Assessing nutrient use efficiency

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Seminar, Coromandel International Ltd., 9 May 2024

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Objectives

1) Learn about the different indicators that can be used to assess nutrient use efficiency in agriculture
2) Understand which indicators to use for what purposes, and how to interpret their values
3) Focus on agronomically important indicators of fertilizer use, but also discuss indicators for environmental and system-level performance assessment

Resources

1) Scientific Panel on Responsible Plant Nutrition. 2023. Defining nutrient use efficiency in responsible plant nutrition. Issue Brief 04. Available at https://sprpn.org/issue-brief/defining-nutrient-use-efficiency-in-responsible-plant-nutrition/
2) Dobermann, A. 2005. Nitrogen use efficiency - state of the art. IFA international workshop on enhanced-efficiency fertilizers. https://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1319&context=agronomyfacpub
3) Dobermann, A. 2007. Nutrient use efficiency - measurement and management. IFA International Workshop on Fertilizer Best Management Practices. https://digitalcommons.unl.edu/agronomyfacpub/1442/

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SCIENTIFIC PANEL
ON RESPONSIBLE PLANT NUTRITION

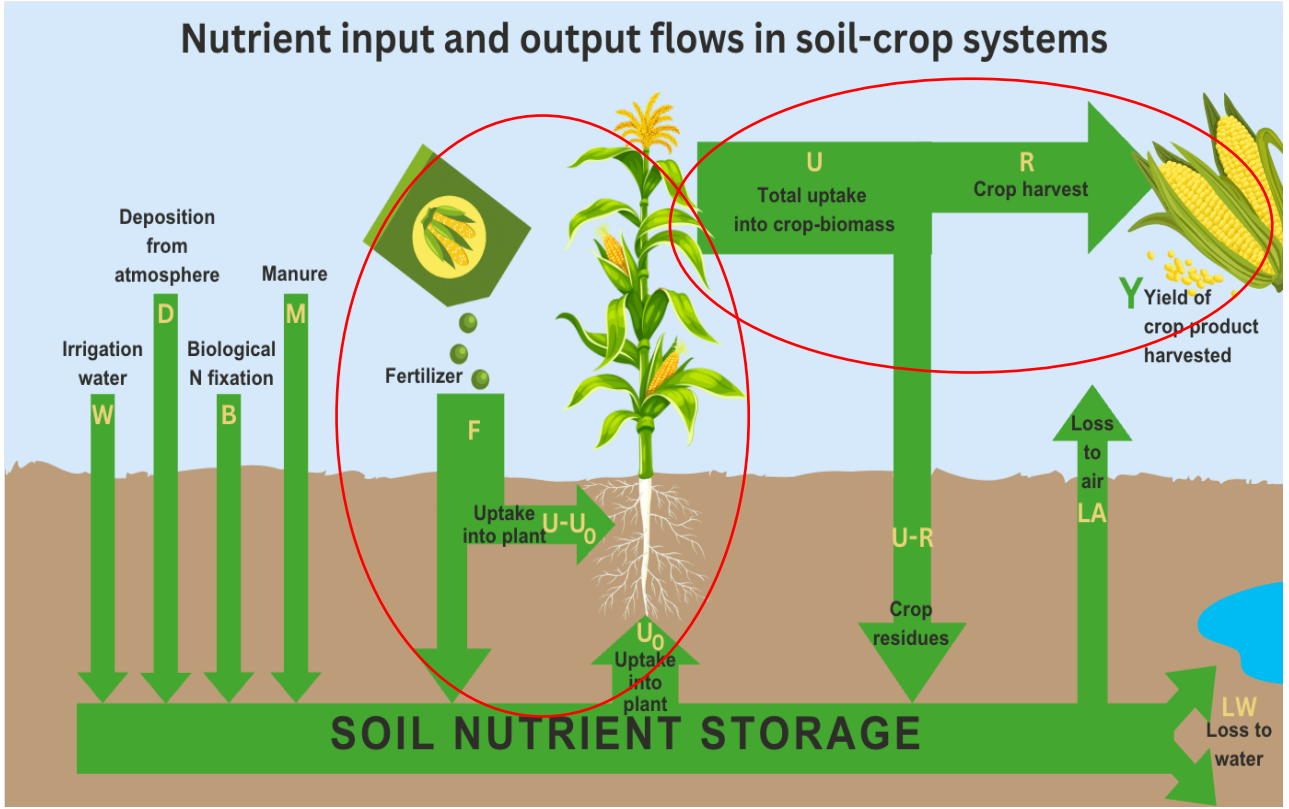
DEFINING NUTRIENT USE EFFICIENCY IN RESPONSIBLE PLANT NUTRITION

Issue Brief 04, August 2023

KEY POINTS

- Nutrient use efficiency indicators are important for sustainability and efficiency assessment in farming.
- Different indicators, with various combinations of nutrient outputs and inputs, are required to quantify nutrient use efficiency in relation to the multiple aims of responsible plant nutrition.
- Comprehensive assessment of sustainable crop production requires additional indicators.

Fertilizer Indicators



Fertilizer indicators:

Partial Factor Productivity (kg/kg)

PFP = Y/F

Agronomic Efficiency (kg/kg)

AE = $(Y-Y_0)/F$

Recovery Efficiency (%)

RE = $((U-U_0)/F) \times 100$

Physiological Efficiency (kg/kg)

PE = $(Y-Y_0)/(U-U_0)$

<u>Footprint for calculation:</u>
field trials, management zones, whole field, farm by crops, groups of farms, etc.

<u>Time scale:</u>
one cropping season

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Fertilizer Indicators

0 N 100 N 300 N

Measurements:

F – amount of (fertilizer) N applied (kg N/ha)
Y – crop yield or total dry matter (kg/ha)
U – crop N uptake (kg N/ha)

in field plots that receive no fertilizer and plots that receive fertilizer at different rates

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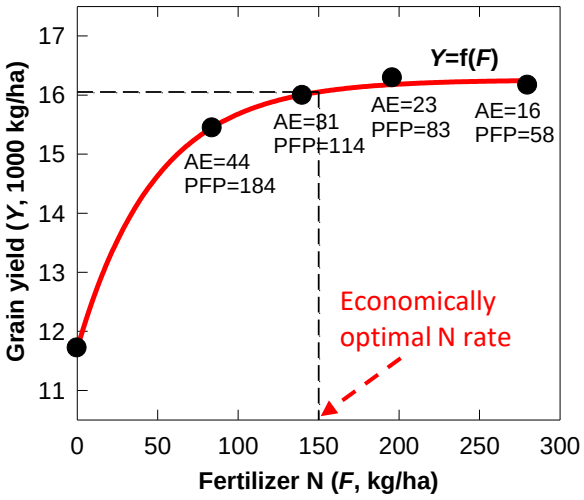

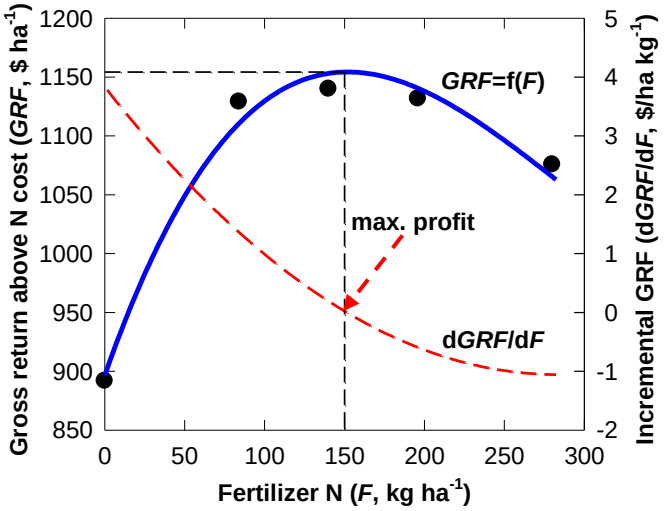

Fertilizer indicators:

Partial Factor Productivity (kg/kg)

PFP = Y/F or PFP = $(Y_0 + \Delta Y)/F$

Agronomic Efficiency (kg/kg)

AE = $(Y-Y_0)/F$

Gross return above fertilizer cost:

