Using Nitrogen Balance to Assess Environmental Performance of Crop Production

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Indiana CCA conference, 19 December 2023

Environmental Defense Fund

Worl

Nitrogen

er is Precious, Fragile and Dangerous – It Can Sustain or Destroy

News and Press Release • **Source:** IPS • **Posted:** 31 Jul 2017 • **Originally published:** 31 Jul 2017 • **Origin:** View original

78% of air (as N_2)

Most limiting crop nutrient

NH_3 a key air pollutant

N_2O: largest anthropogenic cause of atmospheric ozone depletion

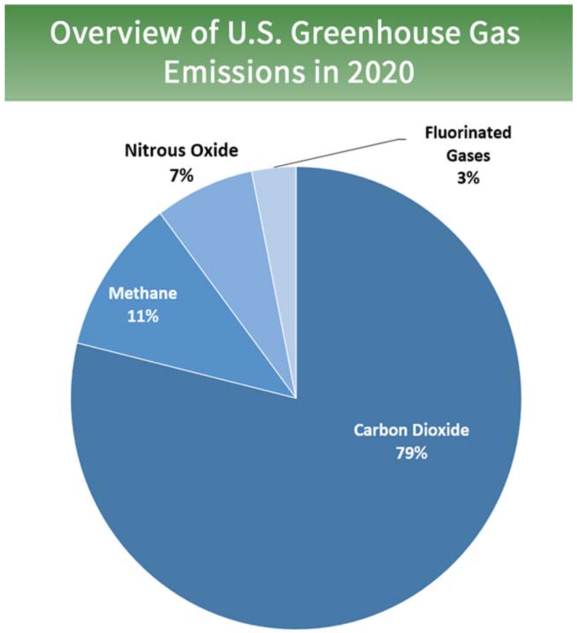
Essential element in [plant, animal] proteins
-- and in soil organic matter!

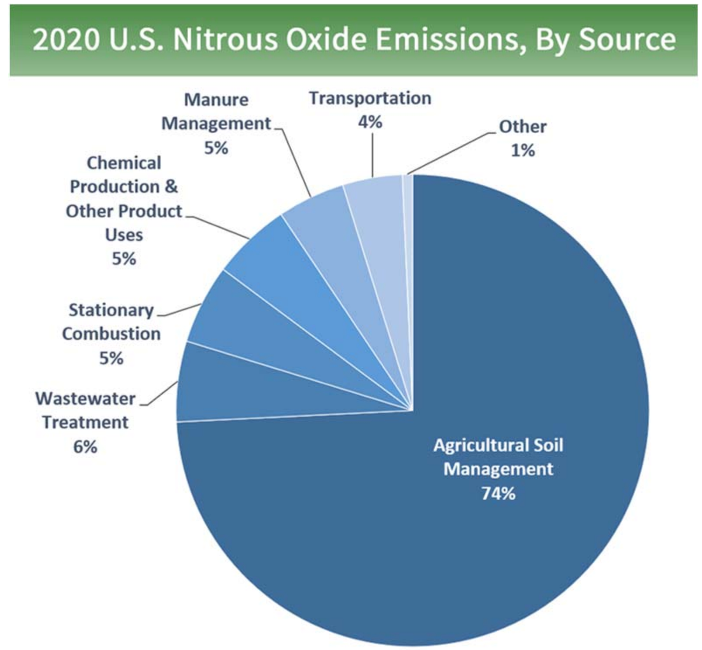
NO_3 a primary cause of coastal dead zones

AND N_2O causes climate change

Farmers are criticized for causing fertilizer pollution

Nitrous oxide is crop production's GHG nemesis





Source: US EPA

<u>Small but Mighty</u>

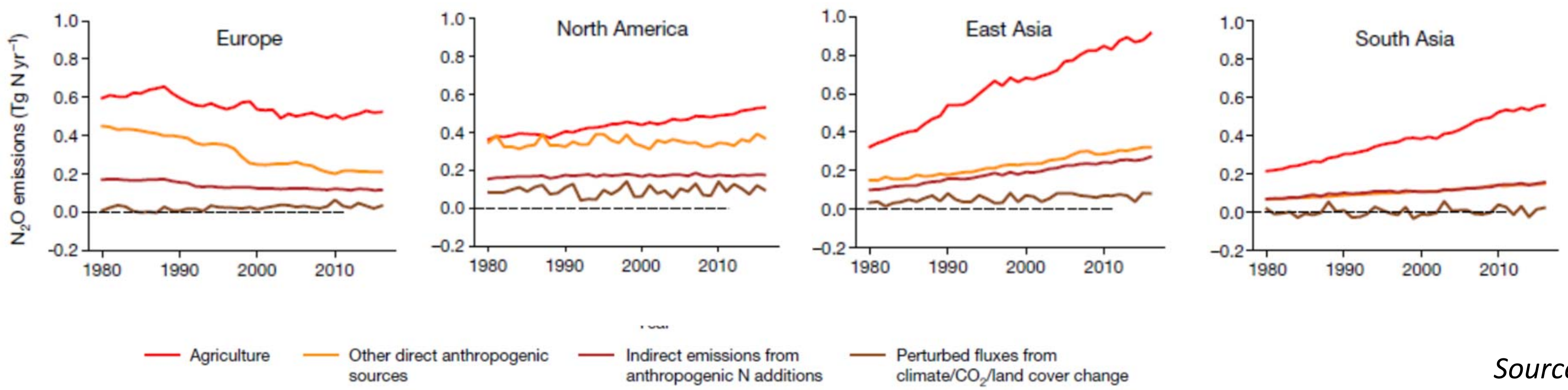
- **N_2O global warming potential is 273 times that of CO_2.**
- N_2O makes up 6% of the world's GHG emissions (7% in US).

<u>N_2O Prevalence in Agriculture</u>

- N_2O accounts for 22–27% of global agricultural GHG emissions.
- 64% of global N_2O emissions from N additions in agriculture, another 6% from manure management & aquaculture.

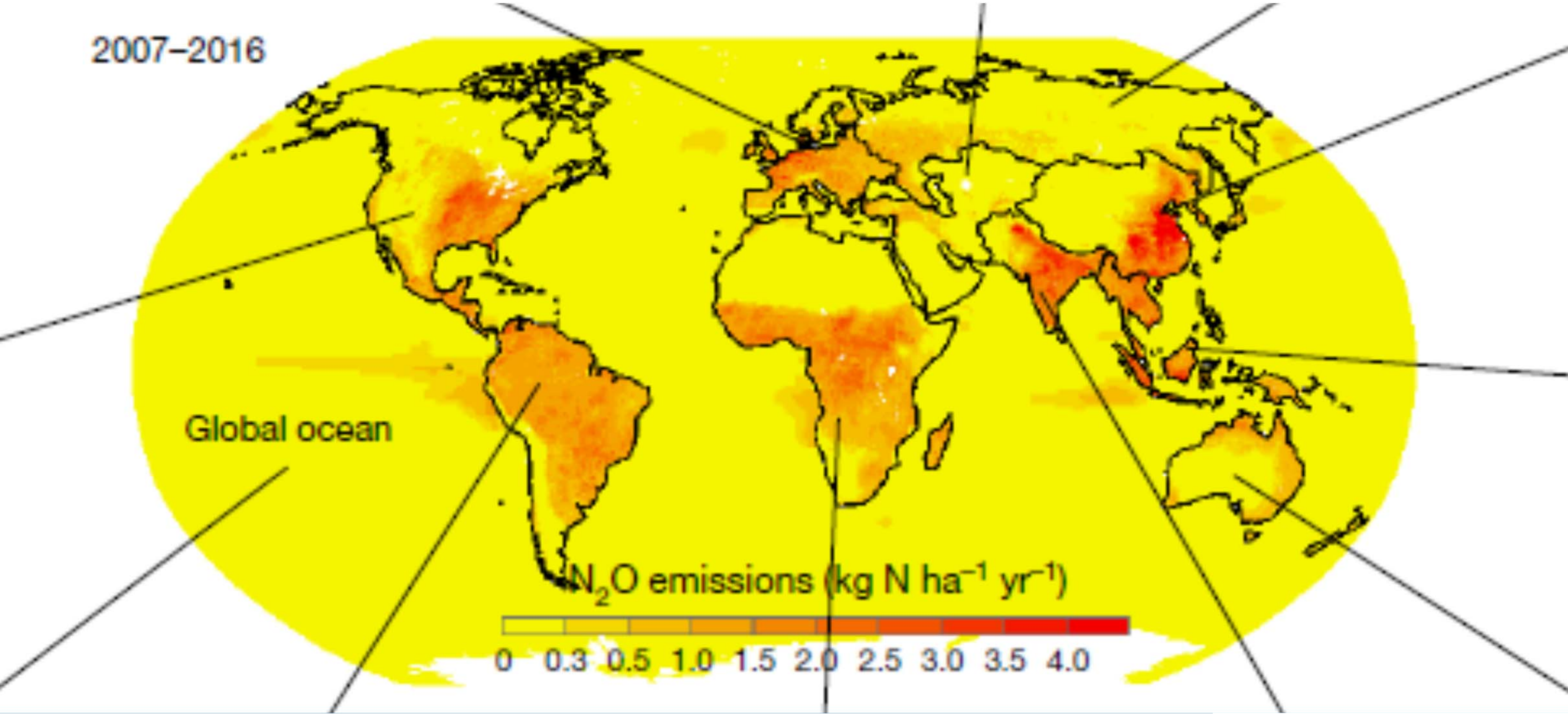
N_2O emissions from agriculture are rising rapidly

- In U.S., overall GHG emissions ↑3.7% over past 30 yrs, but N_2O emissions from ag soils ↑7.1%.
- Globally, GHG emissions ↑53%, N_2O emissions ↑30% over past 30 yrs, still rising in growing economies

