Biogeochemical modeling for sustainability performance standards: Adapt-N and N balance in US corn production

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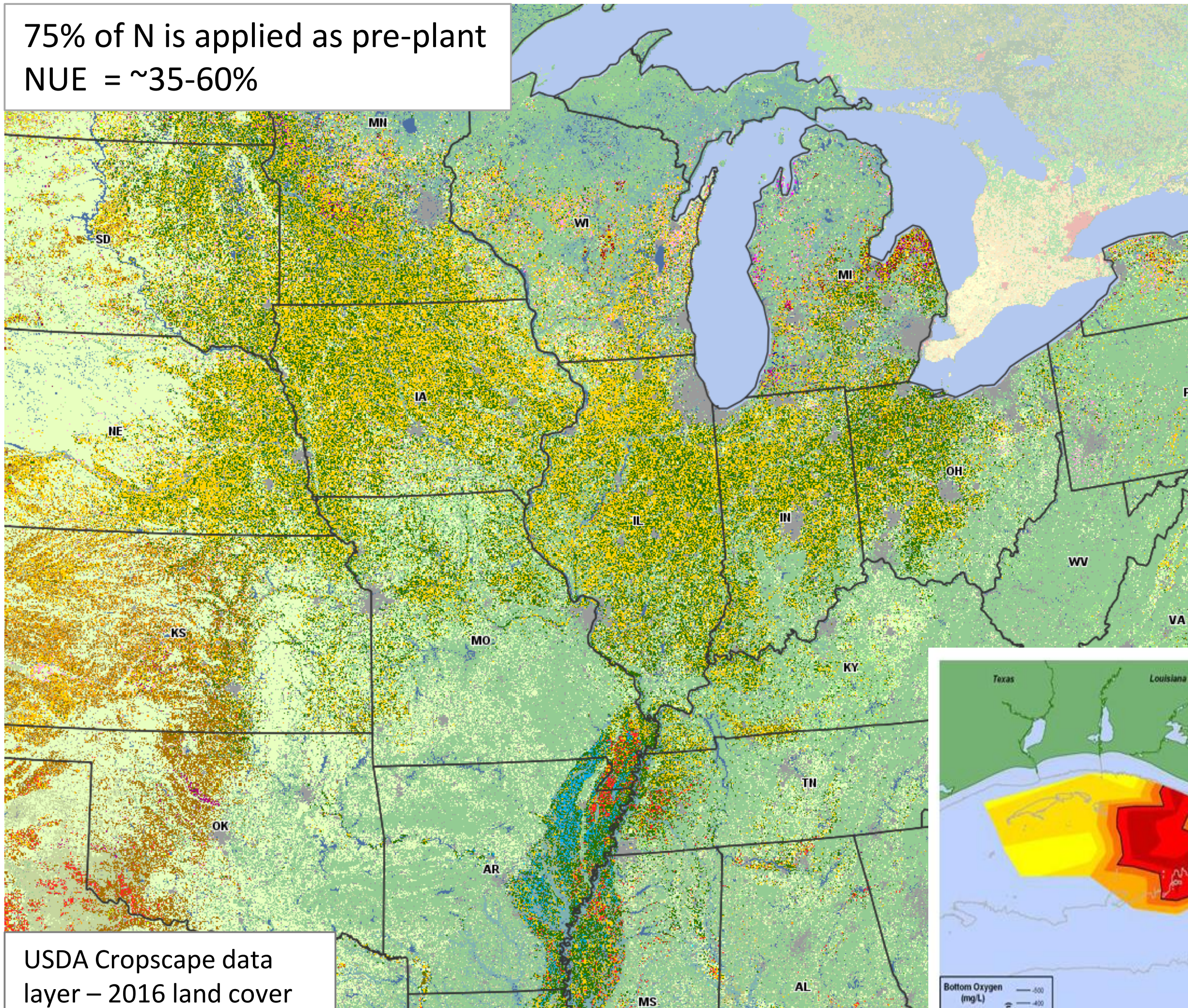
The Nitrogen Problem

1. Essential crop nutrient

2. Environmental concerns
    - High energy needs for synthesis
    - Groundwater contamination (NO_3)
    - Hypoxia in estuaries (NO_3)
    - Greenhouse gas emissions (N_2O)
    - Small particulate air pollution (NH_3 and NO_x)

At the USA - very low regulatory power over N management

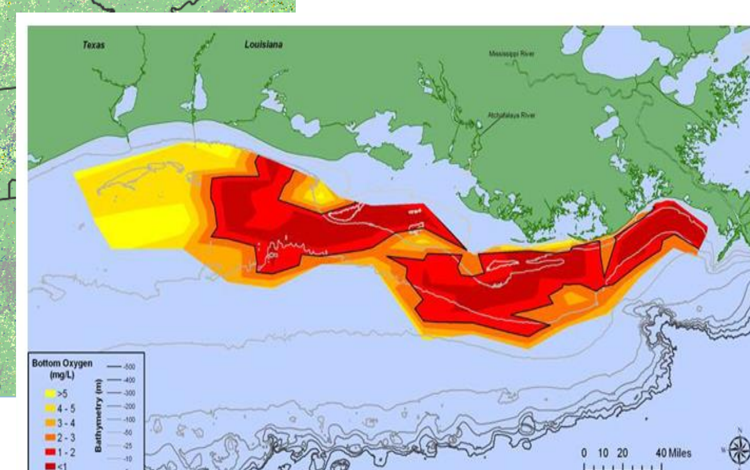
75% of N is applied as pre-plant
NUE = ~35-60%



USDA Cropscape data layer – 2016 land cover

Corn
Soy

'Dead zone' at the Golf of Mexico



Growing interest by retailers and consumers to increase efficiency of food production

Walmart Carbon Footprint:

“fertilizer is by far the “hottest” input in our supply chain”

N balance is a suitable indictor to track agriculture sustainability

BioScience

American Institute of Biological Sciences

Article Contents

The Nitrogen Balancing Act: Tracking the Environmental Performance of Food Production

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Abstract

Farmers, food supply-chain entities, and policymakers need a simple but robust indicator to demonstrate progress toward reducing nitrogen pollution associated with food production. We show that nitrogen balance—the difference between nitrogen inputs and nitrogen outputs in an agricultural production system—is a robust measure of nitrogen losses that is simple to calculate, easily understood, and based on readily available farm data. Nitrogen balance provides farmers with a means of demonstrating to an increasingly concerned public that they are succeeding in reducing nitrogen losses while also improving the overall sustainability of their farming operation. Likewise, supply-chain companies and policymakers can use nitrogen balance to track progress toward sustainability goals. We describe the value of nitrogen balance in translating environmental targets into actionable goals for farmers and illustrate the potential roles of science, policy, and agricultural support networks in helping farmers achieve them.

