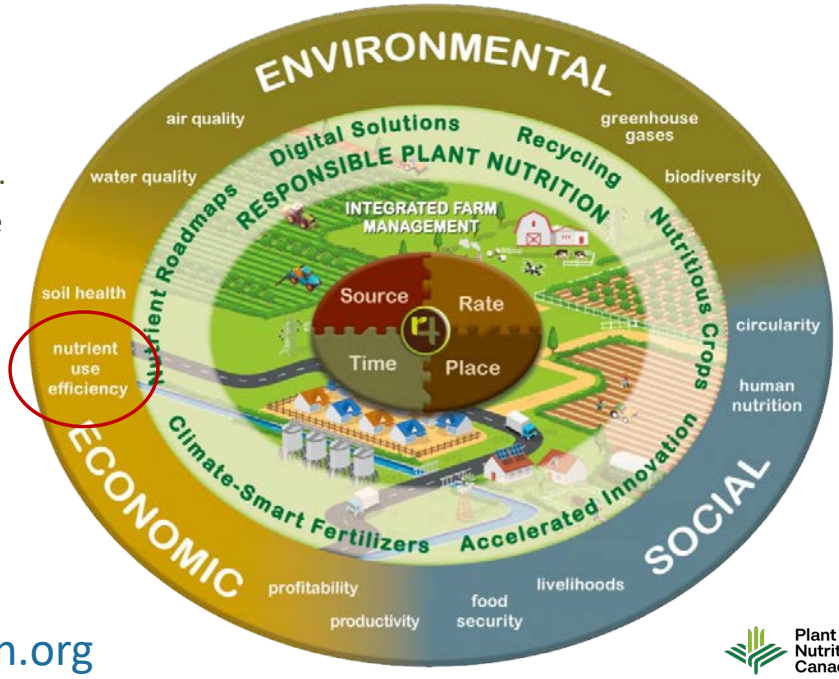
Furthering 4R

Relevant to each of the 5 aims and 6 actions of responsible plant nutrition.

Connected to performance outcomes, including NUE and N balance.

Site-specific.

Recognized.



SCIENTIFIC PANEL
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https://www.sprpn.org

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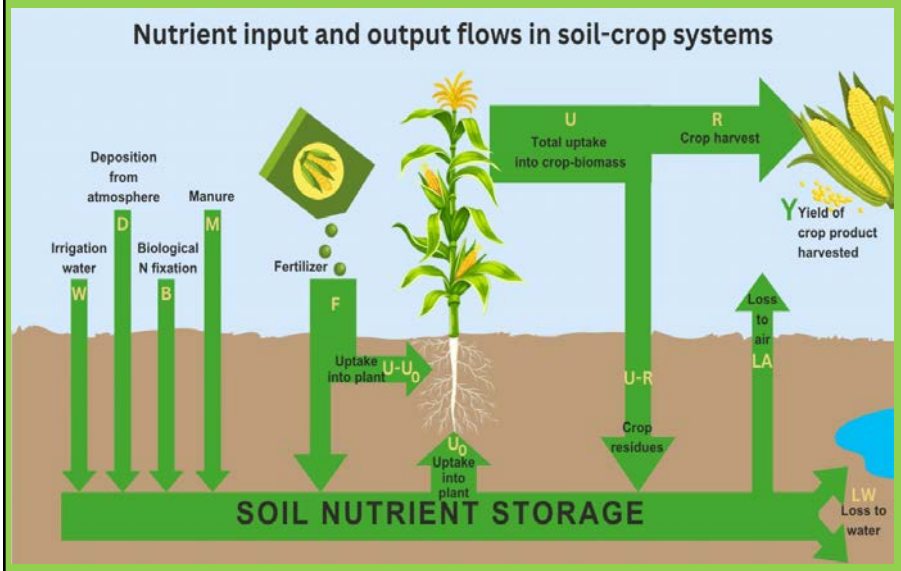
NUE definitions



Partial Factor Productivity
PFP = Y/F

Agronomic Efficiency
AE = $(Y-Y_0)/F$

Recovery Efficiency
RE = $(U-U_0)/F$

Nutrient Concentration
NC = R/Y

Nutrient Harvest Index
NHI = R/U

Partial Nutrient Balance
PNB = R/(W+D+B+M+F)

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NUE indicators for N in corn

NUE INDICATOR	CALCULATION	TYPICAL VALUES
PFP	Y/F	40-80 lb/lb
AE	$(Y-Y_0)/F$	20-50 lb/lb
RE	$(U-U_0)/F$	40-75%
NC	R/Y	1.1-1.5%
NHI	R/U	60-80%
PNB	**R/(W+D+B+M+F)**	**50-90%**

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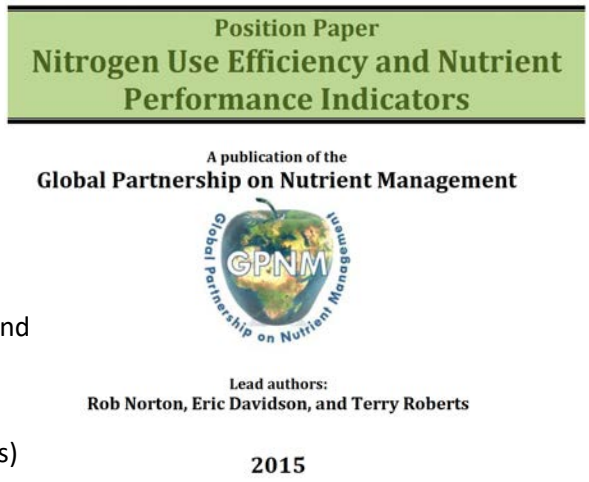
NUE as performance indicator

STRENGTHS:

1. Measurable outcome of management
2. Scalable benchmark for accountability
3. Limits input use only in relation to yield
4. Relates to every loss pathway, upstream and down

LIMITATIONS:

1. Critical values vary among farming systems and regions
2. Does not prescribe practices
3. Does not guarantee reduced N pollution (lags)
4. Should be considered in context of **productivity** and **soil health** indicators



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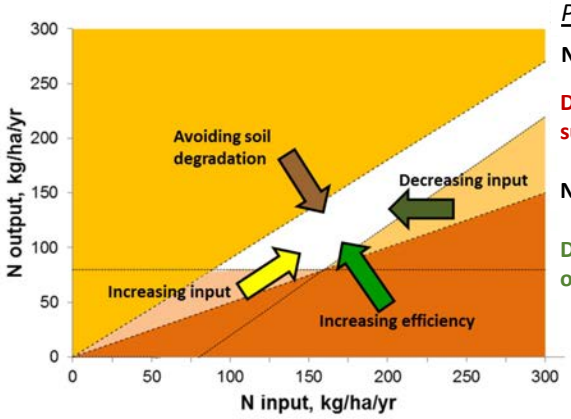
"Safe Operating Space"

- N output vs N input
- N output represents productivity
- Slope from any point to origin represents NUE
- **N surplus (F-R)** can also be plotted as a line
- Excessive NUE can degrade soil



Possible targets

NUE = 90%

Desired maximum N surplus < 72 lb/A

NUE = 50%

Desired minimum N output > 72 lb/A

EU Nitrogen Expert Panel, 2015

WAGENINGEN UR
For quality of life

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NUE indicators for the 5 aims of RPN