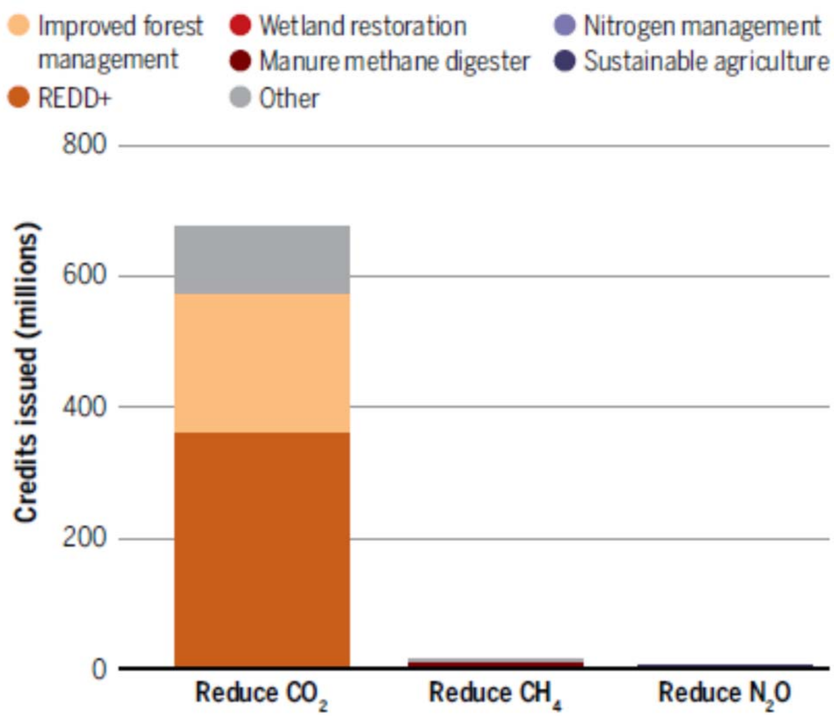


Source: Tian et al. 2020, Nature

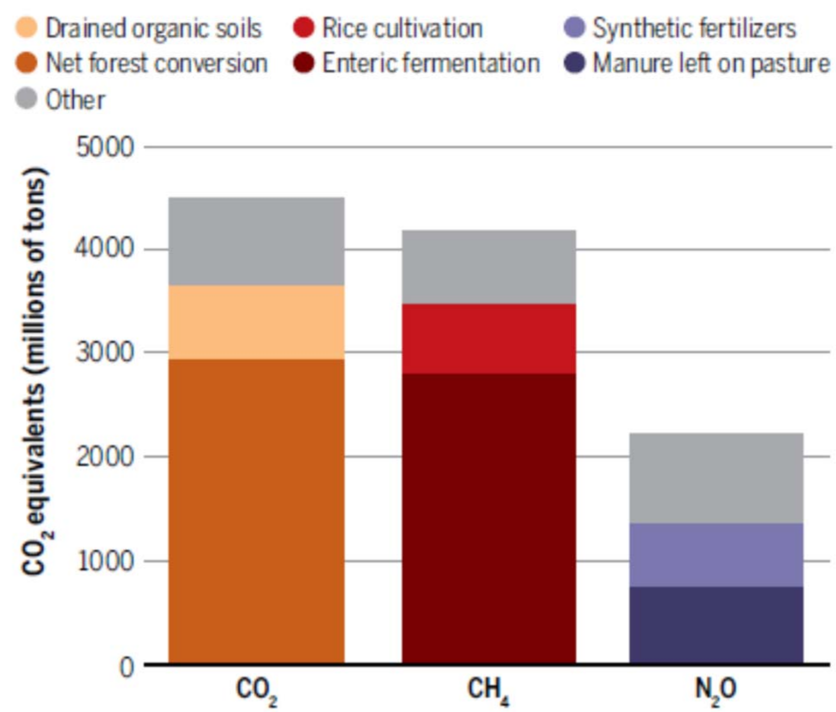
Agricultural hotspots visible even with both natural and anthropogenic N_2O emissions on same map



Mitigation credits are a different mix of GHGs than overall land-based emissions



Credits issued, voluntary markets, 1996 - 2021

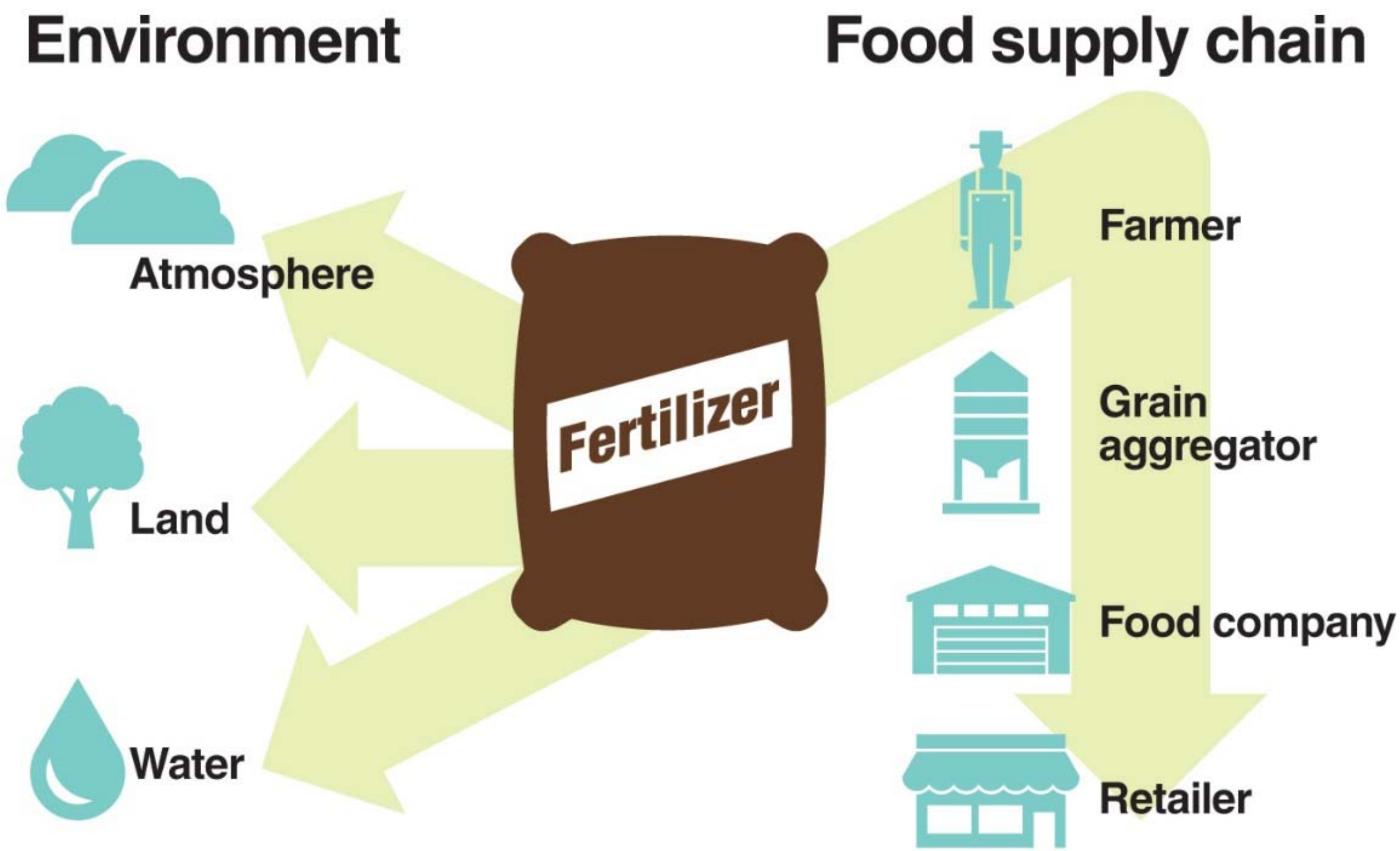


Global land-based emissions, 2019, 100-yr GWPs

(DeFries et al. 2022, *Science*)

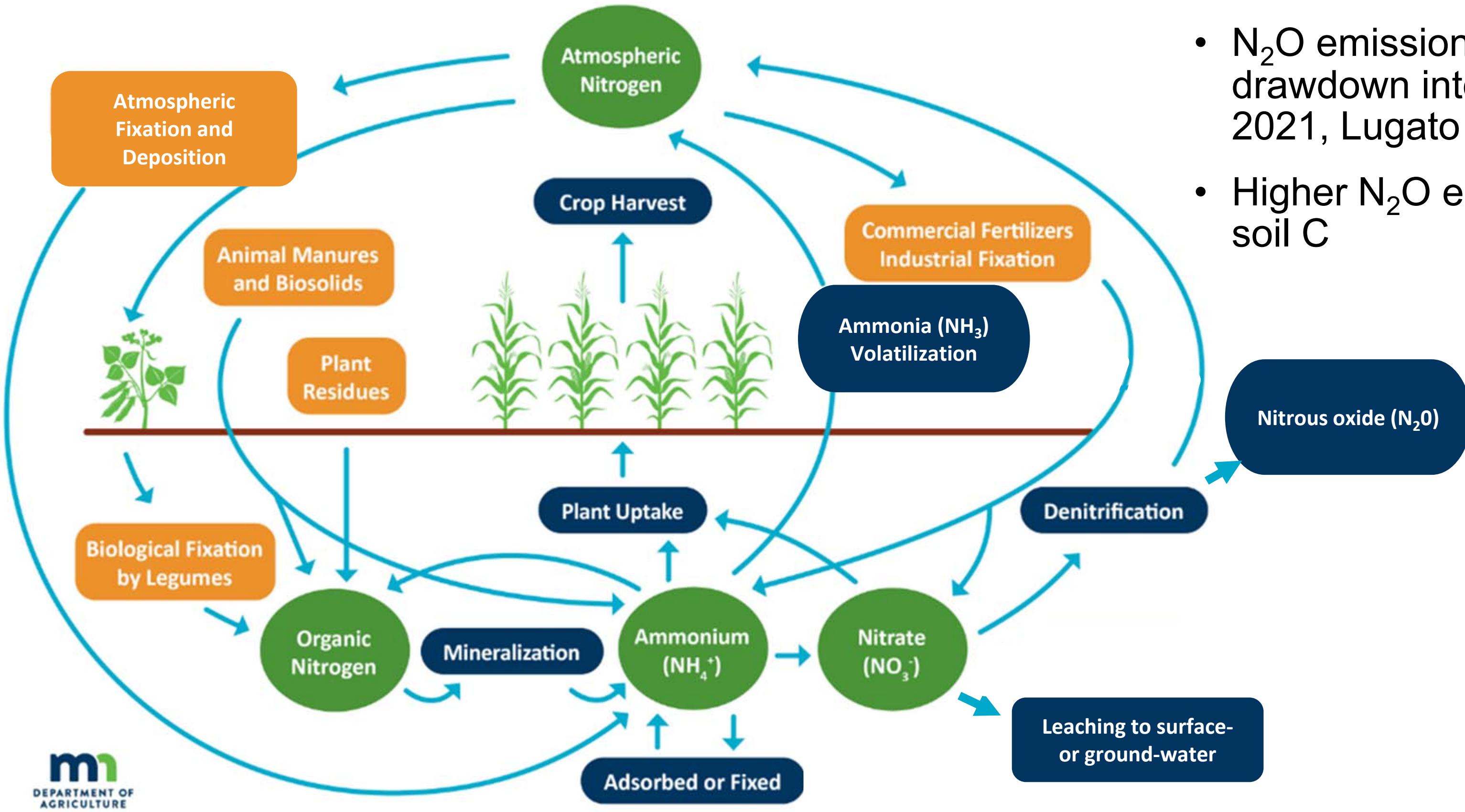
Measuring N_2O has been challenging

- Current inventories may underestimate N_2O emissions (e.g., Eckl et al. 2021, Lawrence et al. 2021, Thompson et al. 2019)
- N_2O emissions are episodic, with hot spots and hot moments. This makes measurement challenging, and thus N_2O is most uncertain of global GHG emissions (Solazzo et al. 2021)