GRF = (Y x price of grain) – (F x price of F) – application cost

Partial Factor Productivity

= kg grain yield per kg N applied

→ soil fertility and fertilizer efficiency

Agronomic Efficiency

= kg grain yield increase per kg N applied

→ fertilizer management, genetics, crop management, weather

→ product of recovery efficiency x physiological efficiency of fertilizer

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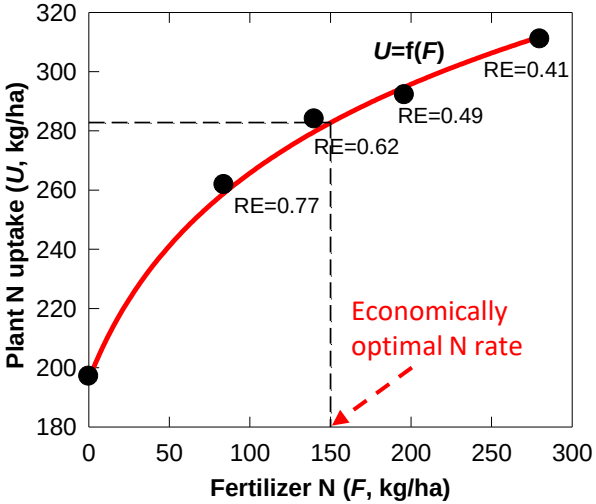
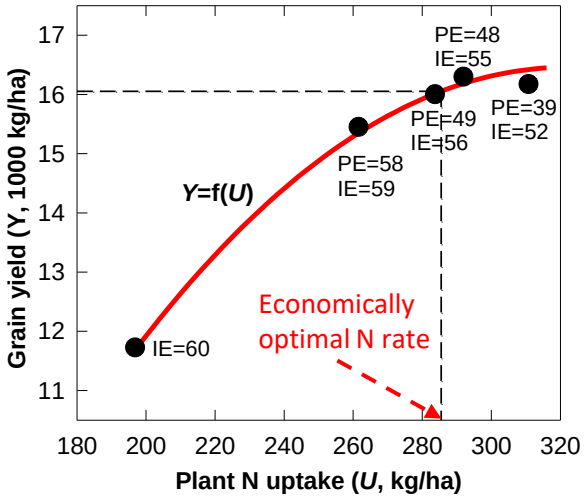
Fertilizer Indicators





Fertilizer indicators:

Recovery Efficiency (fraction,%)

RE = $(U-U_0)/F$

Physiological Efficiency (kg/kg)

PE = $(Y-Y_0)/(U-U_0)$

Recovery efficiency ('apparent')

= kg <u>increase in crop uptake</u> per kg nutrient applied

→ Crop sink size and crop health

→ Fertilizer management (4R)

Physiological efficiency

= kg <u>yield increase</u> per kg increase in crop uptake

→ Climate, crop variety & crop management

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Fertilizer Indicators: Application & Interpretation

	Indonesia (2004-05, N=20)	**Nebraska, USA** (2002-03, N=20)
Yield potential (t/ha)	8-14	15-20
Grain yield 0N (t/ha)	5.7	10.1
Grain yield +N (t/ha)	9.1	14.1
Fertilizer-N (kg/ha)	200	158
PFP_N (kg/kg)	46	89
AE_N (kg/kg)	17	25
RE_N (%)	37	65

Indonesia: rainfed and irrigated maize, on-farm trials, same N rate at all sites, 3 N applications

Nebraska: irrigated maize, on-farm trials, location-specific N rate based on UNL-algorithm (includes yield goal, SOM, soil NO_3-N, and other N credits), 2-3 N applications

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Fertilizer Indicators: Influencing Factors

$$PFP_N = (Y_0 + \Delta Y_N)/F_N$$

Management and environmental factors	Influence on Y_0	Influence on ΔY_N (Y_{max}, RE_N, PE_N)
Climate	**	***
Genotype	**	**
Soil drying, longer fallow periods (rice)	**	*
Manure, crop residues , legume as previous crop	***	*
Land preparation and crop establishment	**	*
Balanced nutrition and amelioration of mineral toxicities/deficiencies	**	***
Water management	**	***
Weeds, insects and diseases	*	***
Timing and amount of N applications	-	***
New fertilizer products (slow/controlled release fertilizers, supergranules, N-inhibitors)	-	***
Placement of fertilizer	-	***

- no significant influence; * some influence; ** moderate influence; *** strong influence

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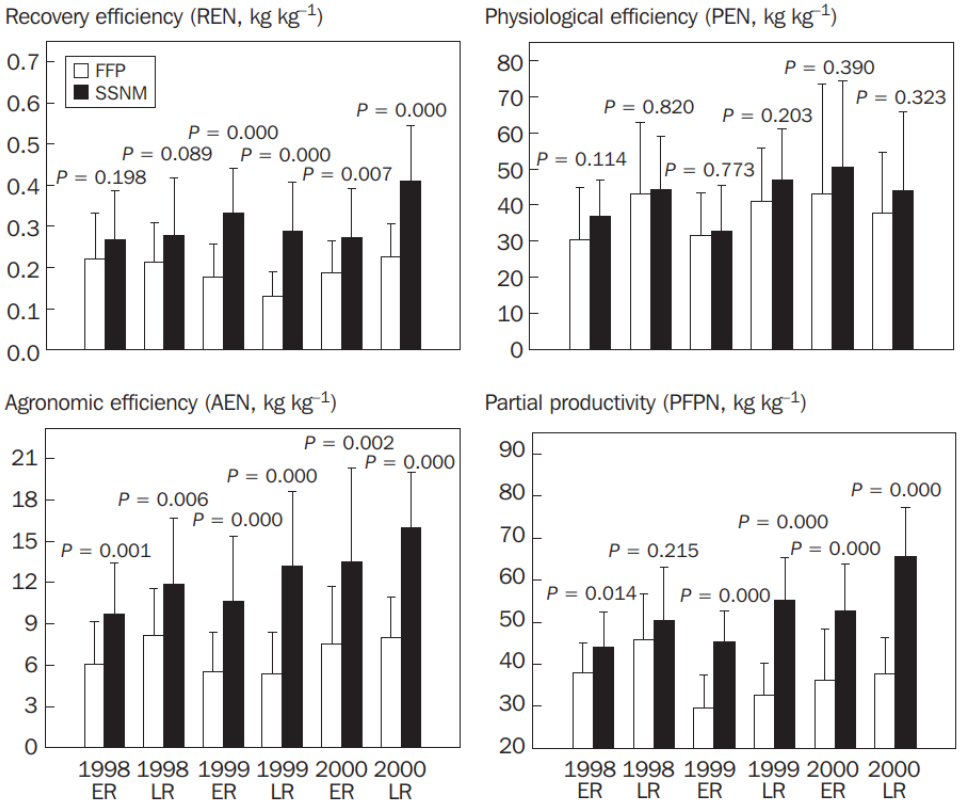
Fertilizer Indicators: improvement over time

FFP – Farmers' fertilizer practice
SSNM – Site-specific nutrient management (field-specific adjustment of N, P, and K)

Means of 23 rice farms in Jinhua District, Zheijiang Province, China, 1998 to 2000
E – early season rice; L – late season rice

1998: Field-specific N rate (SSNM)
1999 & 2000: Field-specific N rate (SSNM) + in-season N adjustment (chlorophyll meter)



