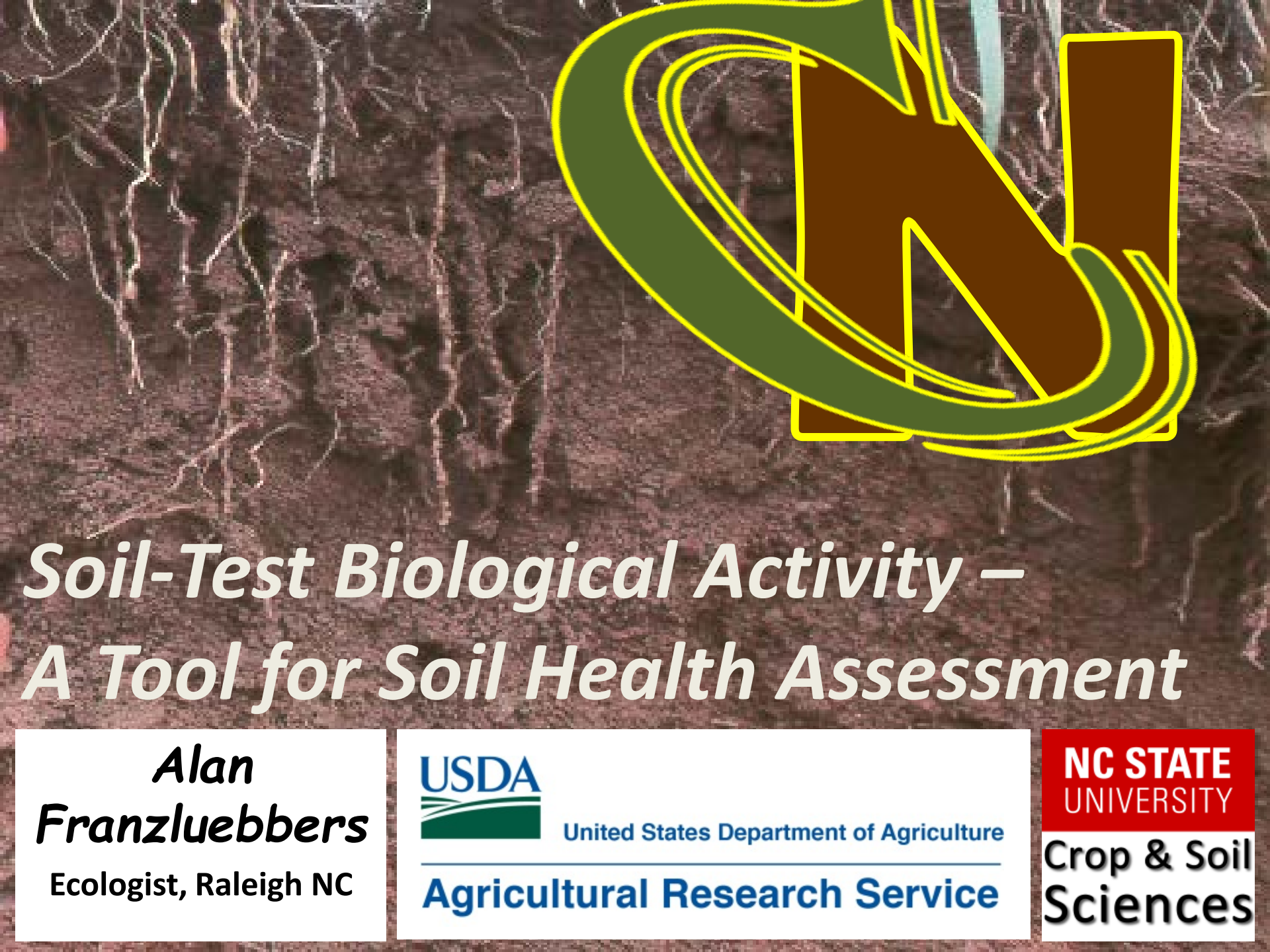


Soil-Test Biological Activity – A Tool for Soil Health Assessment

Alan Franzluebbers

Ecologist, Raleigh NC

USDA United States Department of Agriculture

Agricultural Research Service

NC STATE UNIVERSITY

Crop & Soil Sciences

“We might say that the earth has the spirit of growth; that its flesh is the soil”

– Leonardo da Vinci

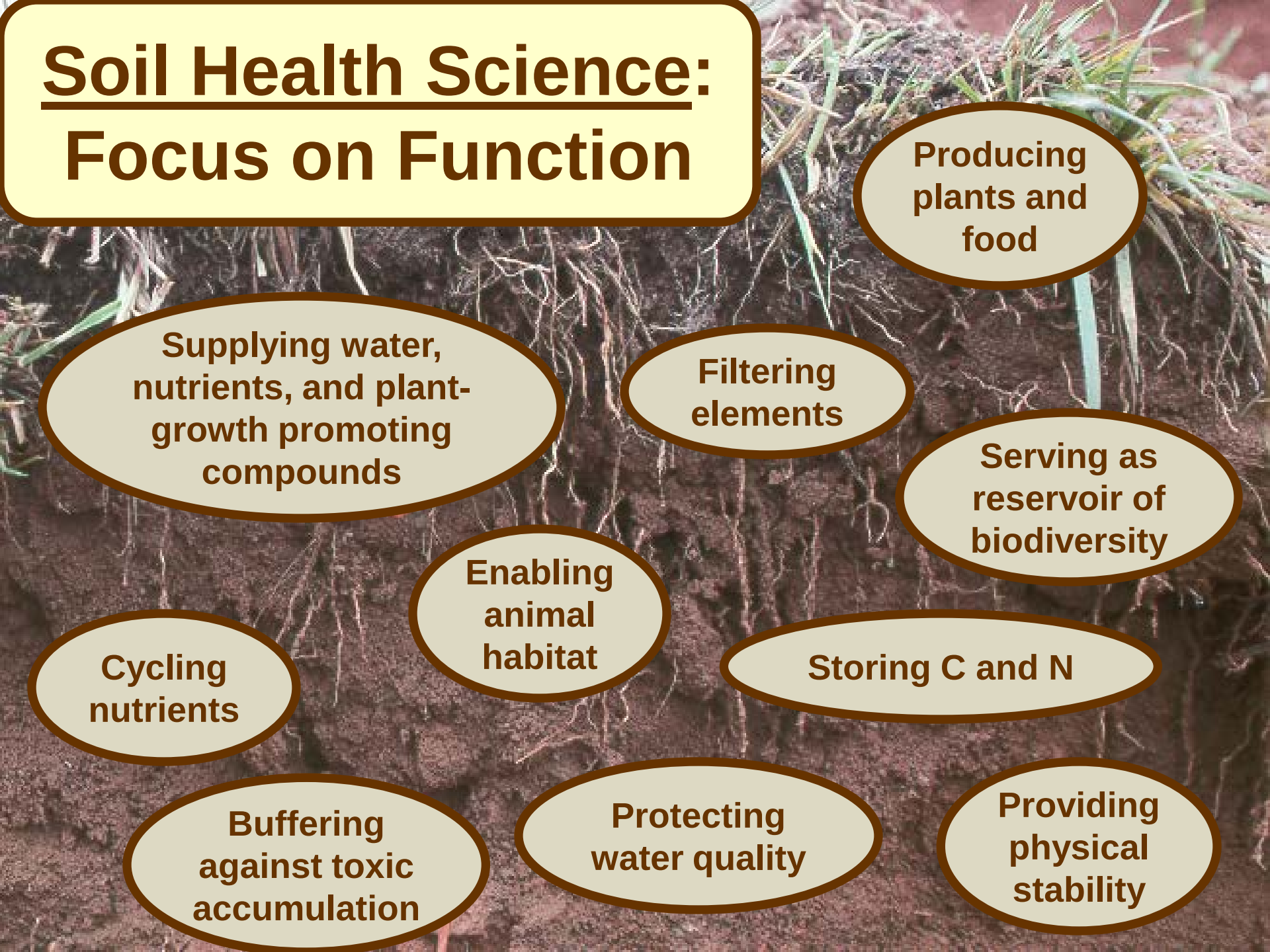
“We are part of the earth and it is part of us ... What befalls the earth befalls all the sons of the earth”

– Chief Seattle

“Essentially, all life depends upon the soil ...there can be no life without soil and no soil without life; they have evolved together”

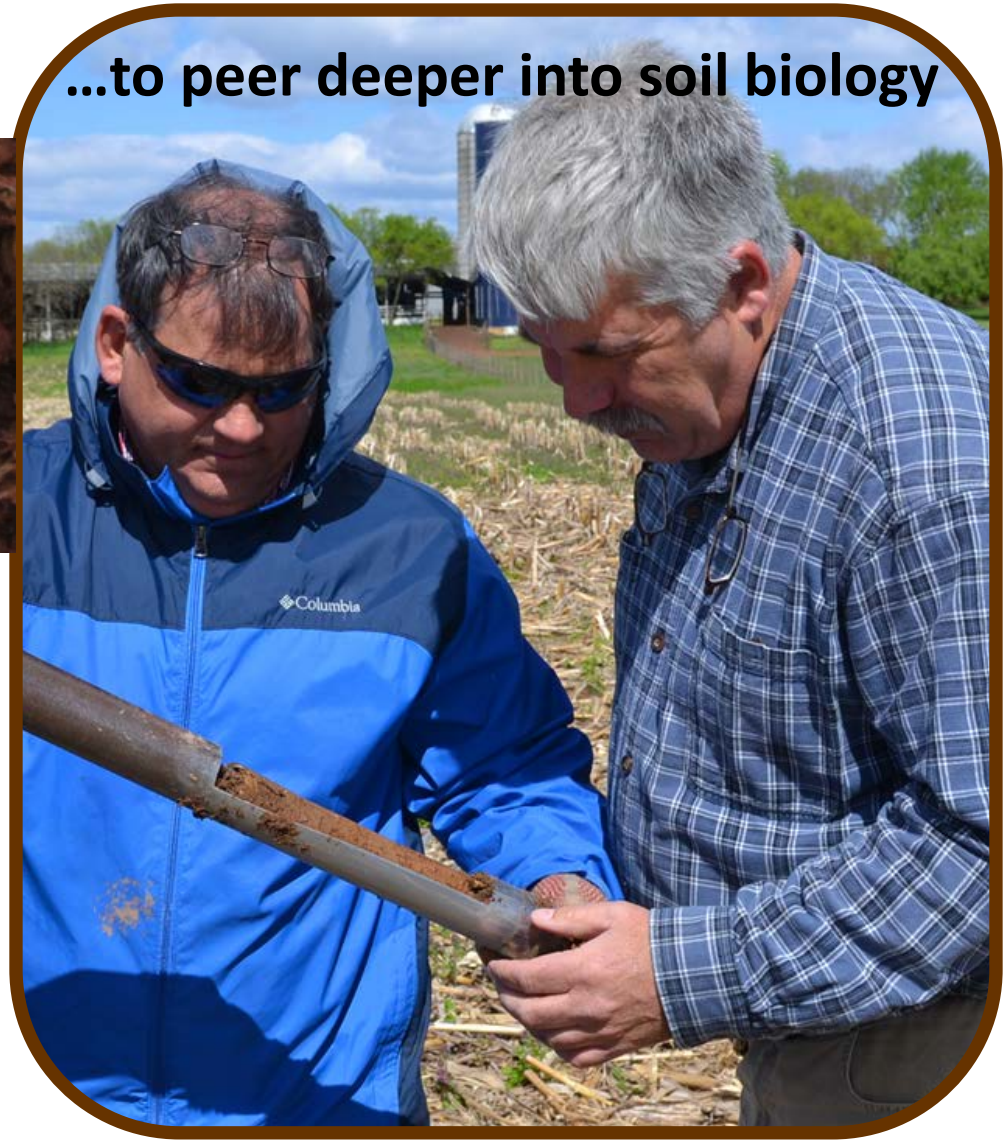
– Charles E. Kellogg

Soil Health Science: Focus on Function



Soil quality / health

Soil quality ⇨ soil health



Properties and processes that relate to soil function, including

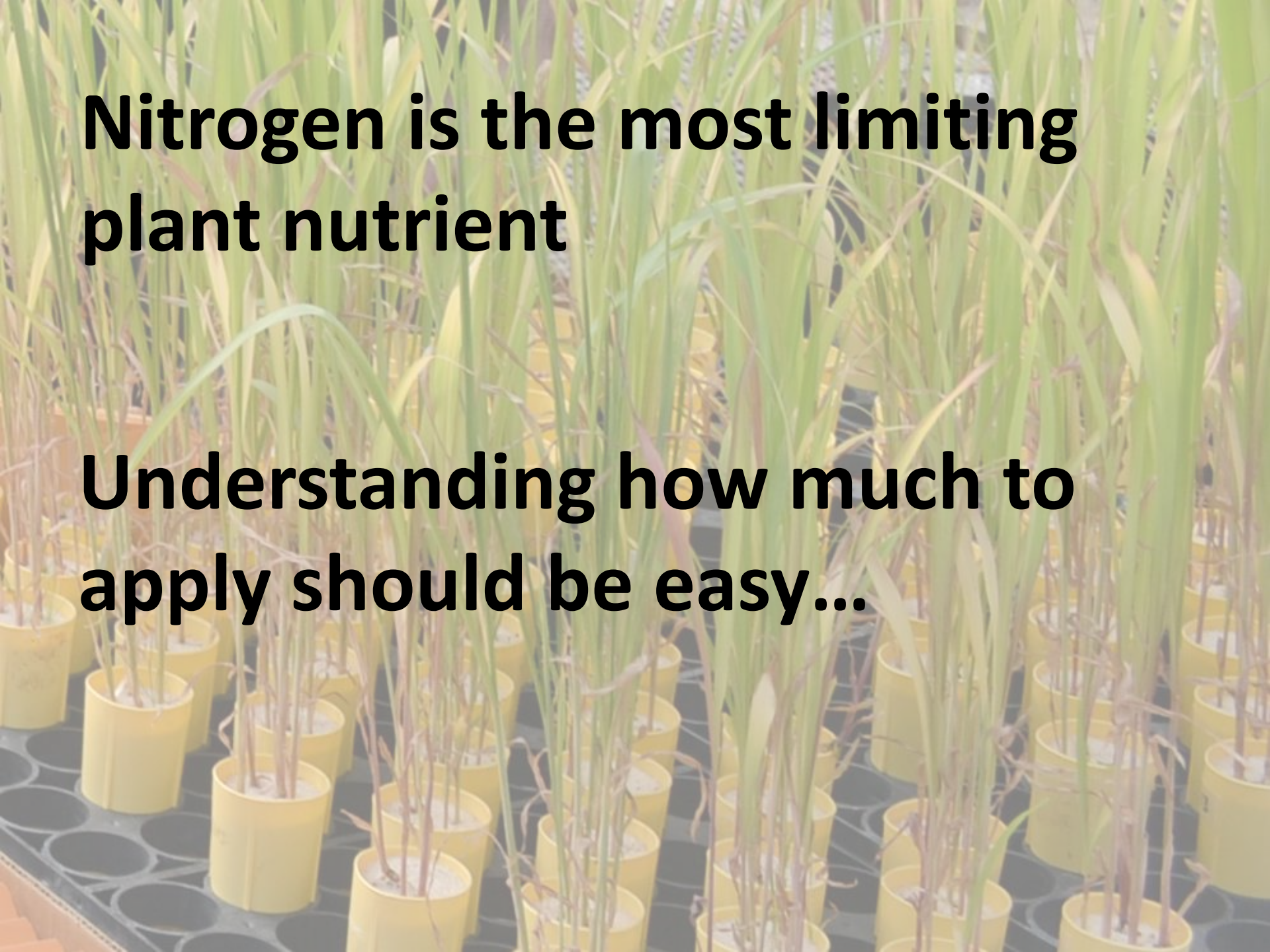
- **Decomposing organic matter**
- **Cycling water and nutrients**
- **Controlling gas emissions**
- **Harboring biodiversity**

There's a problem...

