Reducing the Health Impacts of the Nitrogen Problem

A Virtual Workshop from the Environmental Health Matters Initiative

New sessions every Thursday
from 2:30–5:30 PM (ET)
from January 28 – February 25, 2021

Day 1 session

Role of Nitrogen in U.S. Agricultural Systems, and Need for Robust Metrics to Quantify It

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The National Academies of
SCIENCES · ENGINEERING · MEDICINE

Role of Nitrogen in Agriculture (big picture)

- **Nitrogen (N) is one of 15 or so essential nutrients required for growth of all life on earth, including plants and animals**
  - Of these 15 or so nutrients, N is needed in greatest amounts
  - N is a required to build proteins (and enzymes), DNA, RNA, and other compounds
  - >50% of total leaf N is contained in the RUBISCO enzyme, which catalyzes photosynthesis
  - As crop yields rise, so does the N uptake requirement to support greater crop biomass
- **In soil, N is also an essential nutrient for bacteria, fungi, and other micro- and meso-organisms that govern degradation and turnover of soil organic matter, and which release inorganic N (ammonium and nitrate) to become available for crop uptake or loss**
- **Soil organic matter contains about 5% N, (50 kg N/ton of SOM)**
  - C sequestration depends on having a sufficient N surplus to produce SOM

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Role of Nitrogen in Agriculture

Nitrogen (N) is a triple-edged sword in our agricultural systems.
The sword has three faces:

- **The good (food production)**
- **The bad (health hazard)**
- **The ugly (environmental pollution)**