6 consecutive rice crops grown in the same fields

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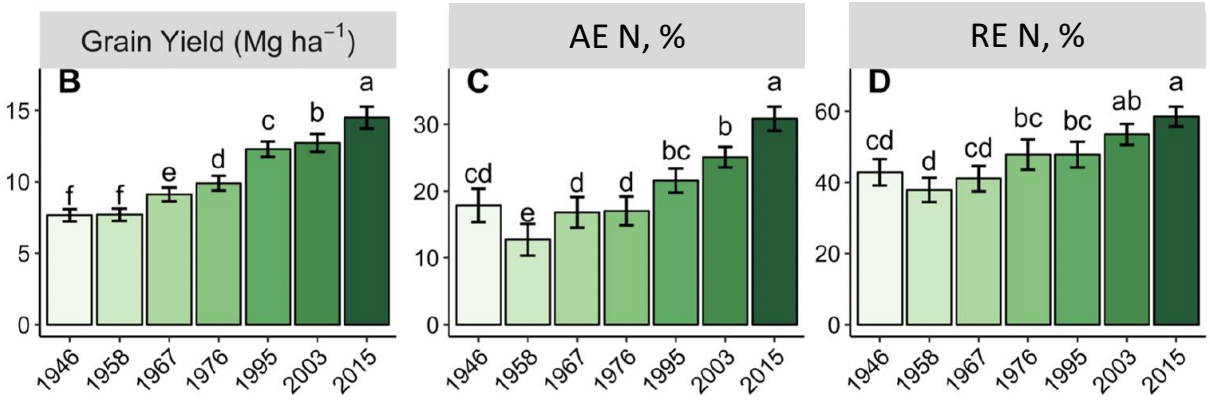
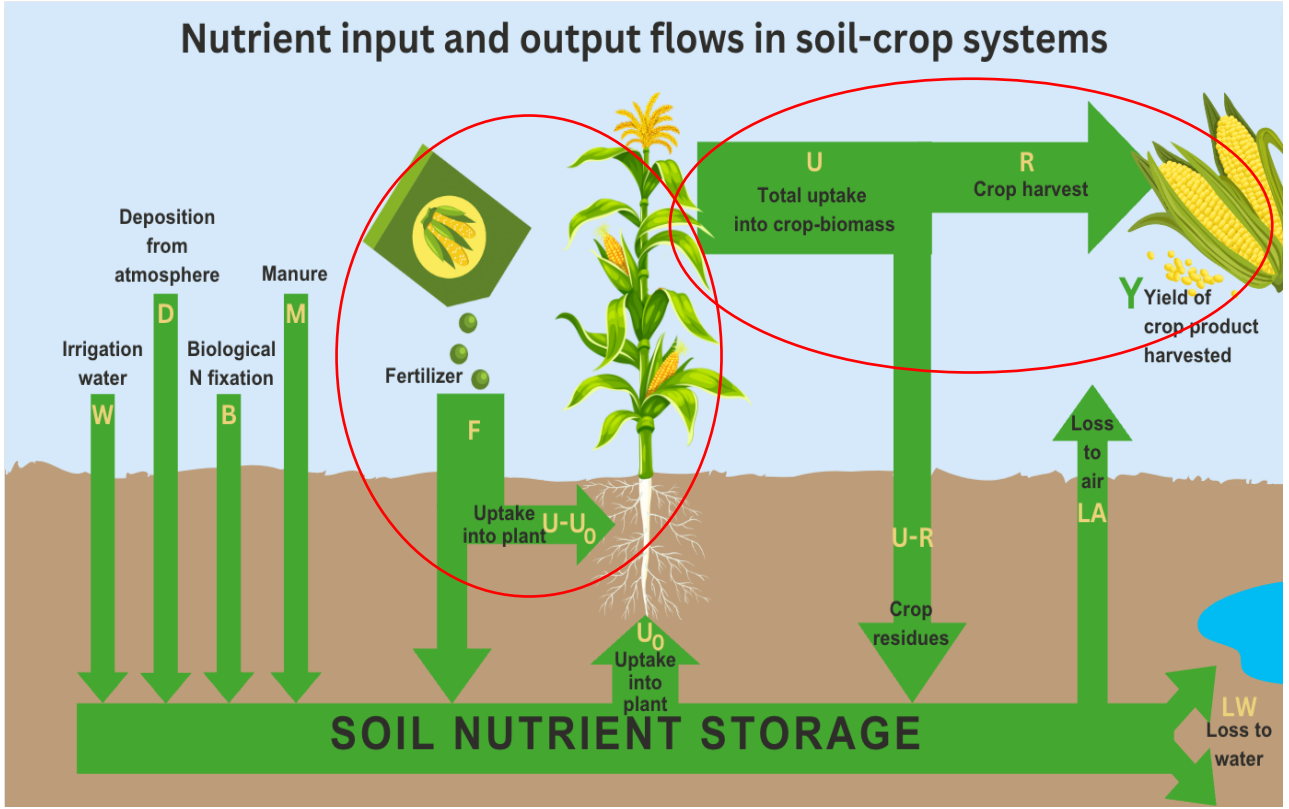
Impact of genetic improvement: maize hybrids in the USA



Year of commercialization

Mueller et al. 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.

Crop Indicators



Crop indicators:

Internal Efficiency (kg/kg)

IE = Y/U

Nutrient Concentration (%)

NC = R/Y

Nutrient Harvest Index

NHI = R/U

Footprint for calculation:
field, farm by crops, groups of farms, etc.

Time scale:
one cropping season

Major uses:
breeding, biofortification (genetic, fertilizer), nutrient management for crop quality (e.g. protein, minerals)

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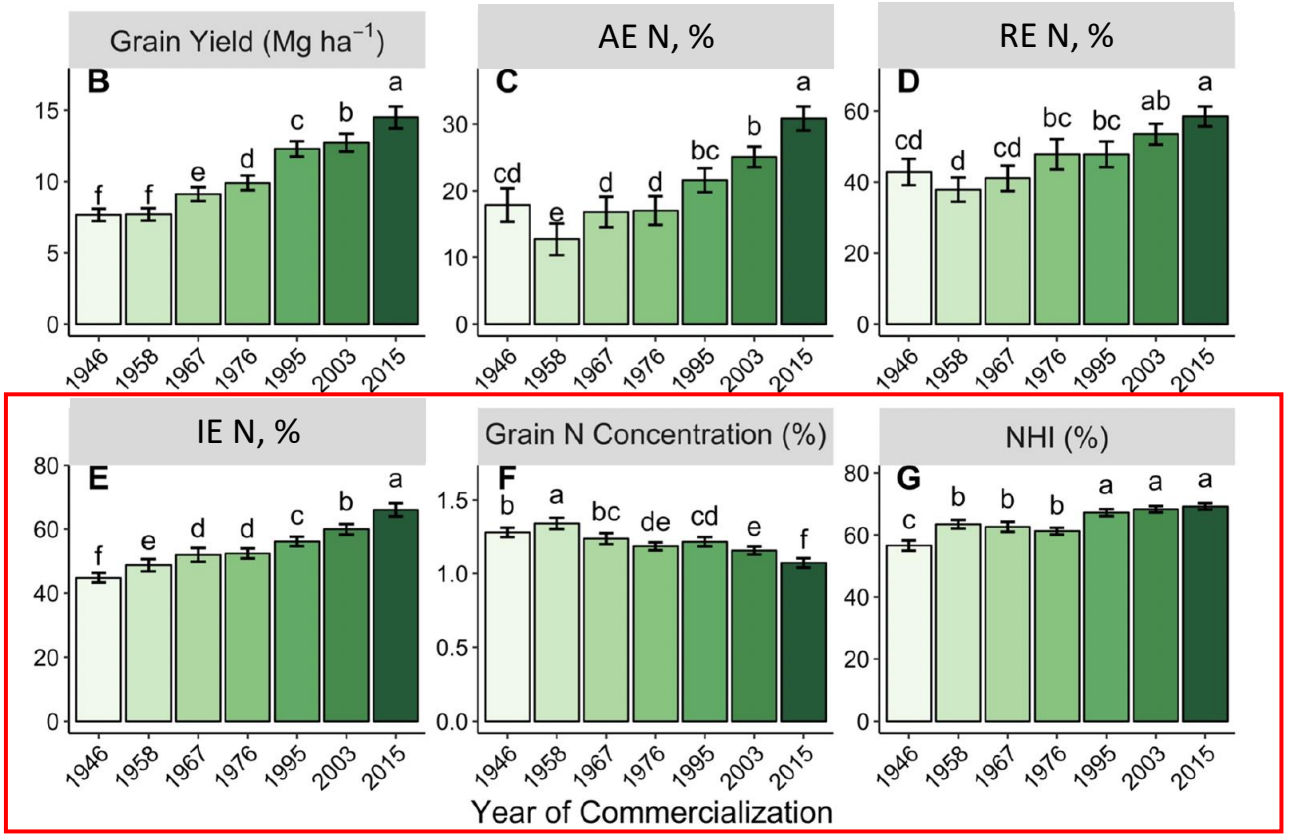
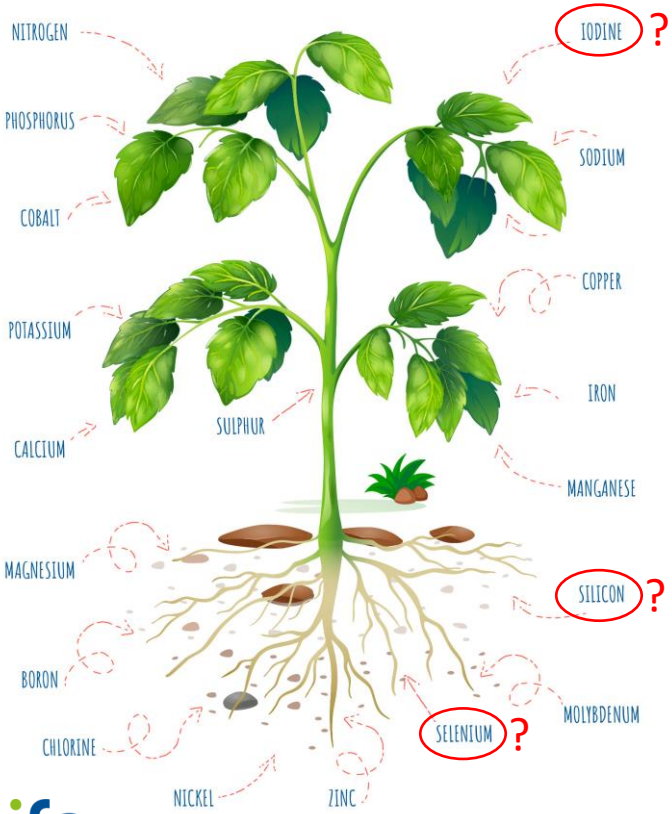


Mueller et al. 2019. Simultaneous gains in grain yield and nitrogen efficiency over 70 years of maize genetic improvement. Scientific Reports 9(1): 9095. doi: 10.1038/s41598-019-45485-5.