AIM	NUE INDICATORs	USES
1. Improve income, productivity, efficiency & resilience of farmers	a) PFP & PNB (on farm) b) AE & RE (in research)	Assess efficacy of practices and efficiency of cultivars & products
2. Increase nutrient recovery & recycling from waste	a) PNB – farm gate b) AE & RE	a) Opportunity b) Nutrient availability
3. Lift & sustain soil health & soil carbon	PNB (NHI)	Potential change in soil nutrient storage
4. Enhance human health through nutrition-sensitive agriculture	NC & NHI	Transfer of nutrient to nutritional quality
5. Minimize losses (GHG, pollution, biodiversity)	PNB (RE)	Potential for nutrient losses

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RPN Aim #1. Improve income, productivity, efficiency & resilience of farmers

NUE INDICATORs	USES
a) PFP & PNB (on farm) b) AE & RE (in research)	Assess efficacy of practices and efficiency of cultivars & products

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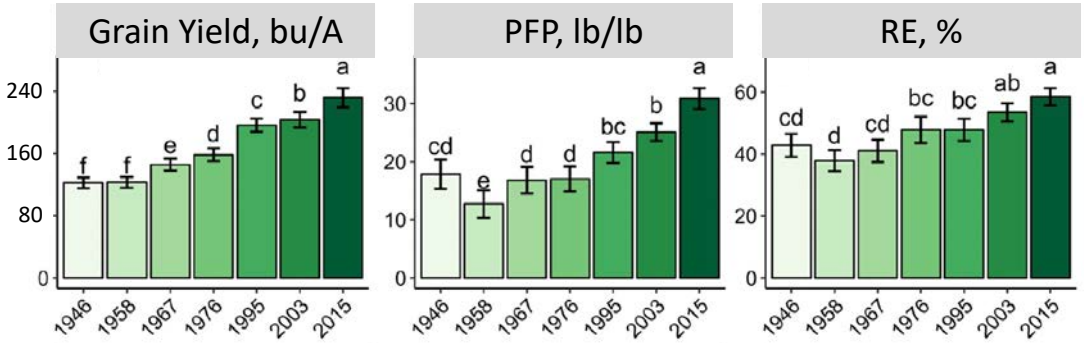
Genetic improvement in corn hybrids has increased yield & NUE



Mueller, S.M., C.D. Messina, and T.J. Vyn. 2019. Simultaneous gains in grain yield and nitrogen efficiency over 70 years of maize genetic improvement. Scientific Reports 9(1): 9095. doi: 10.1038/s41598-019-45485-5.

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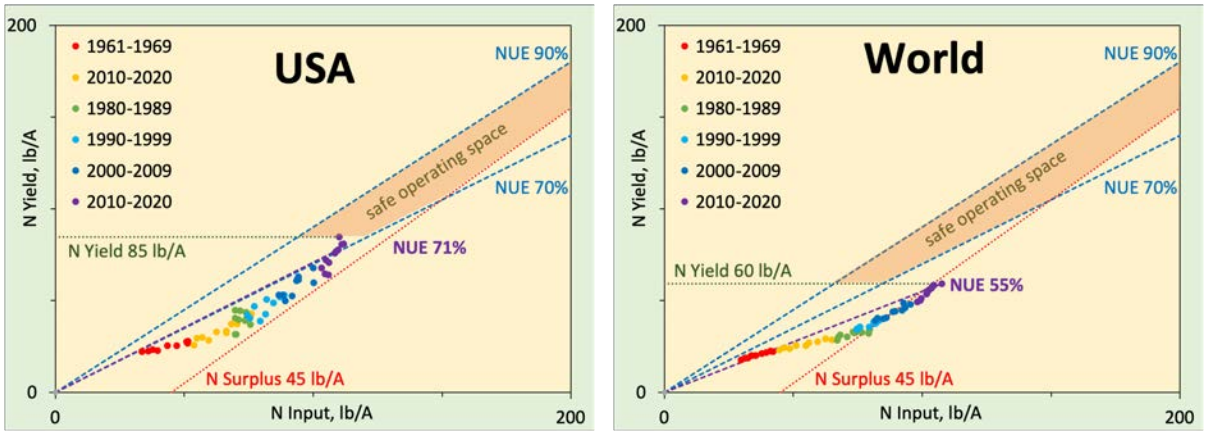
Cropland NUE is increasing with productivity



NUE = N outputs/ N inputs

N Outputs: Crop removal.

N Inputs: Fertilizer + manure applied + biological fixation + atmospheric deposition

Data Source: FAOSTAT Crop Nutrient Budgets

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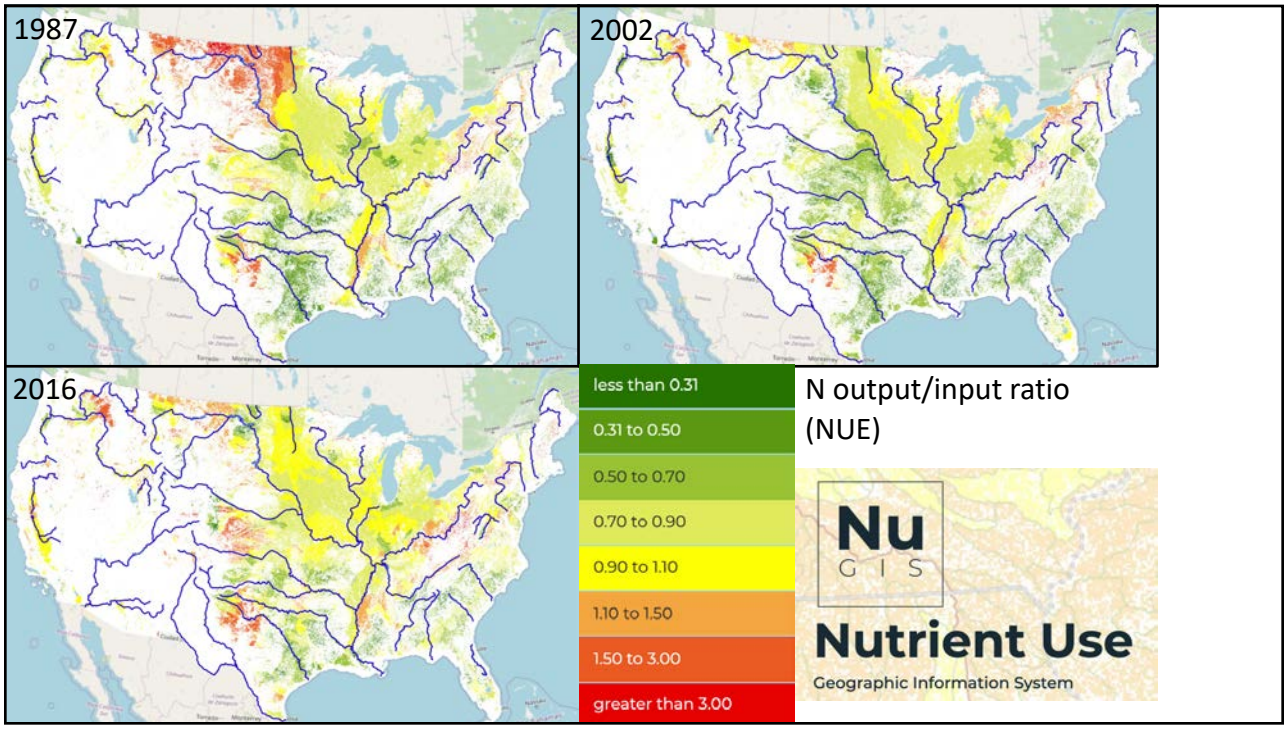
1987
2002
2016
less than 0.31
0.31 to 0.50
0.50 to 0.70
0.70 to 0.90
0.90 to 1.10
1.10 to 1.50
1.50 to 3.00
greater than 3.00
N output/input ratio (NUE)
Nu
GIS
Nutrient Use
Geographic Information System