Role of Nitrogen in Agriculture

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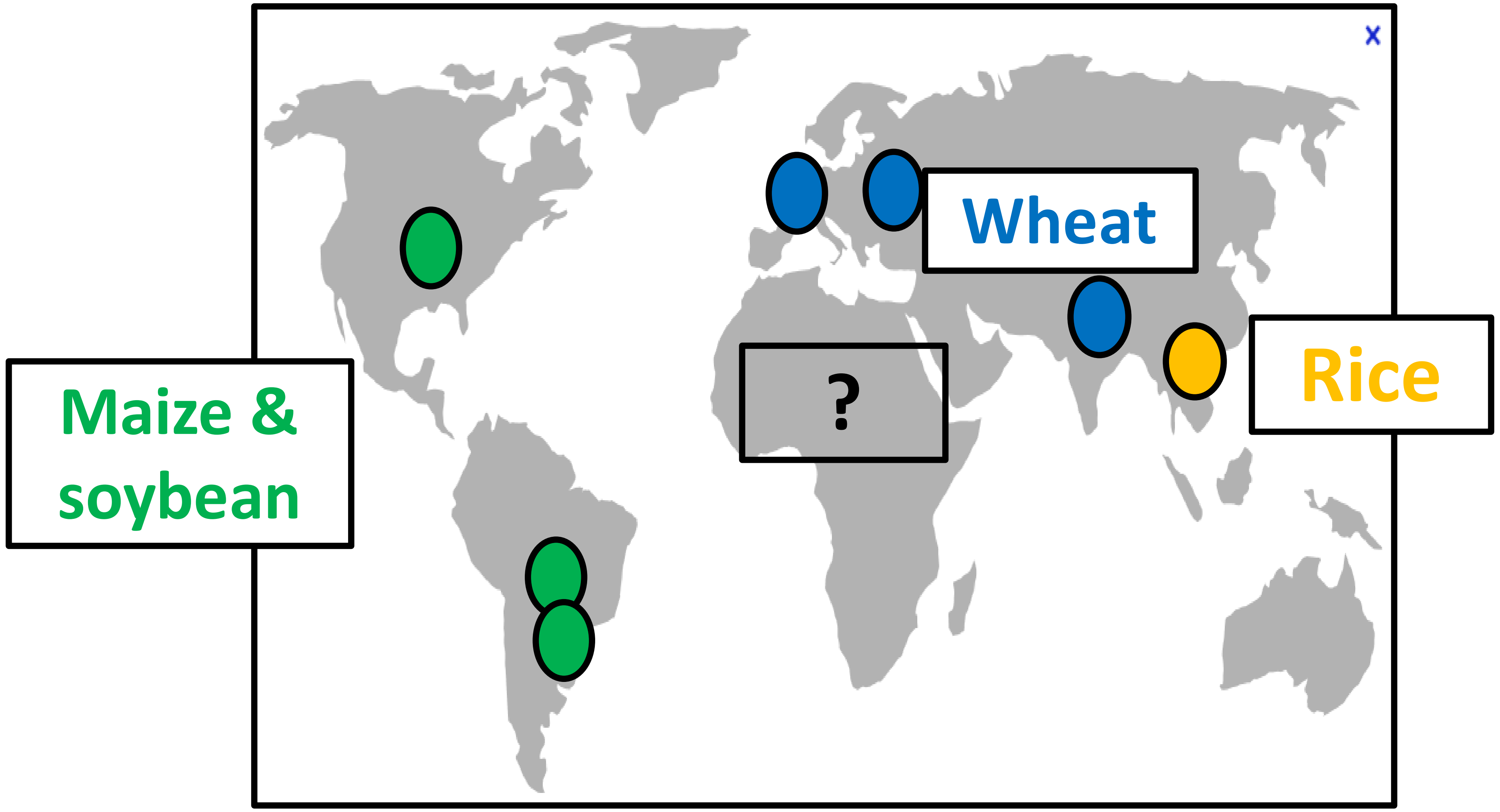
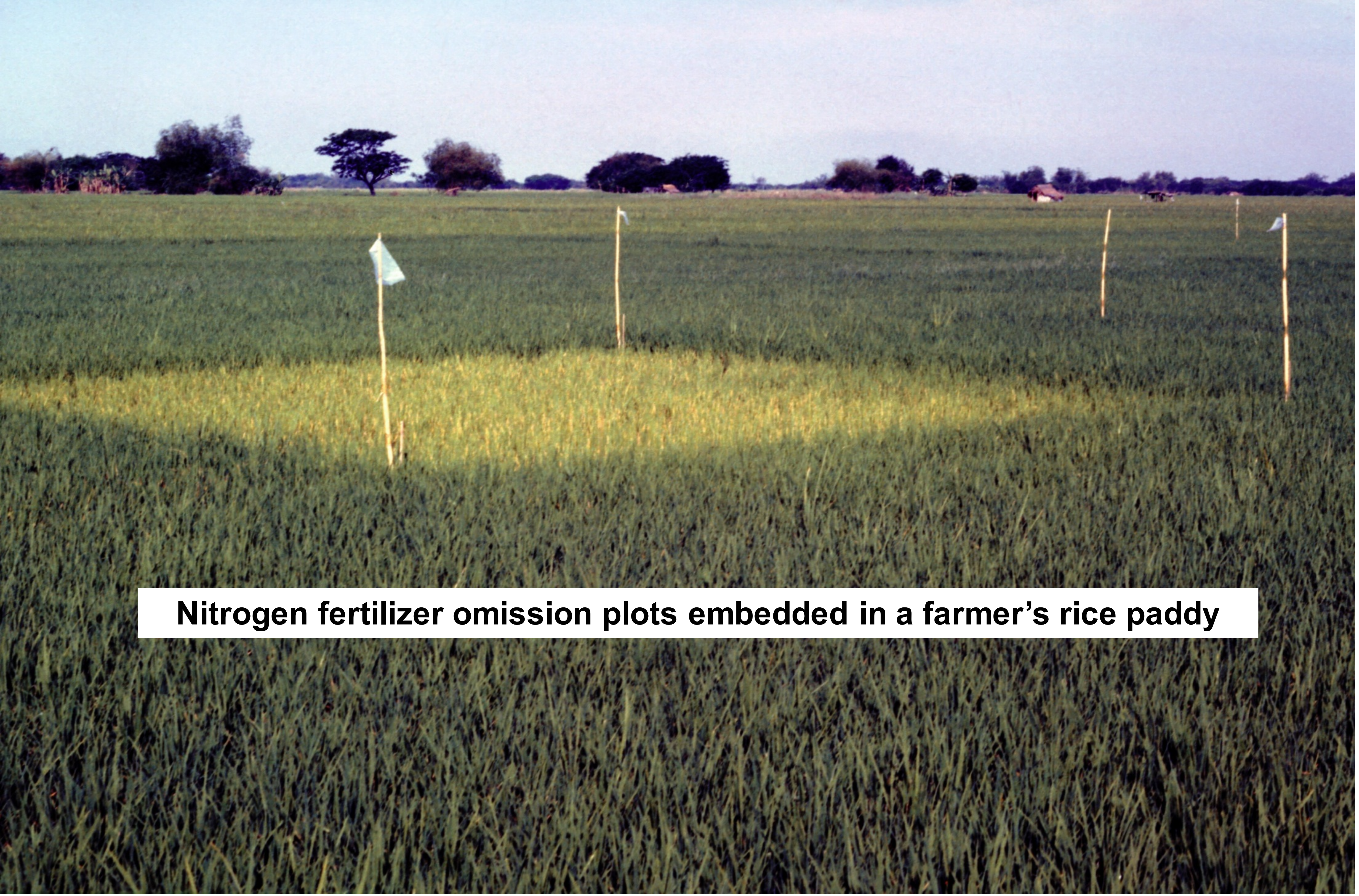
What is a breadbasket?