N_2O

$

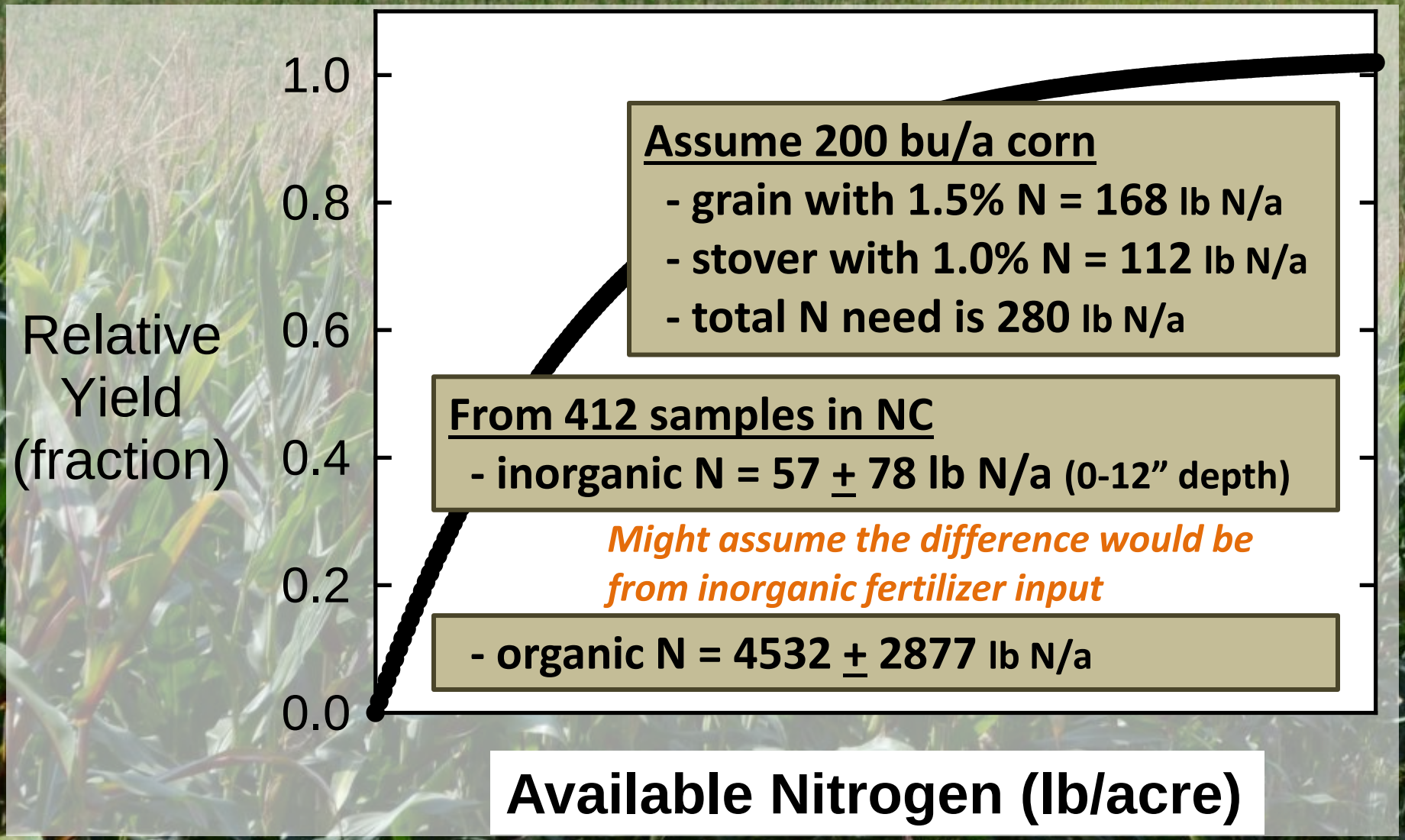
Fossil-fuel energy



Nitrogen is the most limiting plant nutrient

Understanding how much to apply should be easy…

The reality


Relative Yield (fraction)
1.0
0.8
0.6
0.4
0.2
0.0
Assume 200 bu/a corn
- grain with 1.5% N = 168 lb N/a
- stover with 1.0% N = 112 lb N/a
- total N need is 280 lb N/a
From 412 samples in NC
- inorganic N = 57 ± 78 lb N/a (0-12" depth)
Might assume the difference would be from inorganic fertilizer input
- organic N = 4532 ± 2877 lb N/a
Available Nitrogen (lb/acre)

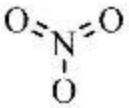
Nitrogen availability to crops

Fertilizer –>

Surface

Surface-soil inorganic N

1’ depth



Deep-profile residual inorganic N

2’ depth

3’ depth

4’ depth

Mineralizable nitrogen

a.ka. biologically active nitrogen

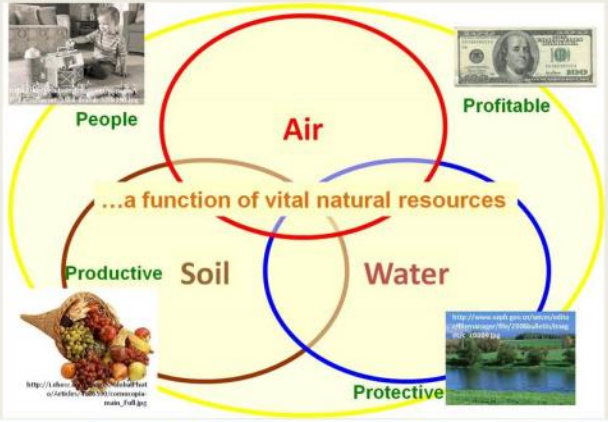
Loss mechanisms
- Runoff
- Leaching
- Volatilization
- Denitrification

Additional inputs
- Biological N fixation
- Compost
- Precipitation / dust
- Irrigation water

Limits to availability
- Soil temperature
- Soil moisture
- Root accessibility
- Binding to clays
- Binding to organic matter

Agriculture faces a dilemma

How to balance food production with environmental quality?

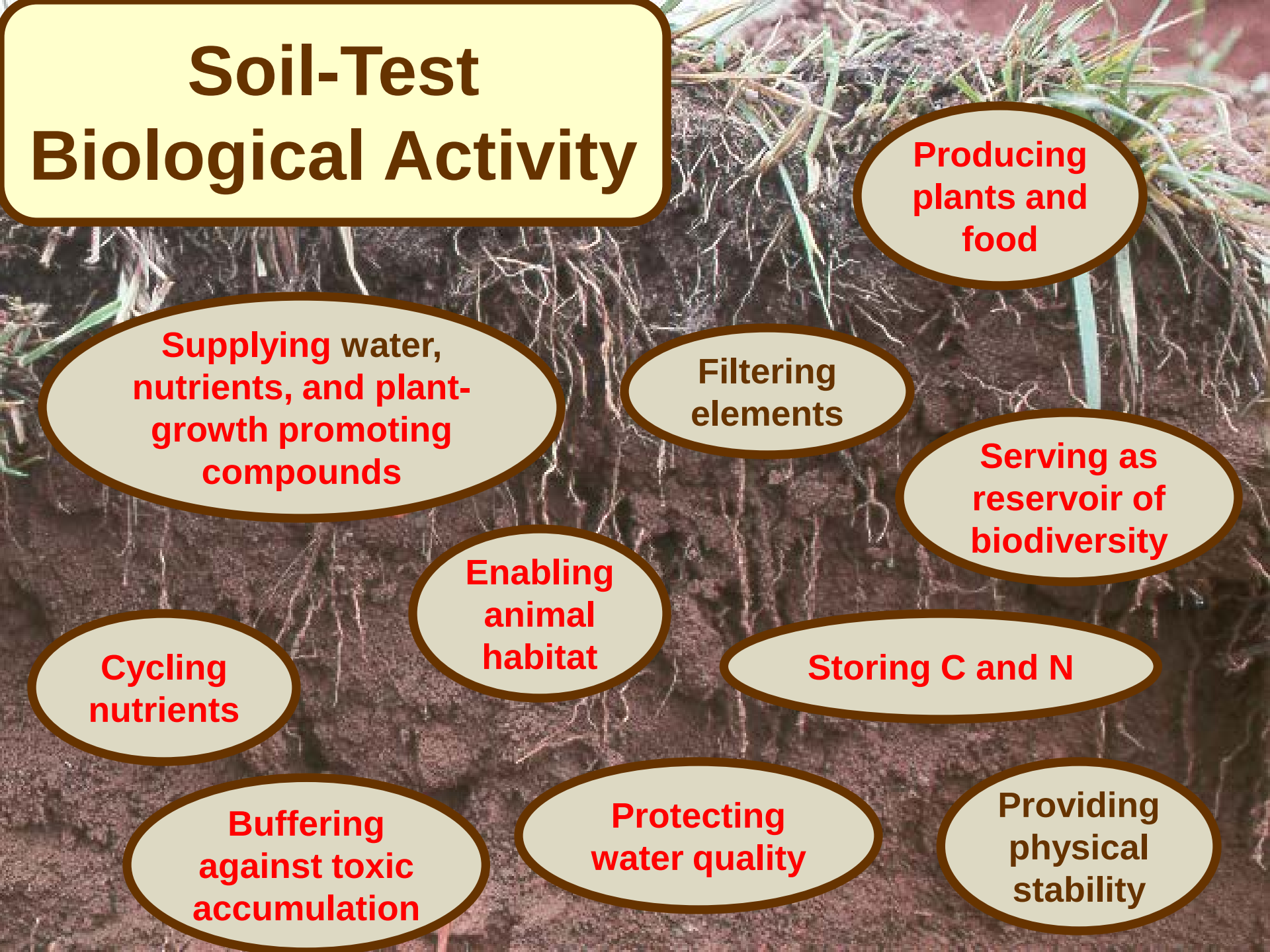


There's a problem...

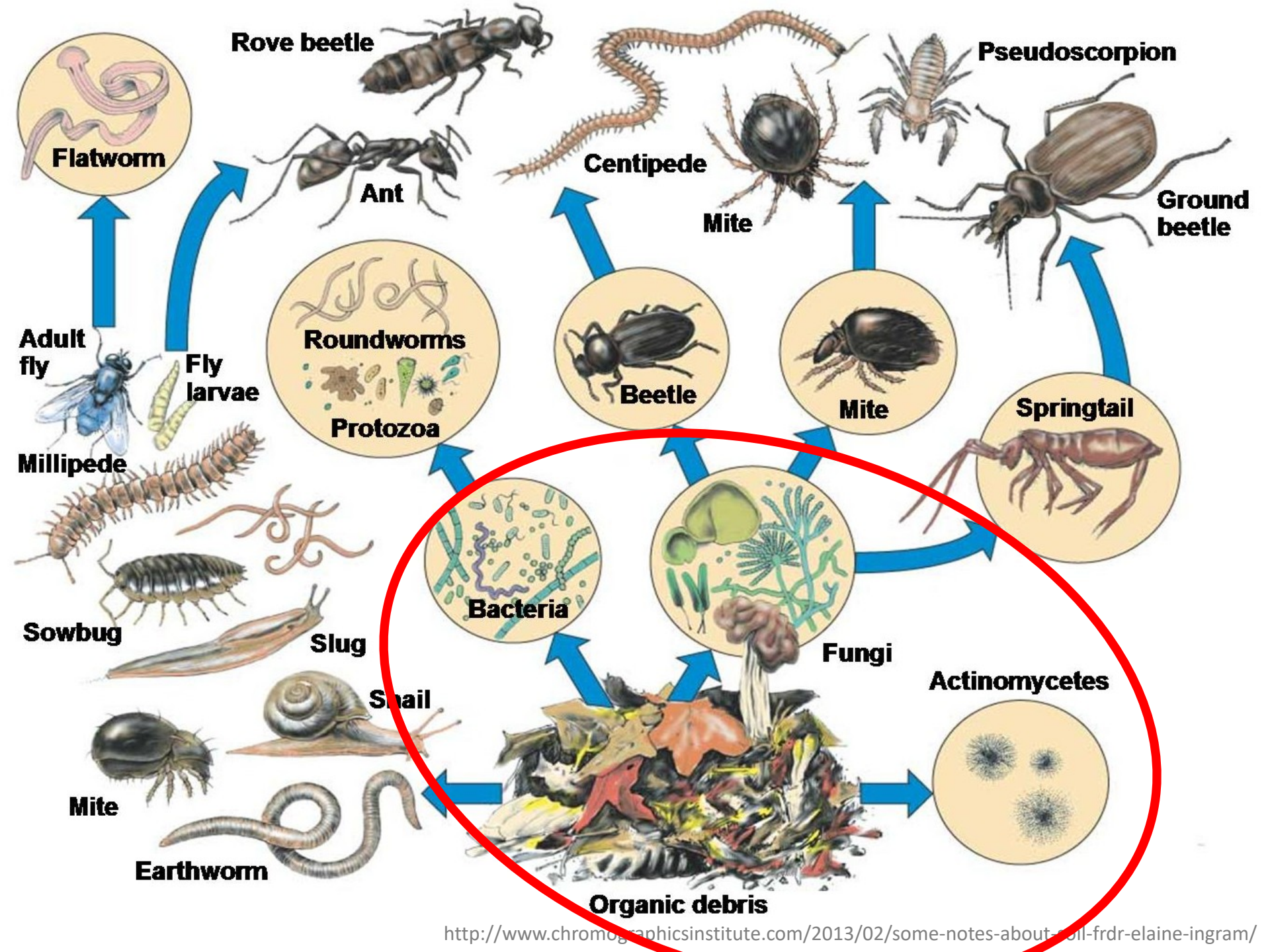
N_2O

$

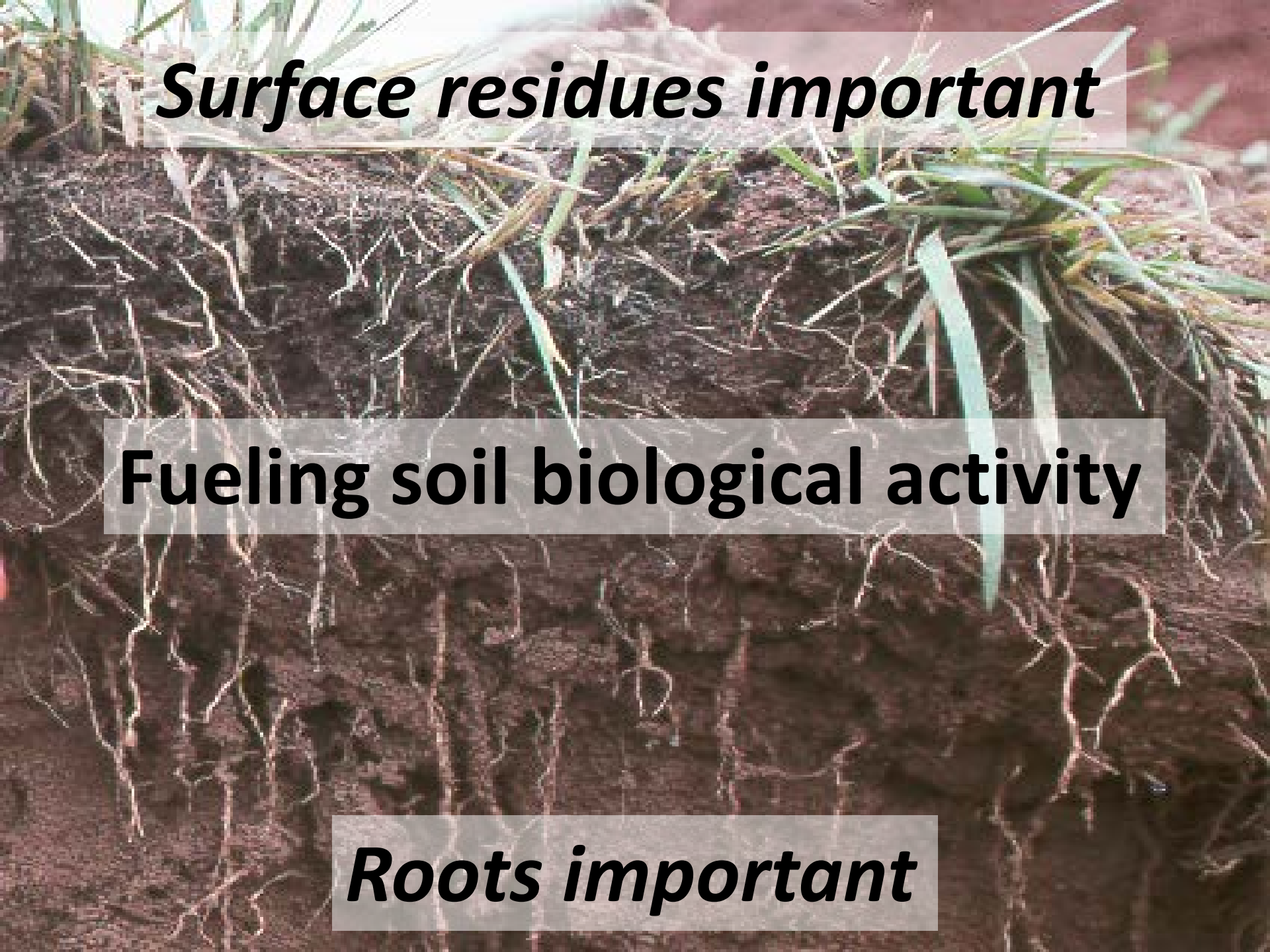
Fossil-fuel energy


Soil-Test Biological Activity
Producing plants and food
Supplying water, nutrients, and plant-growth promoting compounds
Filtering elements
Serving as reservoir of biodiversity
Enabling animal habitat
Cycling nutrients
Storing C and N
Buffering against toxic accumulation
Protecting water quality
Providing physical stability

What is soil biology



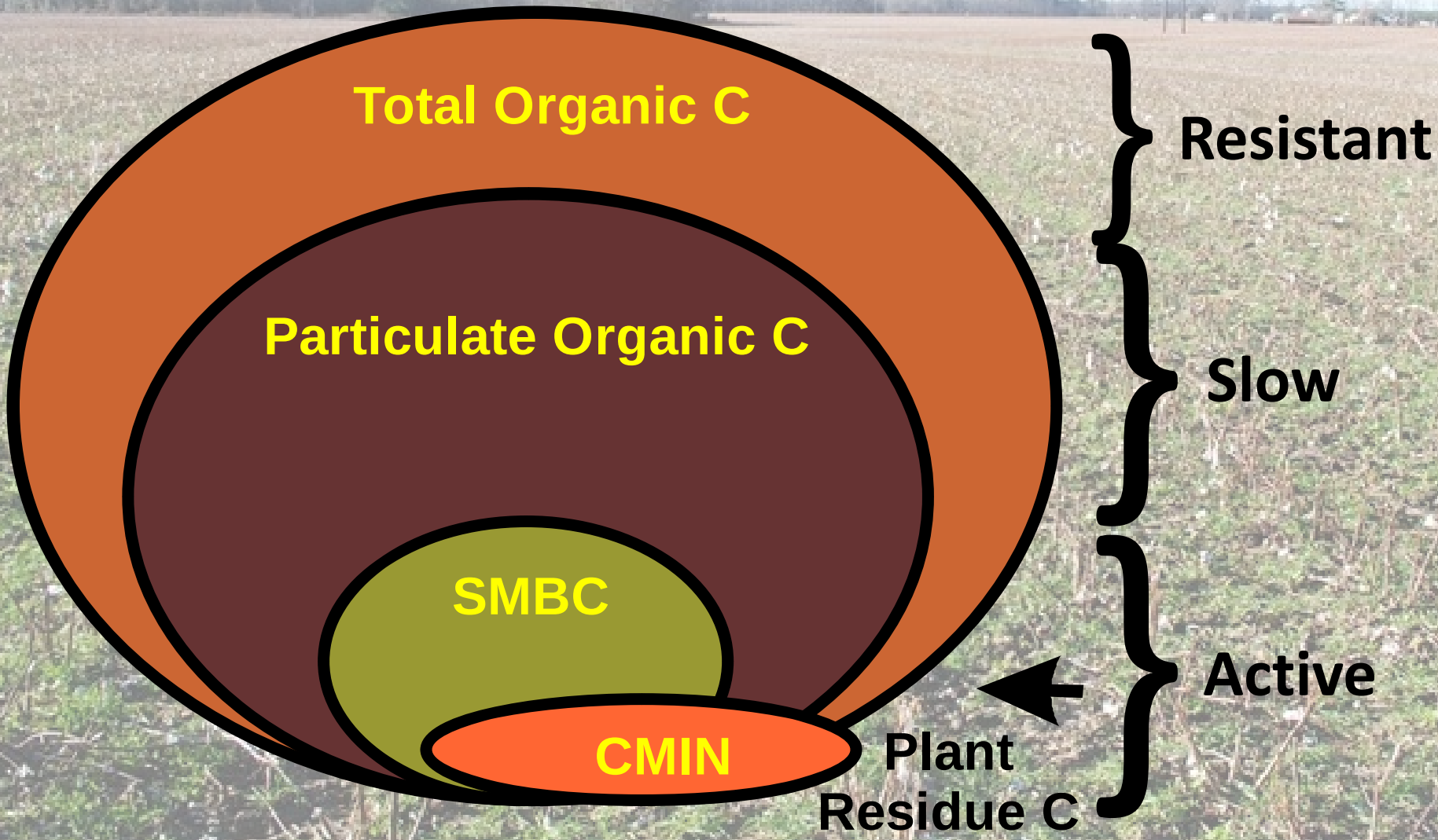
http://www.chromographicsinstitute.com/2013/02/some-notes-about-soil-frdr-elaine-ingram/