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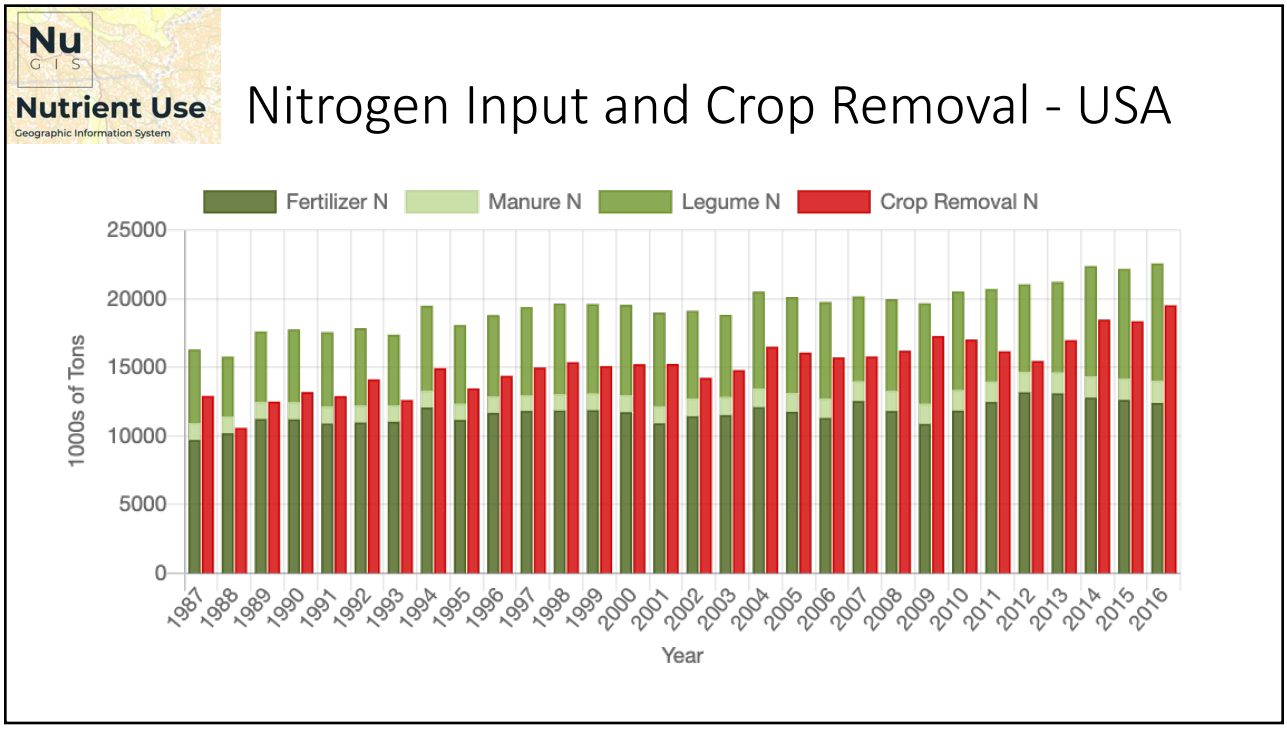
Nu
GIS
Nutrient Use
Geographic Information System
Nitrogen Input and Crop Removal - USA
Fertilizer N
Manure N
Legume N
Crop Removal N
1000s of Tons
25000
20000
15000
10000
5000
0
1987
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Year

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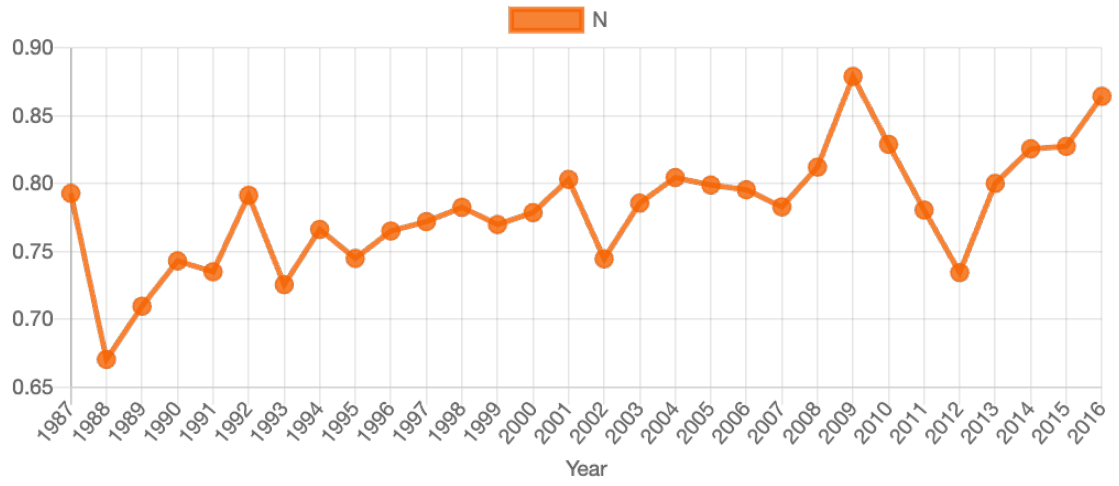
Nitrogen Use Efficiency (PNB) - USA



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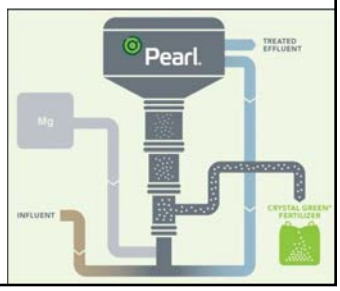
RPN Aim #2. Increase nutrient recovery & recycling from waste

NUE INDICATORs	USES
a) PNB – farm gate b) AE, RE	a) Opportunity b) Nutrient availability

4R source principle: Use recycled forms where feasible.

- Struvite
- Processed manure
- Nutrients recovered from food waste



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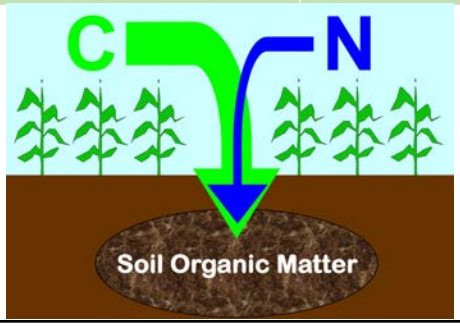
RPN Aim #3. Lift & sustain soil health & soil carbon