A region that produces a large surplus of one or more agricultural commodities (typically cereals and oilseeds) to not only meet regional demand, but also contributes to food supply at a globally important scale



Role of Nitrogen in Agriculture (get-real picture)



BOTTOM LINE:

- The sustainable climax human population without inorganic N fertilizer is about half of today's nearly 8 billion, and only one-third of predicted population in 2050, because global crop yields will be reduced by 50% compared to present.

- Controlling the fate N applied in crop production to meet human demand is extremely difficult, and N losses from agriculture are currently causing enormous environmental degradation

Expansion of agriculture: Cutting down virgin rain forest in Brazil

Photo: K.G. Cassman

Unsustainable crop production on marginal land: Poor families without options

Contest-winning maize field in SE Nebraska that produced 18.5 t/ha grain (300 bu/ac) and another 18.5 t residue/ha-yr returned to soil

Photo: K.G. Cassman

Grain yield, energy yield and efficiency, and greenhouse gas (GHG) emissions from maize production in Nebraska

Crop-system variable	Rainfed	Irrigated	Difference ¶
Grain yield (t ha^{-1})	5.9 (CV = 23%)	13.2 (CV = 3%)	+124%
Energy input (GJ ha^{-1})	10.8	30.0	+178%
Net energy yield (grain energy minus fossil-fuel energy)	74	159	+115%
N fertilizer efficiency (kg grain kg^{-1} N)	54	71	+32
Water productivity (kg $ha^{-1} mm^{-1}$)	8.8	14.0	+59
GHG intensity (kg CO_2e t^{-1})‡	388	231	-40%

¶ Relative to rainfed maize values. Based on data from 2005-2007.
† Includes emissions of CO_2, N_2O, and CH_4 adjusted for CO_2 warming equivalent. N_2O estimated by the N-surplus method of Van Groenigen *et al.* (2010).
‡ GHG emissions per metric ton of grain production

Grassini & Cassman, 2012: Proc. Natl Acad. Sci.