Rethinking plant nutrients



A mineral plant nutrient is an element which is essential or beneficial for plant growth, development or the quality attributes of the harvested product.

Plant Soil
https://doi.org/10.1007/s11104-021-05171-w

SPECIAL ISSUE S97 - 30 YEARS

Check for updates

What is a plant nutrient? Changing definitions to advance science and innovation in plant nutrition

Patrick H. Brown · Fang-Jie Zhao · Achim Dobermann

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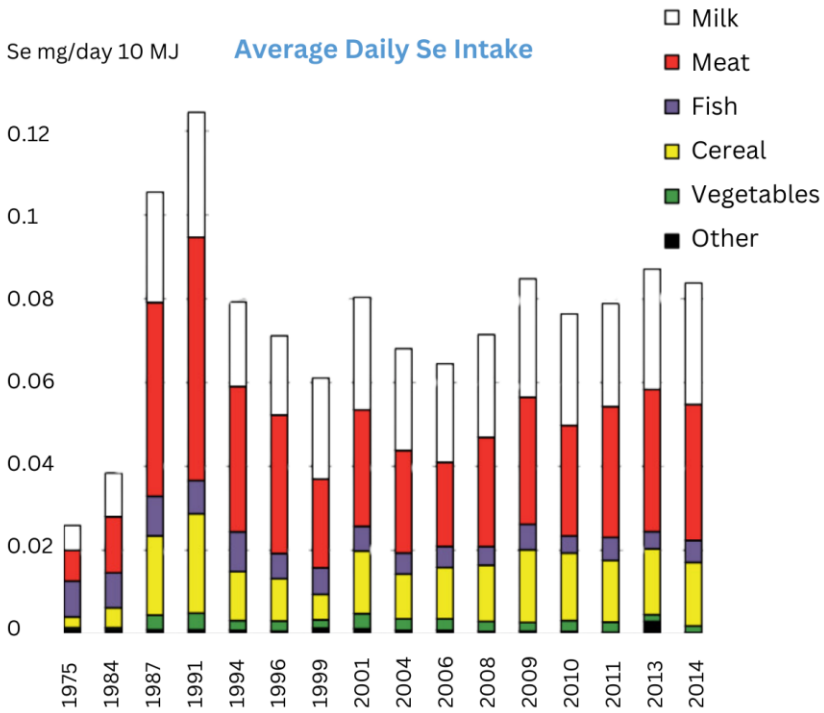
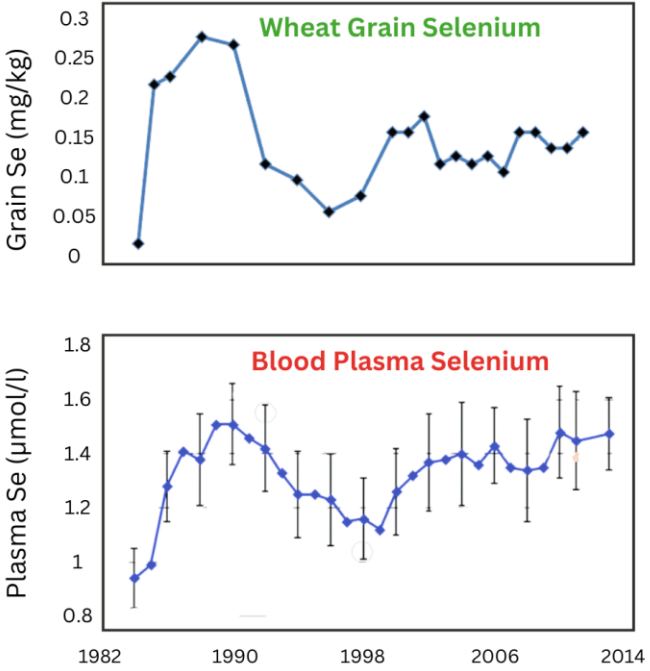
Selenium enrichment through fertilizers in Finland





|-16-|---6---|----10----|------15------|

Fertilizer Se enrichment levels (mg Se/kg fertilizer)

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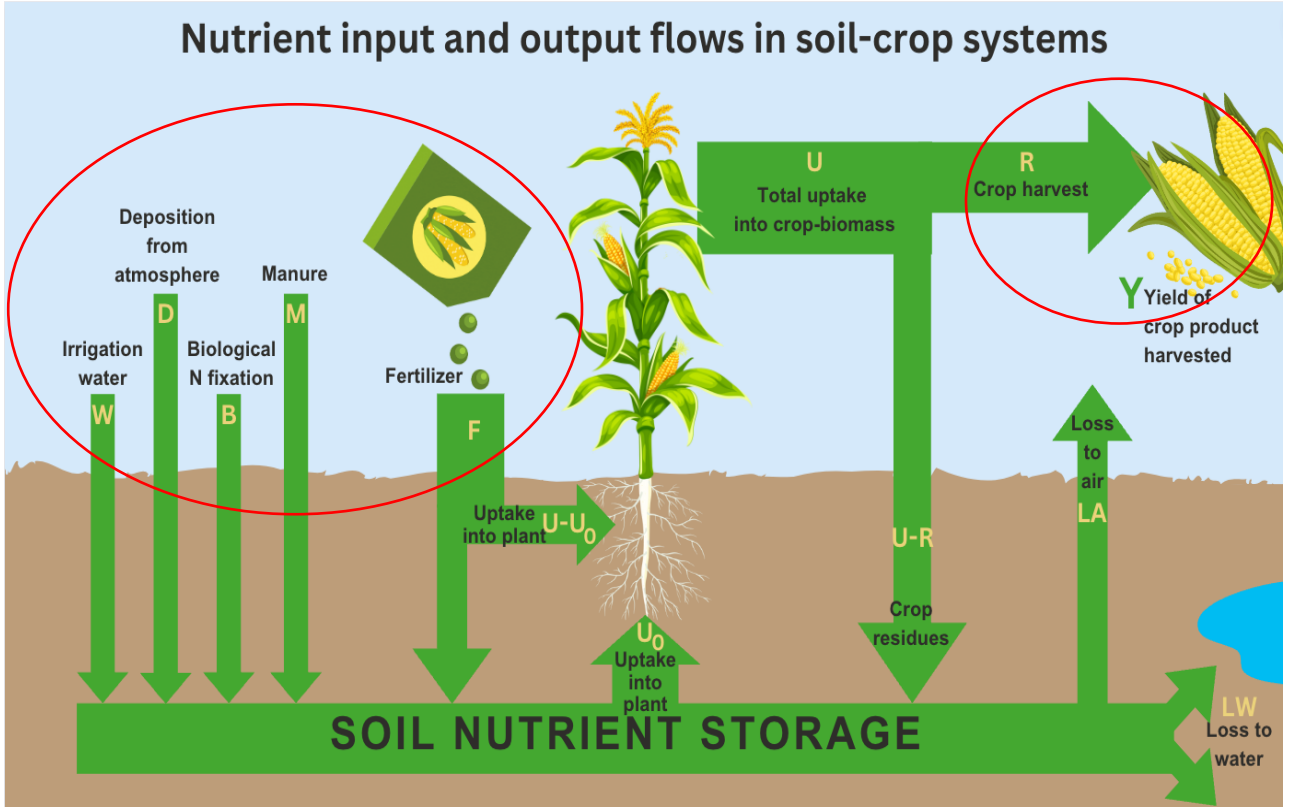
System Indicators



System indicators:

Nutrient balance based on inputs and outputs (partial balance)

Nbal = (W+D+B+M+F) - R

Nutrient use efficiency based on outputs and inputs

NUE = R/(W+D+B+M+F)

<u>Footprint for calculation:</u>
field, farm, group of farms (customers), region, state, country, world, etc.