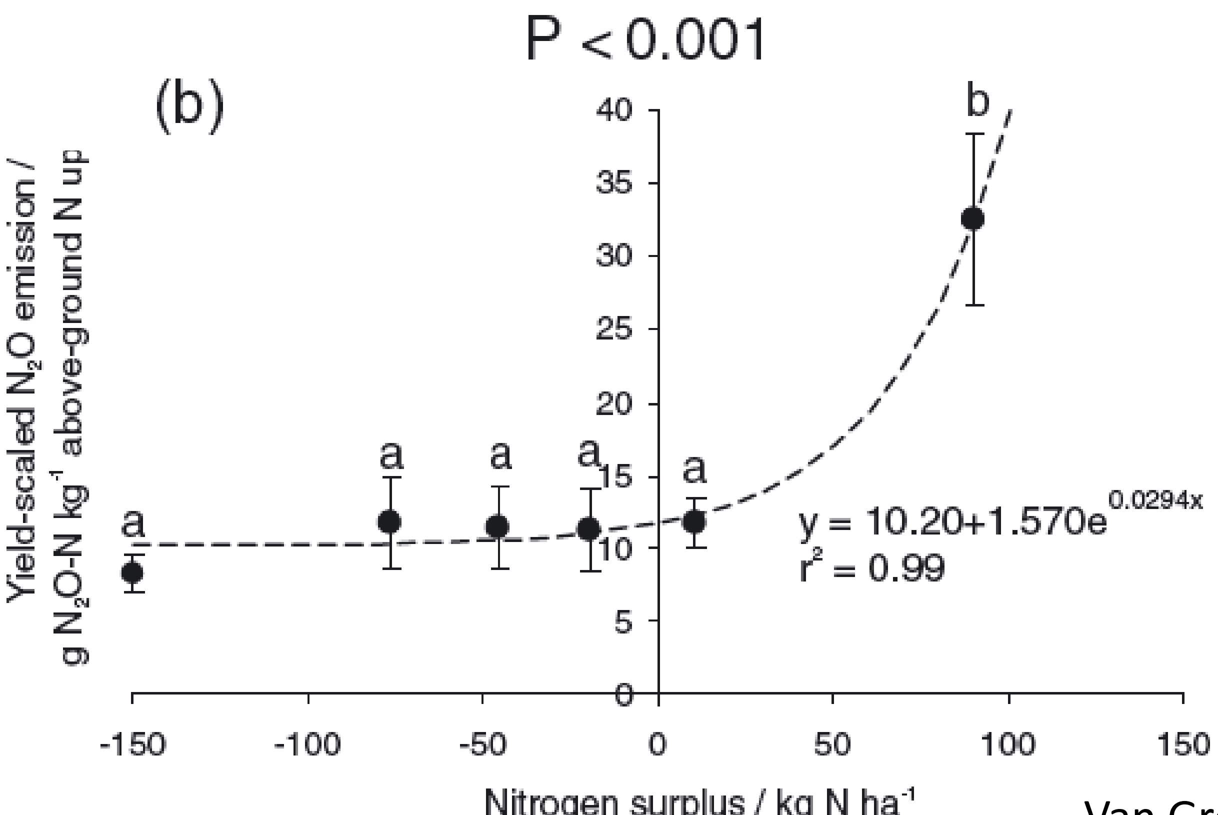
Issue Section: Forum

McLellan et al 2018, *BioScience*.

N balance concept

N balance = Total N applied – N removed by the crop

Growing evidence suggest environmental losses rapidly increase beyond an “optimum” balance value



Van Groenigen et al. 2010

The 4R's of nutrient management

Smart N
nitrification inhibitors

http://www.nutrientstewardship.com/4rs/

But what is the right answer to each of the R's for a specific field in a specific time and season?

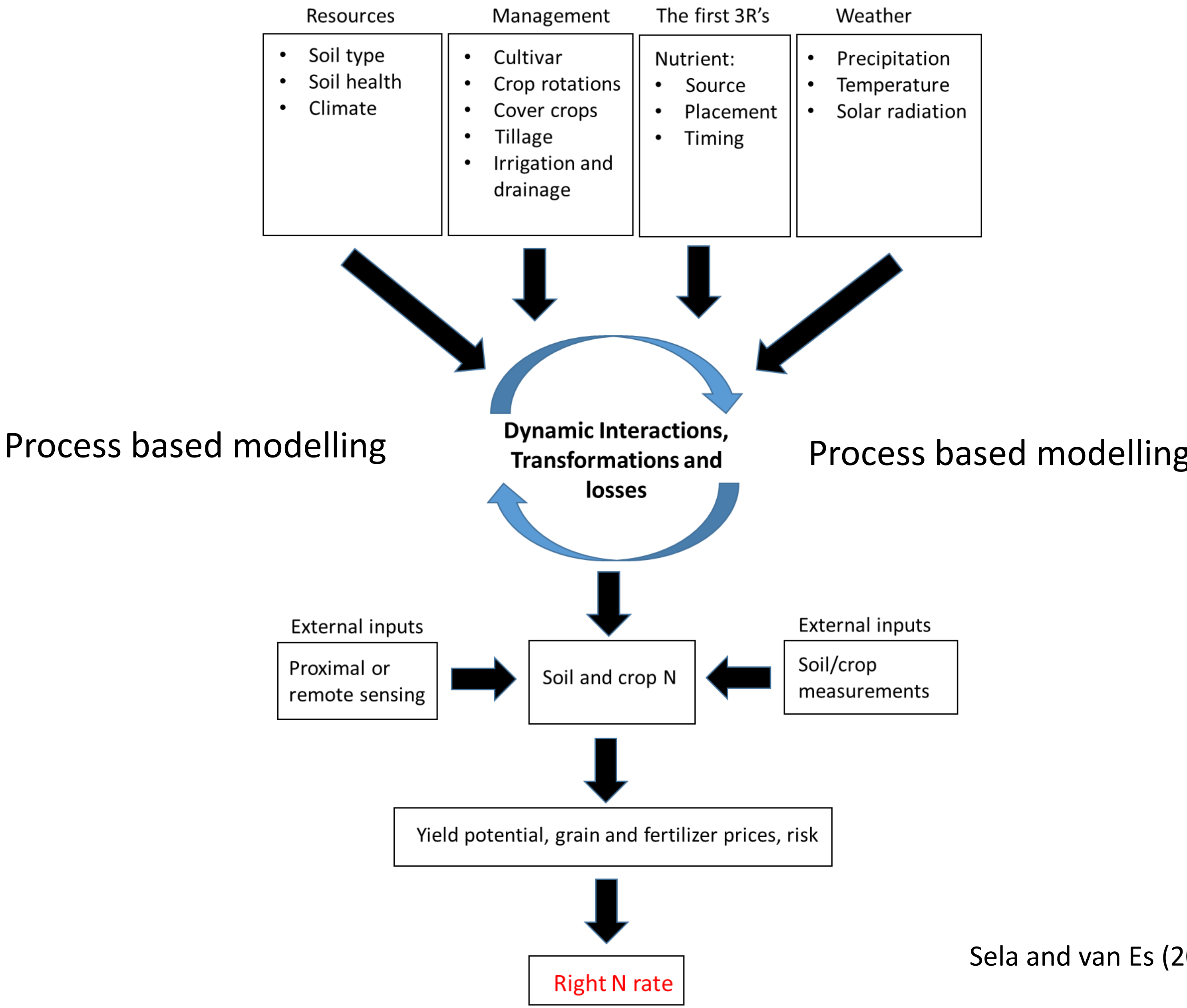
It is a complex optimization problem.