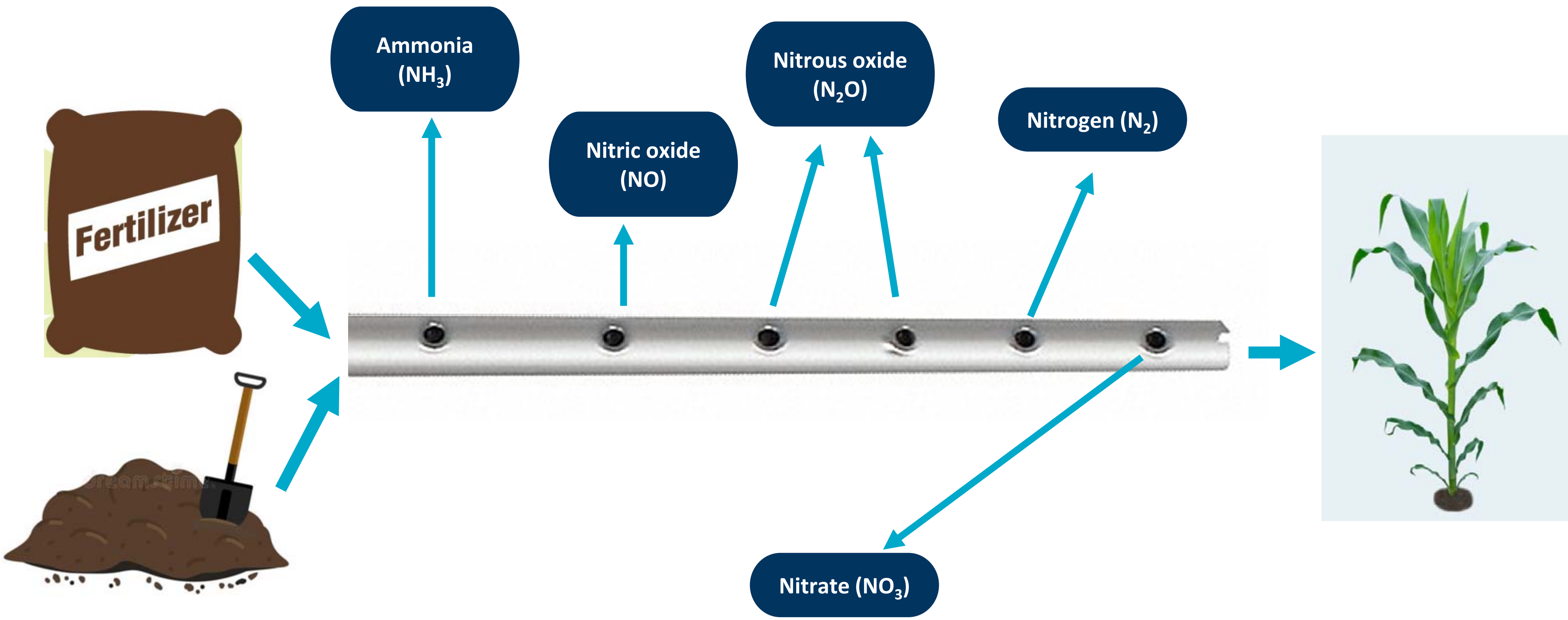
Source: McLellan et al. 2018

Food production *needs* N…
and some reactive N losses are inevitable



- N and C cycles are tightly linked
- N_2O emissions can match or exceed drawdown into soil C (Guenet et al. 2021, Lugato et al. 2018)
- Higher N_2O emissions with greater soil C

The "leaky" nitrogen cycle and tradeoffs



Agriculture can (and must) be part of the solution

- Air and water quality problems and climate impact due to N losses from agricultural production are bad (and are going to get worse).
- Producers have potential to reduce these losses while improving profitability.
- Many producers are trying to reduce N losses, but the public doesn't see any improvements in air and water quality from these efforts.
- The agricultural community needs some way of showing policymakers and the public that they are making progress in reducing N losses.
- A field- and farm-scale indicator will be more credible to the public and more useful to the farmer than current approaches to tracking progress.
- Agriculture has a window of opportunity to be proactive about addressing N pollution in ways that work for farmers. A nitrogen management framework based on a sound indicator of N losses can help farmers improve the overall sustainability of their operations while demonstrating to policymakers and others that they are reducing N pollution.

Agriculture and Human Values
https://doi.org/10.1007/s10460-021-10227-9

Check for updates

Does adopting a nitrogen best management practice reduce nitrogen fertilizer rates?

Does BMP adoption reduce N losses?

Matthew Houser[1]

Accepted: 22 May 2021

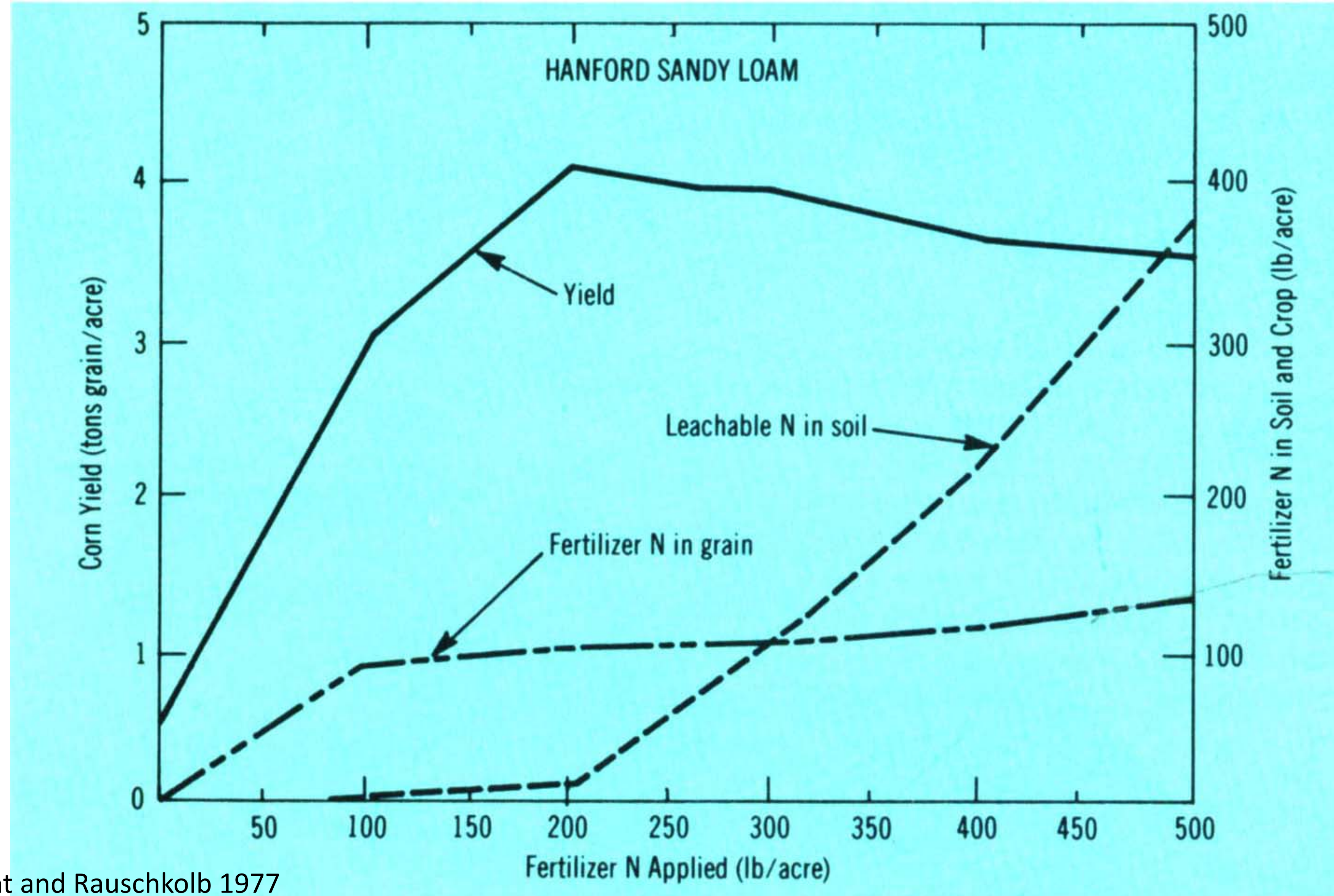
- “green” or more efficient technologies often lead to *increased* resource use (Genskow 2012, Osmond et al. 2014, Ulrich-Schad et al. 2017, Sanderson and Hughes 2019, York and McGee 2016, Houser and Stuart 2000)

Problems with current approaches to quantifying N_2O

Existing Approach	Problems
(Area of practice) x (assumed % reduction by practice)	• Not all practices have same impact on all acres. • 4R practices (e.g., inhibitors, in-season) do not always reduce N_2O emissions
Direct Monitoring	• Expensive • Difficult to track and attribute improvements
Process-based Models	• Lots of inputs • Not farmer friendly • Sometimes there are questions about underlying models

Need:

Robust, meaningful, simple, scalable, credible N_2O metric

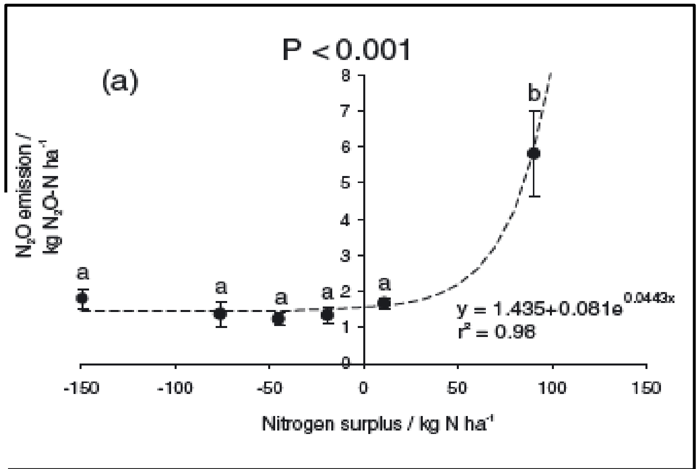


Broadbent and Rauschkolb 1977

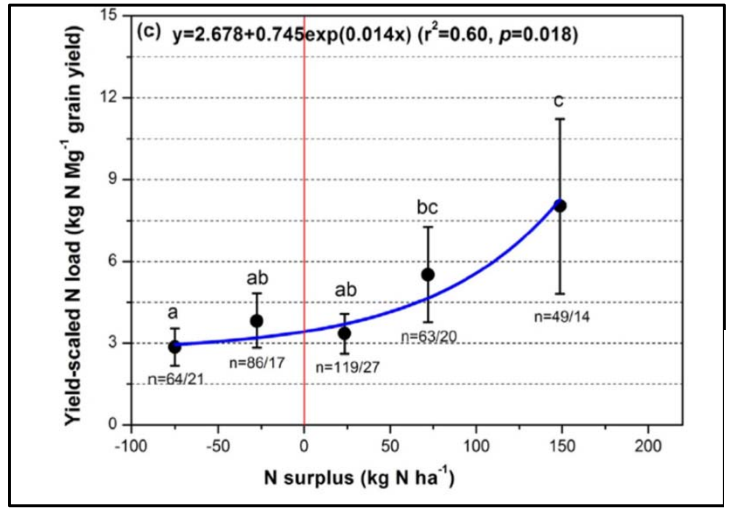
Reducing N balance reduces N_2O and NO_3 Loss

Meta-analyses

van Groenigen et al, 2010



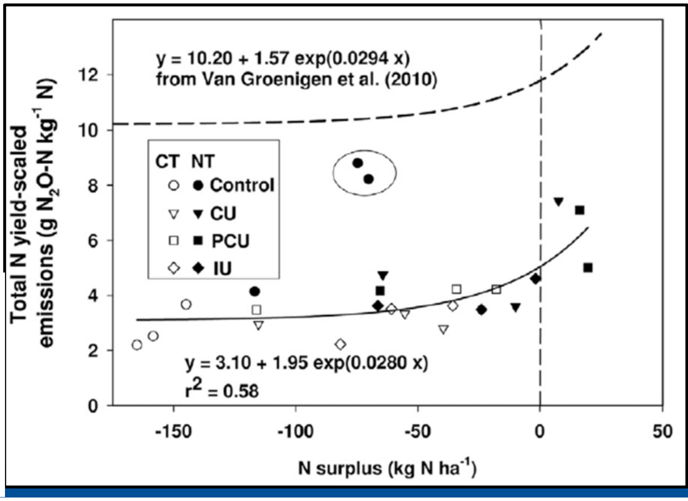
Zhao et al, 2016



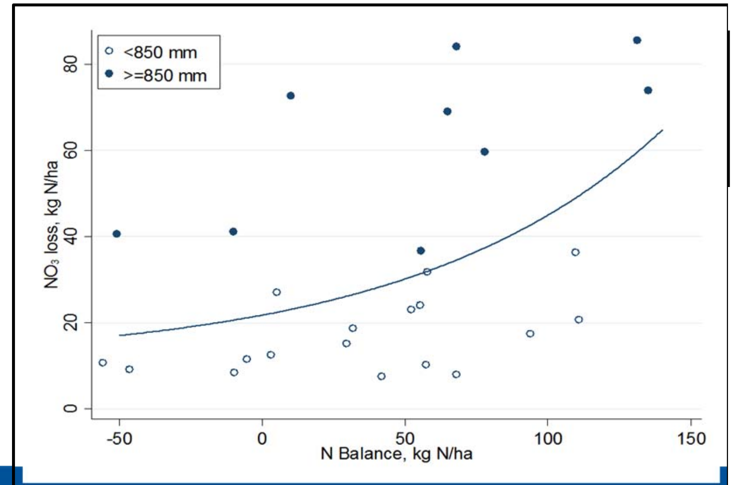
Nitrous oxide

Nitrate

Venterea et al, 2011



Data from Pittelkow et al, 2017. Drawn by A.J. Eagle.

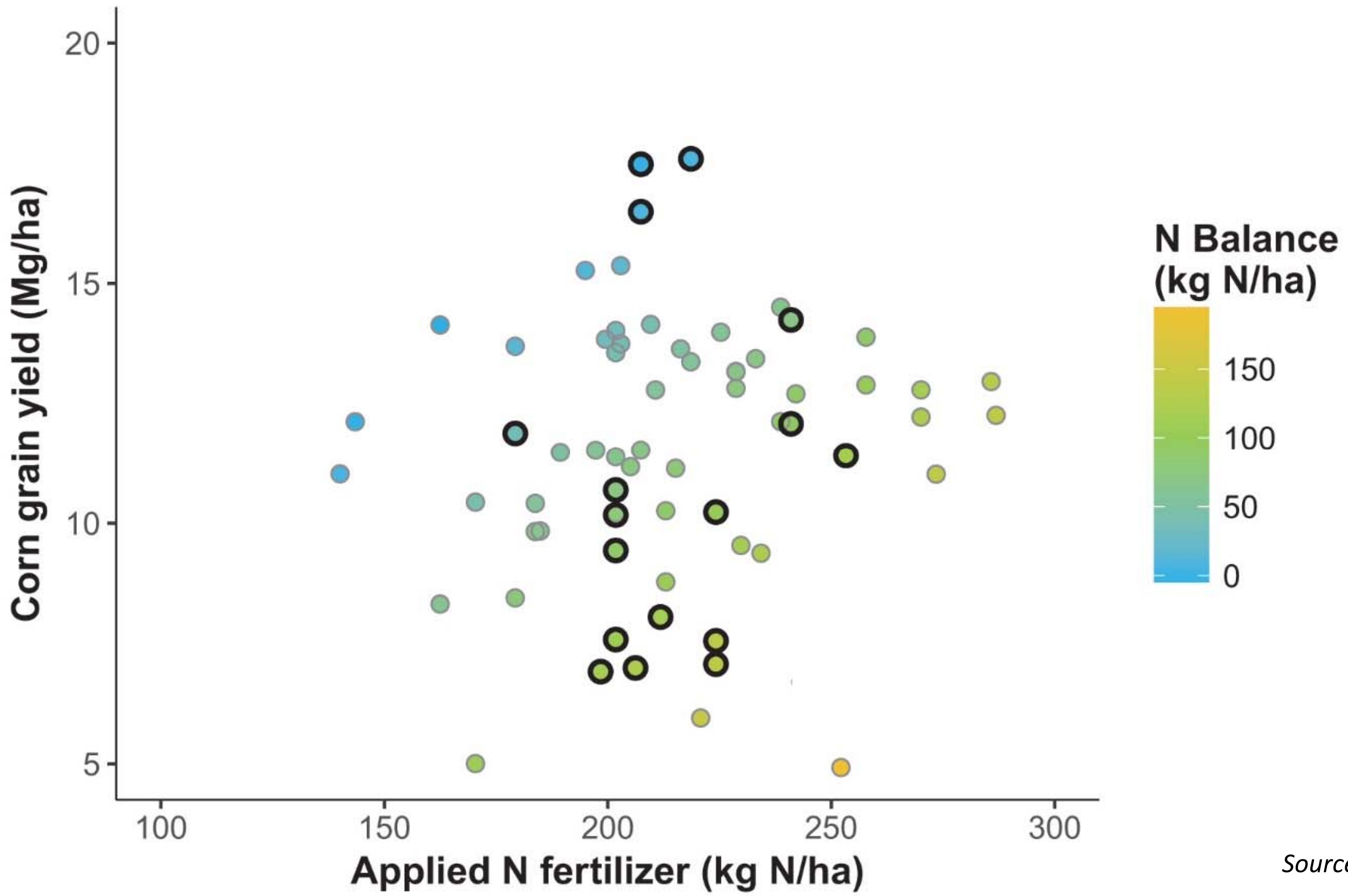


Single-site studies

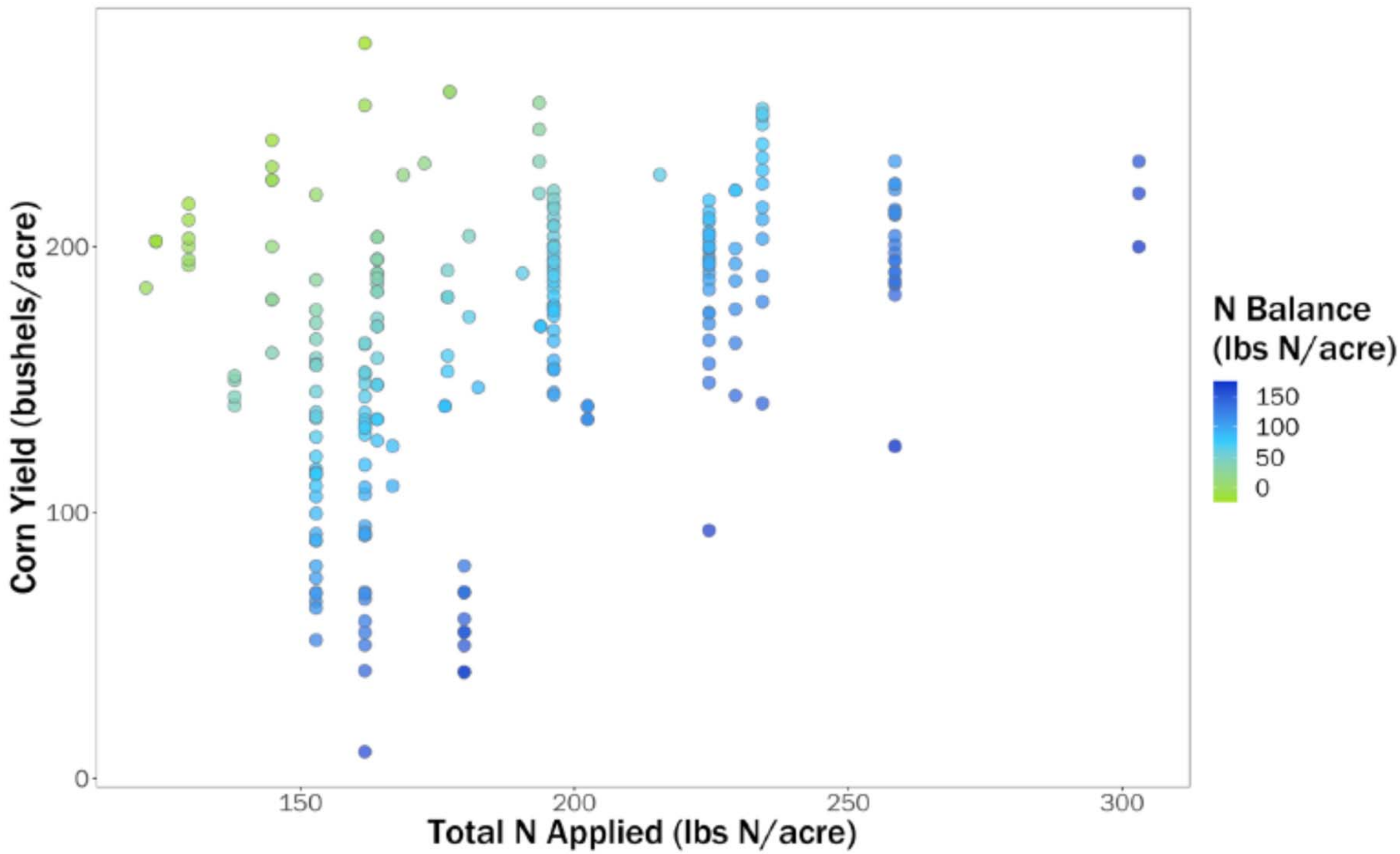
Framework to support measurable improvements

N Balance Score: Lbs. N surplus/acre vulnerable to loss

What is N Balance?