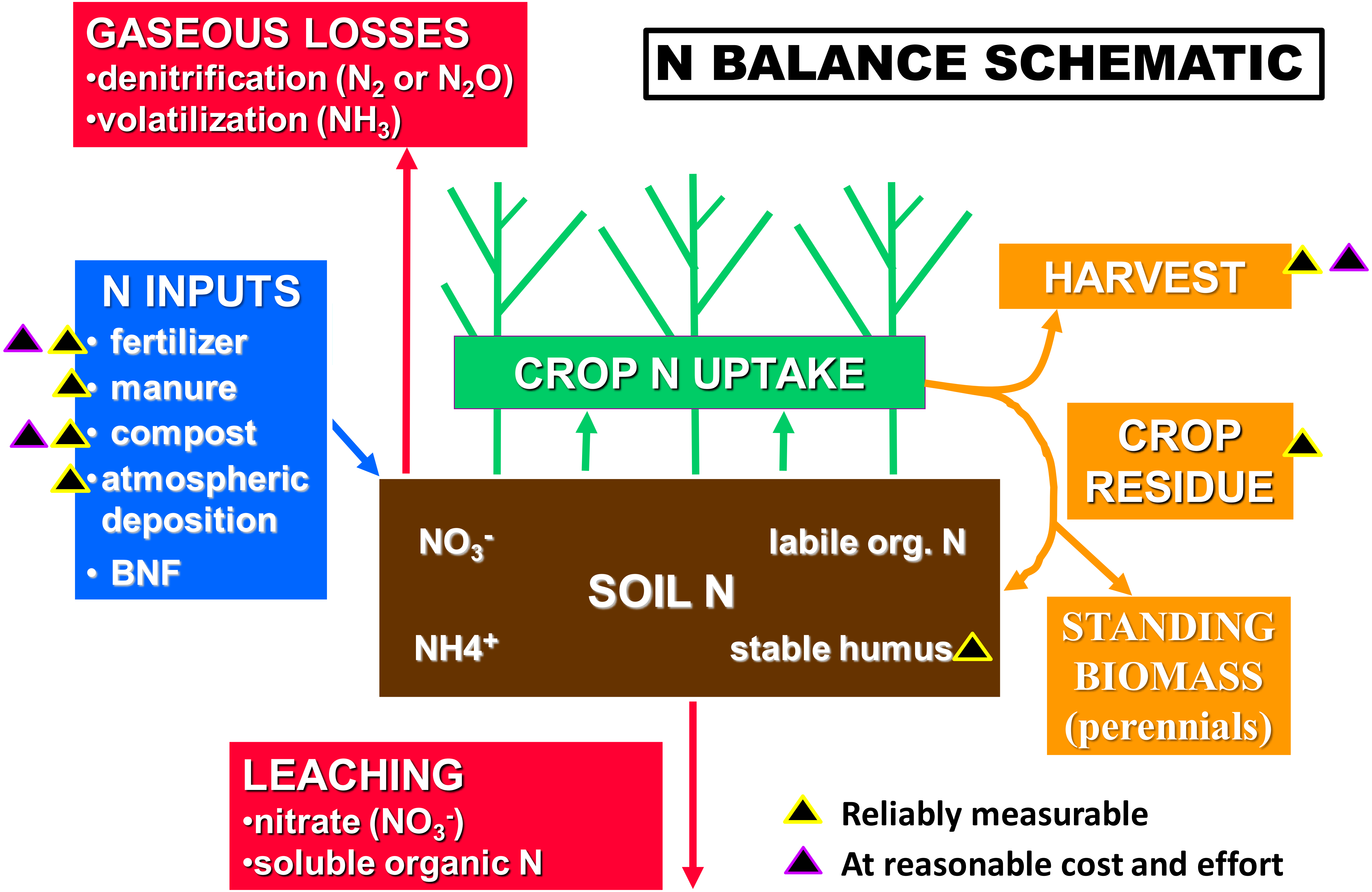
Existential Question?

- **CAN WE SUSTAINABLY INTENSIFY OUR CROP PRODUCTION SYSTEMS ON EXISTING FARMLAND WHILE AVOIDING MASSIVE CONVERSION OF NATURAL HABITAT TO CROP PRODUCTION, AND DO SO WITHOUT ENVIRONMENTAL DEGRADATION BELOW ACCEPTABLE THRESHOLDS?**

Corollary questions

- **Can we measure the N losses from agriculture that contribute to this degradation?**
- **Do farmers have robust tools to estimate their N losses?**

Yes to the existential question, **No** to the corollaries



N BALANCE SCHEMATIC
GASEOUS LOSSES
•denitrification (N_2 or N_2O)
•volatilization (NH_3)
N INPUTS
• fertilizer
• manure
• compost
•atmospheric deposition
• BNF
CROP N UPTAKE
HARVEST
CROP RESIDUE
STANDING BIOMASS (perennials)
NO_3^-
labile org. N
SOIL N
NH4+
stable humus
LEACHING
•nitrate (NO_3^-)
•soluble organic N
Reliably measurable
At reasonable cost and effort