Surface residues important
Fueling soil biological activity
Roots important

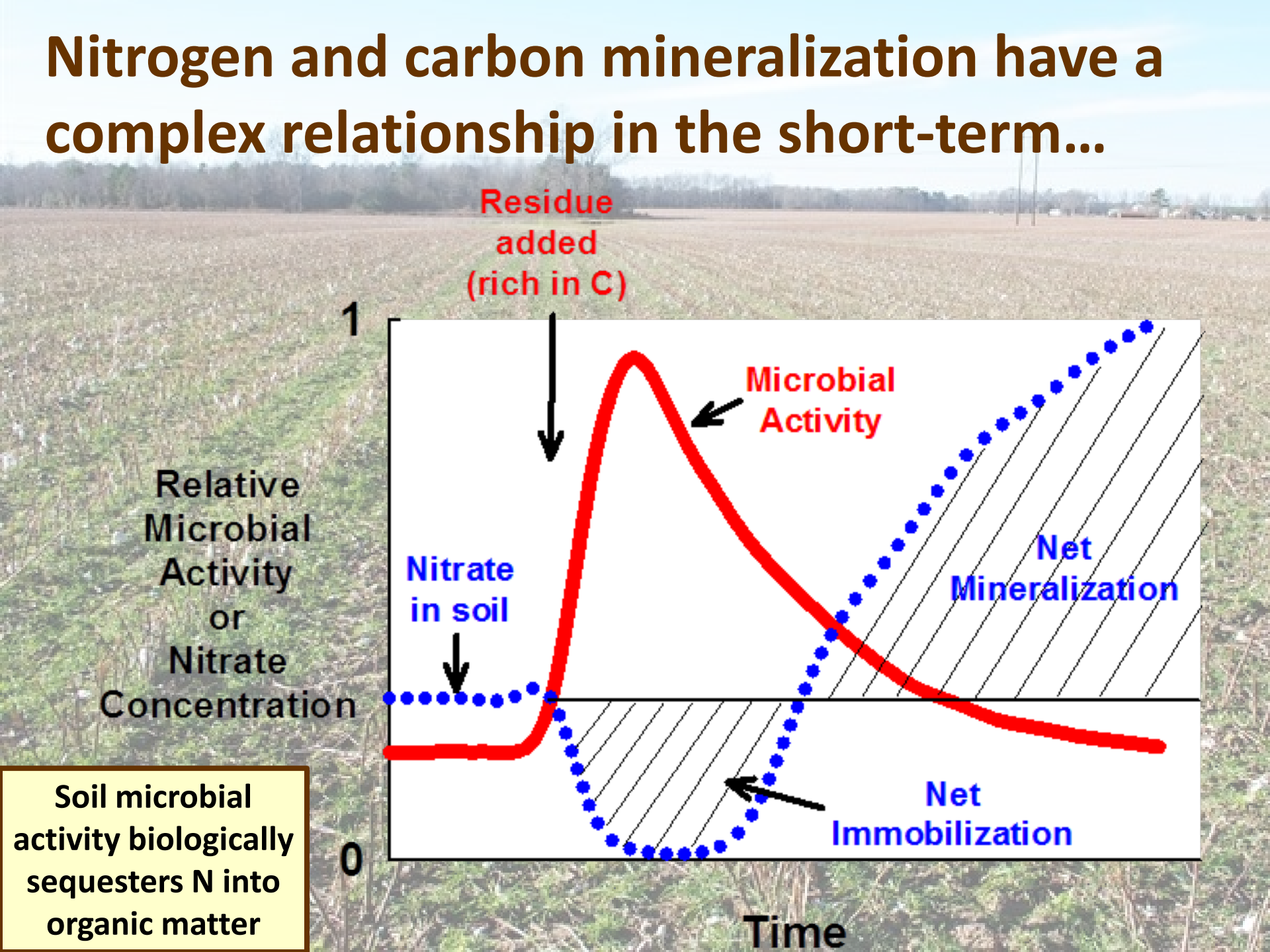
What do soil organisms need?

- ✓Suitable habitat
  - Something to hold onto
  - Water
  - Oxygen
  - Balanced pH
- ✓Carbon sources to consume
- ✓Access to nutrients

Fractions of soil organic carbon

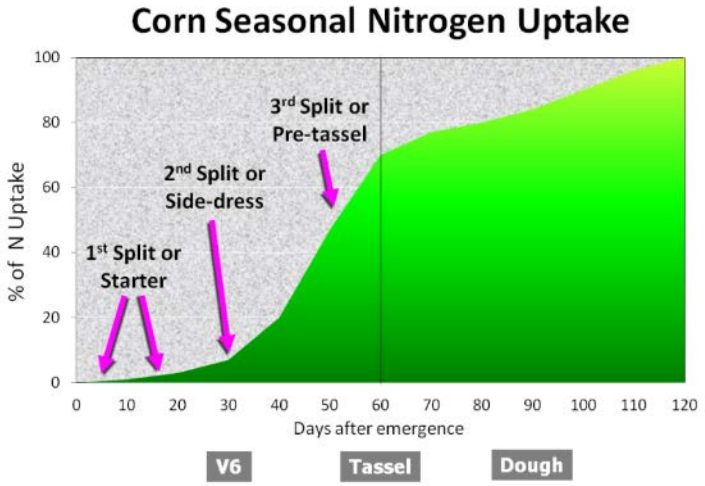


Nitrogen and carbon mineralization have a complex relationship in the short-term…

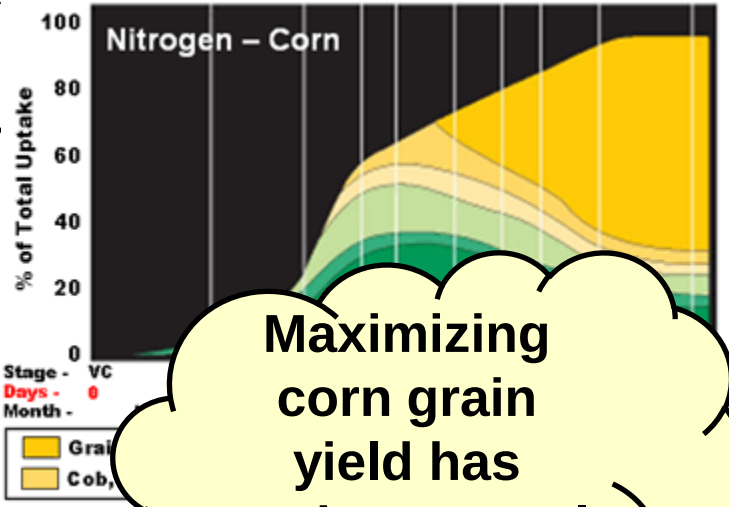


Soil microbial activity biologically sequesters N into organic matter

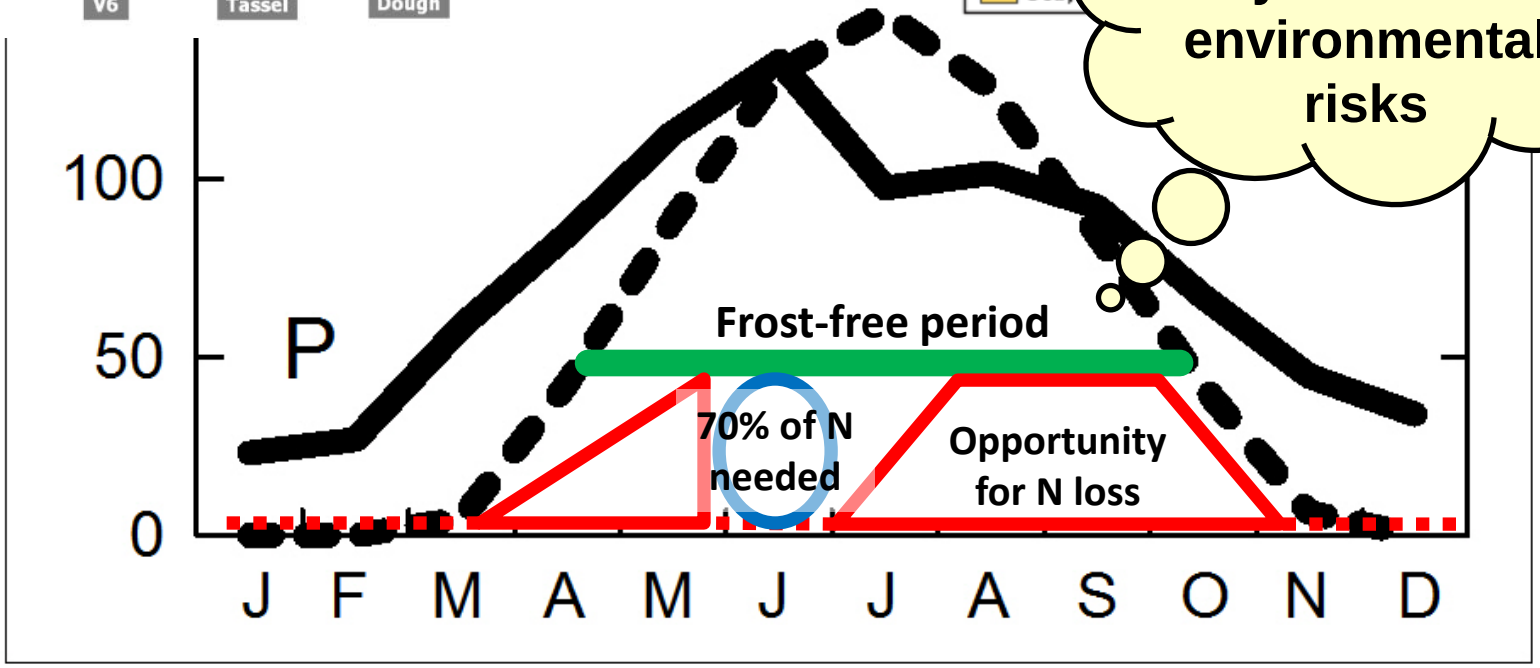
The narrow window of opportunity…



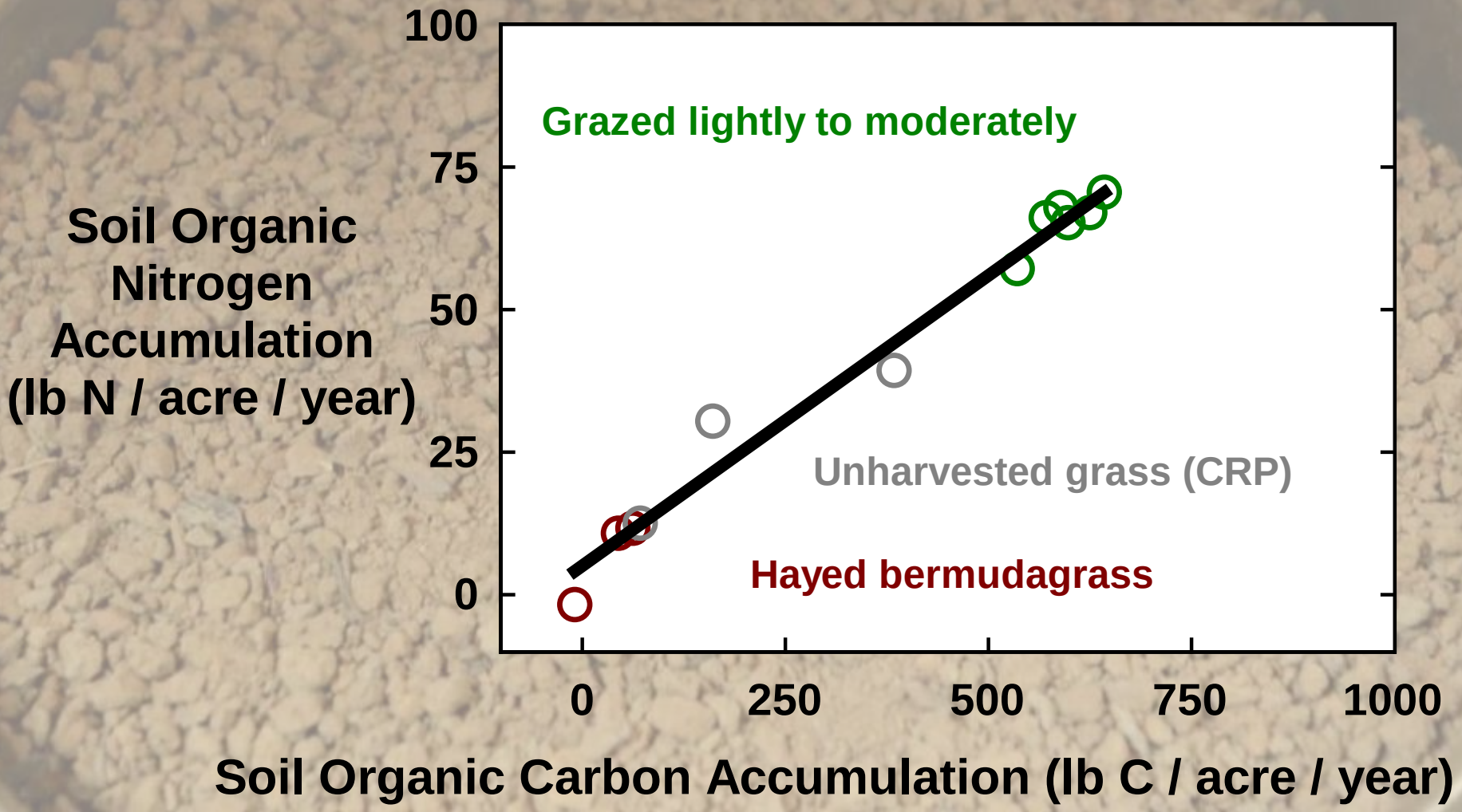
9 °W



Maximizing corn grain yield has environmental risks



Soil organic C and N are closely associated in the long- term

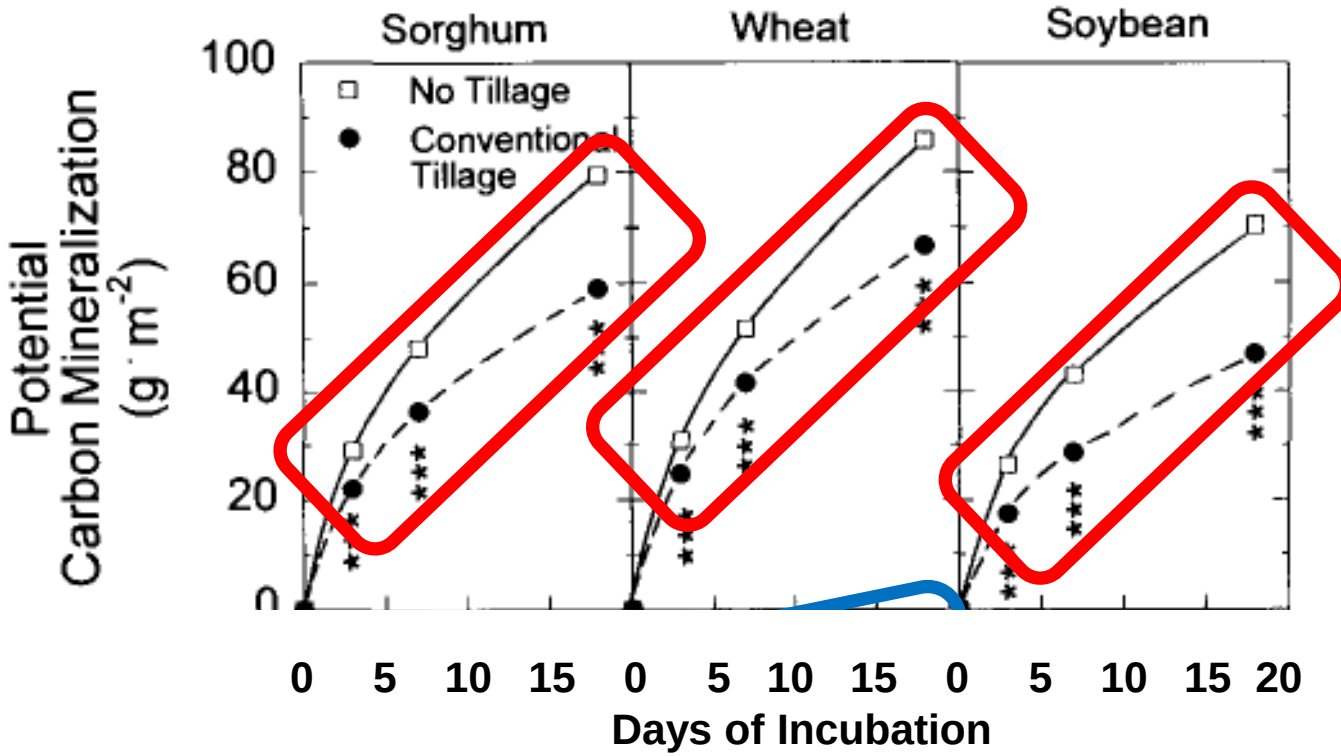


Franzluebbers and Stuedemann (2010) Soil Sci. Soc. Am. J. 74:2131-2141


Questions?