The 4R's of nutrient management

http://www.nutrientstewardship.com/4rs/

Out of the 4R's, the answer to the right N rate is probably the most challenging due to the dynamic nature of N in the soil

Digital tools can aid growers in making N decisions



Sela and van Es (2018), JSWC

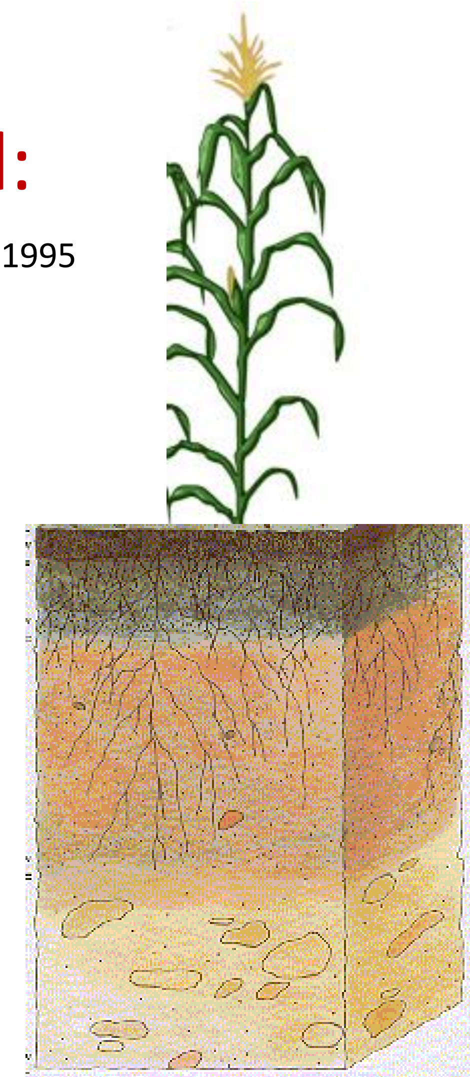
Precision N Management model

Melkonian et al., 2005, 2007

LEACH-N model:

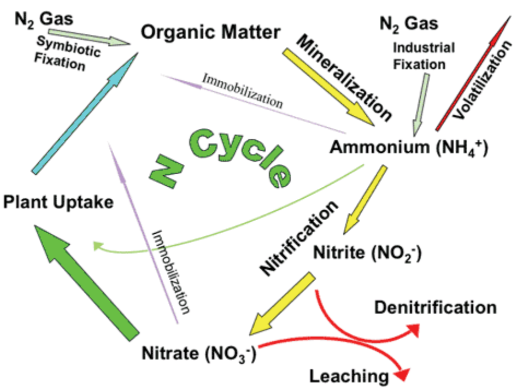
Hutson and Wagenet 1995

Hydrology and
biogeochemistry
N,C cycling



Crop growth model

Sinclair and Muchow, 1995



Validation studies:

Jabro et al. 1995 (*Soil Sci.*)
Sogbedji et al 2001a (*Plant Soil*)
Sogbedji et al 2001b (*Plant Soil*)
Jabro et al. 2006 (*J. Environ. Qual.*)
Sogbedji et al 2006 (*Plant Soil*)
Marjerison et al. 2016 (*J. Environ. Qual.*)
Melkonian et al. 2017 (*Agron. J.)*

Adapt-N

- An in-season decision Support tool to manage N
- Highly scalable and Cloud-based
- Estimating N needs in complex production environments

Effectively addresses multiple environmental concerns:

- water quality
- greenhouse gases and NH_3 emissions
- Energy

Disclosure:

According to Cornell University policy, we are disclosing that this tool was developed as part of our Cornell research program, and that Agronomic Technology Corporation (now Yara International) received a license for the use and further development of the Adapt-N tool, and has in part sponsored associated research efforts.

Features and Inputs for Adapt-N

Feature	Approach
Simulation time scale	Daily time-step. Historical climate data for post-date estimates
Optimum N rate estimation	Mass balance: deterministic (pre) and stochastic (post) with grain-fertilizer price ratio and risk factors
Weather inputs	Near-real time: Solar radiation; max-min temperature; precipitation
Soil inputs	Soil type or series related to NRCS database properties; rooting depth; slope; soil organic content; artificial drainage
Crop inputs	Cultivar; maturity class; population; expected yield; crop price
Management inputs	Tillage (type, time, residue level); irrigation (amount, date); manure applications (type, N & solid contents, rate, timing, incorporation method); previous crop characteristics; cover crop
N Fertilizer inputs	Multiple: Type, rate, time of application, placement depth; fertilizer price; enhanced efficiency compounds (inhibitors, slow-release)
Real-time inputs	Date of emergence, soil nitrate test results

For further details on Adapt-N and its validation see Sela et al. 2016 (*AJ*), 2017 (*JEQ*) and 2018 (*COMPAG*)

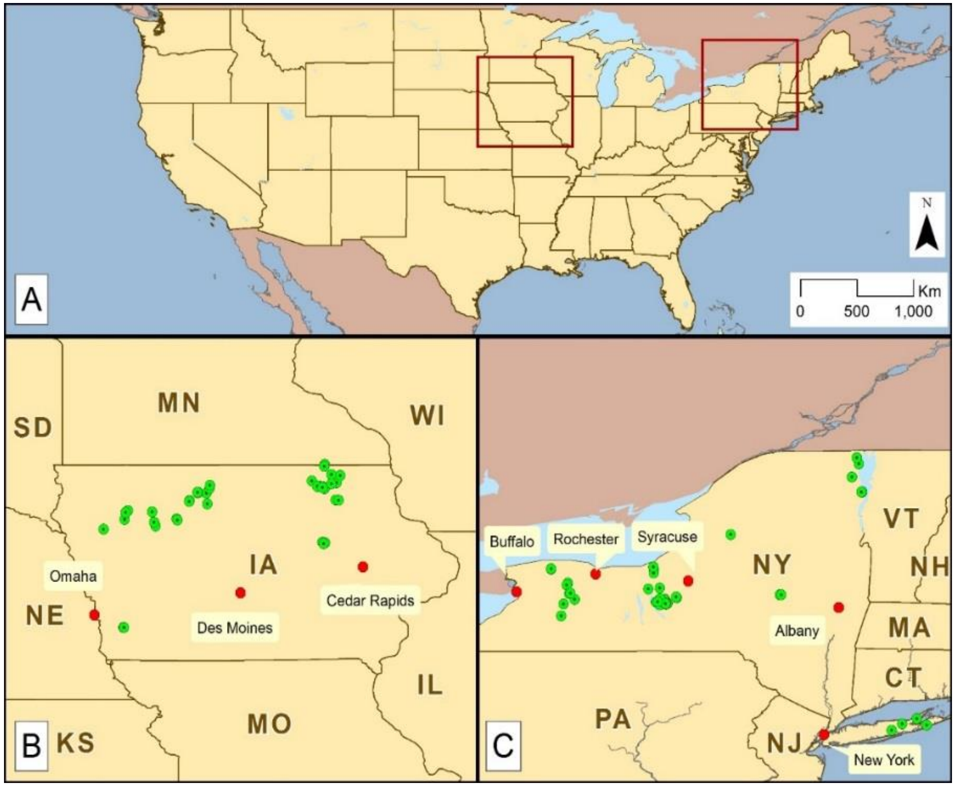
Adapt-N applies a dynamic mass balance approach to generate N optimal N rates

$$N\ rec = N_{potential\ yield} - N_{crop\_now} - N_{soil\_now} - N_{rot\_credit} - N_{fut\_gain\_loss} - N_{profit\_risk}$$

Point-Based	Polygon-Based VRT	Gridded VRT
Fast, easy, N recommendations either flat rate or by manual zone	Fast, powerful VR rec using user-defined management zones	Comprehensive 60x60 ft gridded VR prescriptions with unlimited geometries