NUE INDICATORS	USES
PNB (NHI)	Potential change in soil nutrient storage



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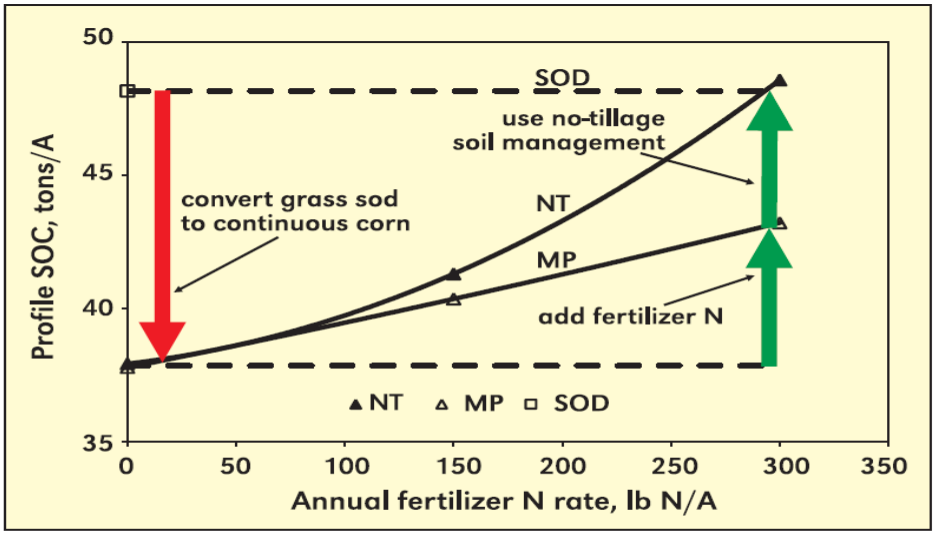

Figure 5. The impact of fertilizer N on total profile SOC levels found after 39 years of cropping to continuous corn with a winter cereal cover crop.

Grove et al., 2009, Kentucky, Better Crops, 2009 issue #4

IPNI

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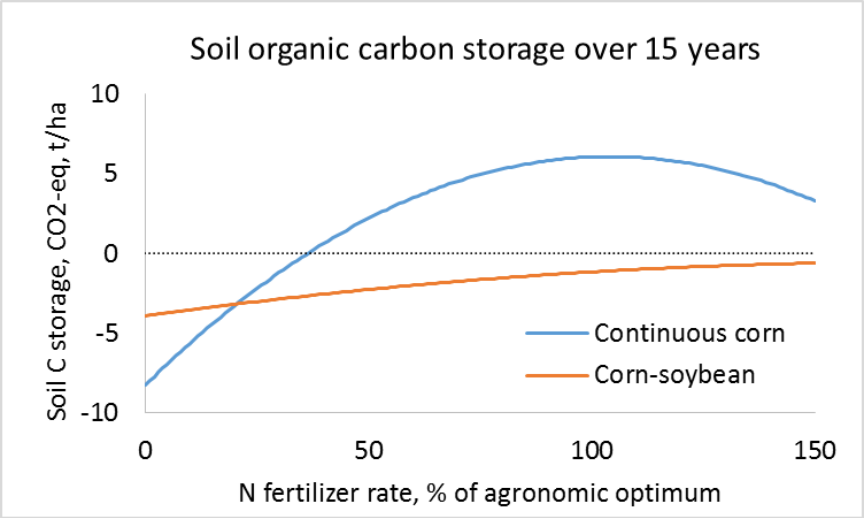
Optimum N rate is similar for yield & soil organic matter



Adapted from Poffenbarger et al., 2017. PLoS ONE 12(3): e0172293

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RPN Aim #4. Enhance human health through nutrition-sensitive agriculture

NUE INDICATORS	USES
NC & NHI	Transfer of nutrient to nutritional quality

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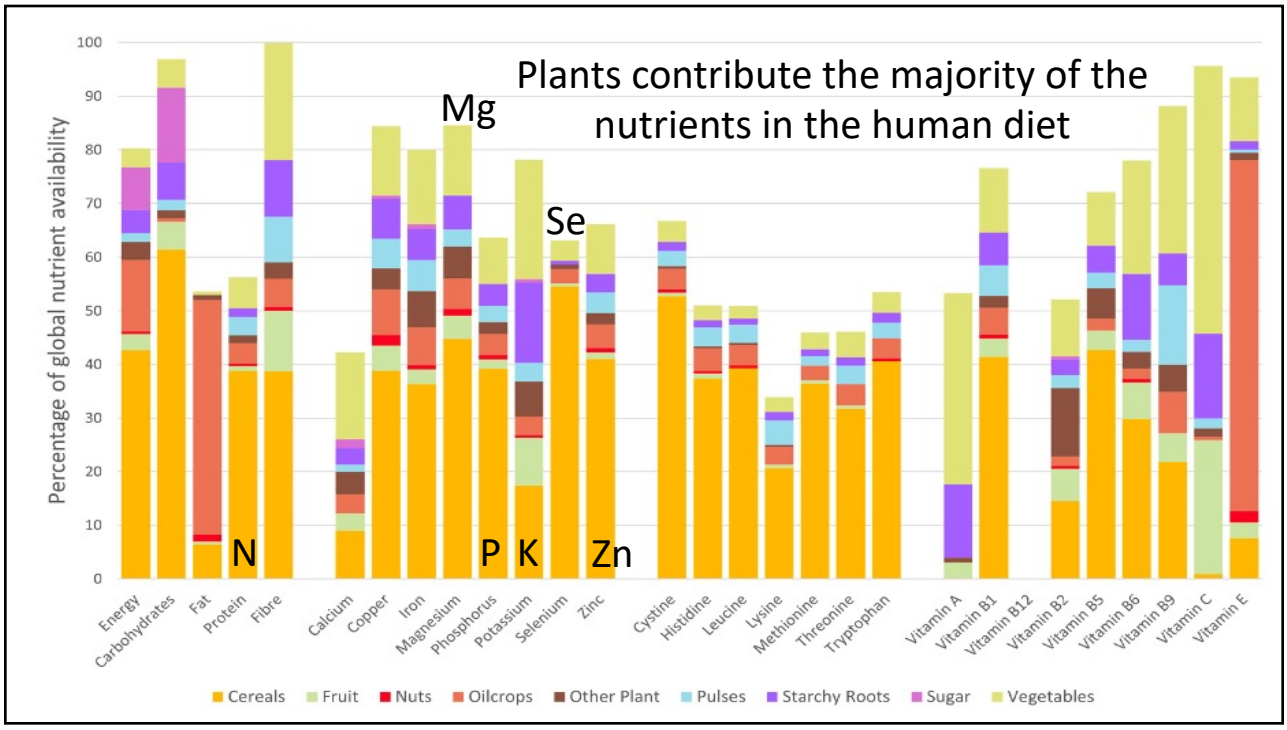

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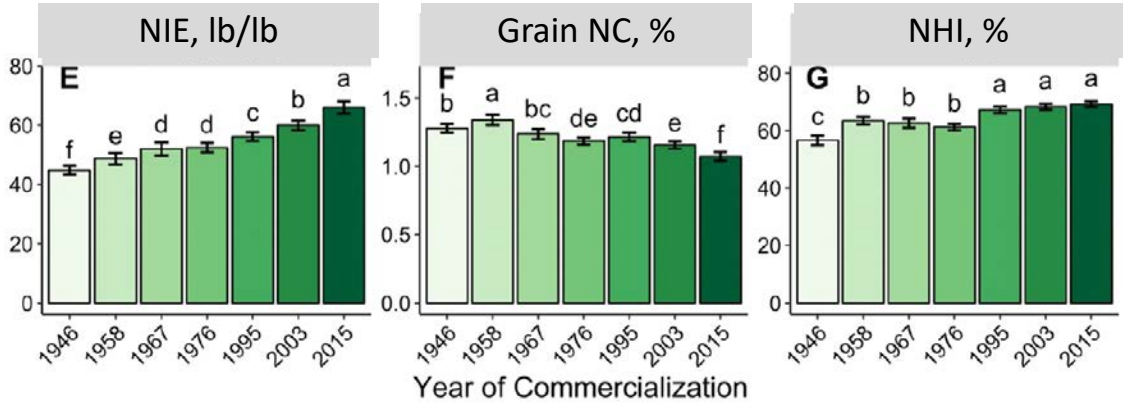
Genetic improvement in corn hybrids has increased yield & NUE but reduced grain N & protein



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Fertilizing corn with zinc for yield improvement improves zinc concentration for human health –but not enough!