Source: McLellan et al. 2018

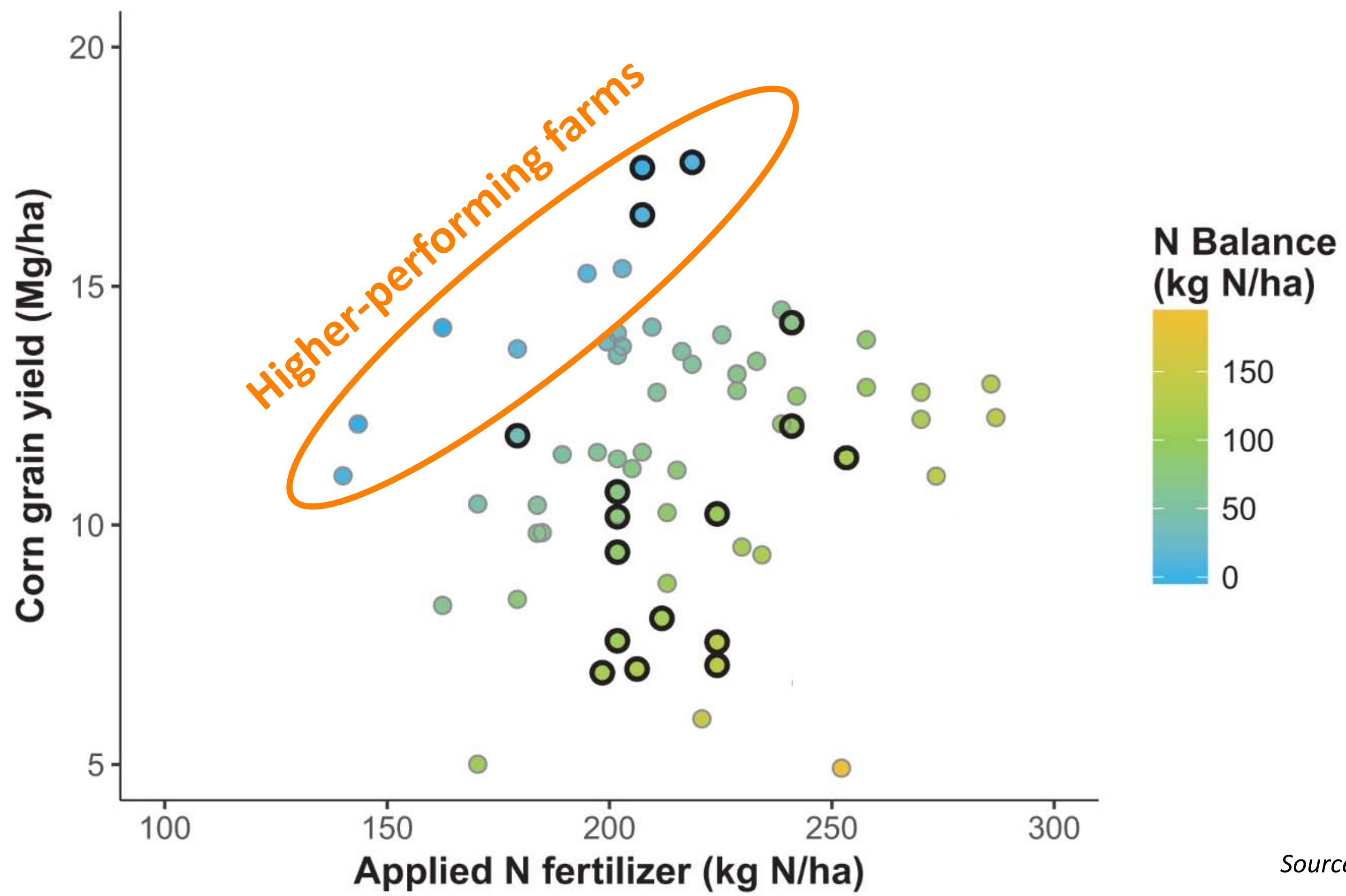


Corn Yield (bushels/acre)
0
100
200
150
200
250
300
Total N Applied (lbs N/acre)
N Balance
(lbs N/acre)
150
100
50
0

Framework to support measurable improvements

N Balance Score: Lbs. N surplus/acre vulnerable to loss

N Balance Analysis: Peer-to-peer benchmarking & adaptive management learning



Source: McLellan et al. 2018

N-Balance values give more information than only NUE

NUE VALUES (lbs/bu)

		N-Rate (lbs/ac)						
		100	**125**	**150**	**175**	**200**	**225**	**250**
Yield (bu/ac)	**100**	*1.0*	*1.3*	*1.5*	*1.8*	*2.0*	*2.3*	*2.5*
	125	*0.8*	*1.0*	*1.2*	*1.4*	*1.6*	*1.8*	*2.0*
	150	*0.7*	*0.8*	*1.0*	*1.2*	*1.3*	*1.5*	*1.7*
	175	*0.6*	*0.7*	*0.9*	*1.0*	*1.1*	*1.3*	*1.4*
	200	*0.5*	*0.6*	*0.8*	*0.9*	*1.0*	*1.1*	*1.3*
	225	*0.4*	*0.6*	*0.7*	*0.8*	*0.9*	*1.0*	*1.1*
	250	*0.4*	*0.5*	*0.6*	*0.7*	*0.8*	*0.9*	*1.0*

**N-Rate (lbs/ac)/Yield (bu/ac) = lbs/bu

N-BALANCE VALUES

		N-Rate (lbs/ac)						
		100	**125**	**150**	**175**	**200**	**225**	**250**
Yield (bu/ac)	100	*33.0*	*58.0*	*83.0*	*108.0*	*133.0*	*158.0*	*183.0*
	125	*16.3*	*41.3*	*66.3*	*91.3*	*116.3*	*141.3*	*166.3*
	150	*-0.5*	*24.5*	*49.5*	*74.5*	*99.5*	*124.5*	*149.5*
	175	*-17.3*	*7.8*	*32.8*	*57.8*	*82.8*	*107.8*	*132.8*
	200	*-34.0*	*-9.0*	*16.0*	*41.0*	*66.0*	*91.0*	*116.0*
	225	*-50.8*	*-25.8*	*-0.8*	*24.3*	*49.3*	*74.3*	*99.3*
	250	*-67.5*	*-42.5*	*-17.5*	*7.5*	*32.5*	*57.5*	*82.5*

**Nrate (lbs/ac)-[Yield (bu/ac)*0.67 (lbs/bu)] = lbs/ac

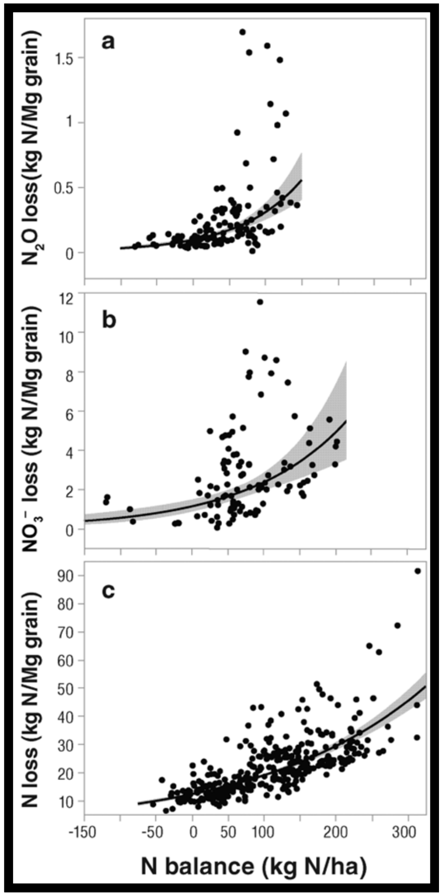
Framework to support measurable improvements

N Balance Score: Lbs. N surplus/acre vulnerable to loss

N Balance Analysis: Peer-to-peer benchmarking & adaptive management learning

Environmental Outcomes: Nitrate & nitrous oxide models

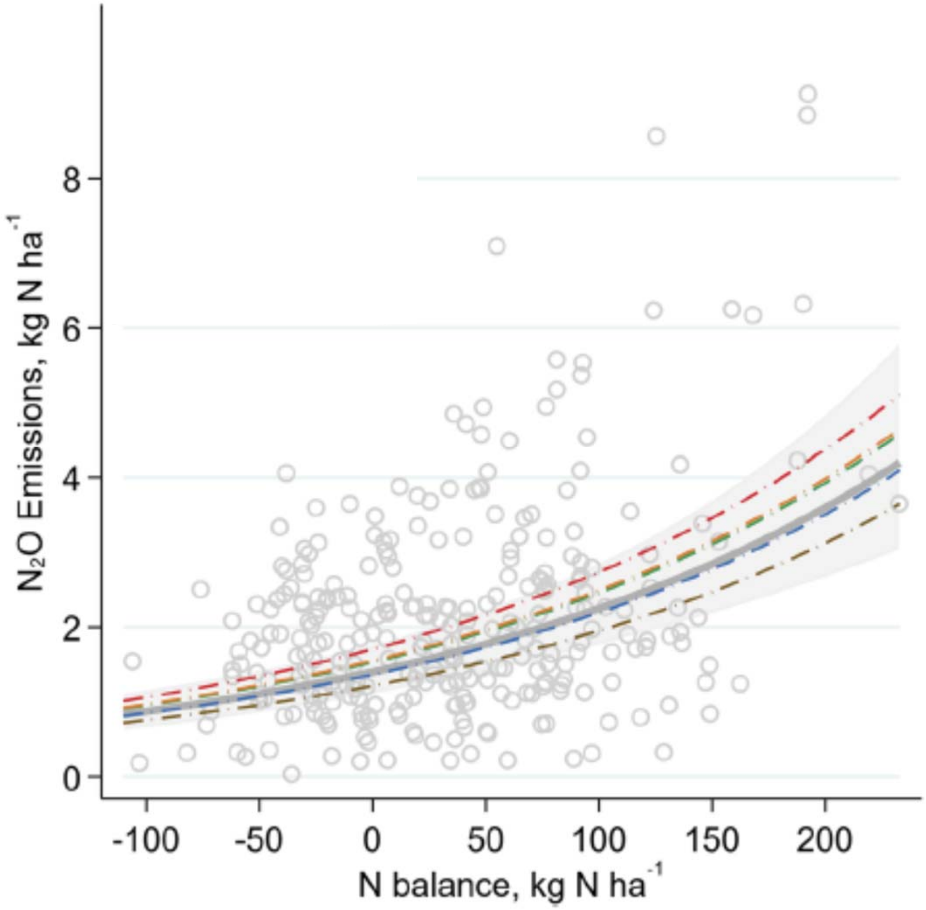
EDF analyzed N balance relationship to losses for maize production in the Corn Belt