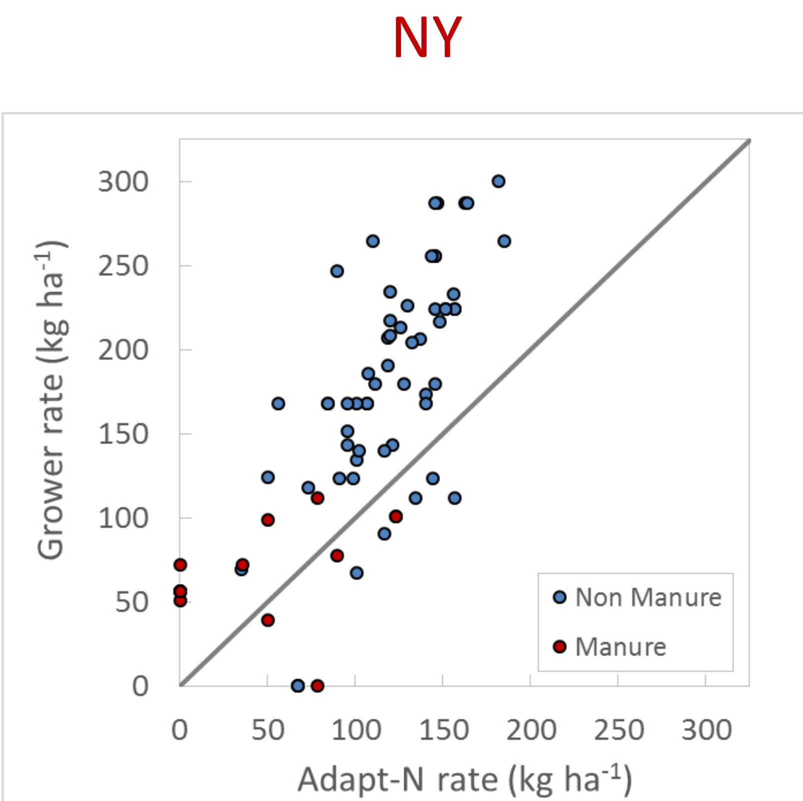
The tool was independently evaluated in multiple studies

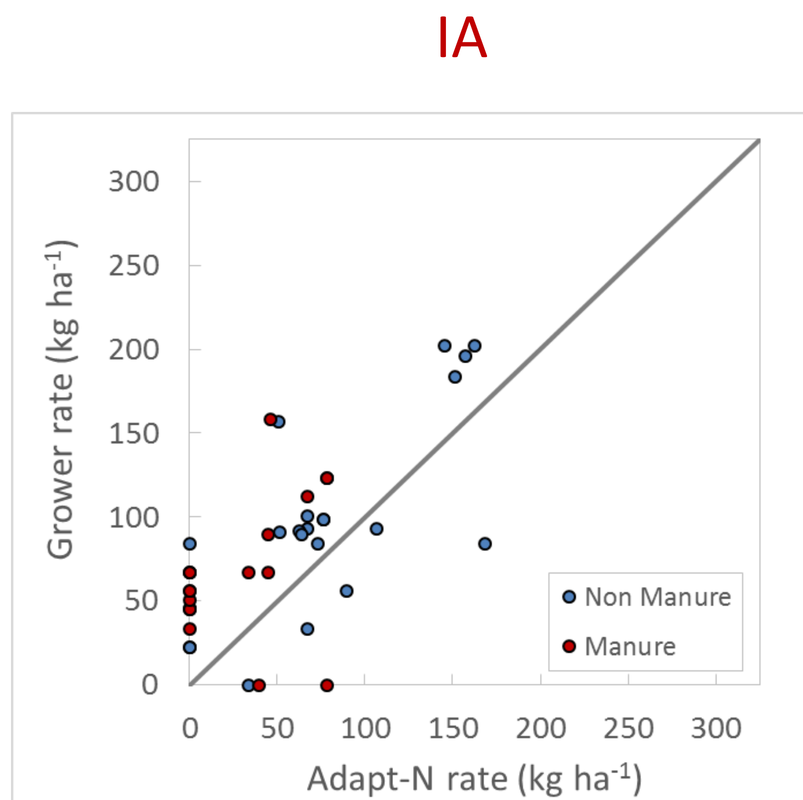
- 113 paired field strip trials (2011-2014)
- Each trial had 2-7 replications
- In each trial, the sidedress rates were:
  - (i) the Adapt-N recommendation
  - (ii) a Grower-selected rate



Sela et al. 2016 , *Agronomy Journal*

Results – applied N rates

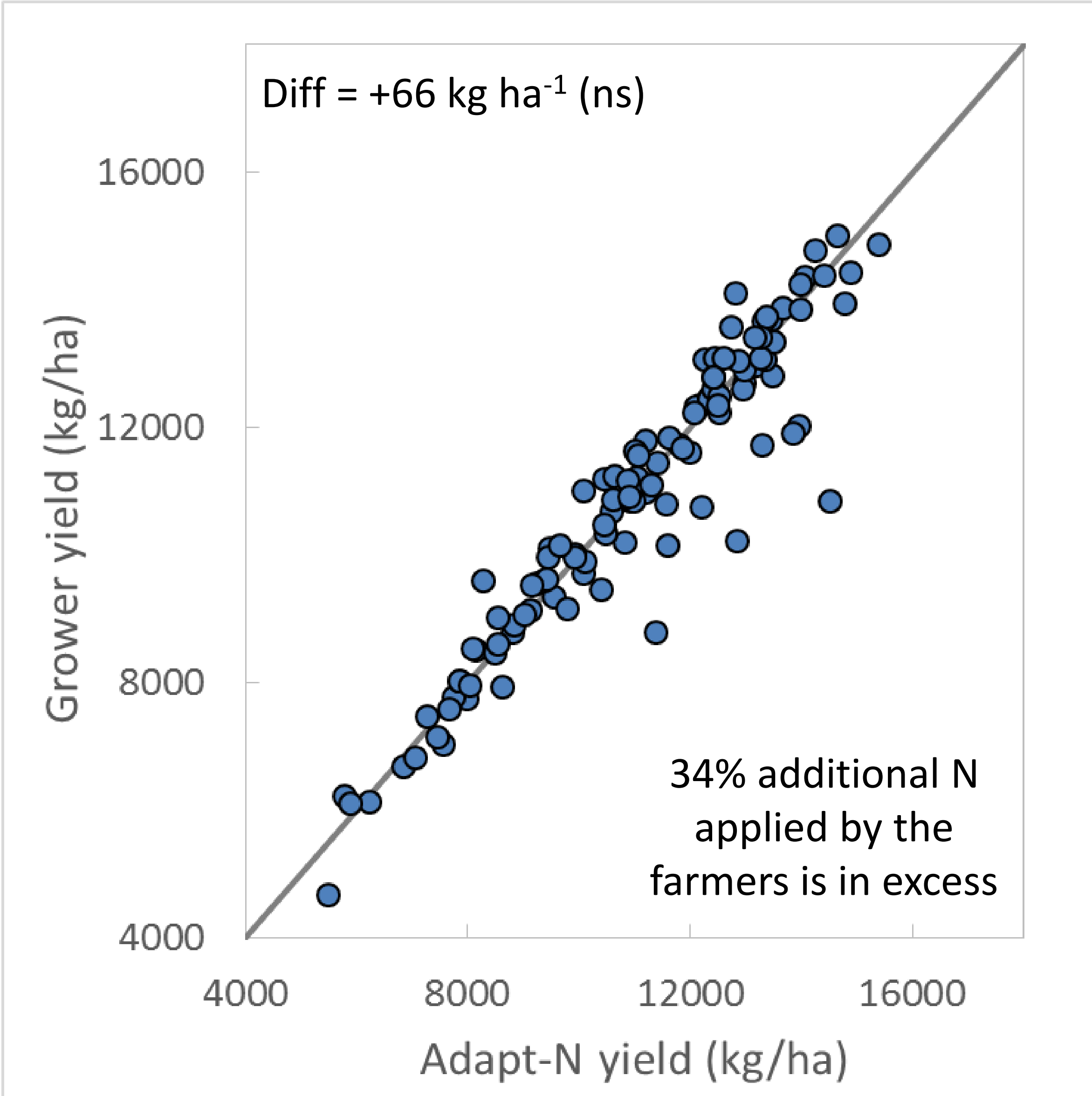




In 83% of all 113 trials the Adapt-N tool recommended lower N application than the respective Grower rate, an average reduction of 45 kg ha^{-1} (34%)