<u>Time scale:</u>
cropping season, cropping system (year), several years

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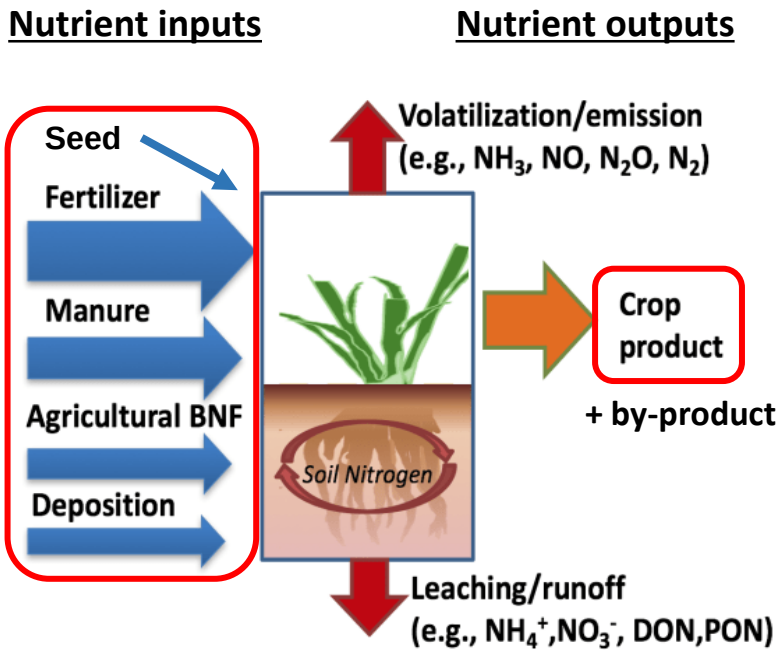
System Indicators: Nutrient Balance and Nutrient Use Efficiency



Nutrient balance = Inputs – Outputs
Nutrient use efficiency = Outputs/Inputs

Both based on partial nutrient balance

Calculation is simple and based on:

- Farm records (e.g. seed, fertilizer, manure, crop yield)
- Average values (coefficients) for other components (e.g. biological N fixation, atmospheric N deposition, grain nutrient concentration, manure nutrient content)

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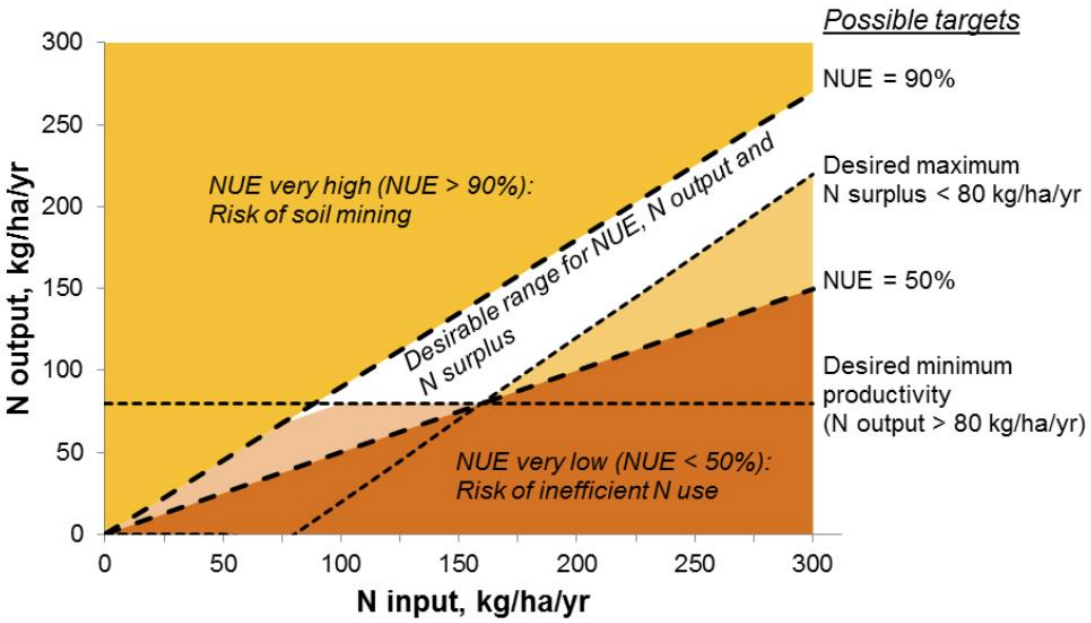
System NUE: Application & Interpretation

- Plot N output vs N input
- N output represents productivity
- Slope from any point to origin represents NUE
- N surplus can also be plotted as a line
- Very high NUE can degrade soil (nutrient depletion)
- Very low NUE represents risk of environmental pollution and waste of money



EU Nitrogen Expert Panel https://www.eunep.com/

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Interpretation	Nitrogen Use Efficiency (NUE) (%)		
	Cropping systems	Mixed crop-livestock systems, 1 LSU/ha	Mixed crop-livestock systems, 2 LSU/ha
Soil N mining	>100	>80	>60
Risk of soil N mining	90-100	60-80	50-60
Balanced N fertilization	70-90	40-60	30-50
Risk of N losses	50-70	30-40	20-30
High risk of N losses	<50	<30	<20

Proposed for different farm types in Europe

EU Nitrogen Expert Panel https://www.eunep.com/

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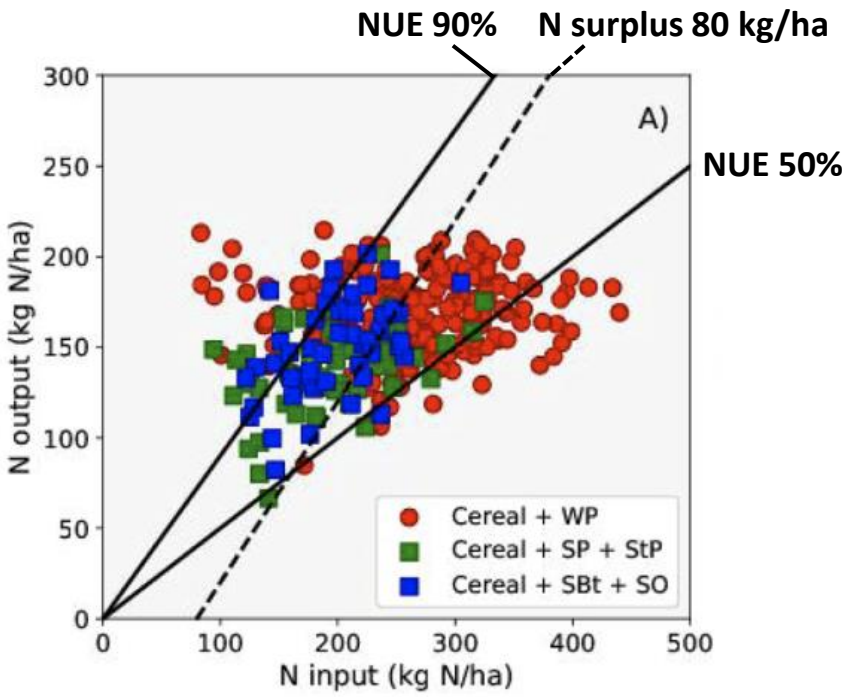
System NUE: Application & Interpretation

- Good for analyzing and benchmarking farms and tracking progress over time

<u>Example:</u>

- NUE in farms in the Netherlands during 2015–2017 cultivating cereals and ware potato (WP), cereals, seed (SP) and starch potato (StP), and cereals, sugar beet (SBt) and spring onion (SO)
- Self-recorded by farmers in commercial farm management systems for crop registration



Silva et al. 2021. Field Crops Research
https://doi.org/10.1016/j.fcr.2021.108176

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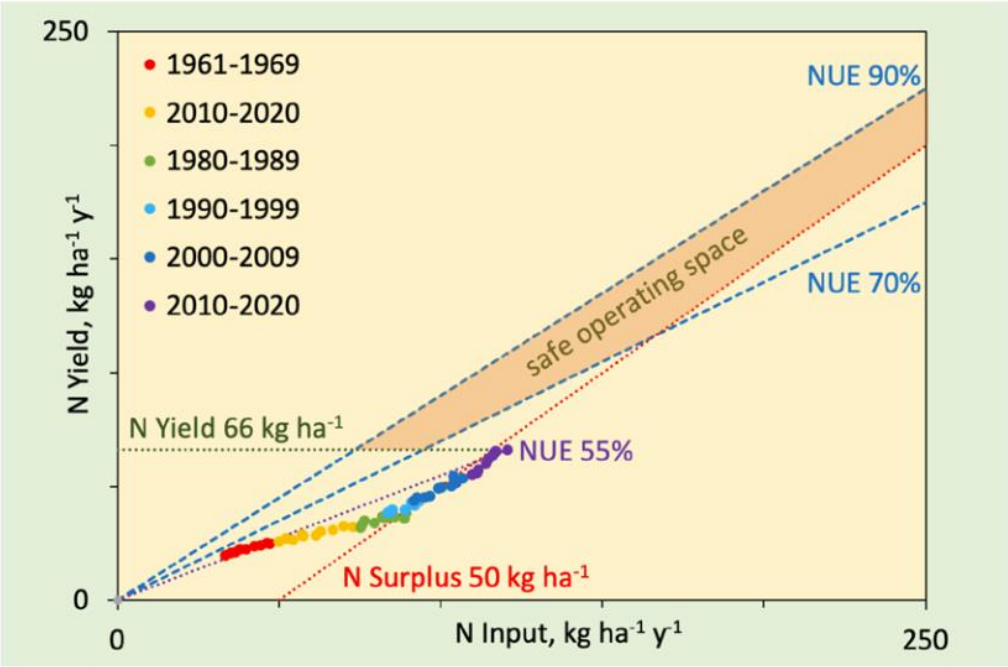
System NUE: National to Global Application

- Good for analyzing and benchmarking countries and regions and tracking progress towards a target