Global meta-analysis, 67 studies:

Zn fertilizer	Yield, bu/A	[Zn], ppm
Without	**79**	**22**
With	**96**	**27**
% increase	17%	25%

Target for alleviating human Zn deficiency: ***38 ppm***

Mutambu, D., J. Kihara, M. Mucheru-Muna, P. Bolo, and M. Kinyua. 2023. Maize grain yield and grain zinc concentration response to zinc fertilization: A meta-analysis. Heliyon 9(5). doi: 10.1016/j.heliyon.2023.e16040.

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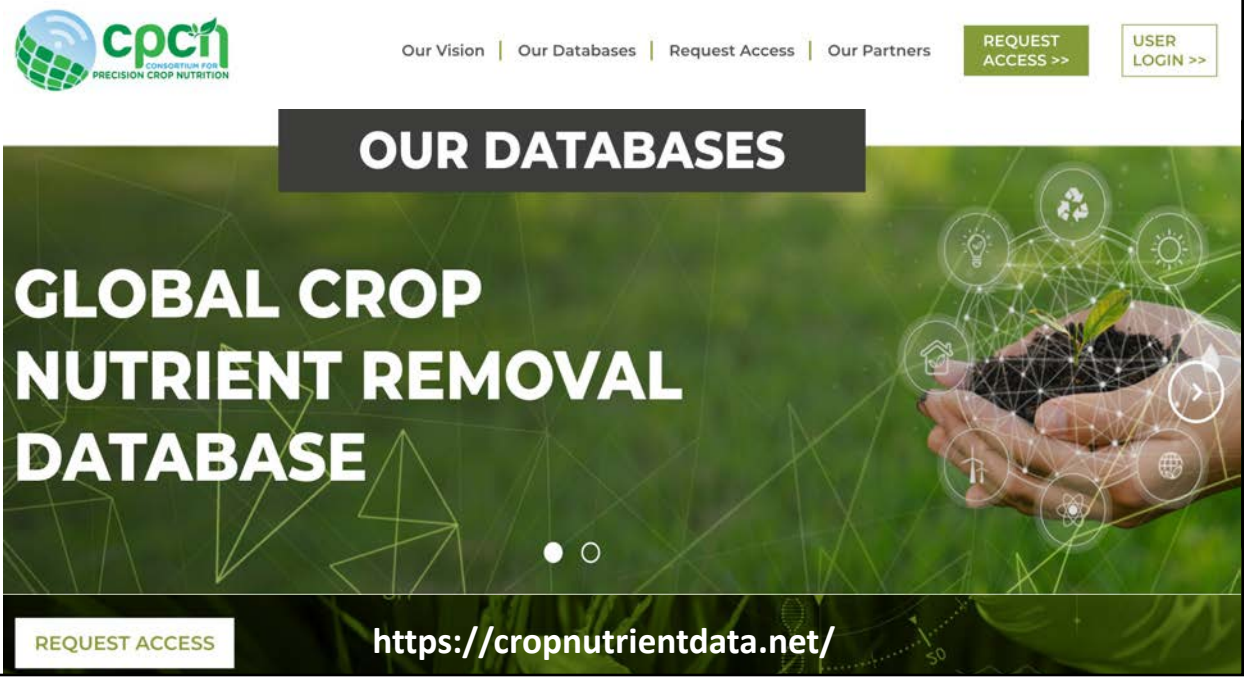

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RPN Aim #5. Minimize losses (GHG, pollution, biodiversity)

NUE INDICATORS	USES
PNB (RE)	Potential for nutrient losses

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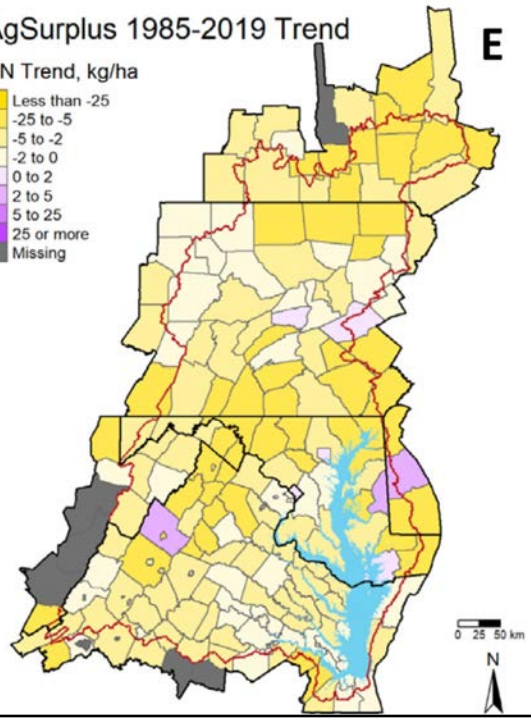

Does higher NUE reduce N loads?

"*Over the 1985–2019 time period, declines in total nitrogen (TN) loads have been reported in nearly all of the major tributaries to the Chesapeake Bay*"

"Despite all of these positive developments, recent increases in agricultural surpluses from 2009–2019 highlight that water quality gains may soon be reversed in many agricultural areas of the basin."

Sabo, R.D., B. Sullivan, C. Wu, E. Trentacoste, Q. Zhang, et al. 2022. Major point and nonpoint sources of nutrient pollution to surface water have declined throughout the Chesapeake Bay watershed. Environmental Research Communications 4(4):045012. doi: 10.1088/2515-7620/AC5DB6.