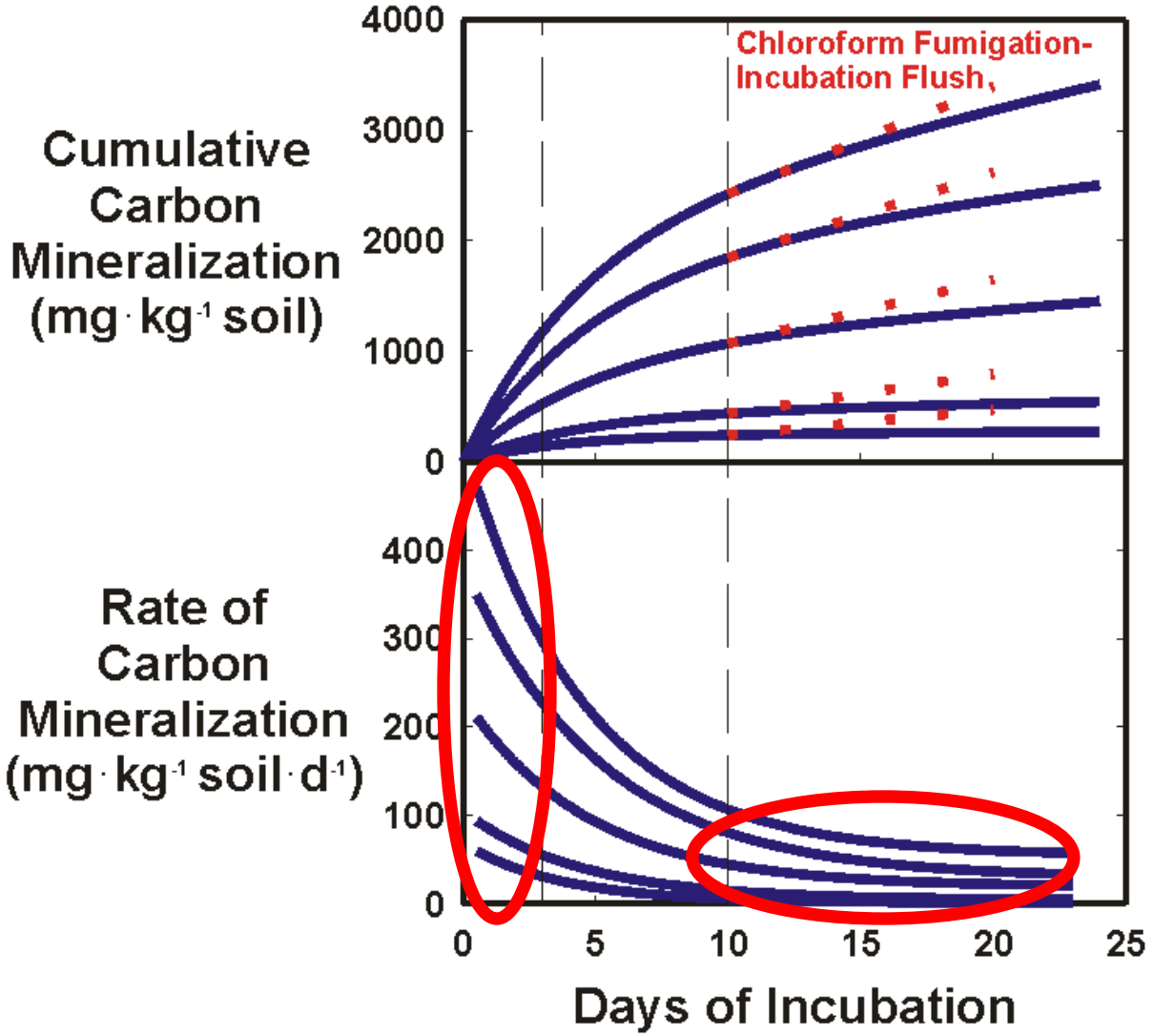
…most farm fields will be in some steady-state condition due to family-farm management

Thus, balancing the short- and long-term effects



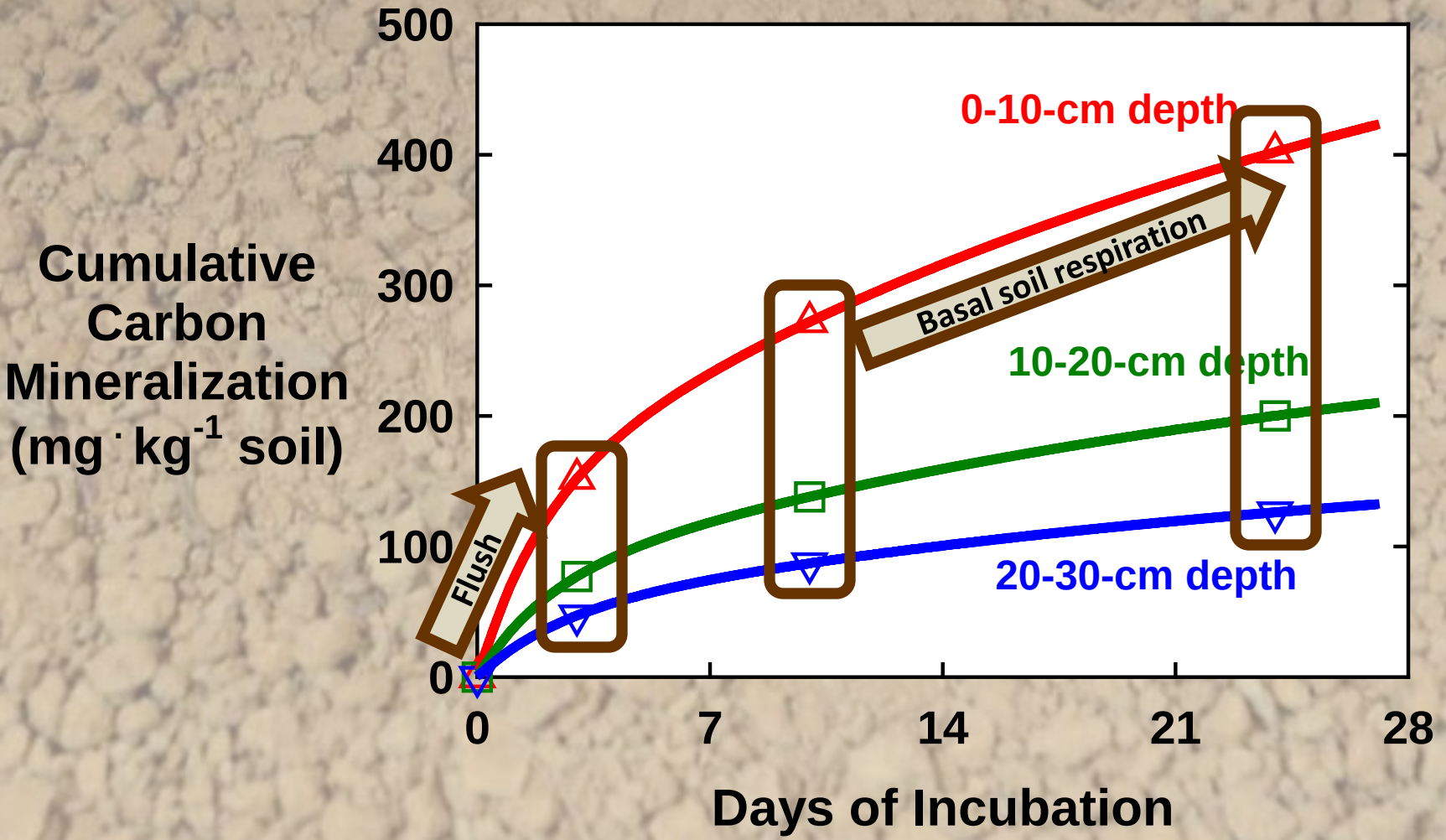
Franzluebbers et al. (1995) Soil Sci. Soc. Am. J. 59:1618-1624

Soil process relationships



Franzluebbers et al. (1999) Soil Sci. Soc. Am. J. 64:613-623

The flush of CO_2 following rewetting of dried soil



SOLVITA®

RESPIRATION TEST SYSTEMS

Soil | Compost | Manure | Grain | Blog | Store

Soil Biological Responsiveness

Test for Soil CO_2 Respiration reveals Soil Biomass and N-Mineralization Potential

A NEW CATEGORY OF SOIL TESTING

Solvita is an important new soil test which measures soil microbial respiration in a modified static-flux system.

Soil respiration represents the biological energy inherent in soil systems. While it has become customary to ignore soil biology in fertilizer and fertility budgets, this recurring cycle of respiration represents the absorption and release of massive amounts of carbon which is increasingly recognized to be tied to the productivity of flora and vegetation.

One significant form of this biology are drying and re-hydration cycles in soil which are natural events and which comprise a "biological animal" delivering soluble carbon to microbes and nutrients to growing plants. A result of testing soils with this method is to reveal the soil's underlying biological (and sustainable) yield component.

...reveals the soil's underlying biological and sustainable yield

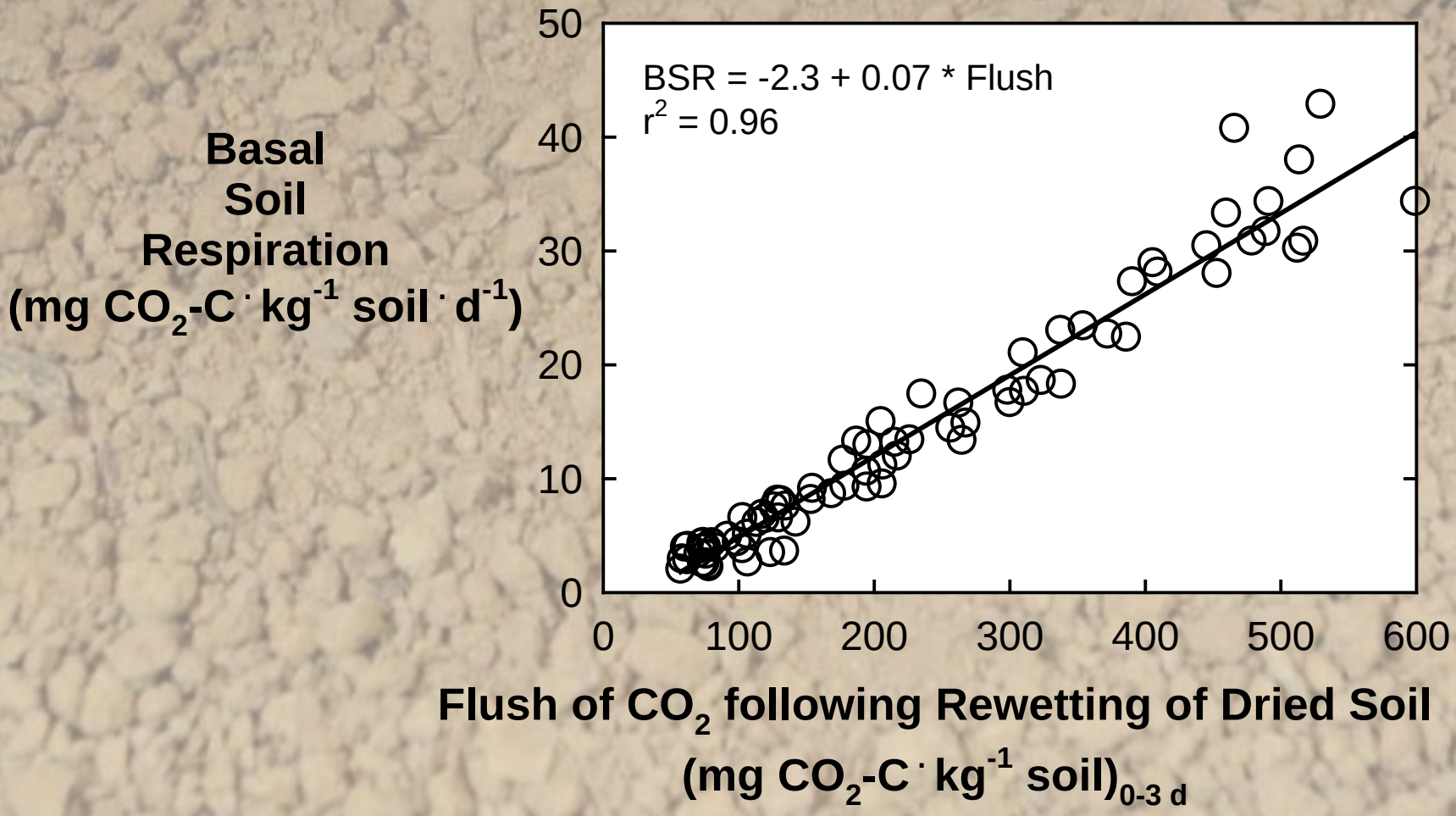
...possible to reduce nutrient inputs and improve yield sustainability

By accurately measuring the magnitude of this biological activity, soil biomass and nutrient delivery potential. By factoring this information into nutrient budgets, it is possible to both reduce chemical inputs and to improve yield sustainability - hence improve net economic yield.

Variations in protocol…

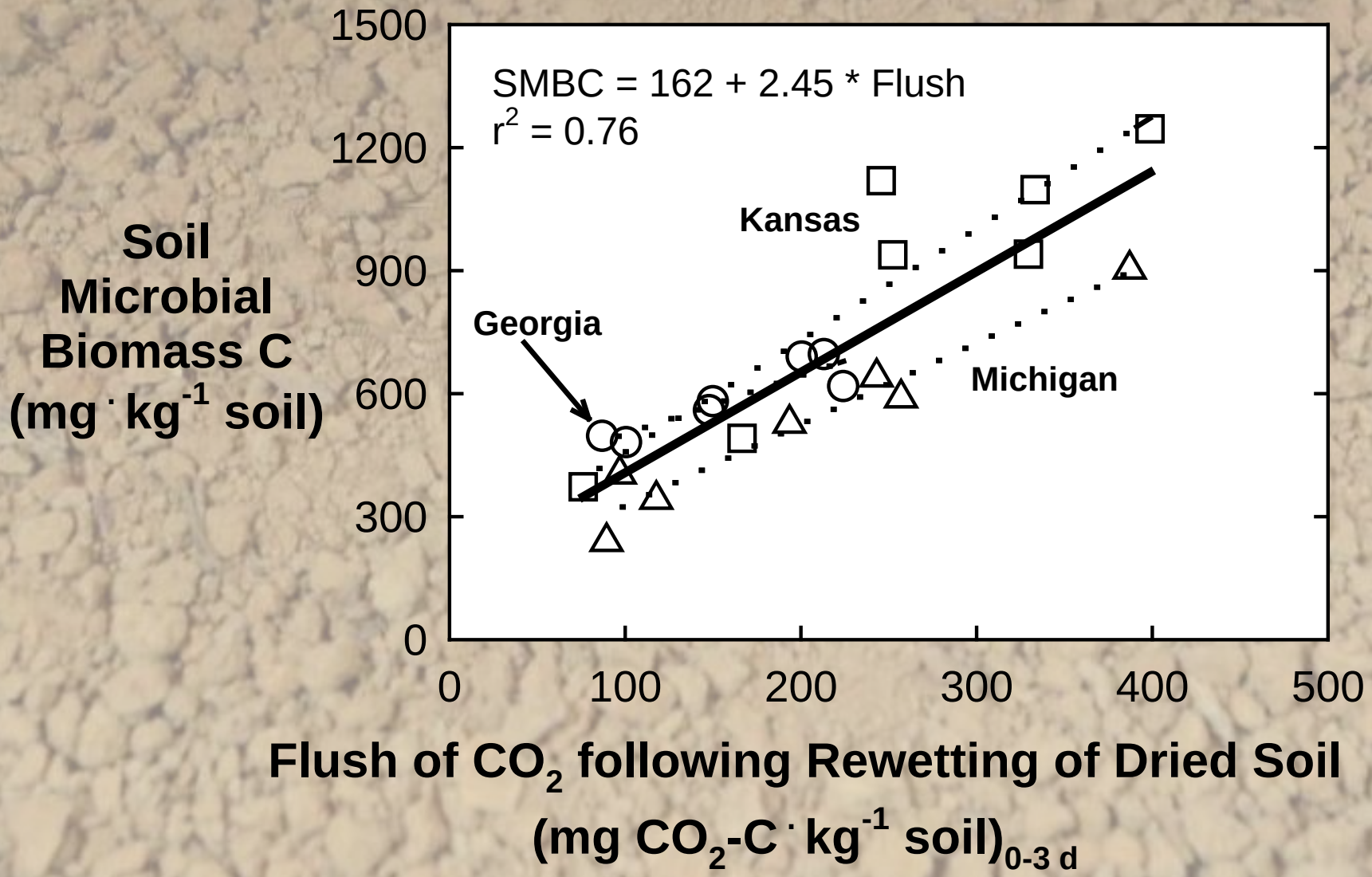
Component	Soil Ecology & Mgt NC State	Haney Soil Health Test	Solvita – Woods End	Cornell CASH
Soil processing	55 °C 3 days, sieved <4.75 mm	50 °C 1 day, sieved <2 mm	Shipped wet; dried, roller	Shipped wet; air dried, sieved <8 mm
Soil weight	Two 50-g subsamples	40 g	40 g	20 g
Water	50% WFPS in two 60 mL bottles	Capillary from bottom to saturation	From top to 50% WFPS; previously from bottom	Capillary from bottom to saturation
Incubation	3 days at 25 °C in 1-L jar	1 day at 25 °C in 0.25-L jar	1 day at room temperature in 0.25-L jar	4 days at room temperature (?) in 0.5-L jar
CO_2 detection	Acid titration of 1 M NaOH trap to phenolphthalein endpoint	Infrared gas analysis of headspace	Gel paddle with digital color reader	Electrical conductivity of 0.5 M KOH trap