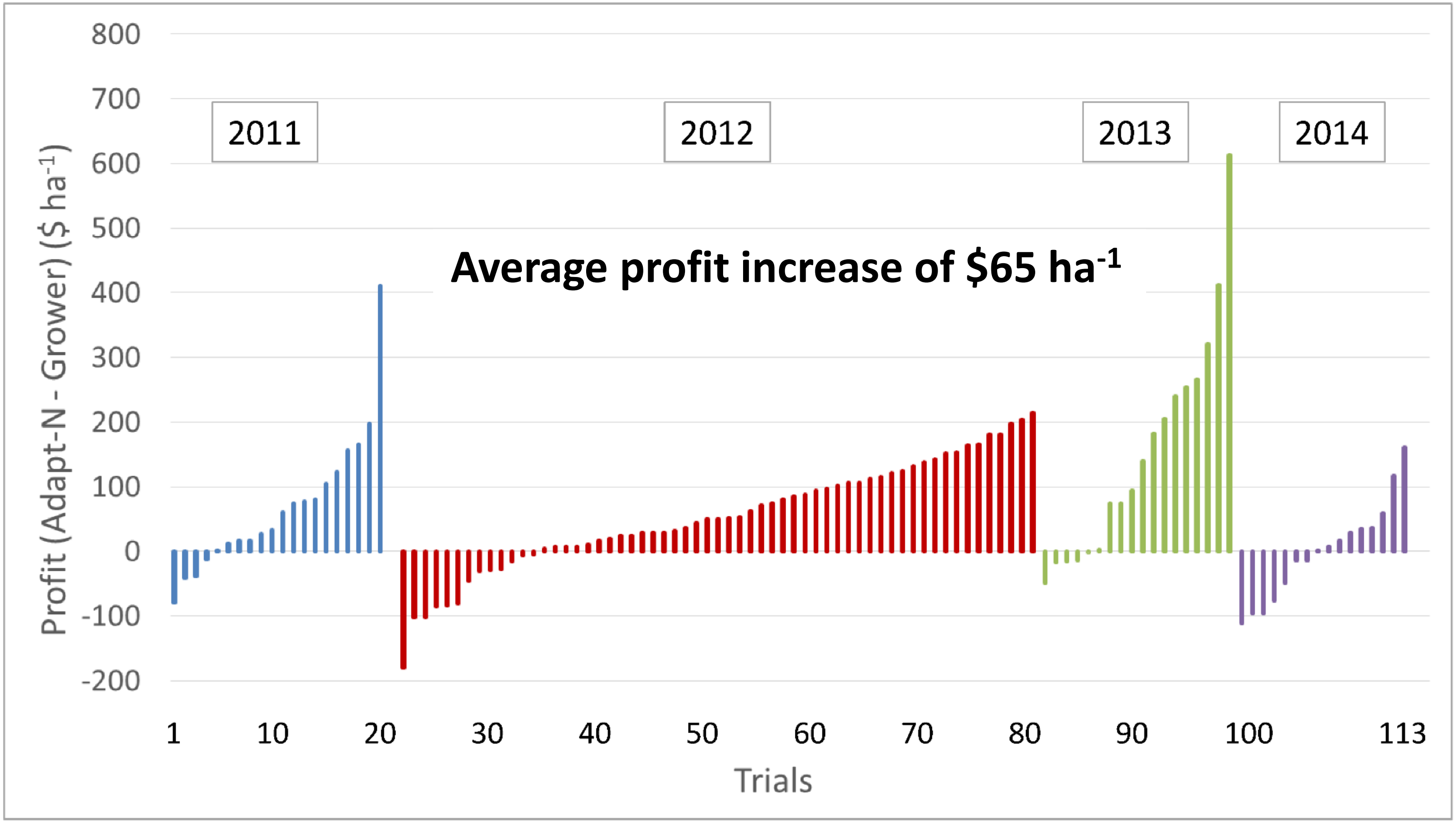
Sela et al. 2016 , *Agronomy Journal*

Results – measured yield



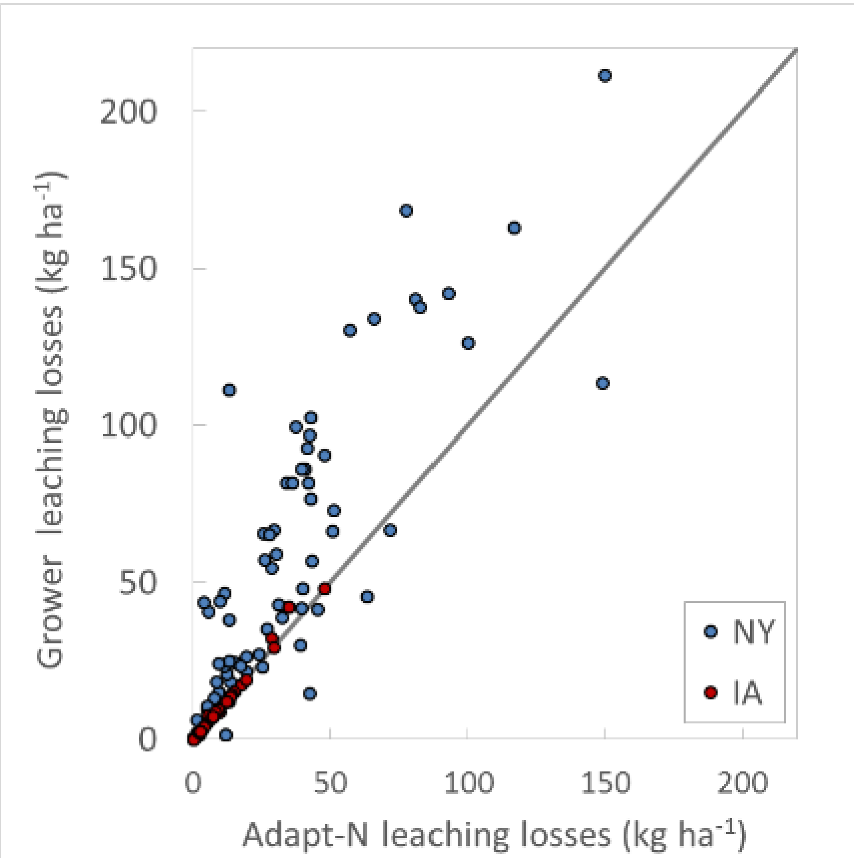
Sela et al. 2016 , *Agronomy Journal*

Adaptive approach allows a win-win situation for both growers and the environment