Non-linear relationship between
N balance and N_2O emissions
(and nitrate leaching and total N loss)

McLellan, E.L., Cassman, K.G., Eagle, A.J., Woodbury, P.B., Sela, S., Tonitto, C., Marjerison, R.D. and van Es, H.M., 2018. The nitrogen balancing act: Tracking the environmental performance of food production. *Bioscience*, *68*(3), pp.194-203.

N balance is a robust indicator of N_2O emissions from cropland



- Maize and other crops
- Synthetic and organic N
- Different soil types and regions

Earth's Future, 2020, Vol 8

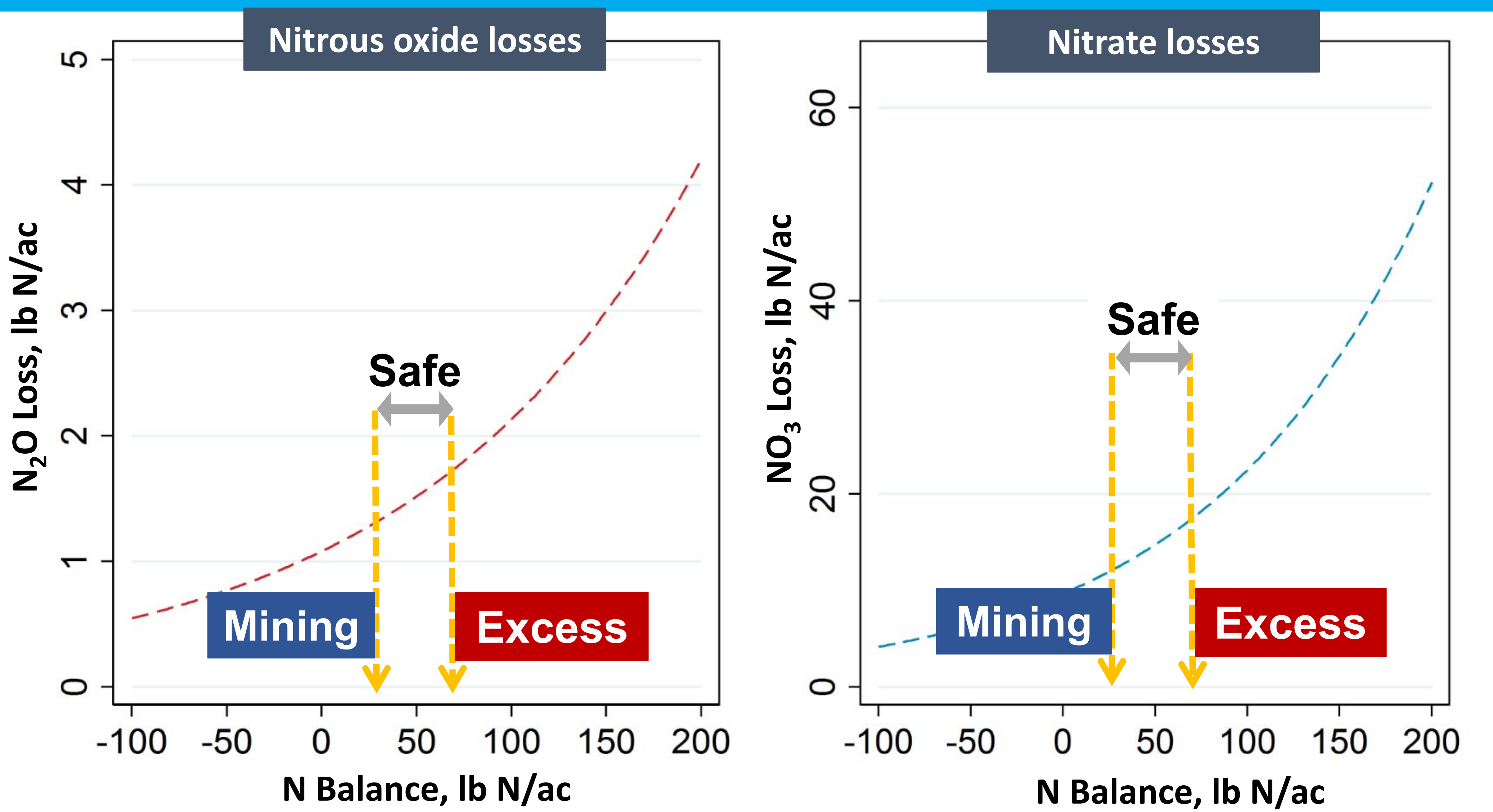
A.J. Eagle, E.L. McLellan, E.M. Brawner, M.H. Chantigny, E.A. Davidson, J.B. Dickey, B.A. Linquist, T.M. Maaz, D.E. Pelster, C.M. Pittelkow, C. van Kessel, T.J. Vyn, K.G. Cassman

Establishing the metric (relationship) with equations

McLellan, E.L., Cassman, K.G., **Eagle, A.J**., Woodbury, P.B., Sela, S., Tonitto, C., Marjerison, R. D. and van Es, H. M., 2018. The nitrogen balancing act: Tracking the environmental performance of food production. Bioscience, 68(3), pp.194-203.

Eagle, A.J., McLellan, E.L., Brawner, E.M., Chantigny, M.H., Davidson, E.A., Dickey, J.B., Linquist, B.A., Maaz, T.M., Pelster, D.E., Pittelkow, C.M. and van Kessel, C., 2020. Quantifying on-farm nitrous oxide emission reductions in food supply chains. Earth's Future, 8(10), art.e2020EF001504.

Tamagno, S., **Eagle, A.J., McLellan**, E.L., van Kessel, C., Linquist, B.A. and Ladha, J.K.. 2022. Quantifying N leaching losses as a function of N balance: A path to sustainable food supply chains. Agriculture Ecosystems & Environment. In press.


Nitrous oxide losses
N_2O Loss, lb N/ac
0
1
2
3
4
5
Safe
Mining
Excess
-100
-50
0
50
100
150
200
N Balance, lb N/ac
Nitrate losses
NO_3 Loss, lb N/ac
0
20
40
60
Safe
Mining
Excess
-100
-50
0
50
100
150
200
N Balance, lb N/ac

Recent research confirms N balance and N_2O relationship, recommends N balance as performance metric

Roy, E.D., Hammond Wagner, C.R. & Niles, M.T.. 2021. Hot spots of opportunity for improved cropland nitrogen management across the United States. Environmental Research Letters 16(3):035004.

Maaz, T.M., Sapkota, T.B., Eagle, A.J., Kantar, M.B., Bruulsema, T.W. & Majumdar, K., 2021. Meta-analysis of yield and nitrous oxide outcomes for nitrogen management in agriculture. Global Change Biology, 27(11): 2343-2360.

Hergoualc'h, K., Mueller, N., Bernoux, M., Kasimir, Ä., van der Weerden, T.J. & Ogle, S.M., 2021. Improved accuracy and reduced uncertainty in greenhouse gas inventories by refining the IPCC emission factor for direct N2O emissions from nitrogen inputs to managed soils. Global Change Biology 27(24):6536-6550.

Cui, X., Zhou, F., Ciais, P., Davidson, E.A., Tubiello, F.N., Niu, X....Zhu, D., 2021. Global mapping of crop-specific emission factors highlights hotspots of nitrous oxide mitigation. Nature Food 2: 886–893. https://doi.org/10.1038/s43016-021-00384-9

Implementation is supported by other publications on N balance

Tenorio, F.A.M., Eagle, A.J., McLellan, E.L., Cassman, K.G., Howard, R., Below, F.E.,…Grassini, P., 2019. Assessing variation in maize grain nitrogen concentration and its implications for estimating nitrogen balance in the US North Central region. Field Crops Research, 240, pp.185-193.

Tenorio, F.A., McLellan, E.L., Eagle, A.J., Cassman, K.G., Andersen, D., Krausnick, M.,…Grassini, P., 2020. Benchmarking impact of nitrogen inputs on grain yield and environmental performance of producer fields in the western US Corn Belt. Agriculture, Ecosystems & Environment, 294, art.106865.

Tenorio, F.A., McLellan, E.L., Eagle, A.J., Cassman, K.G., Krausnick, M., Thorburn, J. & Grassini, P., 2020. Luck versus skill: Is nitrogen balance in irrigated maize fields driven by persistent or random factors? Environmental Science & Technology, 55(1), pp.749-756.

Tenorio, F.A.M., McLellan, E.L., Eagle, A.J., Cassman, K.G., Torrion, J.A. & Grassini, P. 2021. Disentangling management factors influencing nitrogen balance in producer fields in the western Corn Belt. Agricultural Systems, 193, art.103245.

Swaney, D.P. and Howarth, R.W., 2019. County, subregional and regional phosphorus data derived from the net anthropogenic nitrogen inputs (NANI) toolbox. Data in Brief 25:15. https://doi.org/10.1016/j.dib.2019.104265

Elli, E.F., I.A. Ciampitti, M.J. Castellano, L.C. Purcell, S. Naeve, P. Grassini, . . . S.V. Archontoulis. 2022. Climate change and management impacts on soybean N fixation, soil N mineralization, N_2O emissions, and seed yield. Frontiers in Plant Science 13

N Balance as a metric provides other advantages

- Prevents pollution swapping

  Tamagno, S., Eagle, A.J., McLellan, E.L., van Kessel, C., Linquist, B.A. & Ladha, J.K.. 2022. Quantifying N leaching losses as a function of N balance: A path to sustainable food supply chains. Agriculture Ecosystems & Environment. 324:107714.