We lack robust, low cost metrics for measuring these pivotal N balance components at the scale of a single production field

- **Soil N supply available for crop uptake**
  - Key deficiency: N mineralization during crop growth period
- **Biological N fixation from symbiotic (legumes) and asymbiotic (free-living and associative microbes) sources**
- **Soil organic matter contains about 5% N, (50 kg N/ton of SOM)**
  - C sequestration depends on having a sufficient N surplus to produce SOM
- **Gaseous losses via denitrification and ammonification**
- **Nitrate leaching losses**

Hence crop producers lack useful tools to monitor progress towards sustainable improvement in N use efficiency and reduced N losses

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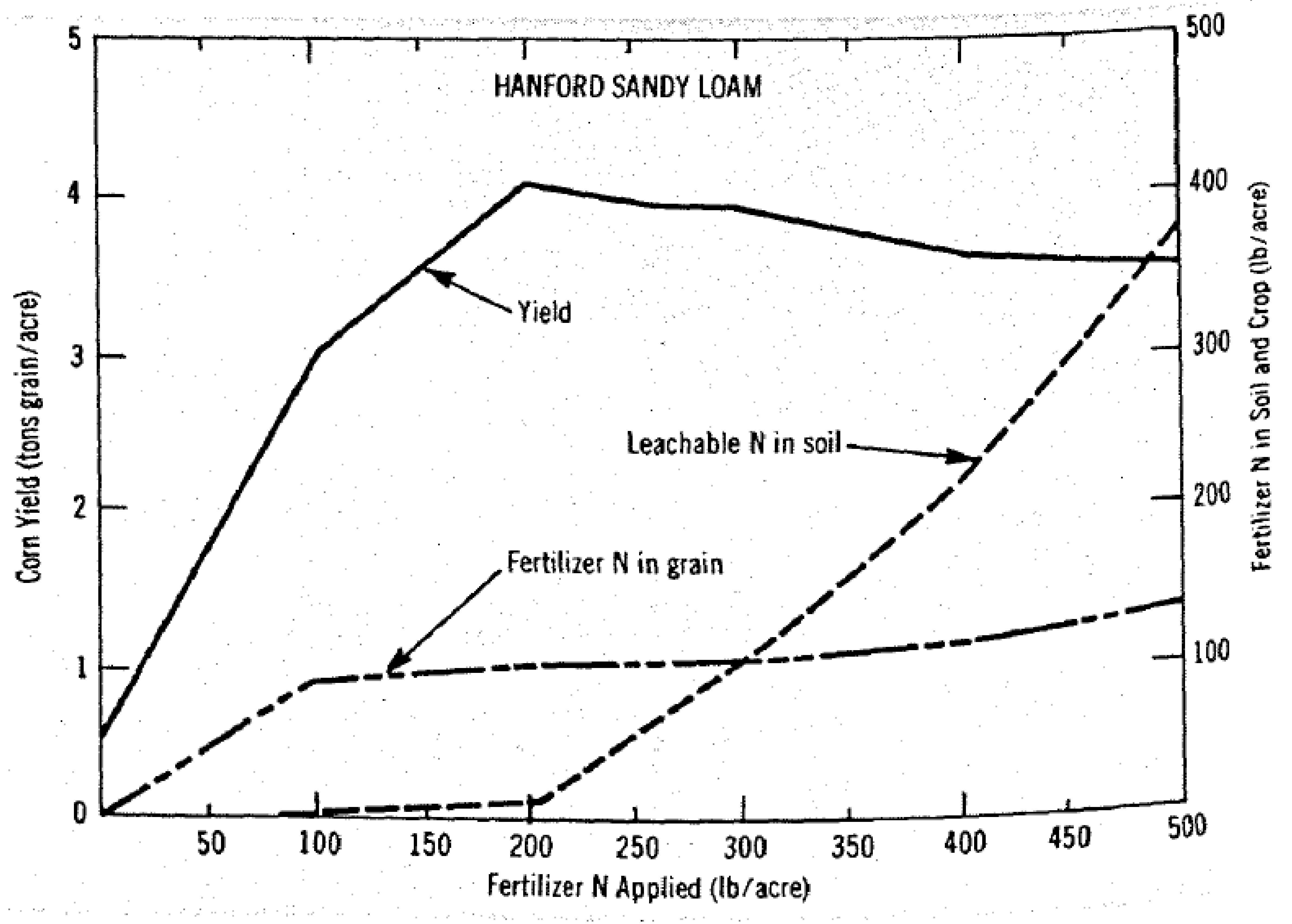
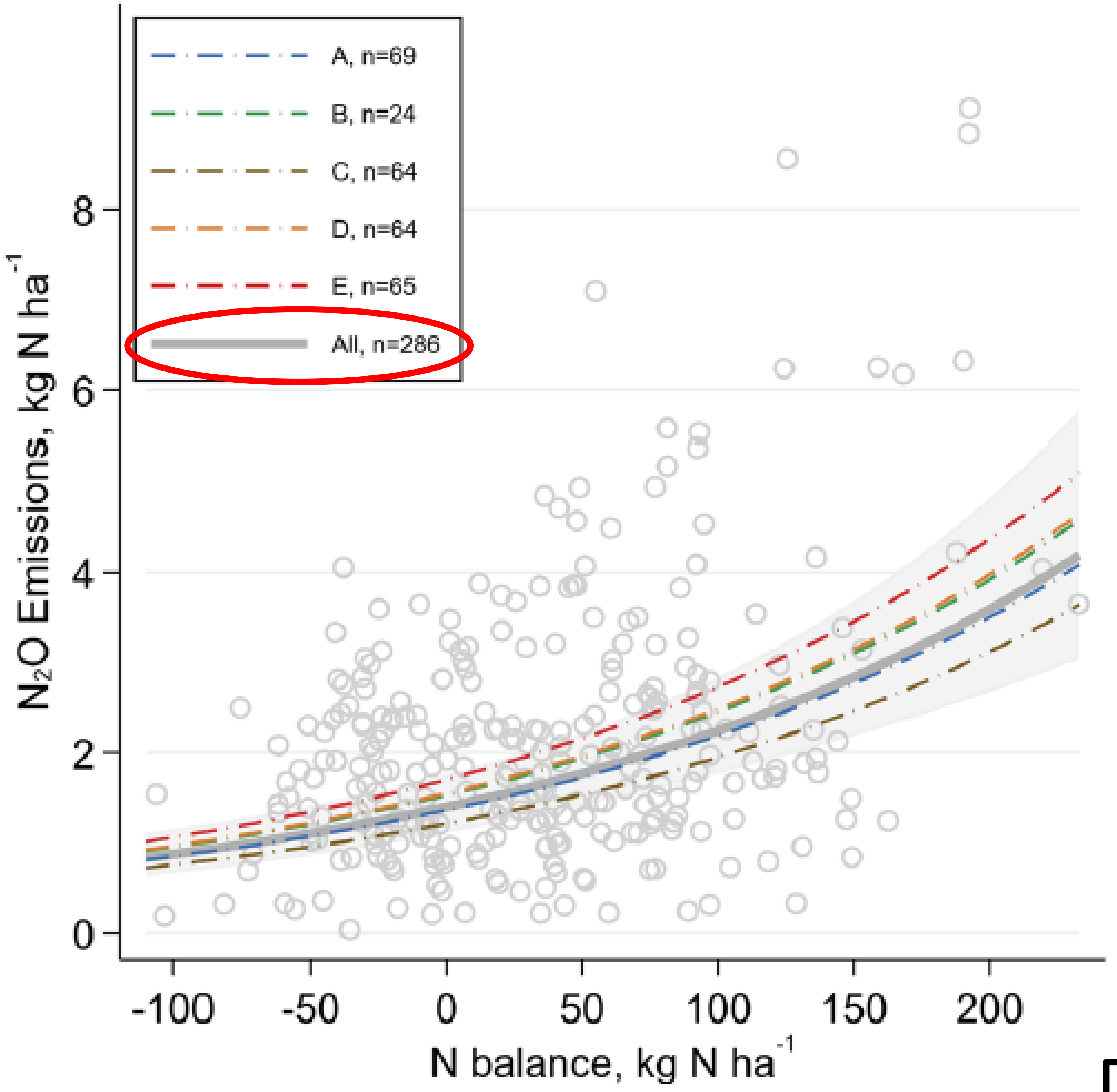
On a given field, increasing N inputs above that required to meet crop demand results in increasingly greater amounts of reactive N at risk of loss from all loss pathways. Example nitrate-Broadbent and Rauschkolb, 1977.