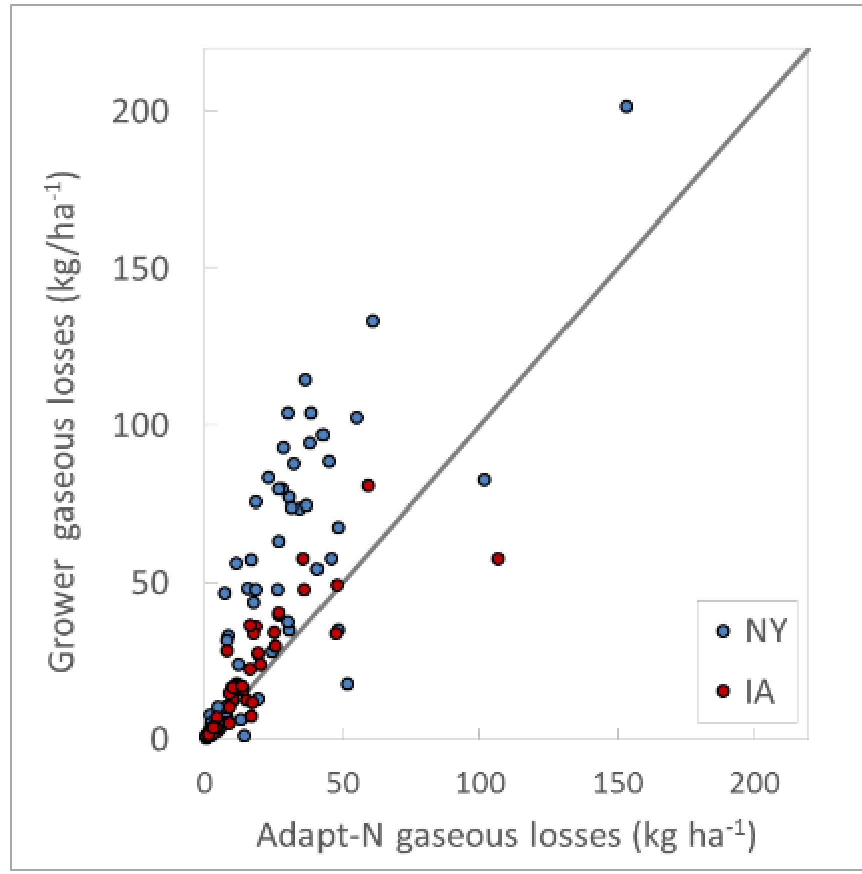


Sela et al. 2016 , *Agronomy Journal*

Simulated environmental losses



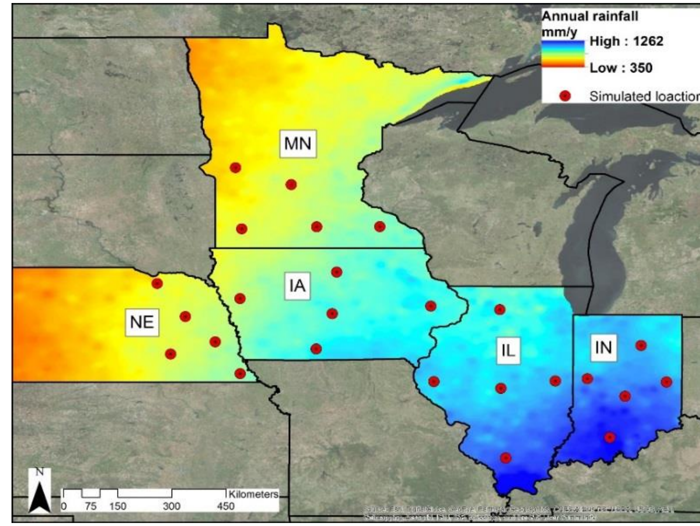
An average reduction of 14.3 kg ha^{-1} (36%) in simulated leaching losses



An average reduction of 13.5 kg ha^{-1} (39%) in simulated gaseous losses

Sela et al. 2016 , *Agronomy Journal*

Without yield reduction, what are achievable N balance targets in the US Midwest?



5 states : **NE, IA, MN, IL, IN**

5 **locations in each state**

3 types of soil texture:
Sandy loam, Loam, Silty clay loam

7 seasons: **2010-2016**

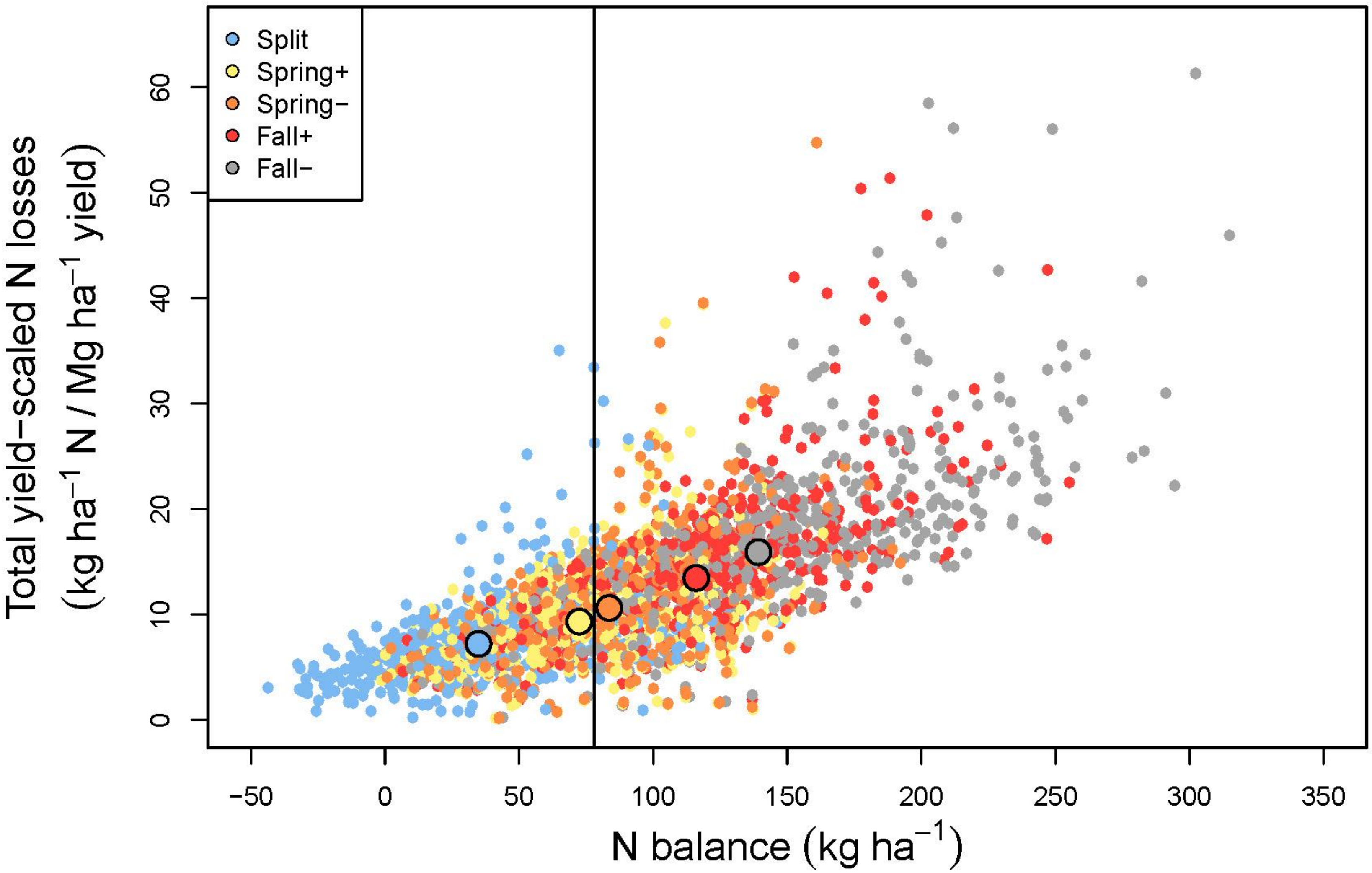
3 timings of N application **– Fall, Spring, split**