<u>Example:</u>

- NUE of all global cropland, 1960-2021
- Based on FAO-IFA Cropland Nutrient Balance database (national statistics)
- Indicated is a global target of 70% NUE (dashed line)



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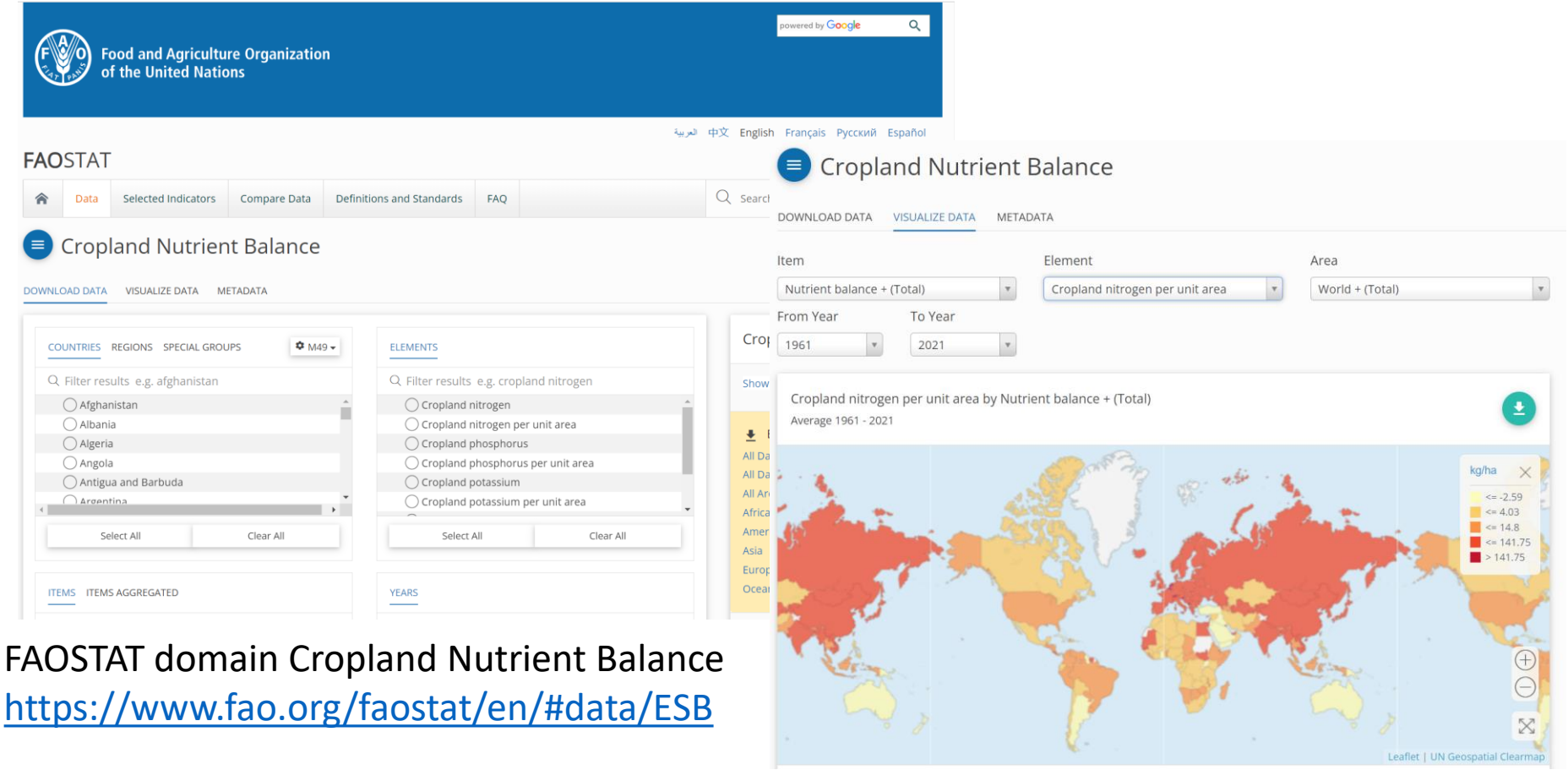
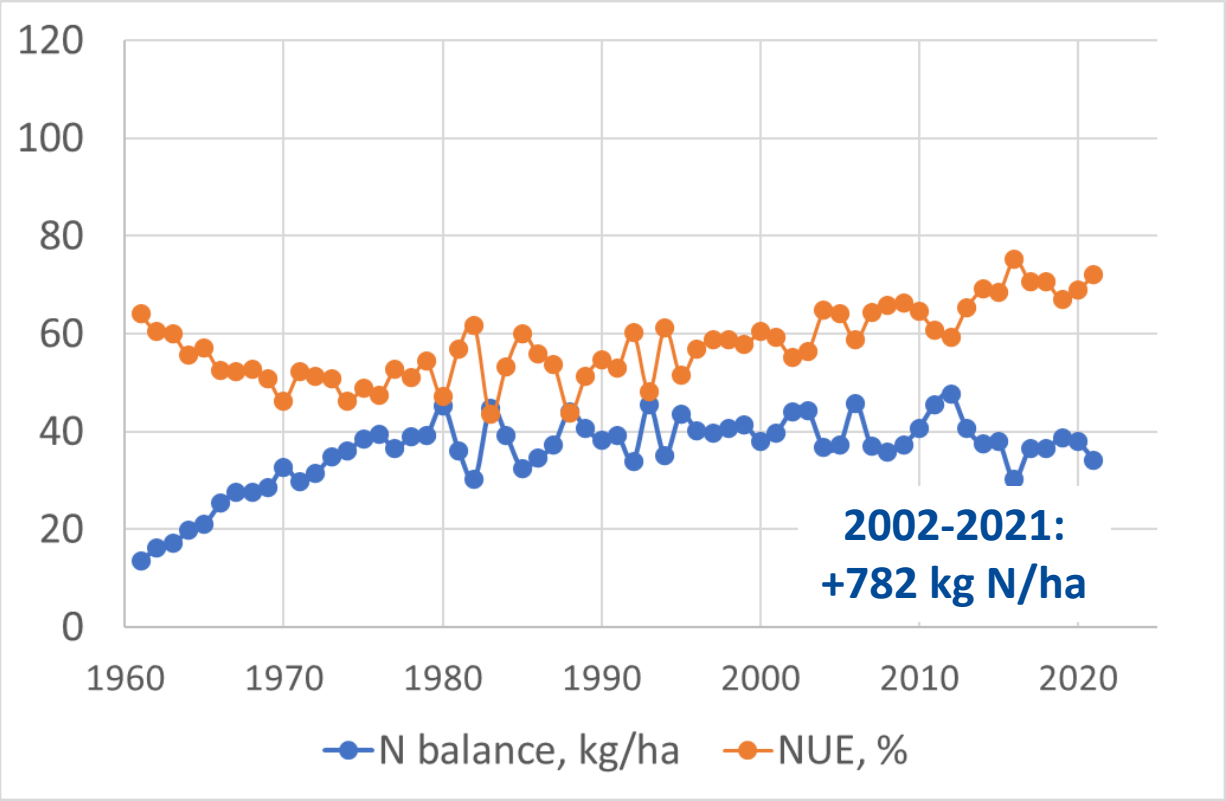


FAOSTAT domain Cropland Nutrient Balance
https://www.fao.org/faostat/en/#data/ESB