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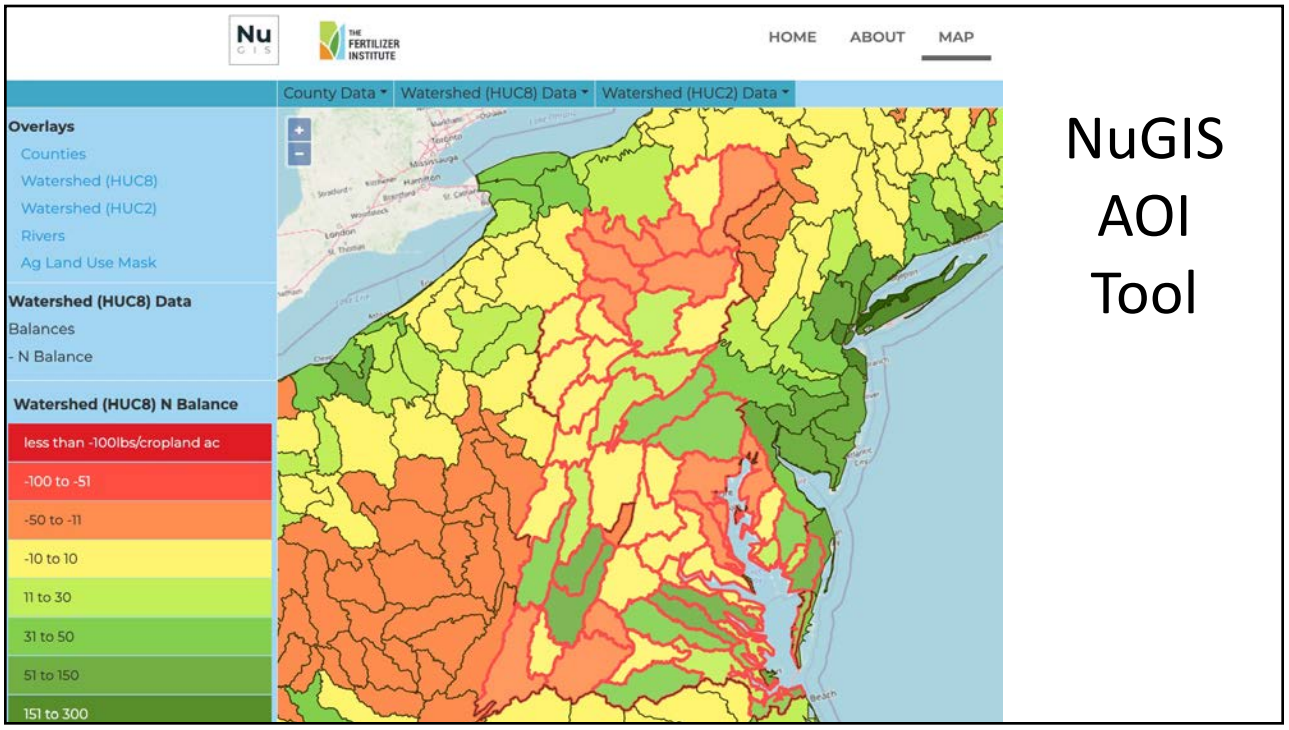

NuGIS AOI Tool

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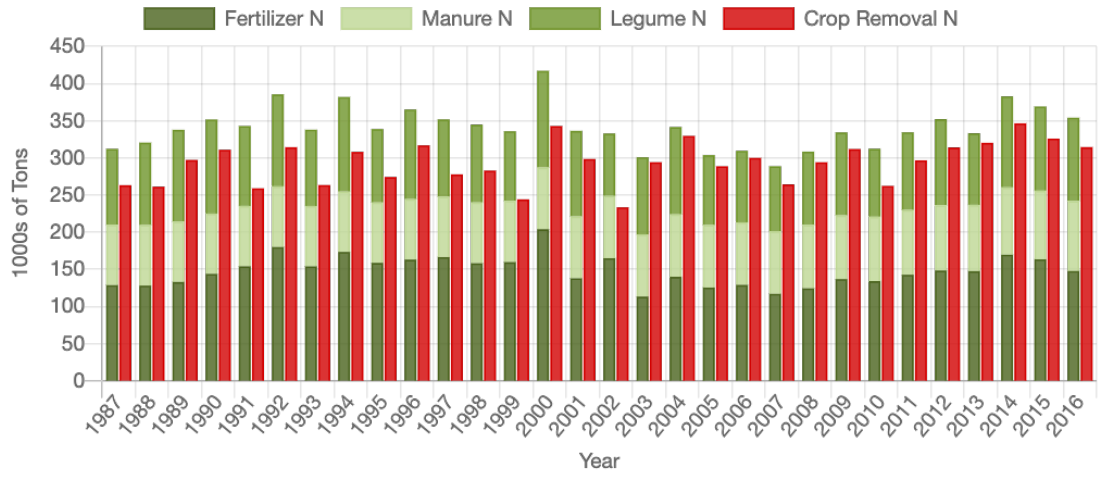
Nu GIS Nutrient Use Geographic Information System

Nitrogen Input and Crop Removal - CBW



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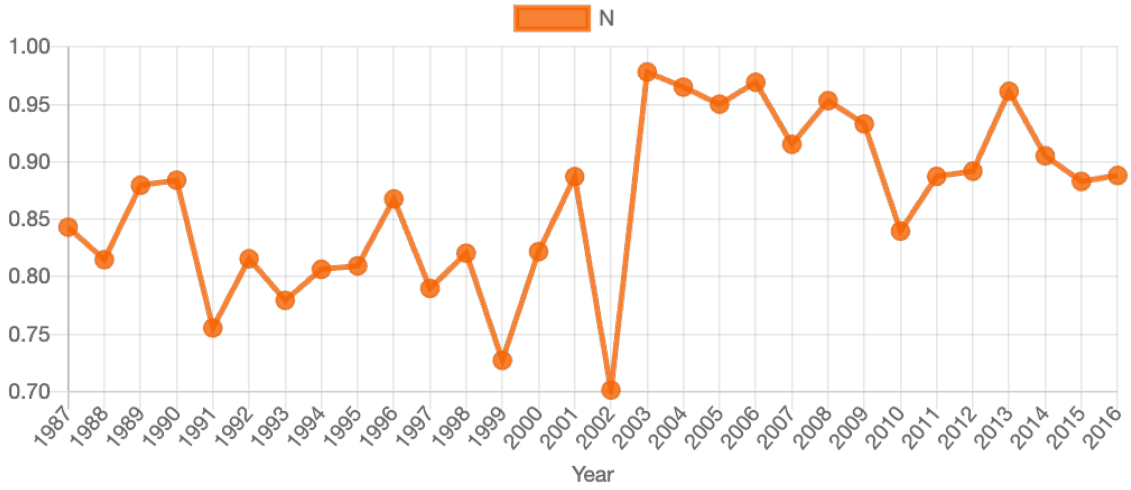
Nu GIS
Nutrient Use
Geographic Information System

Nitrogen Use Efficiency (PNB) - CBW



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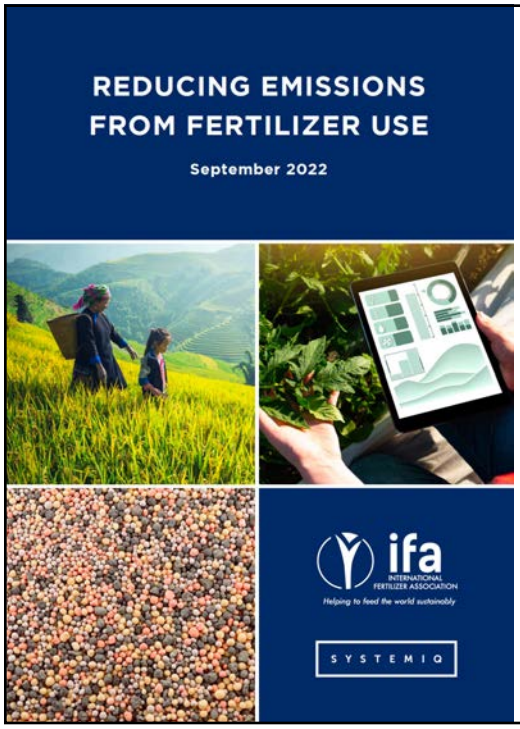

NUE and GHG

By 2050:

- Increasing global **NUE** from 50% to 70% could reduce emissions by 320 Mt CO_2e
- **Baseline** 2020 = 717 Mt CO_2e annually