The flush of CO_2 is an indicator of soil microbial activity



Data from Franzluebbers et al. (2007) Soil Till. Res. 96:303-315

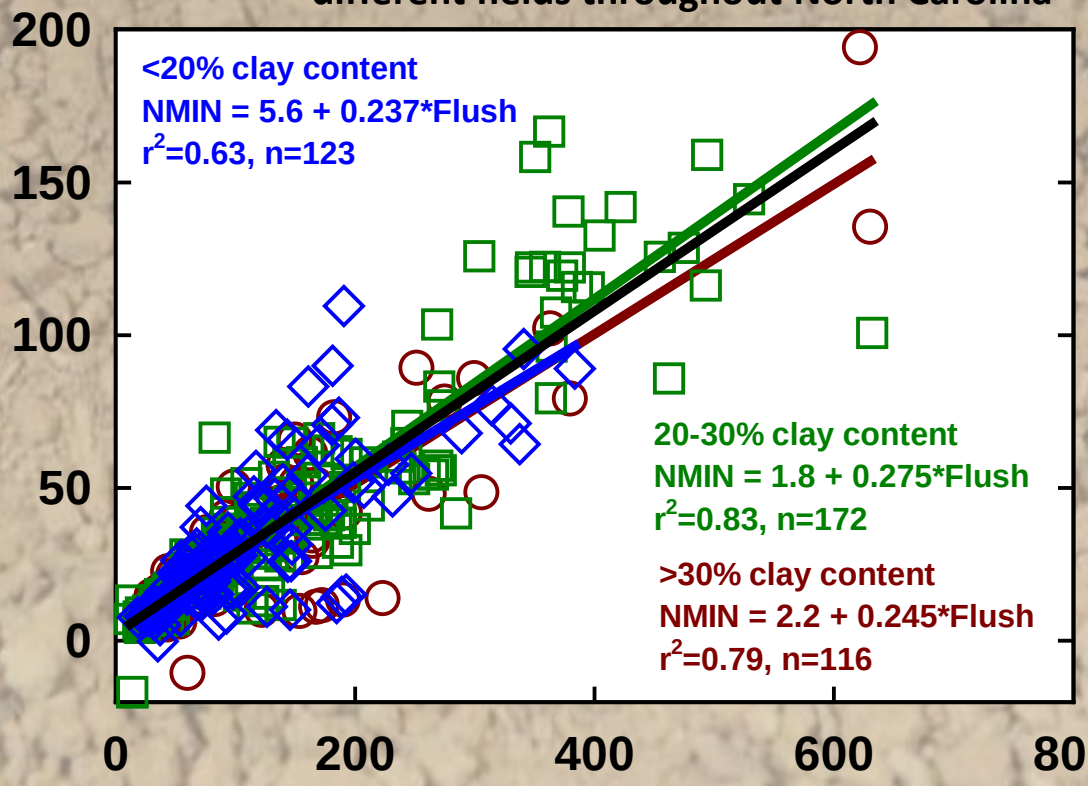
The flush of CO_2 relates well to soil microbial biomass C



Data from Jangid et al. (2008, 2010, 2011) Soil Biol. Biochem. 40:2843-2853; 42:302-312; 43:2184-2193

The flush of CO_2 shows association with N availability

From multiple locations and depths within 61 different fields throughout North Carolina



Net Nitrogen Mineralization $(mg \cdot kg^{-1})_{0\text{-}24\ d}$

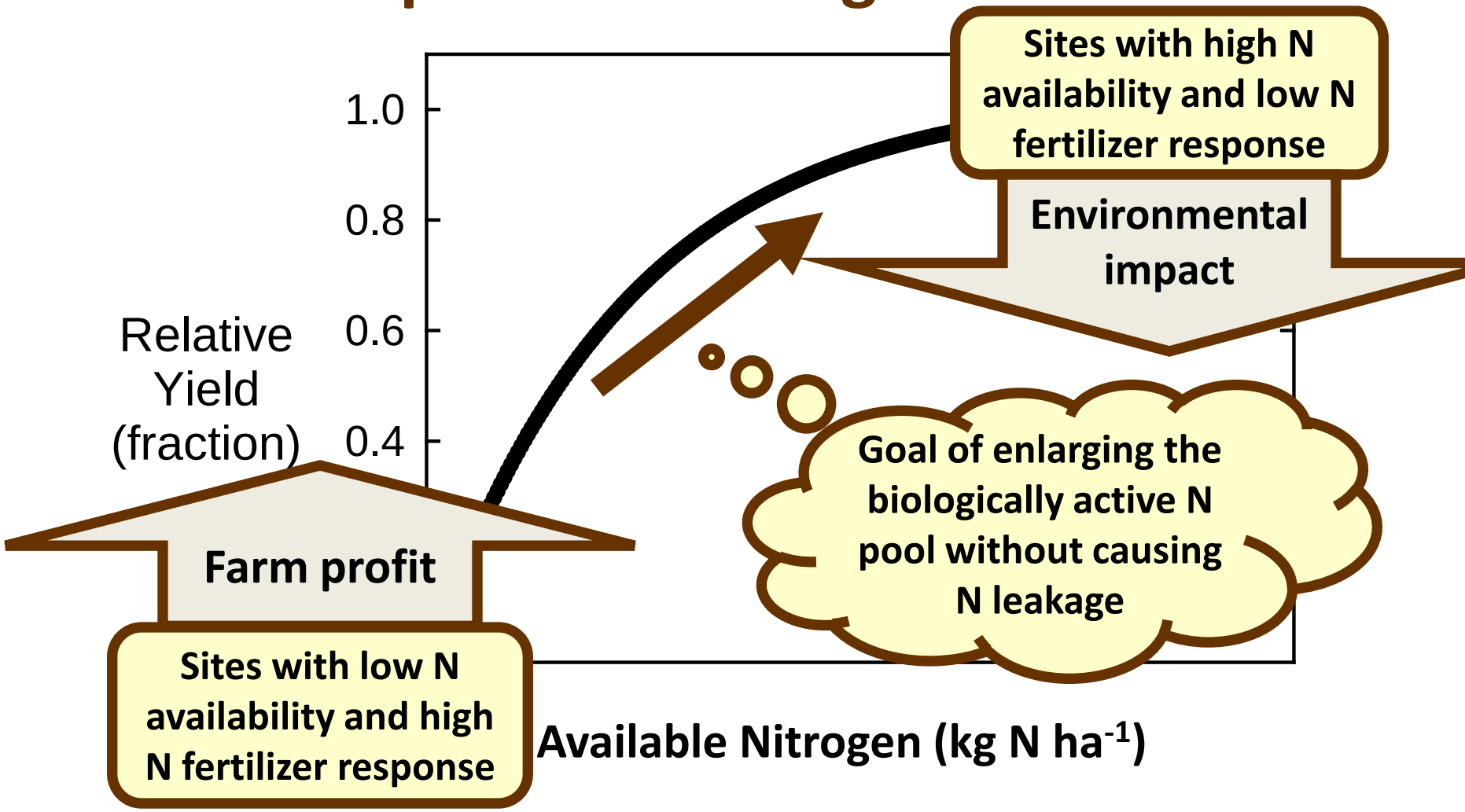
Flush of CO_2 following Rewetting of Dried Soil $(mg\ CO_2\text{-}C \cdot kg^{-1}\ soil)_{0\text{-}3\ d}$

Sandy
32 ± 25 mg N kg^{-1}
Loamy
43 ± 38 mg N kg^{-1}
Clayey
27 ± 27 mg N kg^{-1}

Across all soil textures
NMIN = 2.4 + 0.263*Flush
r^2=0.80, n=411

Data from M.R. Pershing (2016) NC State thesis

Idealized response to nitrogen



Accounting for

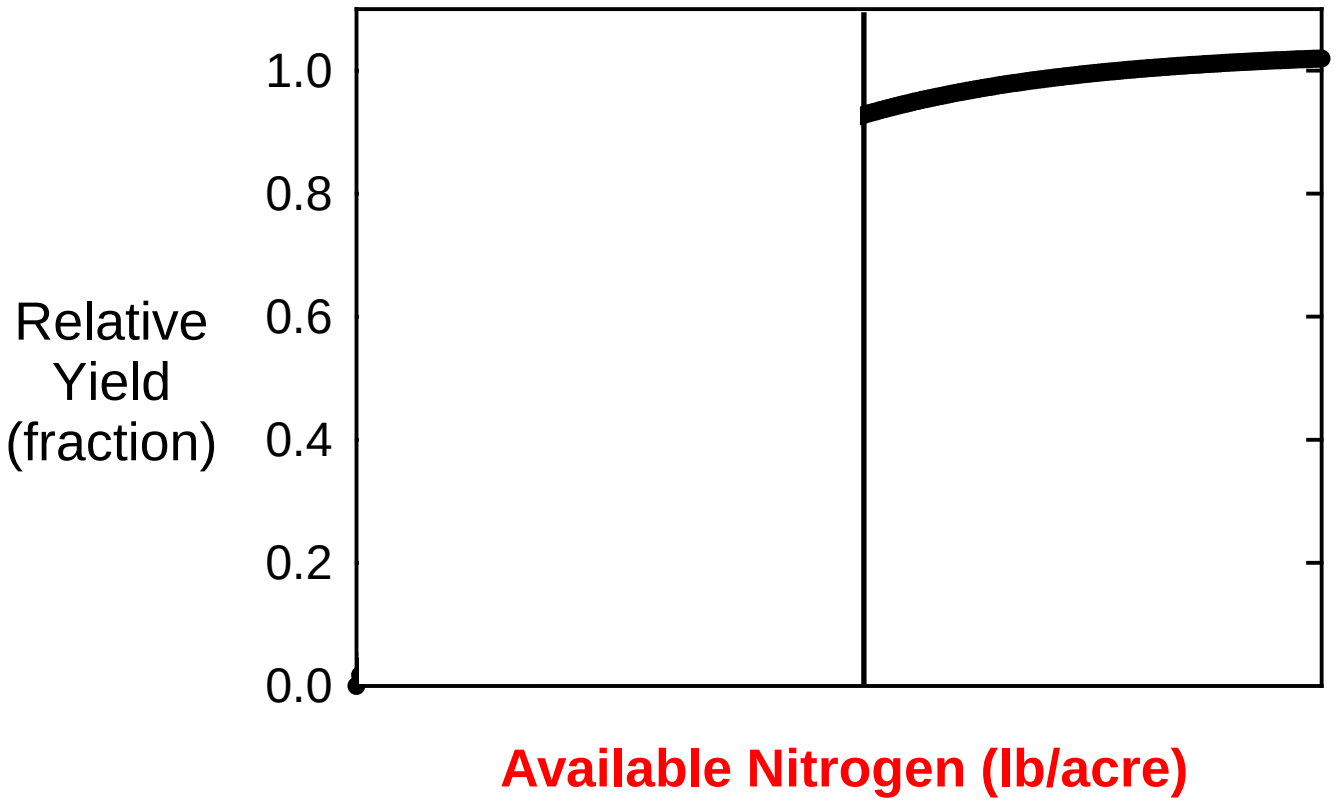
Inorganic nitrogen

- **Surface soil**
- **Residual in profile**

Organic nitrogen

- **Long-term stable**
- **Biologically active**

Not all fields have the same available N



Accounting for

<u>Inorganic nitrogen</u>

- **Surface soil**
- **Residual in profile**

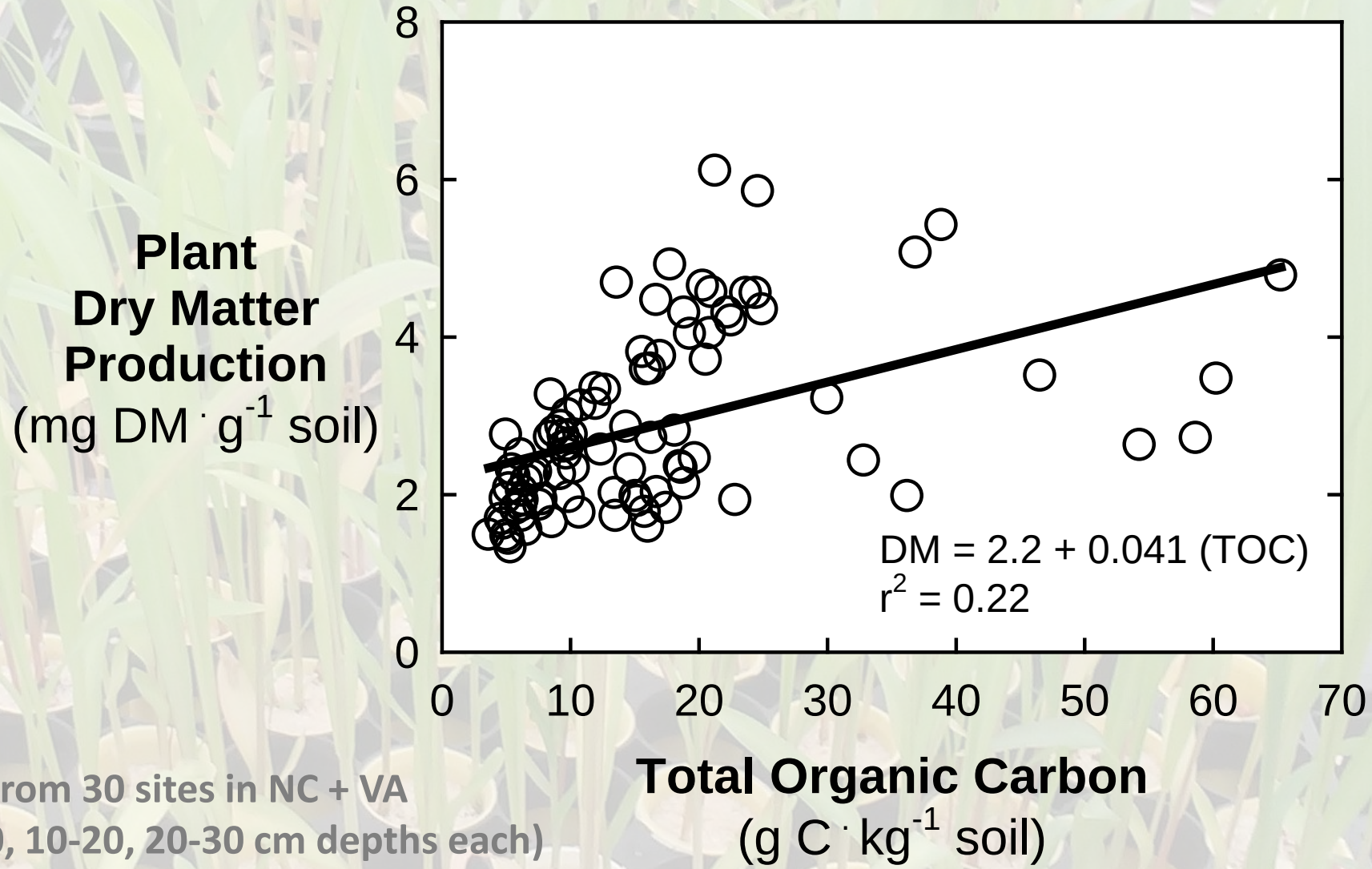
<u>Organic nitrogen</u>

- **Long-term stable**
- **Biologically active**

Consider this evidence…

Plant N uptake in semi-controlled greenhouse experiments

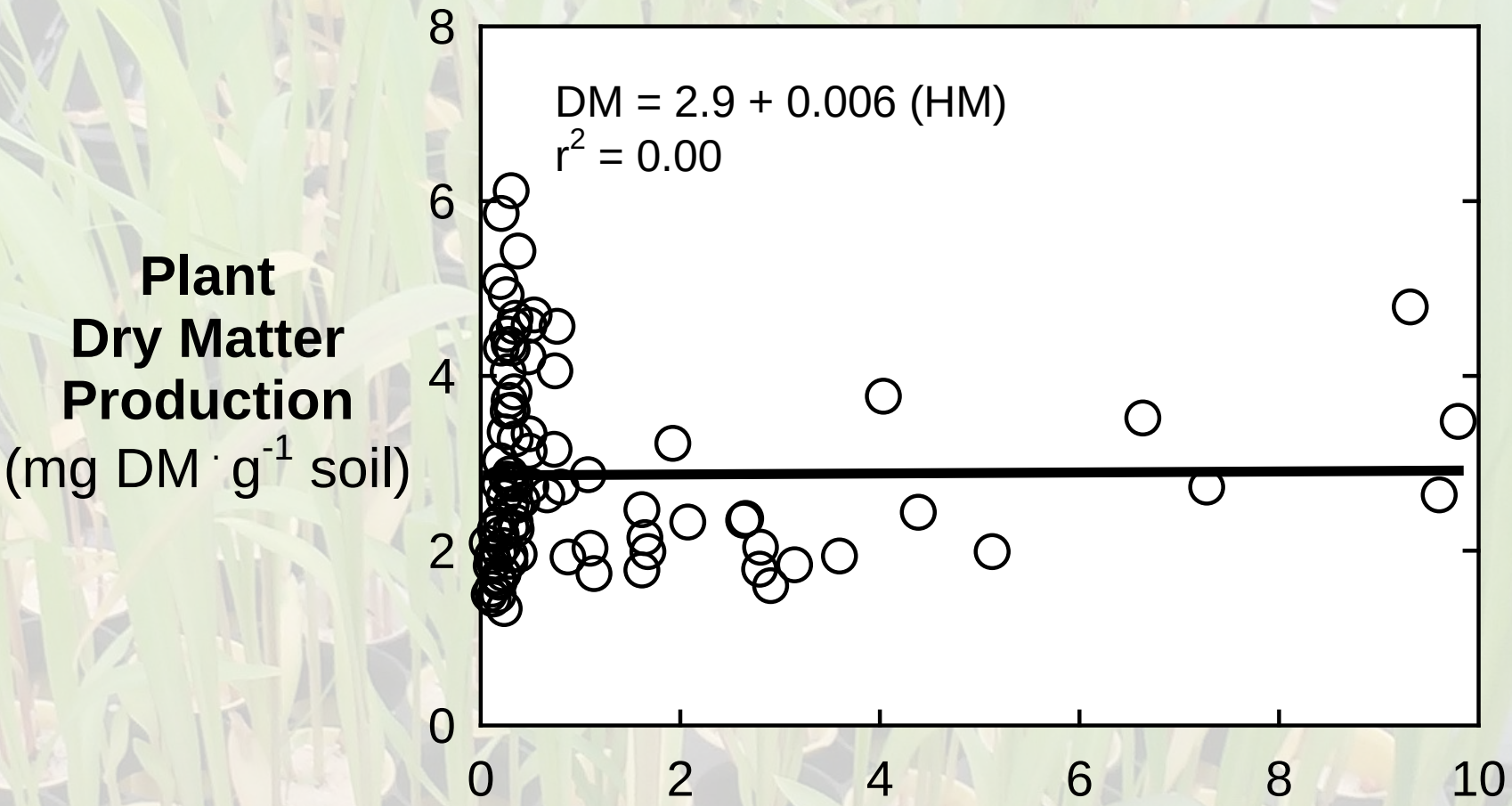
Plant dry matter production in minor relationship with total organic C



Soil from 30 sites in NC + VA
(0-10, 10-20, 20-30 cm depths each)