USA



- Low N surplus
- Increasing NUE – much soybean
- Local hotspots & opportunities

https://www.fao.org/faostat/en/#data/ESB

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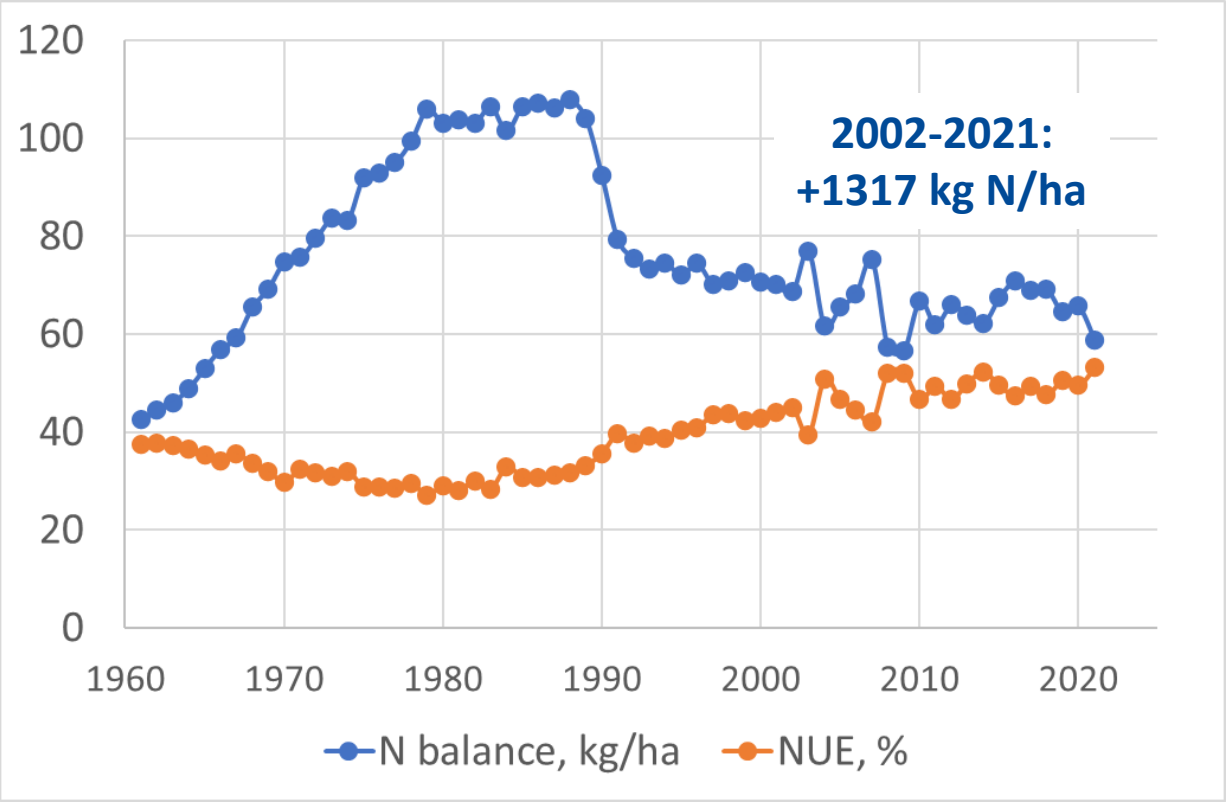
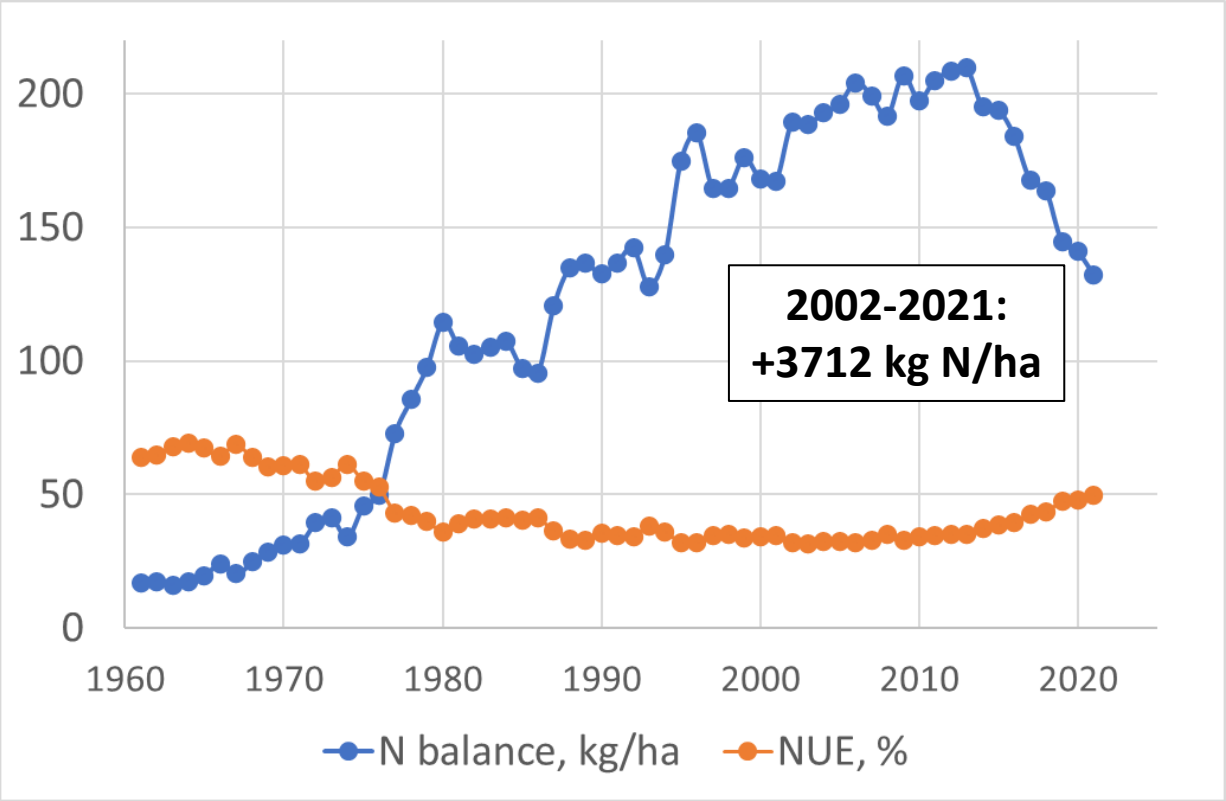
EU27



- Declining N surplus
- Room to improve NUE
- Very diverse among countries and systems

https://www.fao.org/faostat/en/#data/ESB

China



- Rapidly decreasing surplus – but still large
- Rising NUE (2011: 35%; 2021: 50%)
- Change in policy is showing results

https://www.fao.org/faostat/en/#data/ESB

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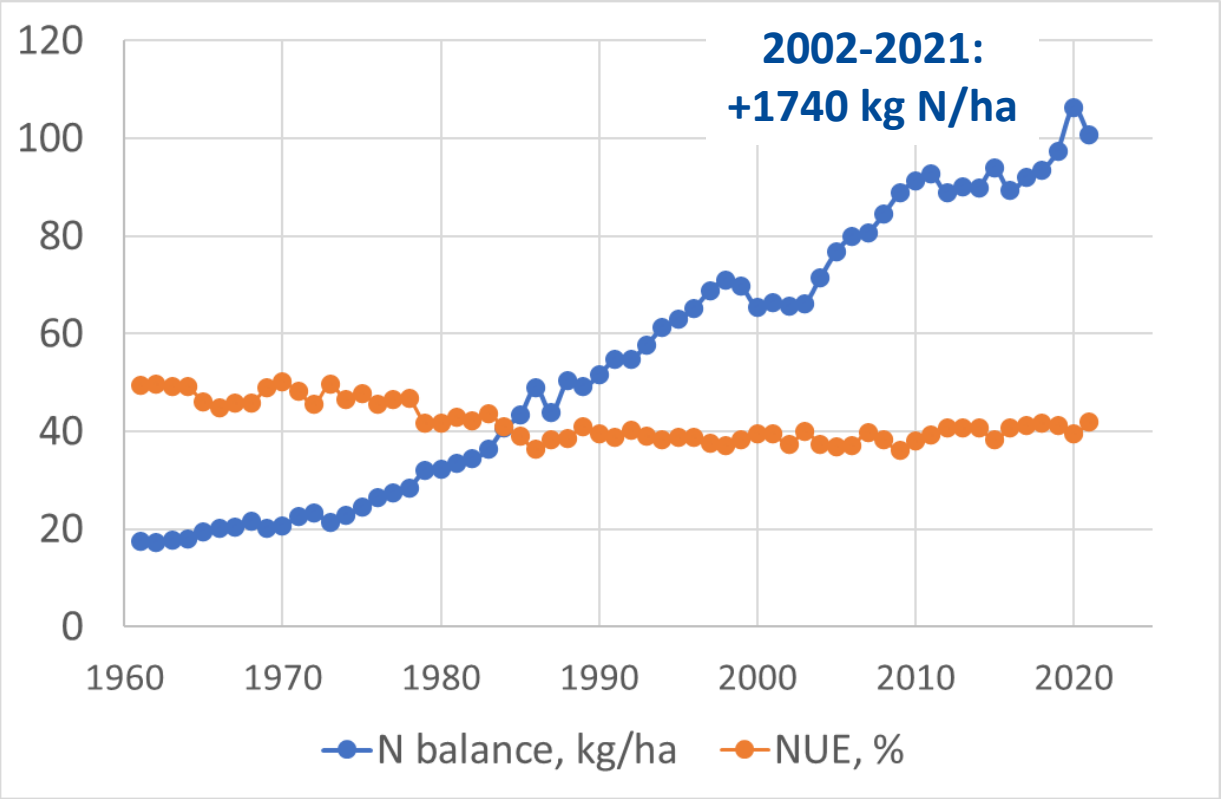
India