  Klages, S., C. Heidecke, B. Osterburg, J. Bailey, I. Calciu, C. Casey, T. Dalgaard, H. Frick, M. Glavan, K. D'Haene, G. Hofman, I. Leitão, N. Surdyk, K. Verloop and G. Velthof (2020). "Nitrogen Surplus—A Unified Indicator for Water Pollution in Europe?" Water 12: 1197.

- Applicable at different scales
- Helps address other unintended consequences, such as SOM mining

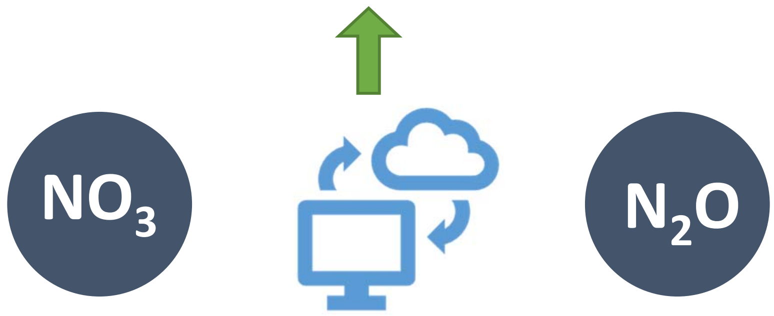
Remaining uncertainties often relate to lack of data or lack of synthesis of existing data

- More field data will allow us to fine-tune the relationships and gain a better understanding.
  - Understanding weather fluctuation and climate change impacts
  - Current research efforts to improve standardization, ensure full data collection
- For now we use the best available science – expecting that it is iterative and will improve over time
- As we move up in scale the certainty of the central tendency increases

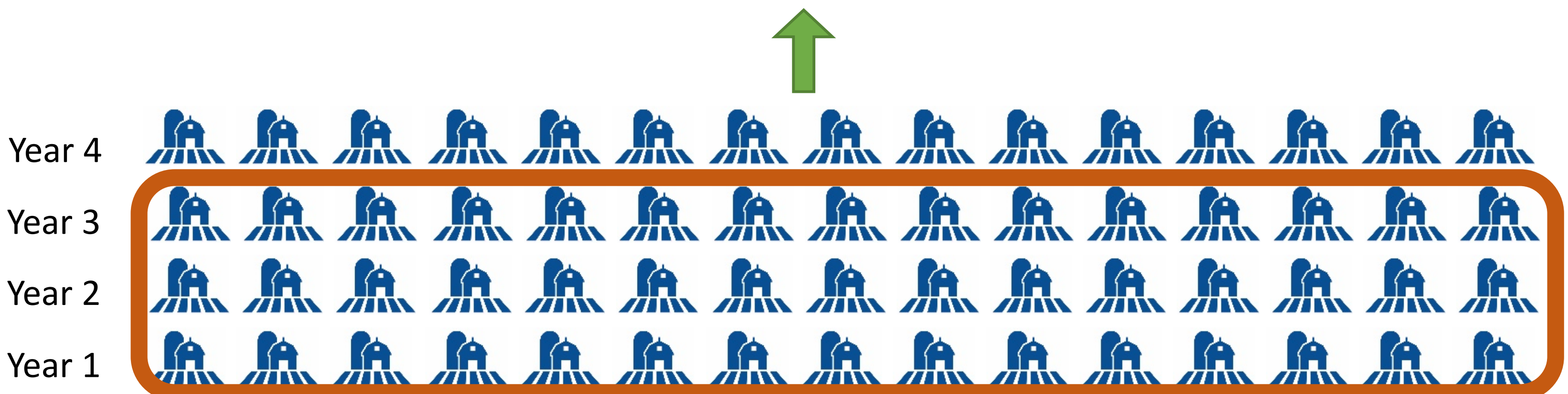
N Balance Implementation

“Company A reduces GHG emissions by 30% in 5 years!”

\- Headline from very big newspaper



N balance



Data requirements for N balance calculation

Necessary to calculate:

- Unique farmer and field IDs
- Crop type and field area
- N fertilizer inputs
  - Synthetic N
  - Manure N
  - Legume N
- N removed
  - Crop yield
  - Fodder removal

Data for continuous improvement:

- N fertilizer & manure management practices (i.e., placement, timing, source, rate recommendations, manure nutrient testing)
- Tillage type & timing
- Planting date for current crop
- Pest management
- Previous year crop and winter cover crops
- Climatic/geographic identifier

NOTE:

1. Data must be collected at the field level
2. Outcome equations work with multi-year data from at least 300 fields/year

N Balance in Action

MyFarms

FARMERS BUSINESS NETWORK®

Climate Action Reserve

Field to Market

Iowa Soybean Assoc.

National Corn Growers Assoc.

Pork Producers

Soil Health Partnership

United Soybean Board

N Balance in Action

MyFarms

FARMERS BUSINESS NETWORK

Tyson

Walmart

Climate Action Reserve

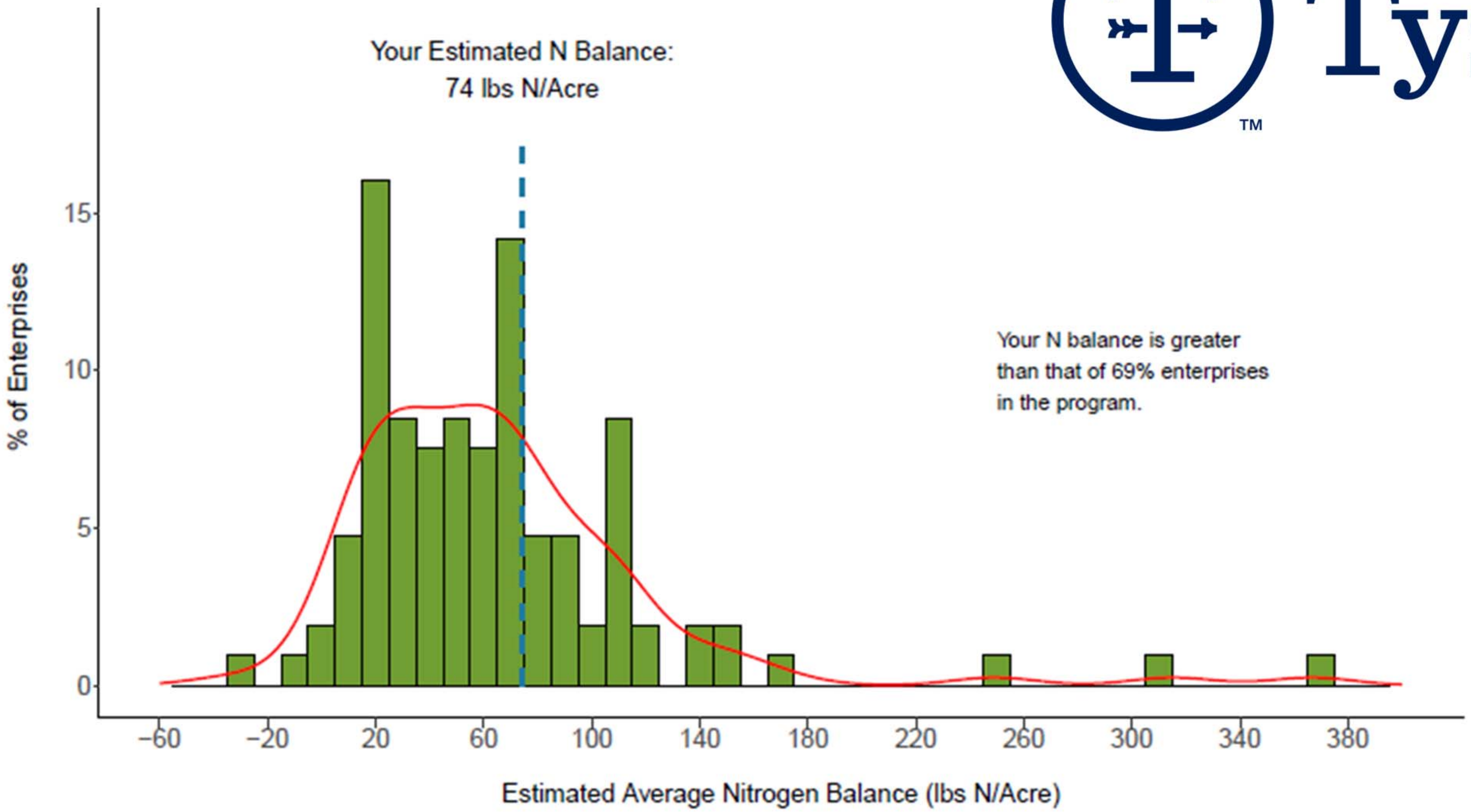
Iowa Soybean Assoc.

National Corn Growers Assoc.