Pershing (2016) NC State University MS thesis

Plant dry matter production with no relationship to humic matter

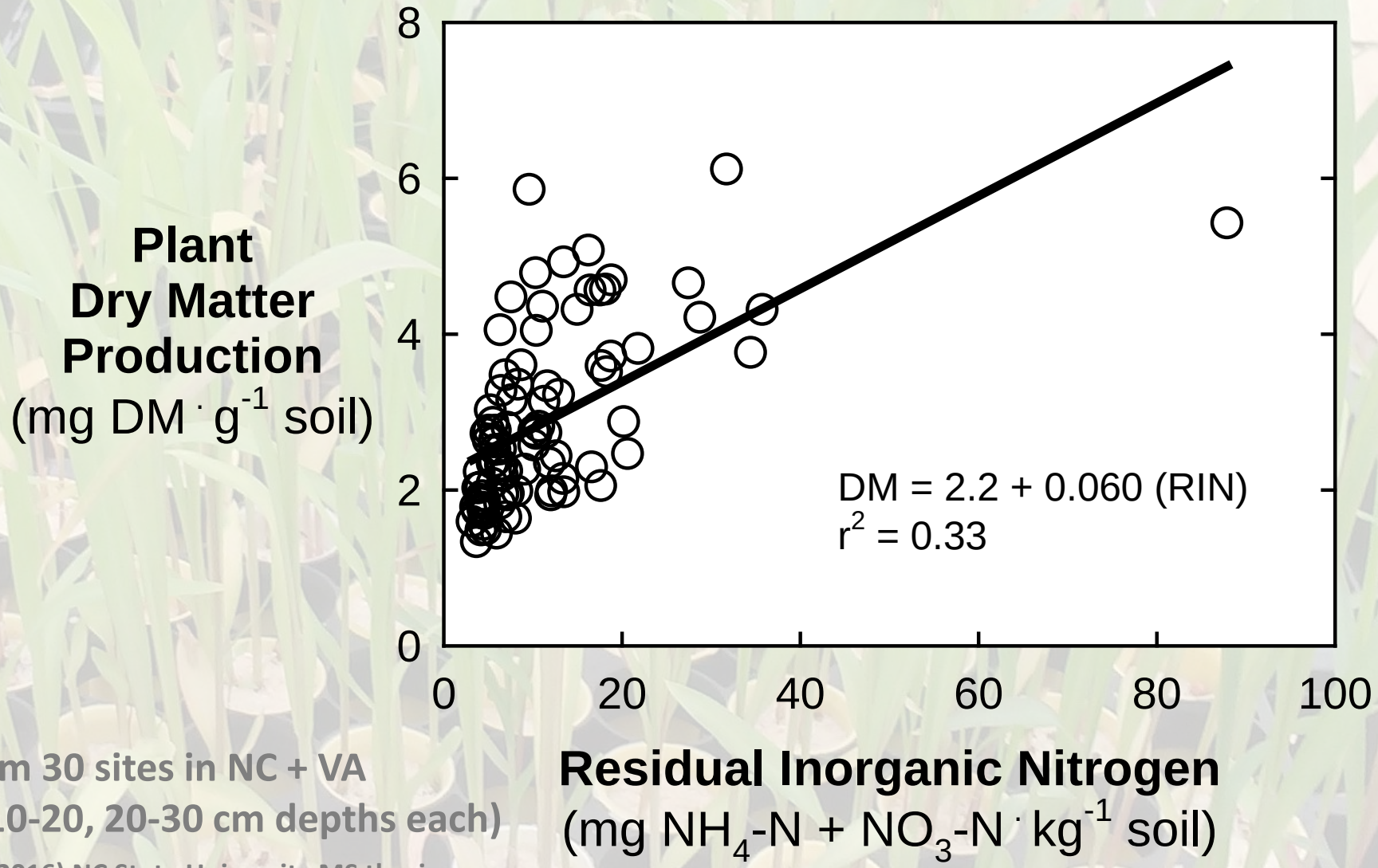


Soil from 30 sites in NC + VA
(0-10, 10-20, 20-30 cm depths each)

Pershing (2016) NC State University MS thesis

from NCDA lab

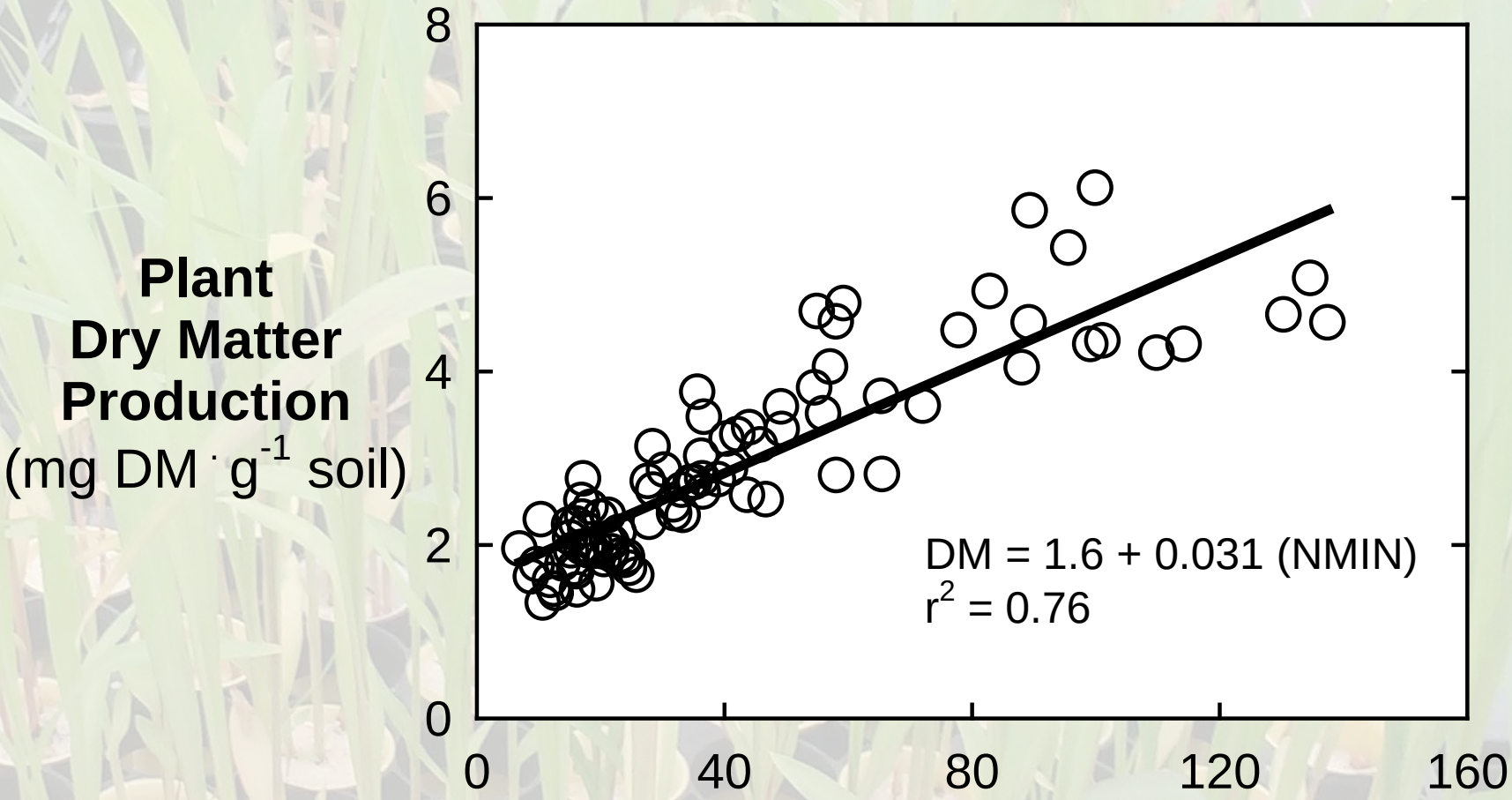
Plant dry matter production in moderate relationship with residual inorganic N



Soil from 30 sites in NC + VA
(0-10, 10-20, 20-30 cm depths each)

Pershing (2016) NC State University MS thesis

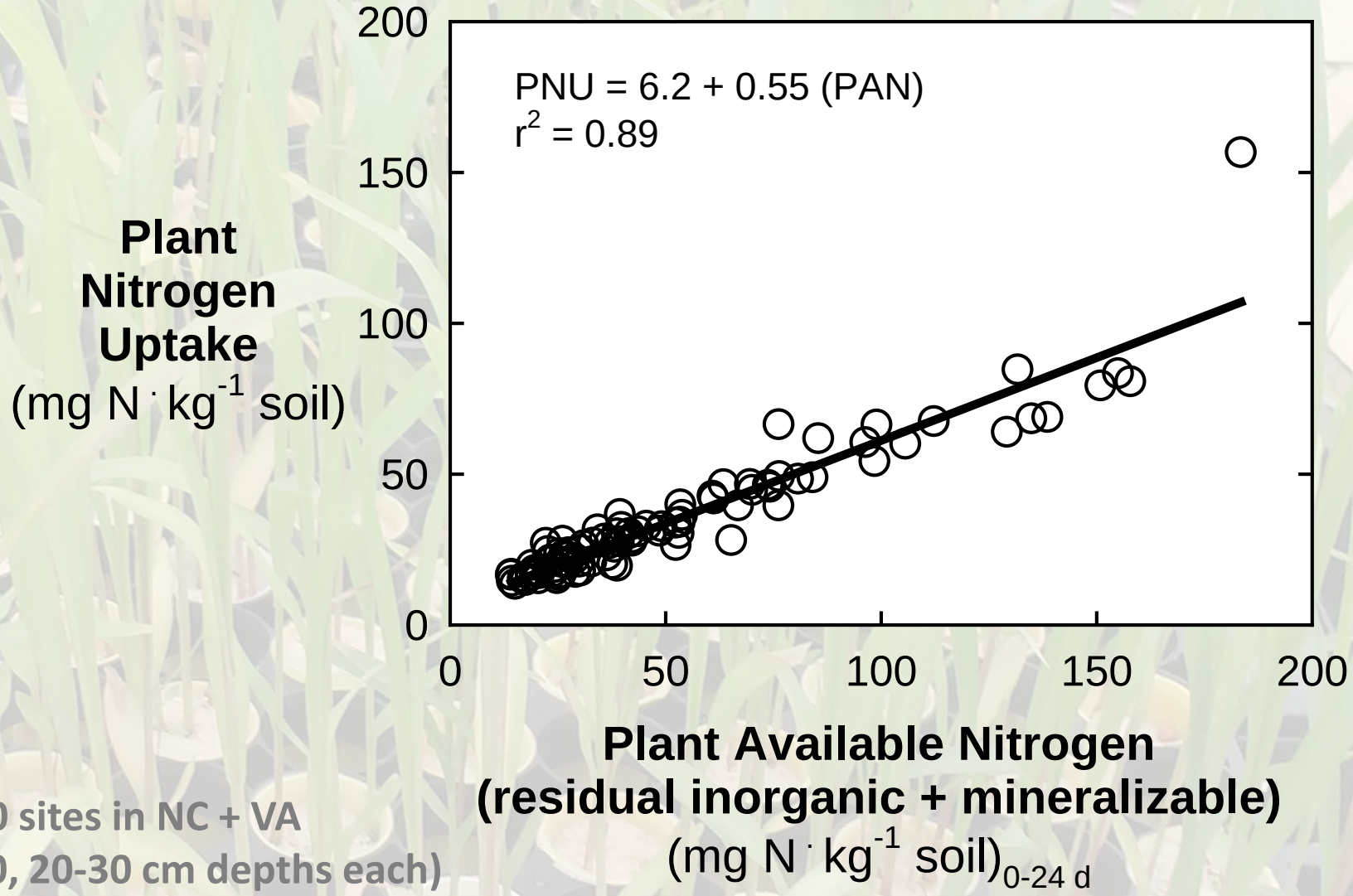
Plant dry matter production in strong relationship with net N mineralization



Soil from 30 sites in NC + VA
(0-10, 10-20, 20-30 cm depths each)

Pershing (2016) NC State University MS thesis

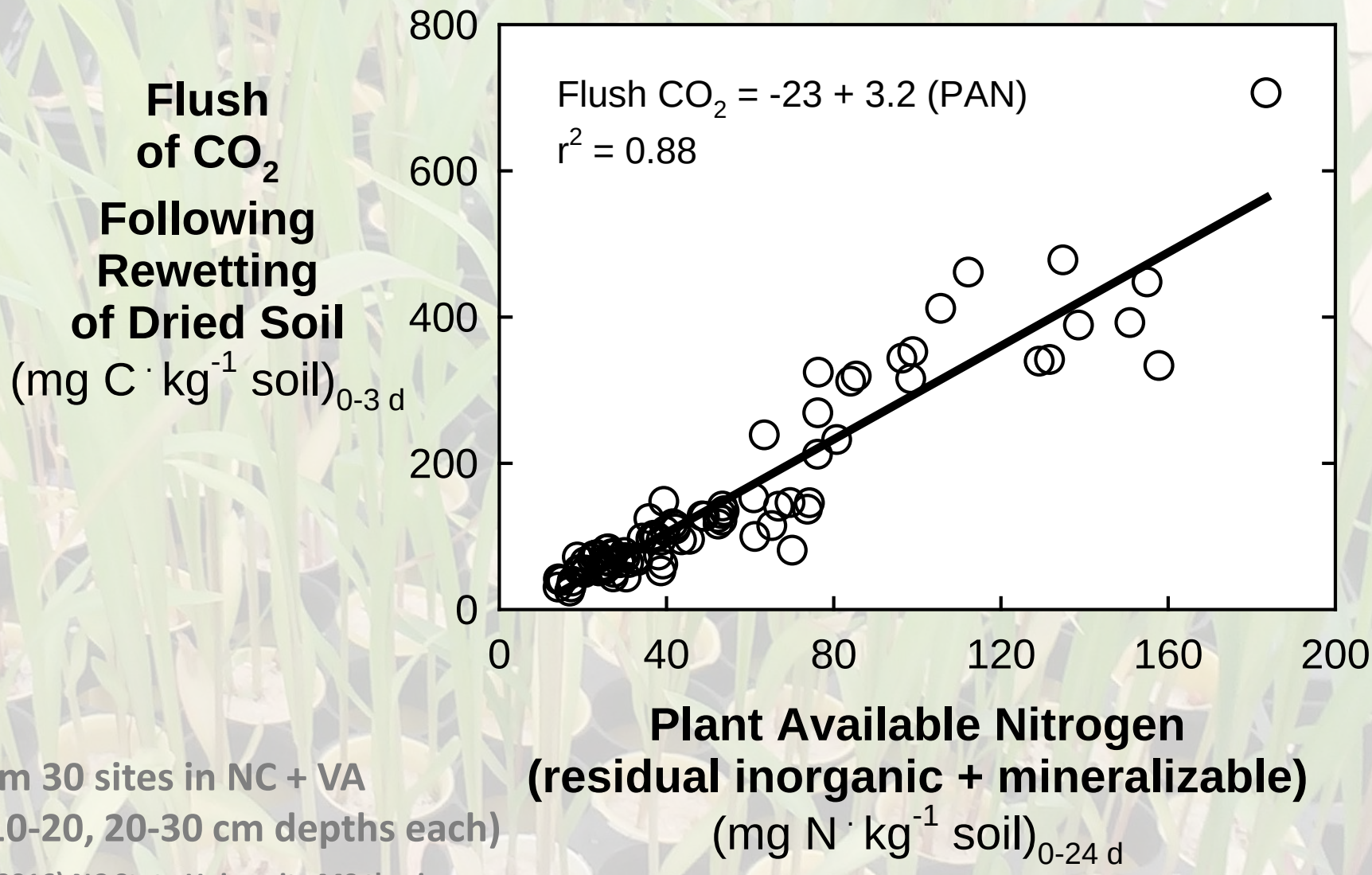
Plant N uptake in strong relationship with plant available N



Soil from 30 sites in NC + VA
(0-10, 10-20, 20-30 cm depths each)

Pershing (2016) NC State University MS thesis

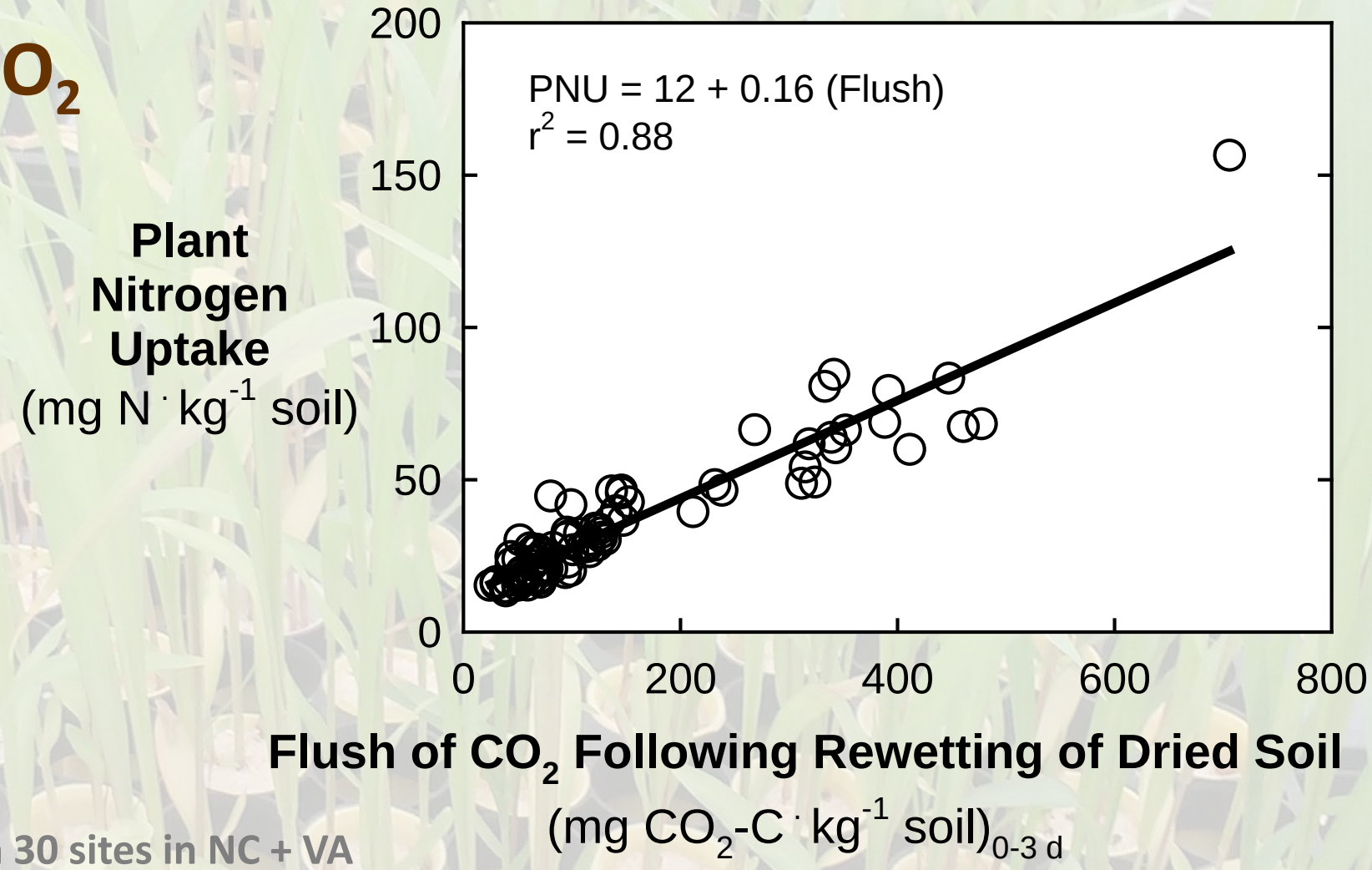
The flush of CO_2 in strong relationship with plant available N