With or without nitrapyrin

N deficiencies were minimized -
always supplied enough N through sidedress

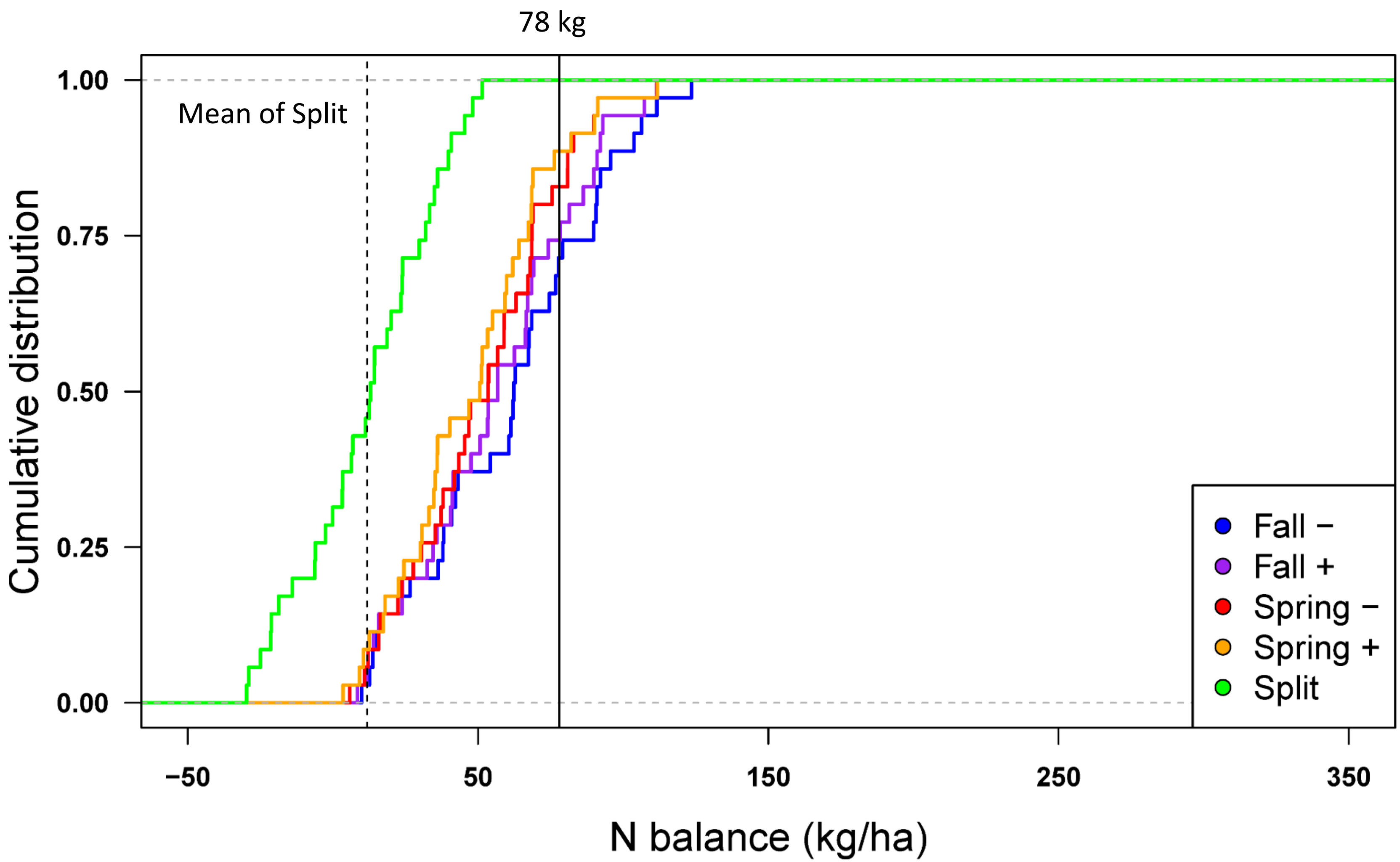
Applying N in better synchronization with crop N uptake substantially reduces N balance and N losses

78 kg/ha sustainable production threshold (Zhang et al. 2015)



Sela et al., *ERL*, Under review

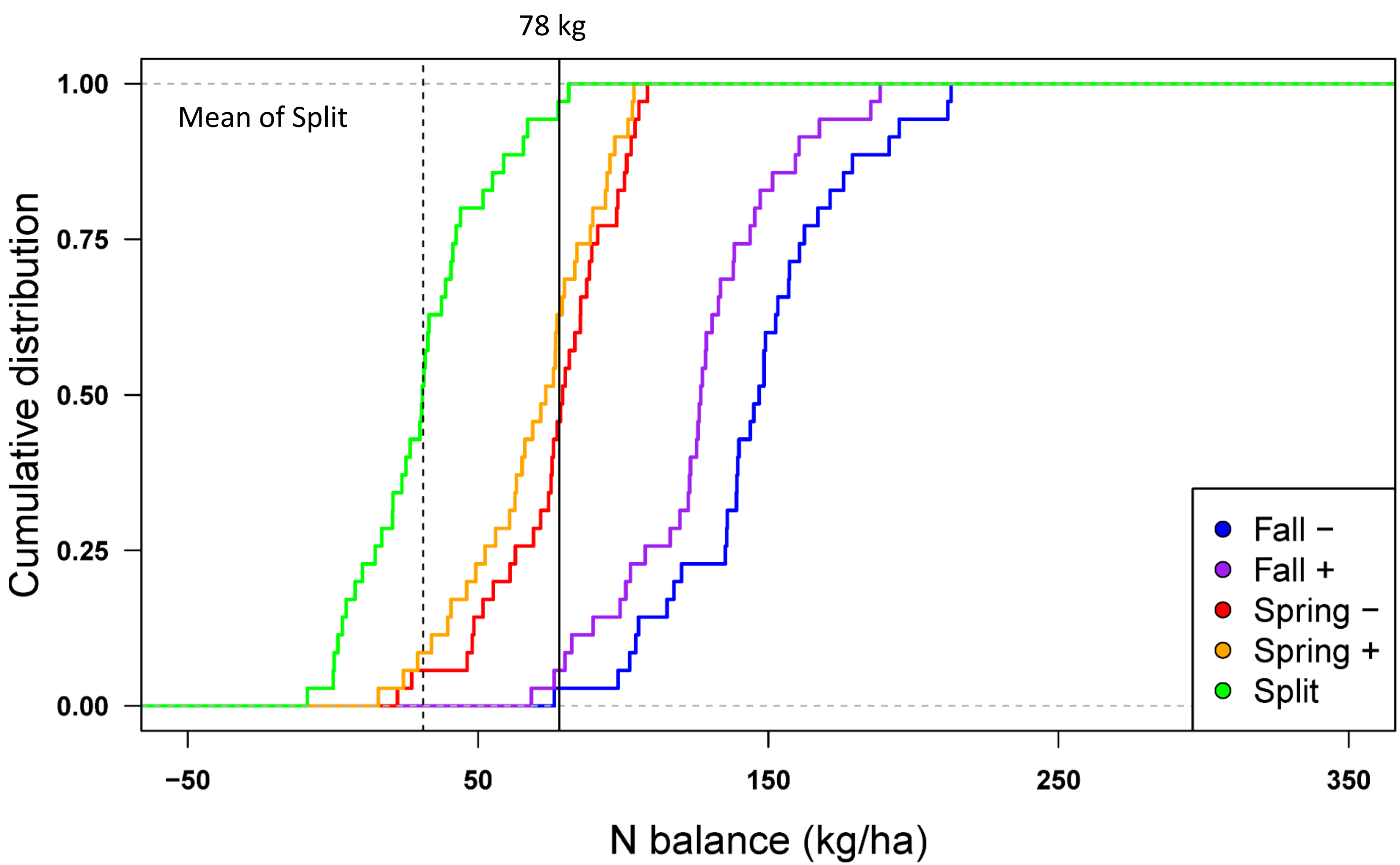
In dryer climates environmental targets could be met with pre-plant applications