- Large, increasing N surplus
- Low NUE, no improvement
- High fertilizer subsidies = lack of incentives

https://www.fao.org/faostat/en/#data/ESB

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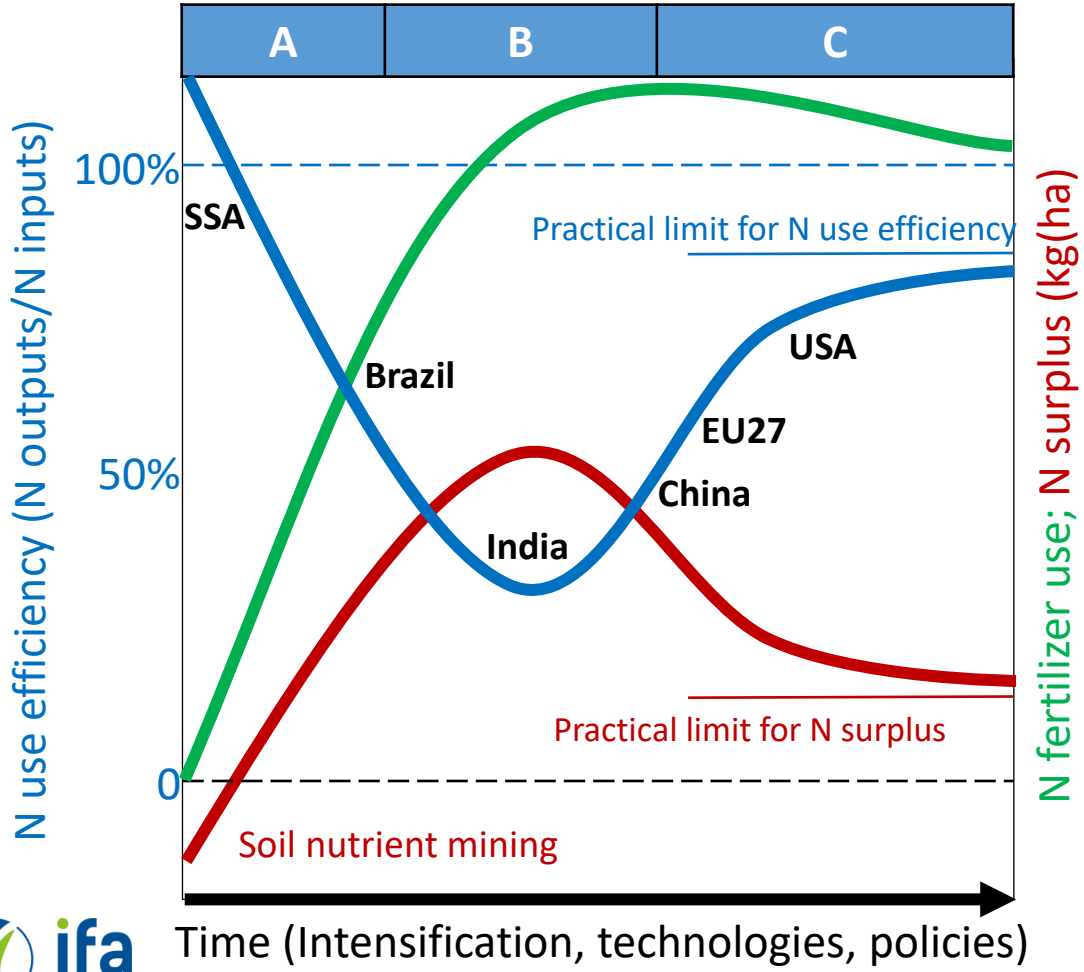
General trajectory of nitrogen use and use efficiency in agriculture



N fertilizer use
N use efficiency
N surplus

Labels indicate the approximate current status of a country or region

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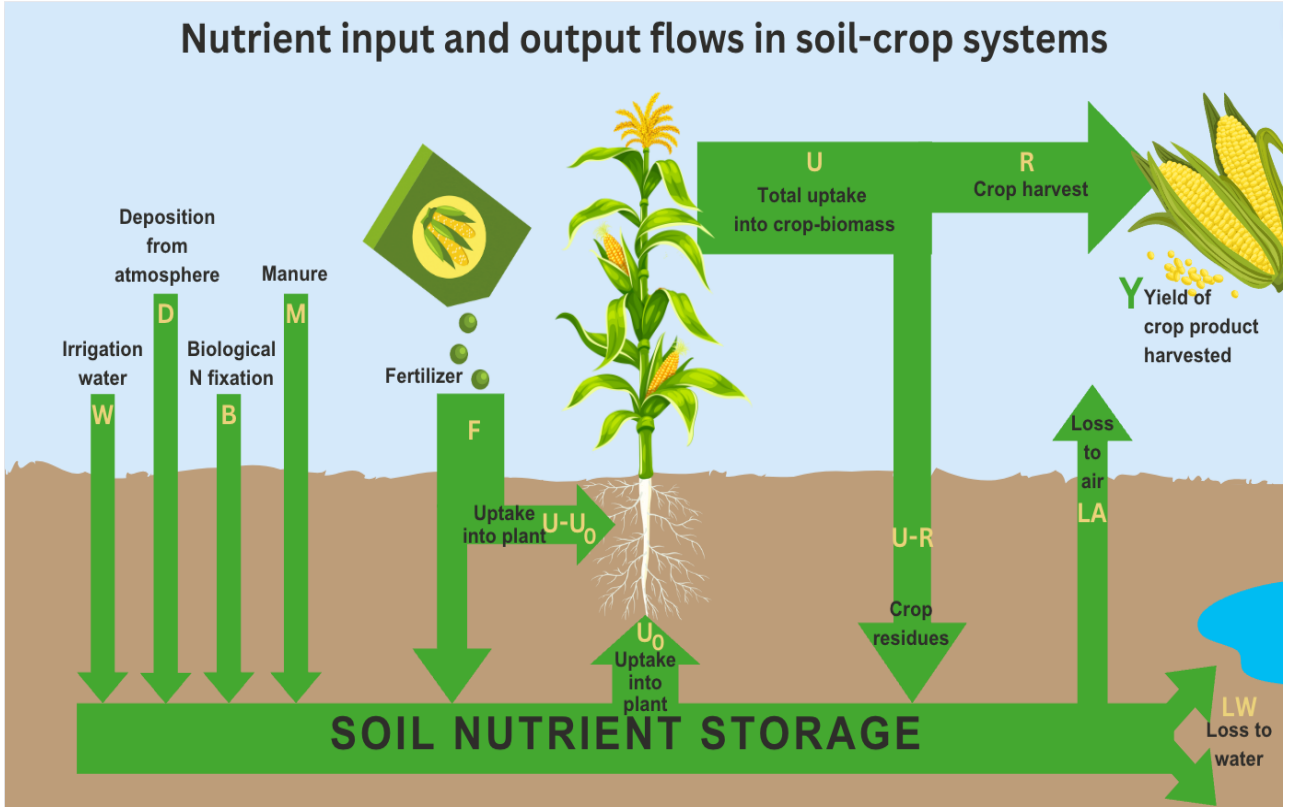
Definitions & Indicators



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Nutrient Indicators: Application & Interpretation

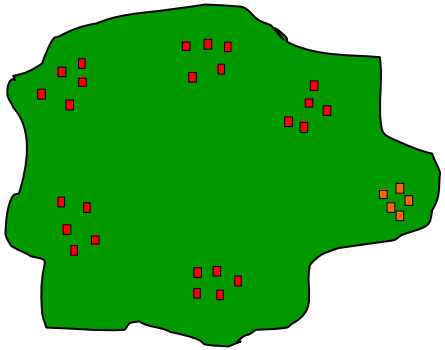
Research:

- Rigorous field evaluation of new products, technologies, management practices
- Development and evaluation of decision support solutions for nutrient management/precision farming
- Use all fertilizer indicators: **PFP, AE, RE, PE, GRF**
- Crop indicators for breeding, biofortification: **NC, IE, NHI**

Farming:

- Quantify and understand fertilizer efficiency
- Performance analysis (agronomic, economic) to guide field (farm) management, including benchmarking against desirable targets or leading farmers
- Monitoring of changes over time (progress in efficiency improvement), including environmental and soil health
- Most useful indicators: **PFP, GRF, NUE and Nbal**

  → PFP, NUE and Nbal are simple to calculate and important for farmers because they integrate the use efficiency of both indigenous and applied nutrients



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What should we aim for?

Indicator	Desirable levels for N efficiency in well-managed cereal crops
Recovery Efficiency	0.50-0.80 kg N in plant/kg N applied (50-80%)
Physiological Efficiency	>50 kg grain/kg fertilizer N taken up
Agronomic Efficiency	>25 kg grain/kg N applied
Partial Factor Productivity	>50 kg grain/kg N applied
N balance	<50 kg N/ha surplus
System NUE	70-80%

→ **But this may vary substantially**

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Summary

- **Research and development**: use a range of fertilizer and crop indicators and ensure complete experimental designs and measurements to calculate them, including proper controls and nutrient response curve
- **Agronomic guidance and farm management**: use PFP, GRF and system indicators (Nutrient balance and NUE)
- **Farm monitoring and benchmarking, large-scale agricultural and environmental monitoring/progress evaluation, policy setting**: use system indicators (Nutrient balance and NUE)