Soil from 30 sites in NC + VA
(0-10, 10-20, 20-30 cm depths each)

Pershing (2016) NC State University MS thesis

Plant N uptake in strong relationship with the flush of CO_2



Soil from 30 sites in NC + VA
(0-10, 10-20, 20-30 cm depths each)

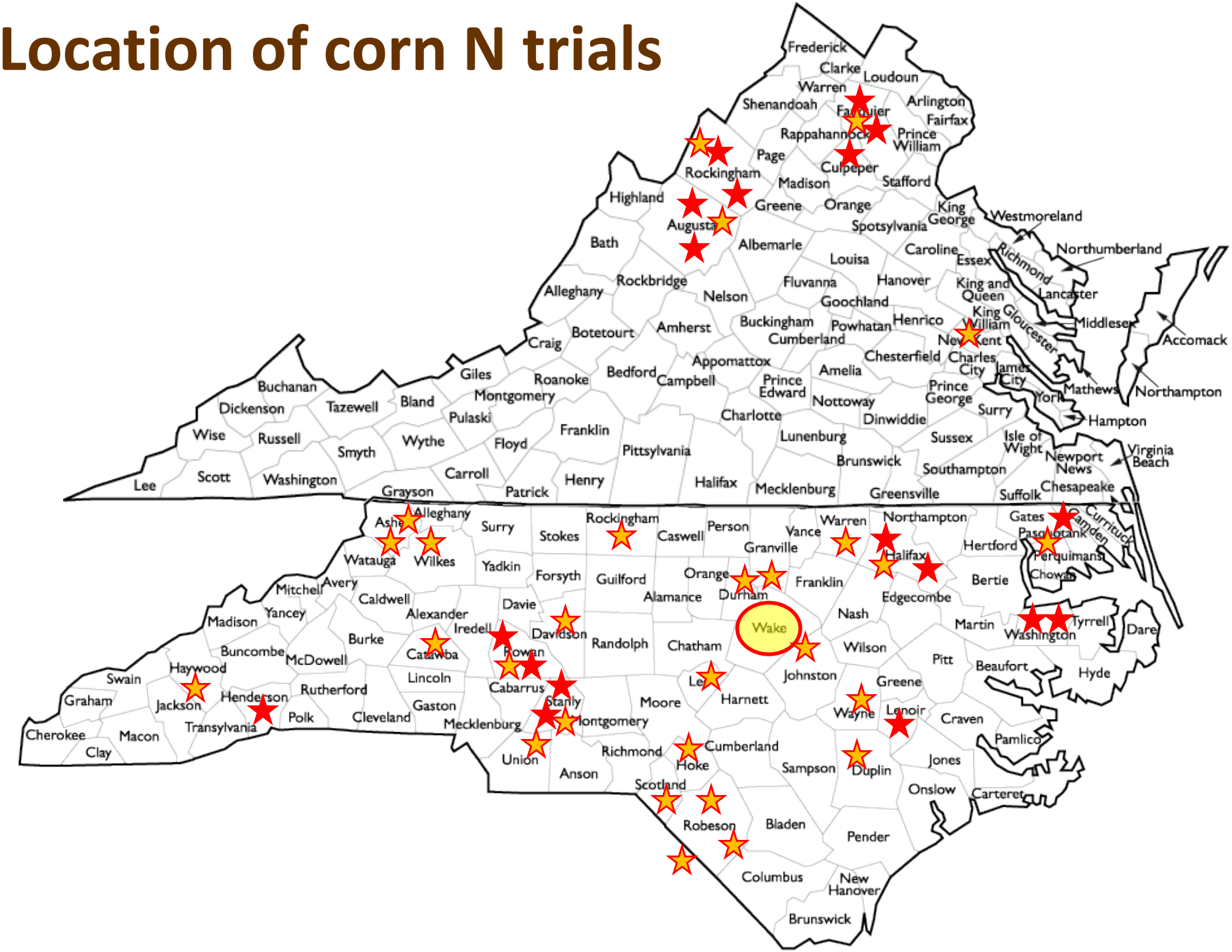
Pershing (2016) NC State University MS thesis


Questions?

Field calibration to N requirements

- Corn grain and silage in North Carolina and Virginia

Location of corn N trials

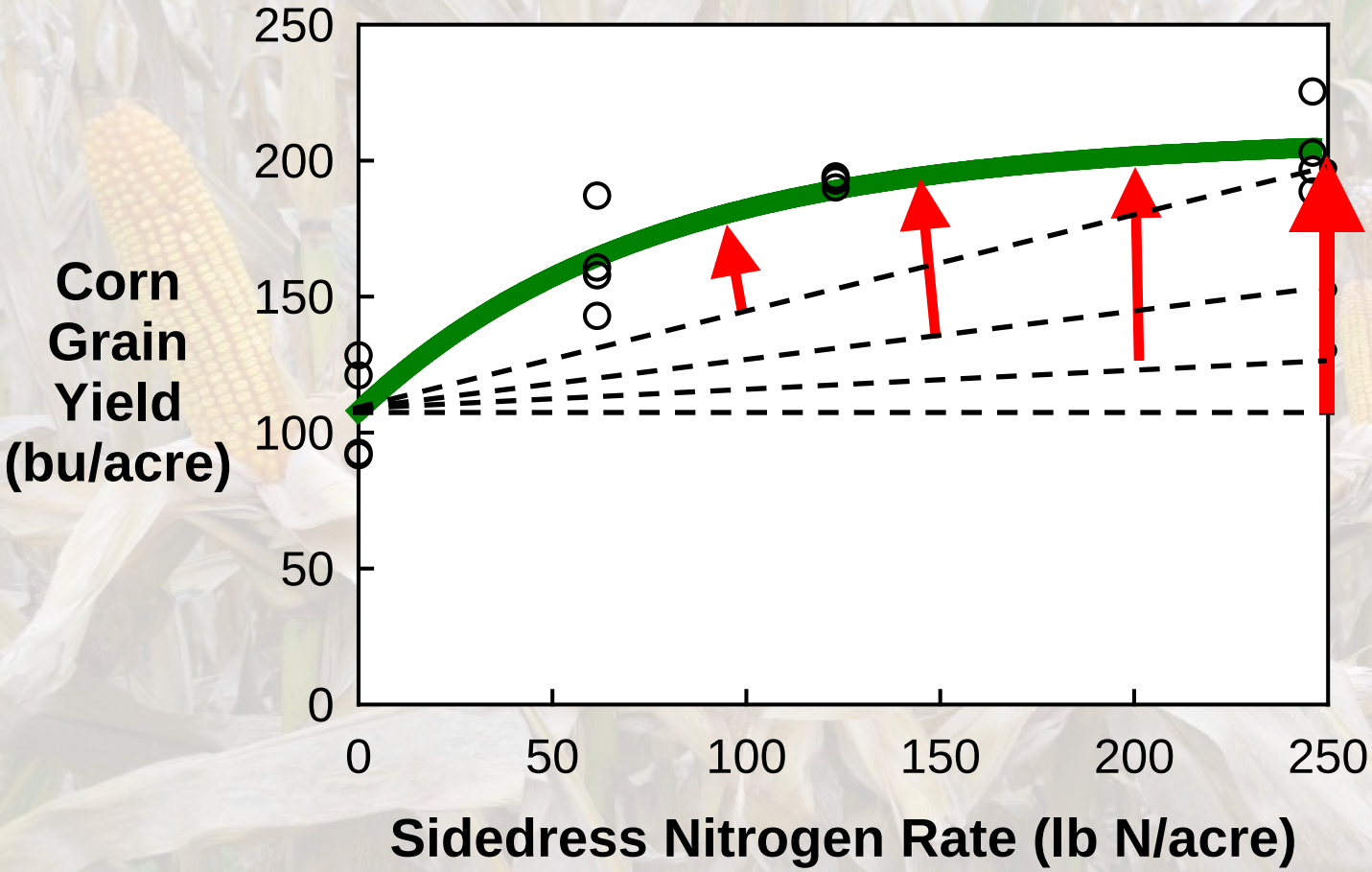


Cost-return scenarios for calculation of econically optimum N rate (EONR)

Cost-to-Value Conditions	Threshold (lb grain/lb N)
Low N ($0.50/lb N) and high grain ($5.60/bu)	5
Low N ($0.50/lb N) and low grain ($2.80/bu)	10
High N ($1.00/lb N) and high grain ($5.60/bu)	10
High N ($1.00/lb N) and low grain ($2.80/bu)	20

Halifax Co NC – NZWC6

- Corn previous crop



Cost-to-Value Threshold (lb grain/lb N)		
L	M	H
5	10	20

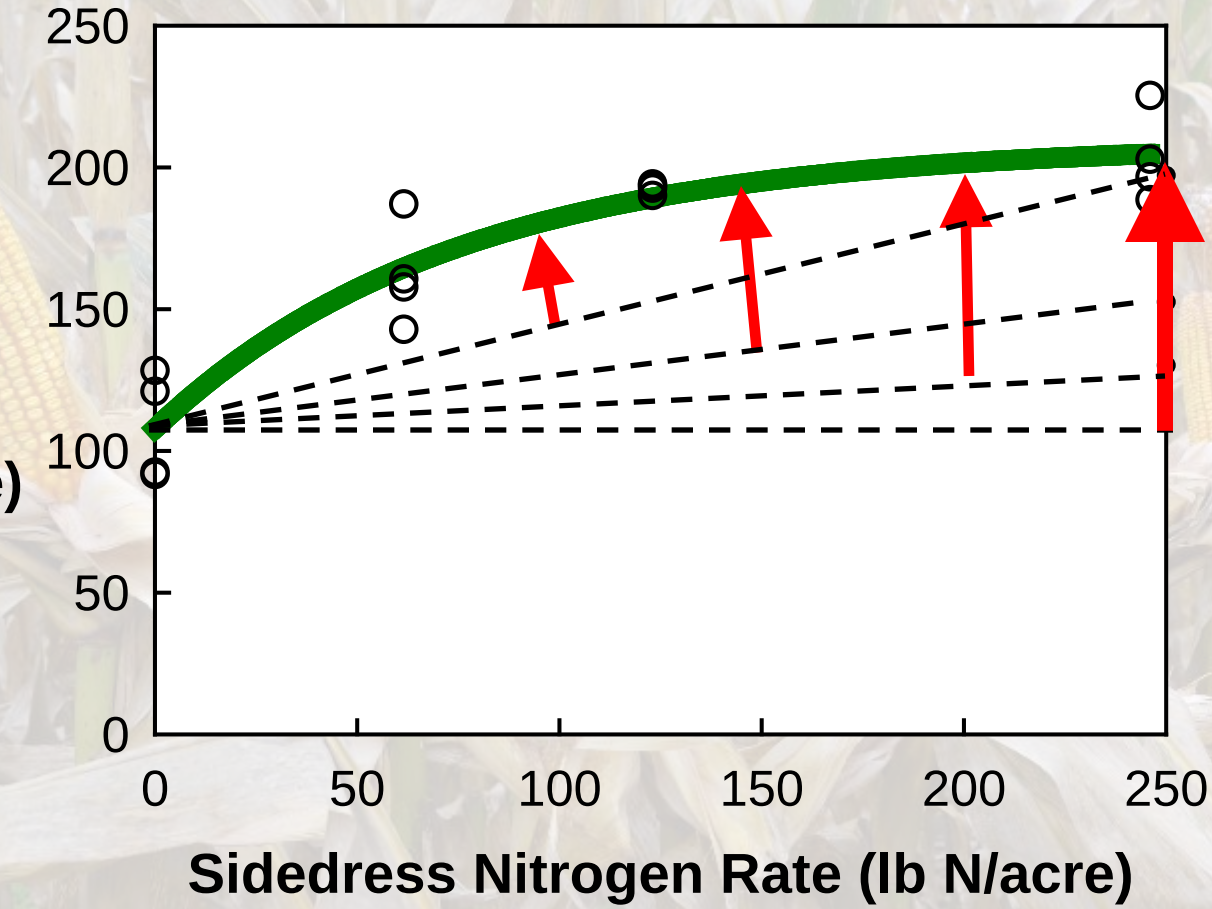
Economically Optimum N Rate (lb N/a)		
202	150	99

Equivalent N Factor (lb N/bu grain)		
0.99	0.73	0.48

Flush of CO_2 = 230 $\pm$ 6 mg/kg/3d

Halifax Co NC – NZWC6

- Corn previous crop



Cost-to-Value Threshold (lb grain/lb N)		
L	M	H
5	10	20

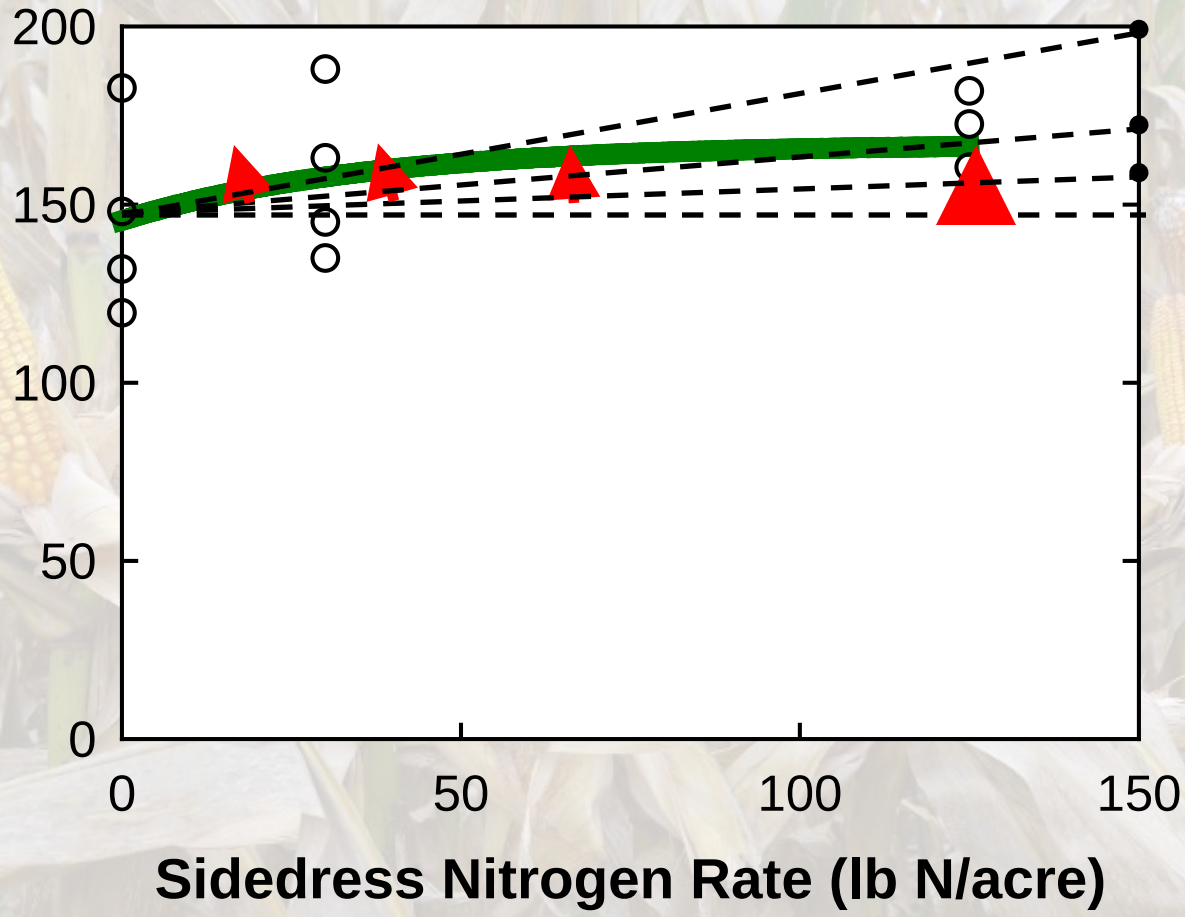
Economically Optimum N Rate (lb N/a)		
202	150	99