Loam – Nebraska – 751 mm/y

Sela et al. , *ERL*, Under review

In wetter climates you really need to go in-season in order to meet environmental targets



Loam – Illinois – 1000 mm/y

Sela et al. , *ERL*, Under review

Established efficiency criteria for different regions and soil types

Iowa

Soil texture	Scenario	Total N applied	N balance
		-------------- kg ha^{-1}--------------	
Sandy loam	Fall -	285.4 (57.2)	172.5 (50.9)
	Fall +	243.9 (36.5)	124.4 (41.3)
	Spring -	221.2 (24.2)	100.8 (39.0)
	Spring +	213.9 (9.7)	87.7 (34.8)
	Split	172.6 (18.3)	46.1 (34.4)
Loam	Fall -	276.4 (64.4)	139.4 (63.7)
	Fall +	260.1 (52.6)	120.3 (56.1)
	Spring -	224.7 (24.7)	84.3 (39.8)
	Spring +	220.8 (18.2)	79.3 (37.7)
	Split	201.3 (22.9)	56.0 (37.0)
Silty clay loam	Fall -	269.0 (45.4)	133.6 (44.6)
	Fall +	252.4 (38.9)	116.1 (40.4)
	Spring -	222.6 (26.4)	88.6 (33.3)
	Spring +	212.8 (18.9)	77.2 (30.4)
	Split	181.4 (19.1)	44.5 (31.9)

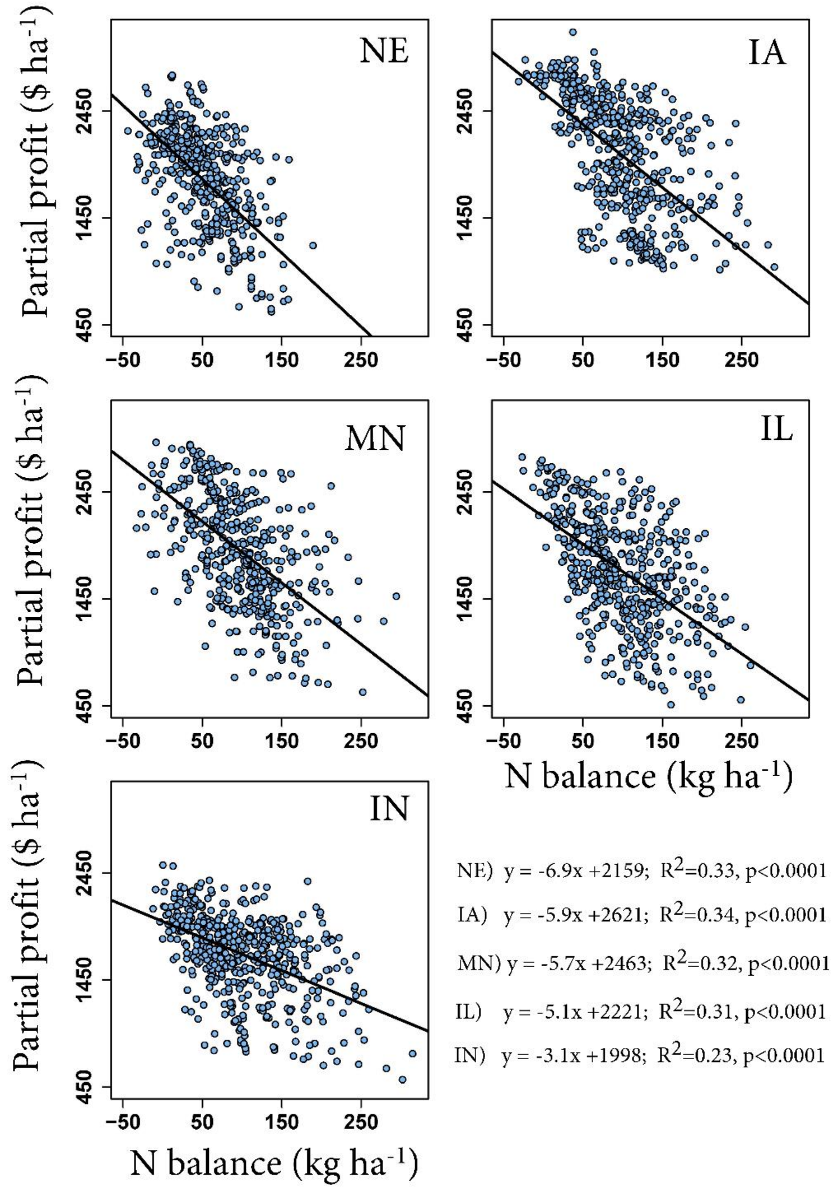
Sela et al. ERL under review

Partial profit analysis

State	Fall -	Fall +	Spring -	Spring +	Split
	------------------------------------ Partial profit $ ha^{-1}	--			
NE	1754.3 (480.2) a	1765.0 (474.4) a	1799.7 (473.1) b	1795.8 (482.7) b	1818.7 (452.0) c
IA	1943.0 (521.7) a	1991.7 (529.6) b	2056.8 (549.2) c	2081.5 (570.5) d	2135.7 (577.3) e
MN	1866.3 (511.6) a	1893.6 (510.2) b	1926.9 (507.4) c	1923.6 (517.6) c	1964.2 (534.3) d
IL	1648.2 (503.6) a	1656.2 (493.4) a	1704.9 (509.6) b	1741.6 (507.3) c	1835.2 (507.9) d
IN	1602.0 (400.4) a	1633.4 (360.8) b	1726.9 (352.2) c	1724.1 (364.9) c	1774.4 (398.0) e

- Fall preplant application have the lowest profit – but nitrapyrin shows benefits in most cases
- In 3 out 5 states adding nitrapyrin to Spring preplant leads to profit loss (*NS*)
- Changing the timing from fall to spring, and all the way in season, consistently pays off

Profit increases as N balance decreases



N balance reductions may be achieved through voluntary approaches

Summary

- New digital agriculture tools (here: a dynamic-adaptive model) allow for the integrated use of the 4R approach.
- Model-based recommendations greatly improve N use efficiency.
- Changing timing of application is more efficient than adding nitrapyrin.
- Reducing N balance increases profit.
- Regionally-based N balance targets can be established and serve as a N use efficiency standards.

Thank You!

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