Observed data on N_2O emissions from field studies with maize and other crops



- **Lines A-D**:

  maize in different regions, with different soil textures, periods of measurement, rotations, N fertilizer types, timing, and amounts.

- **Line E**:

  wheat, canola, barley, sugarbeet, silage maize

So much scatter! How can this be a useful metric?

From: A. Eagle et al. 2020. *Earth's Future*

Component indices of nitrogen use efficiency

Partial factor productivity from applied nitrogen (also called nitrogen productivity)

PFP_N = kg grain kg^{-1} applied nutrient:

$$PFP_N = Y_{+N}/F$$

Agronomic efficiency of applied nitrogen

AE_N = kg grain yield increase kg^{-1} applied nutrient (often called nutrient use efficiency)

$$AE_N = (Y_{+N} - Y_0)/F$$

Recovery efficiency of applied nitrogen

RE_N = kg nutrient taken up kg^{-1} N applied

$$RE_N = (U_{+N} - U_0)/F$$

Physiological efficiency of applied nitrogen

PE_N = kg grain yield increase kg^{-1} fertilizer N taken up

$$PE_N = (Y_{+N} - Y_0)/(U_{+N} - U_0)$$

Only <u>PFP_N</u> can be easily monitored.......

as well as a <u>rough N balance</u> estimated by difference between N inputs in applied fertilizer, manure and compost, and N removal in harvested grain, seed, fruit, and other crop materials

CAN THESE STRAIGHTFORWARD METRICS BE HELPFUL?

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N balance can be a useful metric with Common Sense!

- Depends on scale of assessment: field, farm, watershed, commodity sourcing region, state, nation, globe?
  - Single field or farm: good metric for estimating the DIRECTION of change in N use efficiency if all else held relatively constant and soil organic matter maintained
  - N balance becomes increasingly robust as scale expands to larger regions, from watersheds to nations, and as the amount of farmer-reported data increase, based on the central tendency of the relationship between N balance and N losses, even with large scatter and relatively low R^2 values
  - And, N balance estimates can be improved with a highly focused, national R & D program
- But improving field-level N use efficiency is only part of the answer to reduce N losses below acceptable environmental and health limits
  - Other improvements also needed: landscape design, high-risk cropland retirement, cover crops, etc.

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- Depends on scale of assessment: field, farm, watershed, commodity sourcing region, state, nation, globe?
  - Single field or farm: good metric for estimating the DIRECTION of change in N use efficiency if all else held relatively constant
  - At large spatial scales from watersheds to nations, N balance becomes increasingly more robust as scale expands and the amount of farmer-reported data increase, based on the central tendency of the relationship between N balance and N losses, even with large scatter and relatively low R^2 values
  - And, N balance estimates can be improved with a highly focused, national R & D program
- But clearly only part of the answer to reduce N losses within acceptable (reasonable) environmental and health limits
  - Other measures also needed: landscape design, high-risk cropland retirement, cover crops, etc.