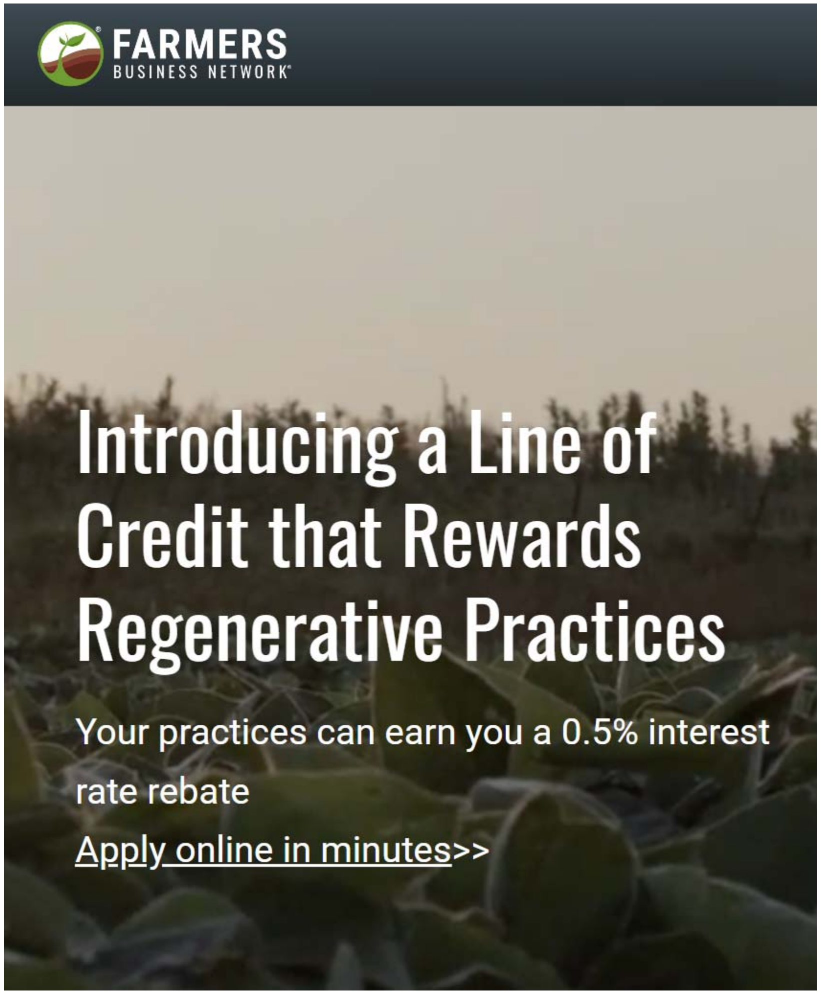
Pork Producers

Soil Health Partnership

United Soybean Board



Your Estimated N Balance:
74 lbs N/Acre
Your N balance is greater than that of 69% enterprises in the program.
% of Enterprises
0
5
10
15
-60
-20
20
60
100
140
180
220
260
300
340
380
Estimated Average Nitrogen Balance (lbs N/Acre)



Regenerative Practices Rebate Program Requirements

To enroll in the Program, Farmers must meet the following criteria:

1. **FBN Membership**: Farmer must be a FBN Member. Membership is free - Sign-up Here
2. **Eligible Crops**: Farmer grows corn, soybeans, and/or wheat
3. **Evidence of Soil Sampling**: Farmer must show evidence of 10-acre density soil sampling in one of the last four years
4. **Soil Health Practices**: On at least 70% of farmed acres, Farmer utilizes one or more of the following practices:
   - Ground is minimally disturbed (strip till, no-till – as defined by the NRCS)
   - Crop rotation has live roots (cash crop, cover crop, perennials) in the soil for at least 70% of the year
   - other regionally appropriate soil conservation practices outlined by the NRCS (e.g. riparian buffers, wind breaks) and approved by the program
5. **Nutrient Efficiency**: 80% of fields achieve an Environmental Defense Fund N balance score between 25 - 75 lbs on a 3 year average. Learn about N Balance scoring

Requirements Questions? Talk to a program specialist

Regenerative Agriculture Finance Fund

Objective: Provide **favorable financing terms on operating loans to farmers implementing regenerative practices** including optimized N management, no-till, cover crops.

2022: $26M operating loan fund, 48 participants, >42K acres
2023: >70K acres

*"I heard about the program through my lender and banker at FBN. I really like to geek out on my numbers and **cut costs per acre**.*

*Wherever a farmer can **save money for doing good work on the land, you know that is a good deal**."*

FARMERS BUSINESS NETWORK

Joel Uthe
Operator of Uthe Farm
Chariton, Iowa

FIGURE 1. Annual timeline for RAF program.

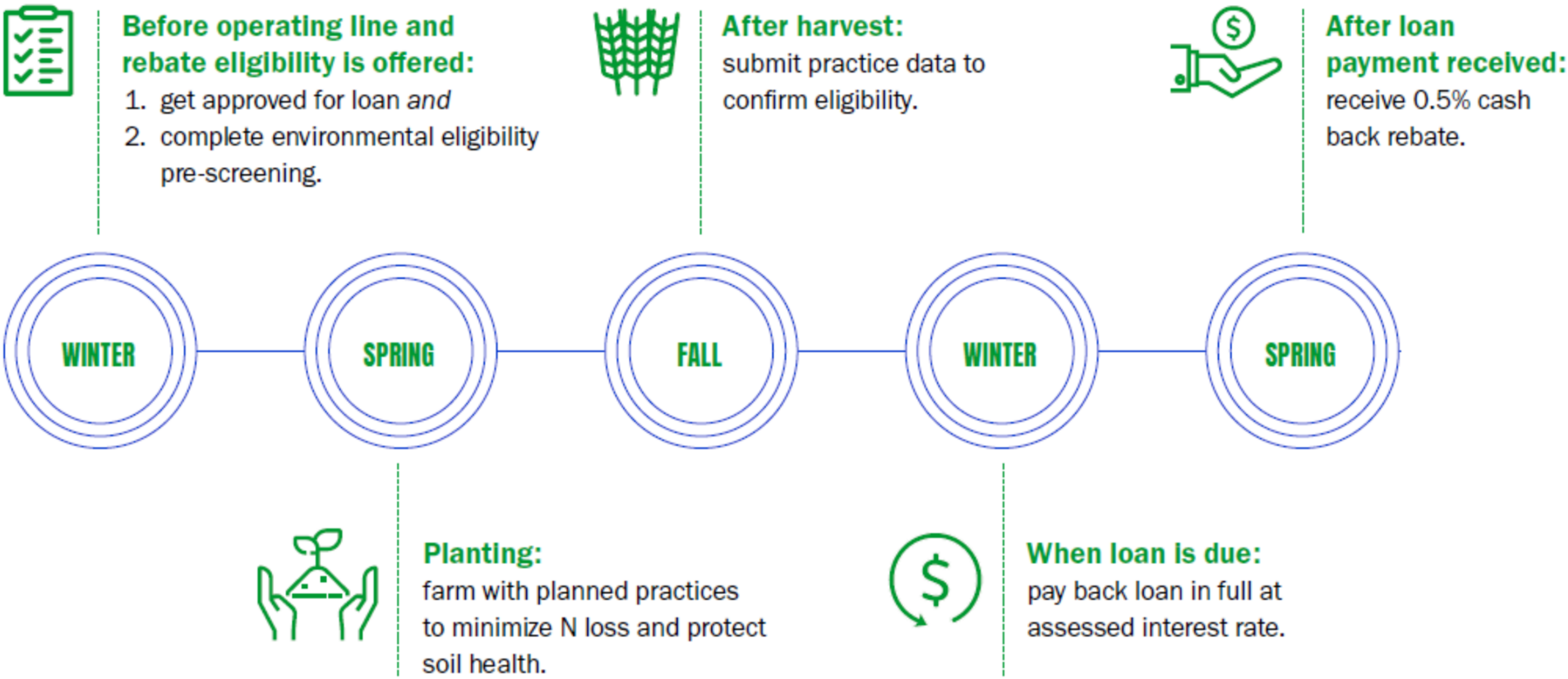
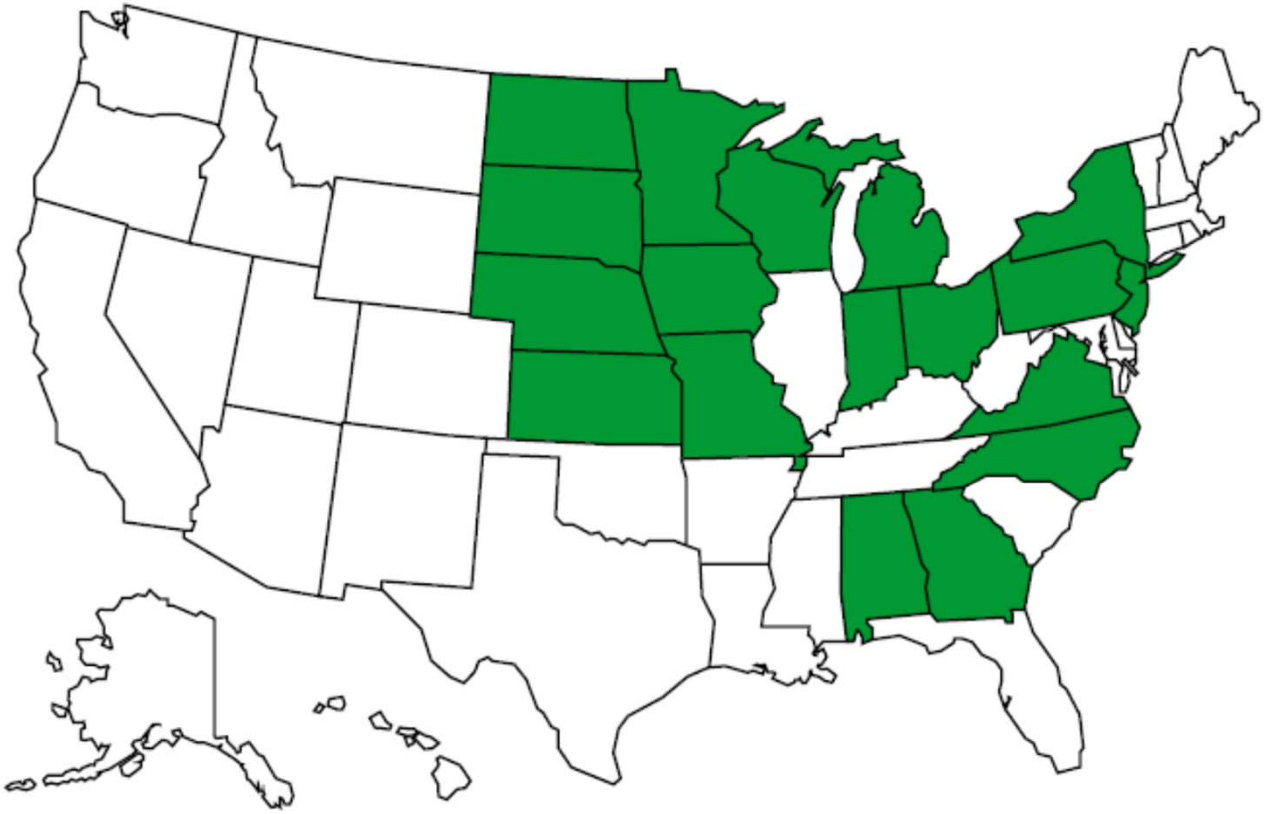


FIGURE 4. States with farmers in the pilot year of the RAF program.



The RAF program was the fastest-selling financial product ever launched by FBN.

Top 6 Reasons for Adopting an N Balance Approach

- N balance is a direct measure of fertilizer pollution;
- It requires very little field- and farm-level data;
- It responds to farm management, and offers flexibility to farmers to use a wide variety of practices;
- It is a direct measure of sustainable intensification;
- It can be used to quantify environmental outcomes (N_2O emissions and NO_3 leaching);
- It relates to other sustainability metrics.

Thank you!

aeagle@edf.org

Environmental Defense Fund