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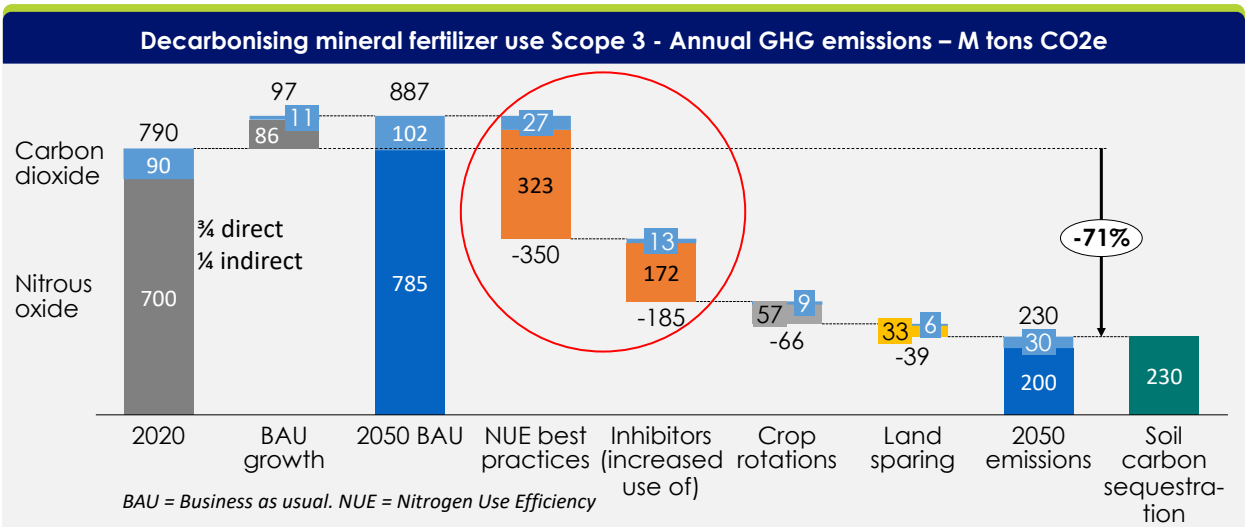
Scope 3 Emissions from the use of fertilizer can be more than halved by 2050 through increasing N use efficiency



https://www.fertilizer.org/Reducing-Emissions

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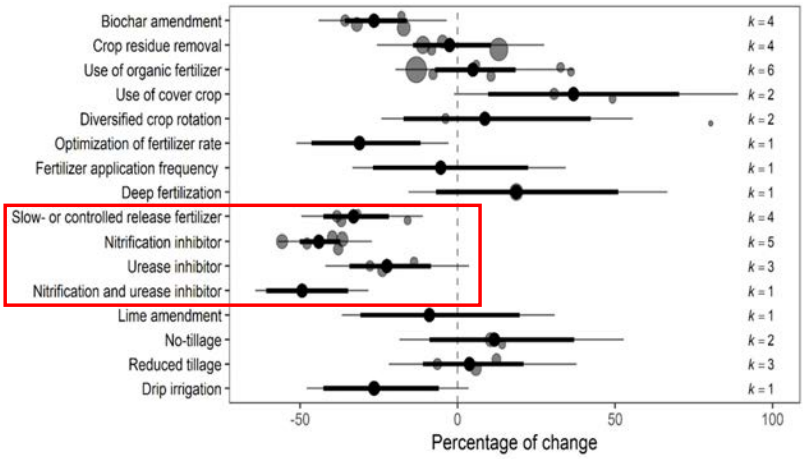
Climate-smart fertilizers emit less N_2O

Inhibitors and polymer coatings

- **0-7% yield gain**
- **0-15% NUE gain**
- **20-50% less N_2O**

Thapa et al. (2016) Effect of enhanced efficiency fertilizers on nitrous oxide emissions and crop yields: a meta-analysis. Soil Sci Soc Am J 80:1121–1134

Abalos et al. (2014) Meta-analysis of the effect of urease and nitrification inhibitors on crop productivity and nitrogen use efficiency. Agric Ecosystems & Environment 189: 136–144



Grados, et al. (2022). Synthesizing the evidence of nitrous oxide mitigation practices in agroecosystems. *Environmental Research Letters*. https://doi.org/10.1088/1748-9326/AC9B50

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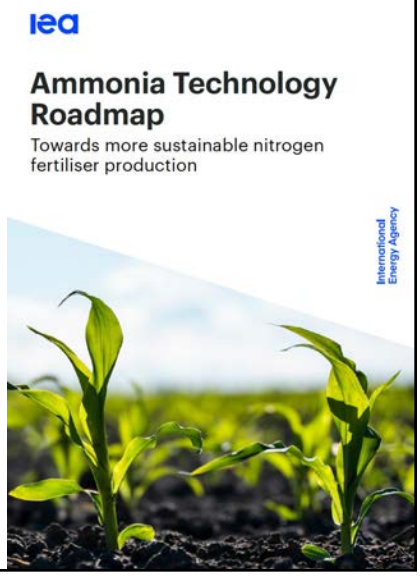
Net-zero future has many moving pieces

- Green ammonia: IFA projects 3.5 Mt by 2027, almost 85 Mt after 2027.
- Urea: CO_2 release = 1.6 tons per ton of N (IPCC)
- "In the Sustainable Development Scenario the use of urea-based fertilisers declines by 28% by 2050 compared to today, replaced by ammonium nitrate and calcium ammonium nitrate."
- "In both scenarios (SD and NZ) some of the CO_2 required for urea has to be obtained from sources other than the process CO_2 emission streams of ammonia plants."
- "if all ammonia were produced via either electrolysis or methane pyrolysis … neither route would generate CO_2 for use in urea production." (IEA, 2021)



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Assessing 4R programs

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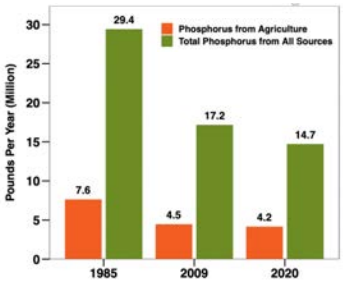
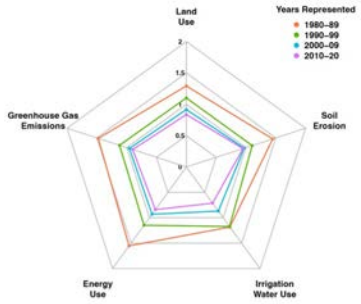
Sustainability Performance Reporting

- Track practices at farm level
- Share tracked data to report performance
- Economic, environmental & social sustainability