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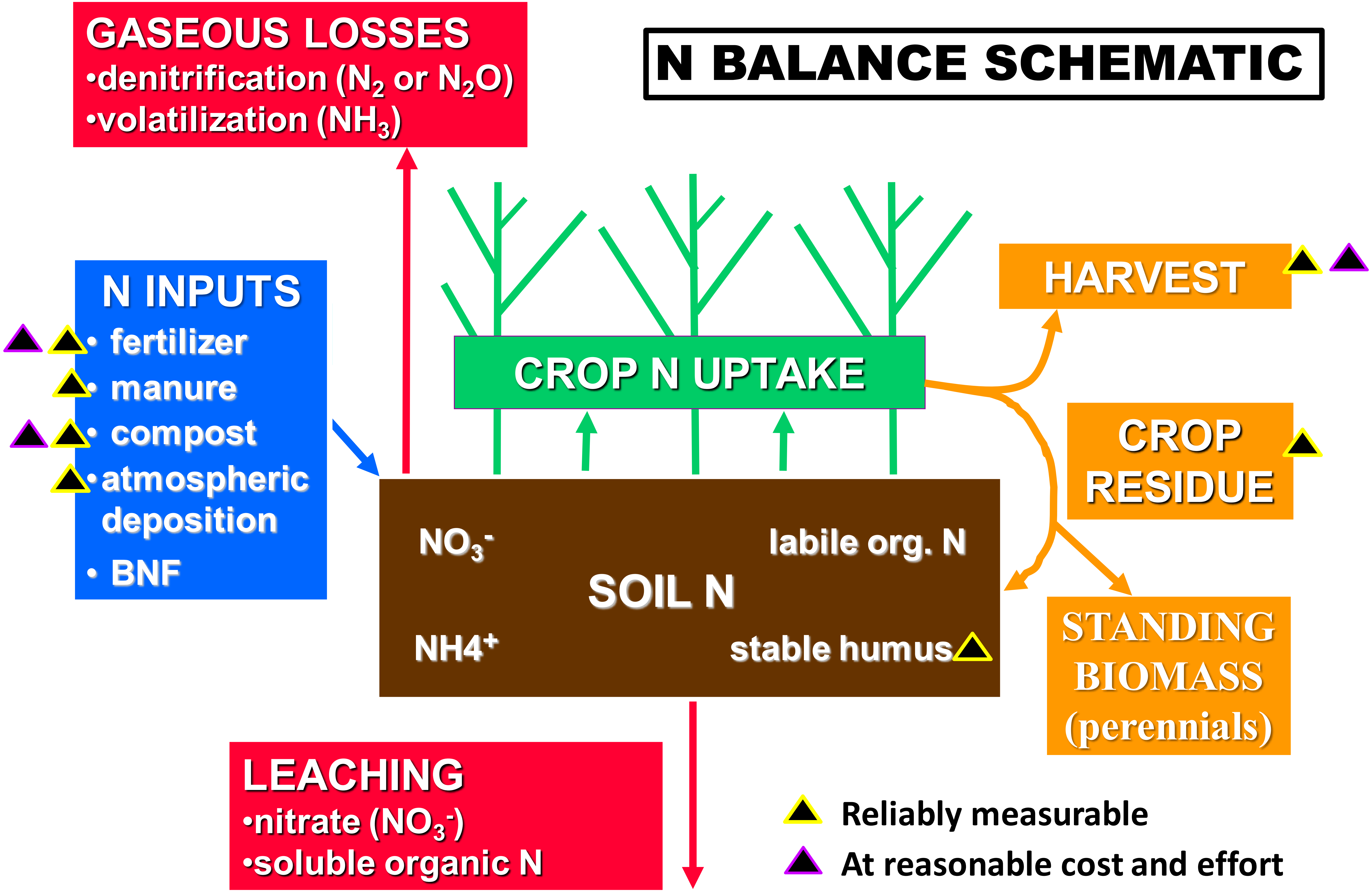
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Summary and Conclusions

- Sustainable intensification is the path forward to meet food demand without massive expansion of crop and livestock production area and negative environmental outcomes because highest efficiencies for land, water, energy, and nutrients are achieved in well-managed high-yield systems in major breadbaskets, as well as in irrigated systems worldwide
- At issue: Is it also possible to control the fate of applied N in these high-yield systems to reduce N losses below levels that damage the environment and cause health problems
- Critical need for robust metrics to help guide and inform growers as they strive to achieve cost-effective solutions, and to provide a strong quantitative framework to unleash public- and private-sector research investments to accelerate development of technological innovations and breakthroughs to address the challenge
- In the interim, simple metrics (PFP_N, rough N balance) are useful proxies for estimating direction of change, but not quantitative performance, at the field level
- A well-funded, national R & D program focused on providing robust estimates of key N cycle components (N supply from soil and BNF, and N losses) is an essential investment with high returns to growers and a robust ag sector, and to address public concerns about N pollution

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