Chesapeake Bay Water Quality



Corn for grain

-------Field to Market 2021 Indicators Report-------

ESMC Ecosystem Services Market Consortium

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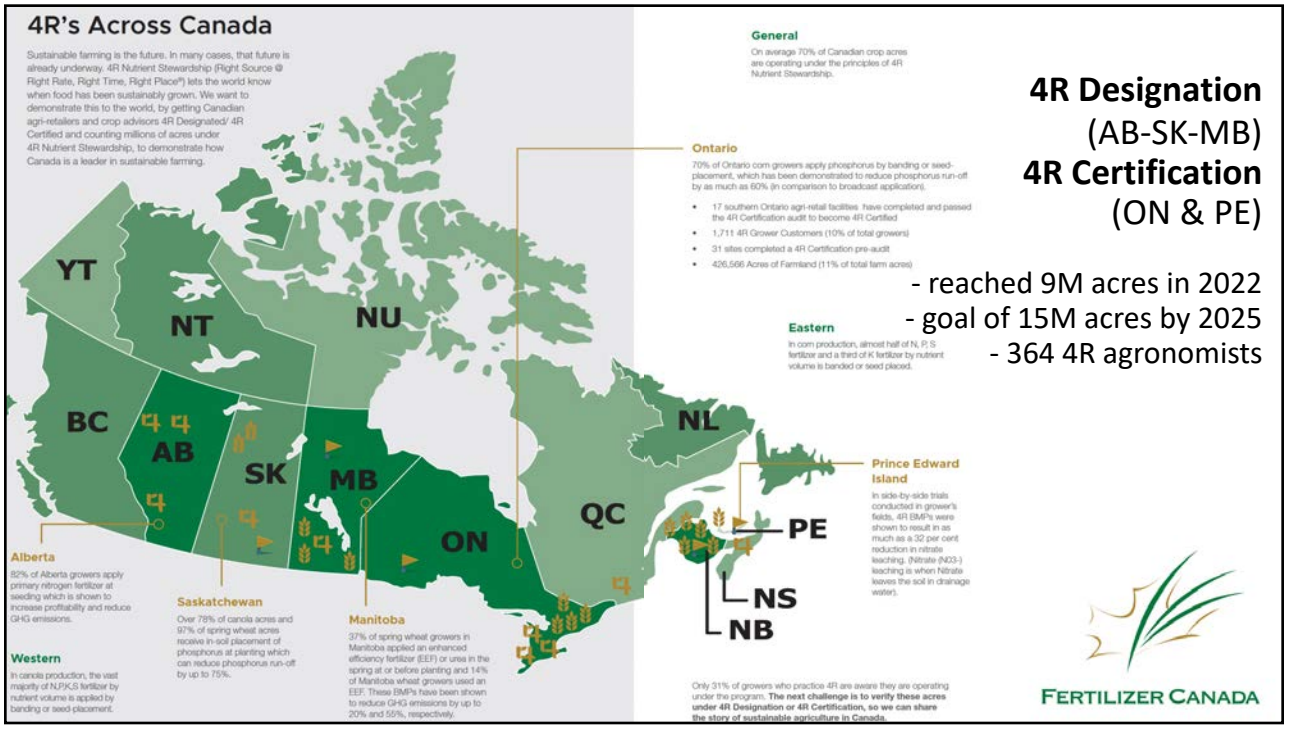

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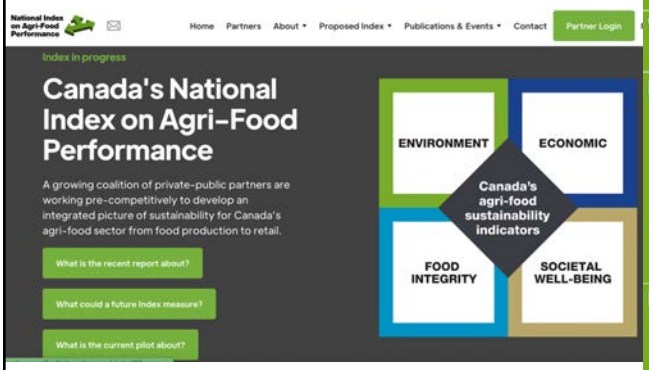
Stakeholders seek indicators on responsible use as well as outcomes



THEMES	INDICATORS	SUB-INDICATORS
Climate change	1. GHGs emissions	A. Emissions
		B. Sequestration/loss
		C. Mitigation
Soil	2. Soil health	A. Soil cover
		B. Soil erosion
		C. Soil organic carbon
Water	3. Water stewardship	A. Water quality
		B. Water use
Biodiversity	4. Biodiversity & agrobiodiversity	A. State of biodiversity & habitat change (interim for C & D)
		B. Conversion of farmland to urbanization
		C. Composite view: state of biodiversity & habitat change
		D. Disaggregated views: state of biodiversity & habitat change
Inputs	5. Crop inputs use / management	A. Responsible pest control product use (pesticides)
		B. Responsible nutrient use (fertilizer)
Waste	6. Food loss & waste	A. Reduce
		B. Repurpose
	7. Packaging & waste	A. Reduce / recycle
		B. Reuse

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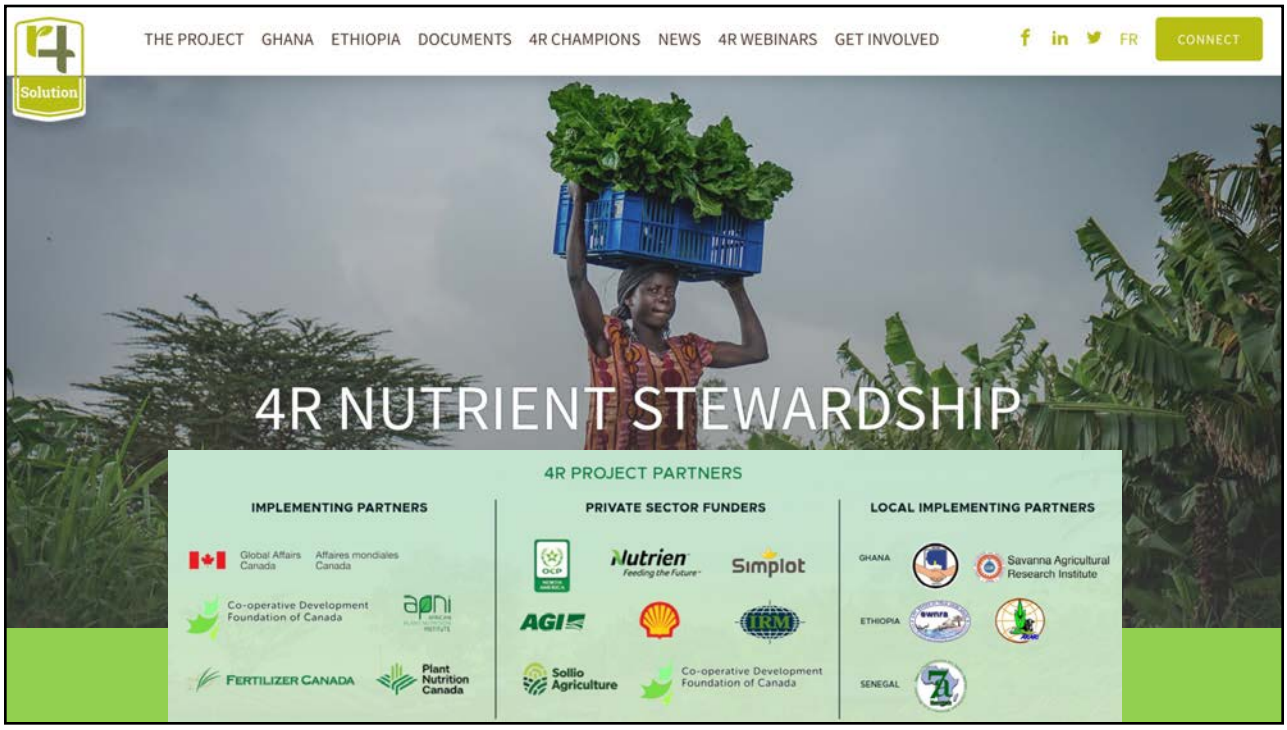

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Summary

1. N use efficiency, considered in context, serves as an important indicator of performance, for 4R efforts, and crop production.
2. Specific indicators of NUE apply to the five aims of responsible plant nutrition: productivity, recycling, soil health, human nutrition, and emissions.
3. A partial nutrient balance, with inputs and outputs clearly defined, is the most applicable NUE indicator.
4. Assessing 4R nutrient stewardship programs depends on tracking both practices and outcomes.

nutrient stewardship

https://www.sprpn.org/issue-briefs

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