Equivalent N Factor (lb N/bu grain)		
0.99	0.73	0.48

Flush of CO_2 = 230 ± 6 mg/kg/3d

Stanly Co NC – NLNP6

- Soybean previous crop



Cost-to-Value Threshold (lb grain/lb N)		
L	M	H
5	10	20

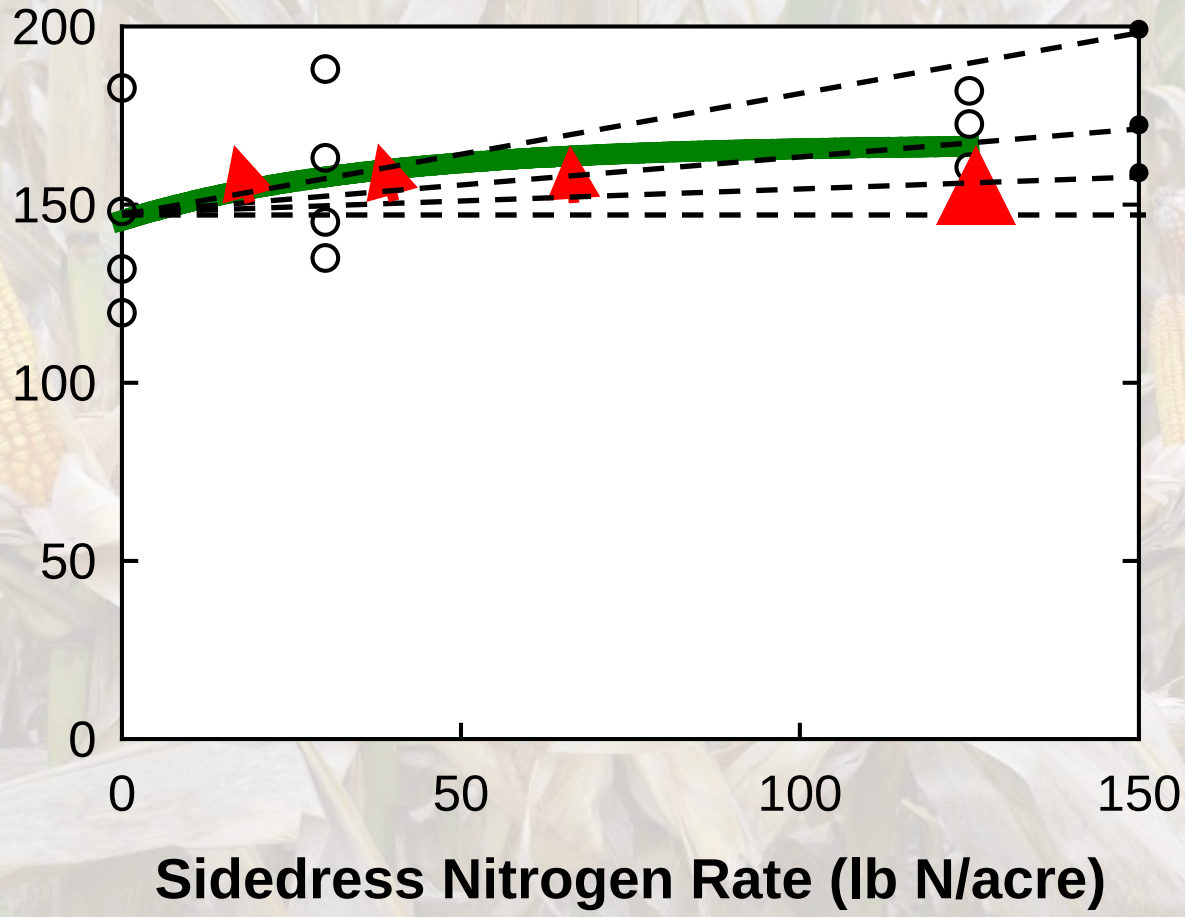
Economically Optimum N Rate (lb N/a)		
68	43	19

Equivalent N Factor (lb N/bu grain)		
0.41	0.26	0.11

Flush of CO_2 = 446 ± 24 mg/kg/3d

Stanly Co NC – NLNP6

- Soybean previous crop



Cost-to-Value Threshold (lb grain/lb N)		
L	M	H
5	10	20

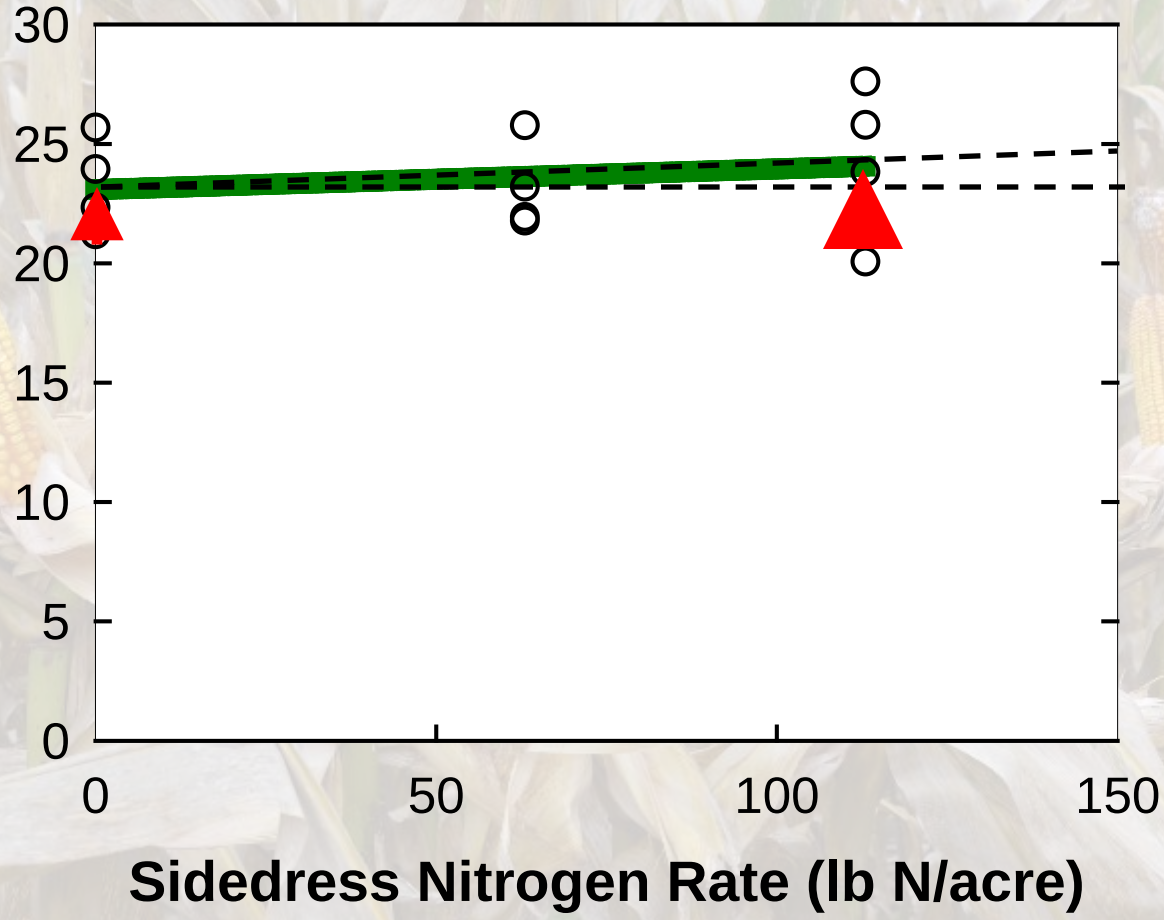
Economically Optimum N Rate (lb N/a)		
68	43	19

Equivalent N Factor (lb N/bu grain)		
0.41	0.26	0.11

Flush of CO_2 = 446 ± 24 mg/kg/3d

Fauquier Co VA – VBH65

- Soybean previous crop



Cost-to-Value Threshold (lb grain/lb N)		
L	M	H
5	10	20

Economically Optimum N Rate (lb N/a)		
0	0	0

Equivalent N Factor (lb N/bu grain)		
0	0	0

Flush of CO_2 = 315 ± 47 mg/kg/3d

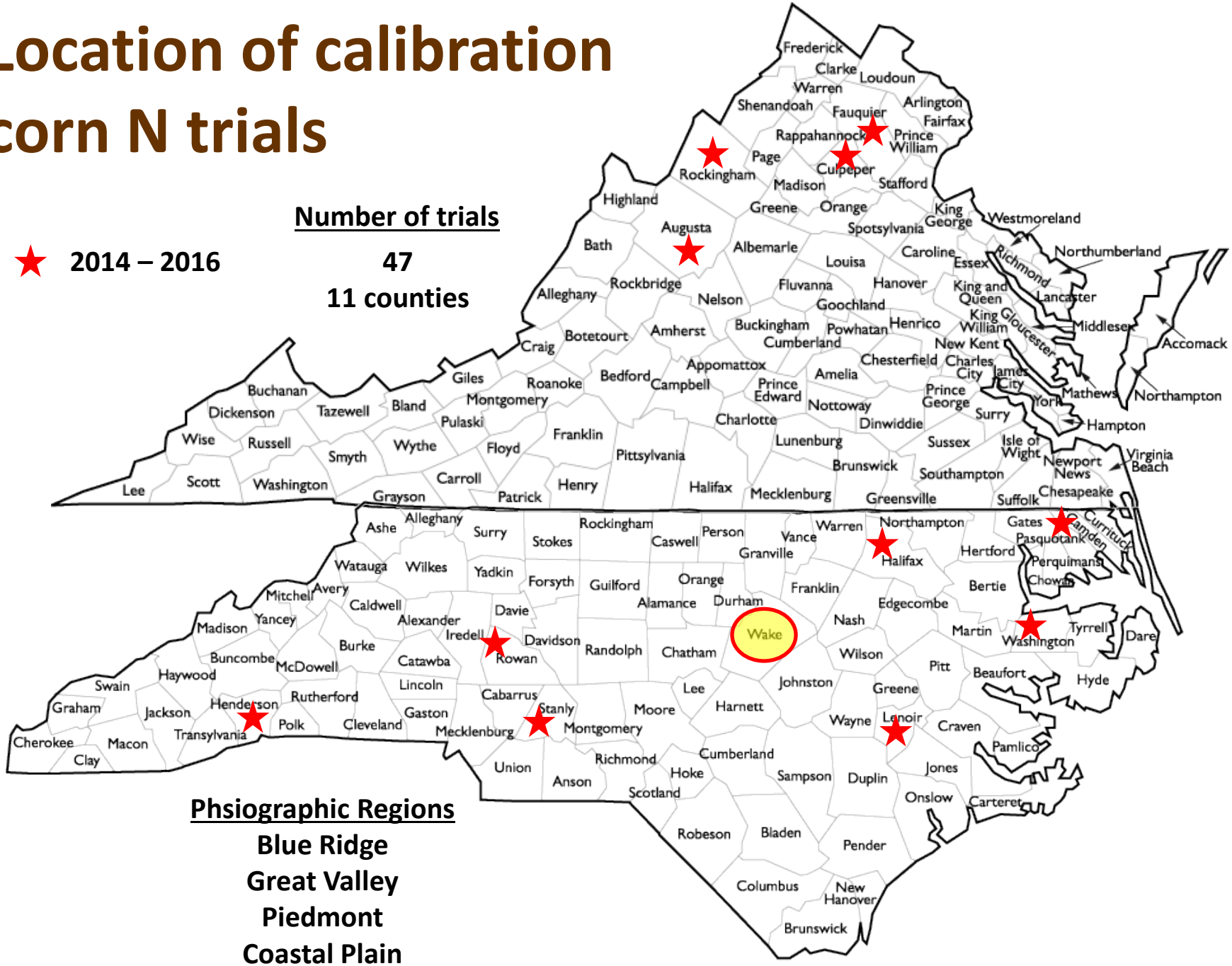
Location of calibration corn N trials

★ 2014 – 2016

Number of trials

47

11 counties



Phsiographic Regions

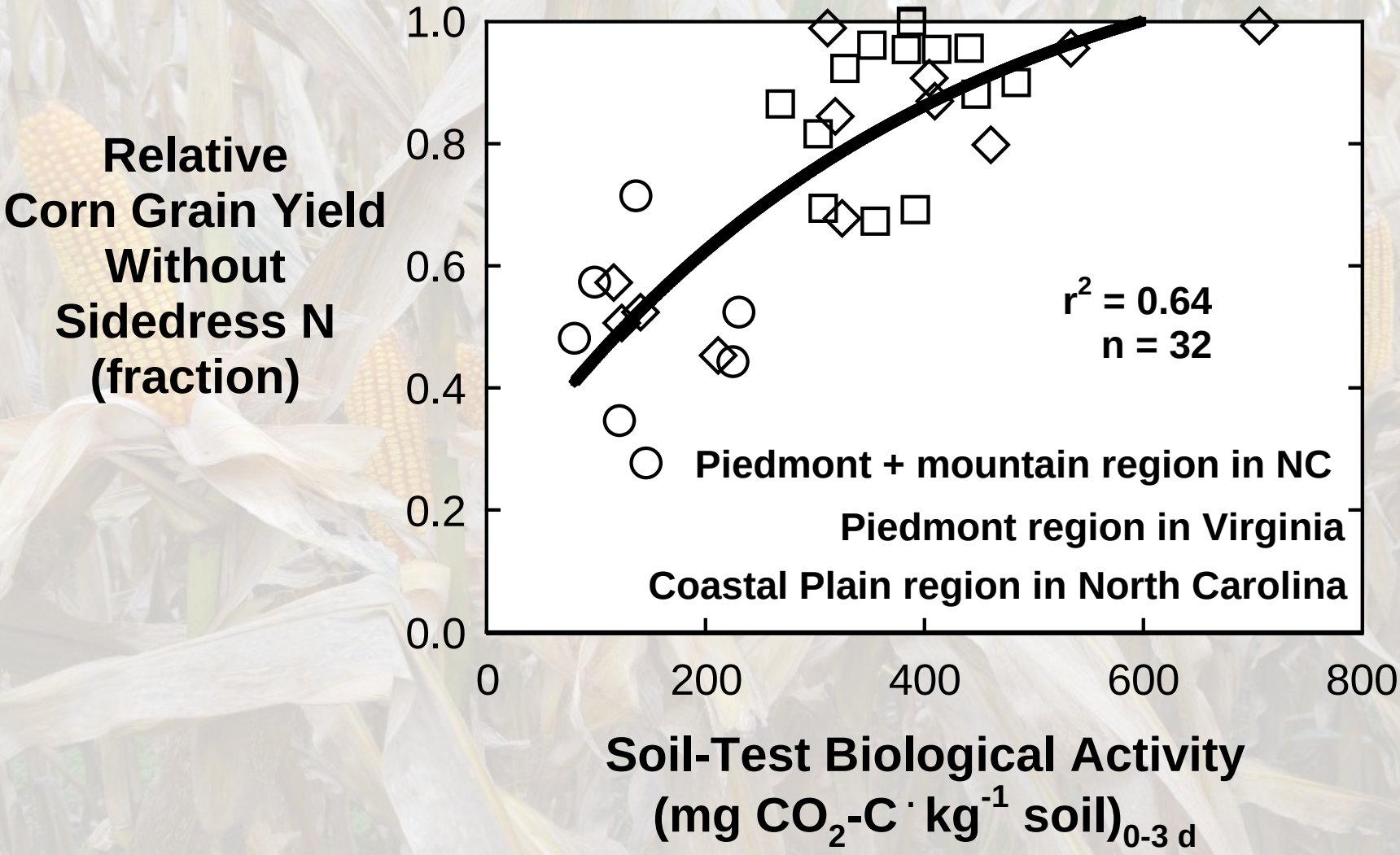
Blue Ridge

Great Valley

Piedmont

Coastal Plain

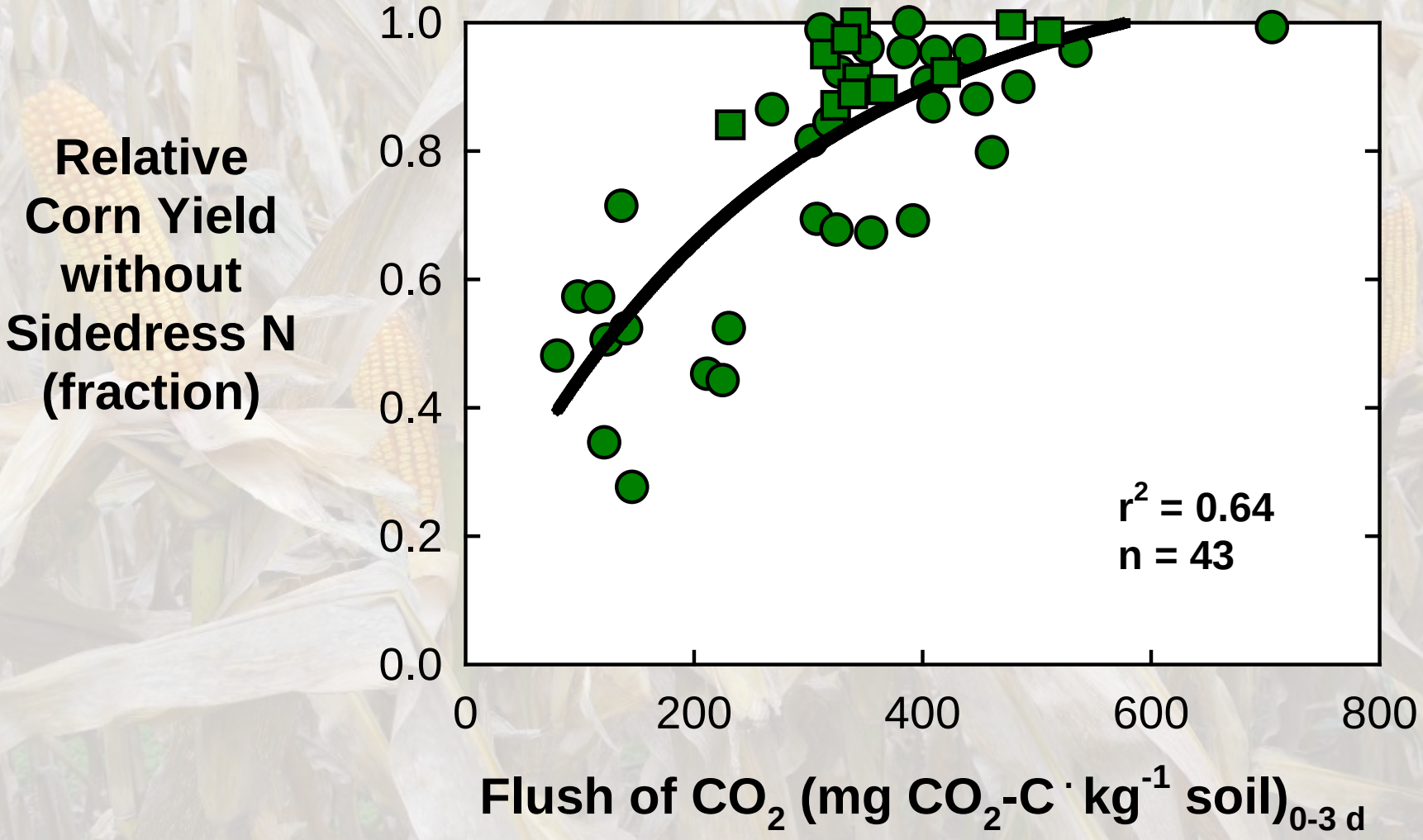
Yield data from across farms in NC and VA



Total of 32 fields in NC + VA

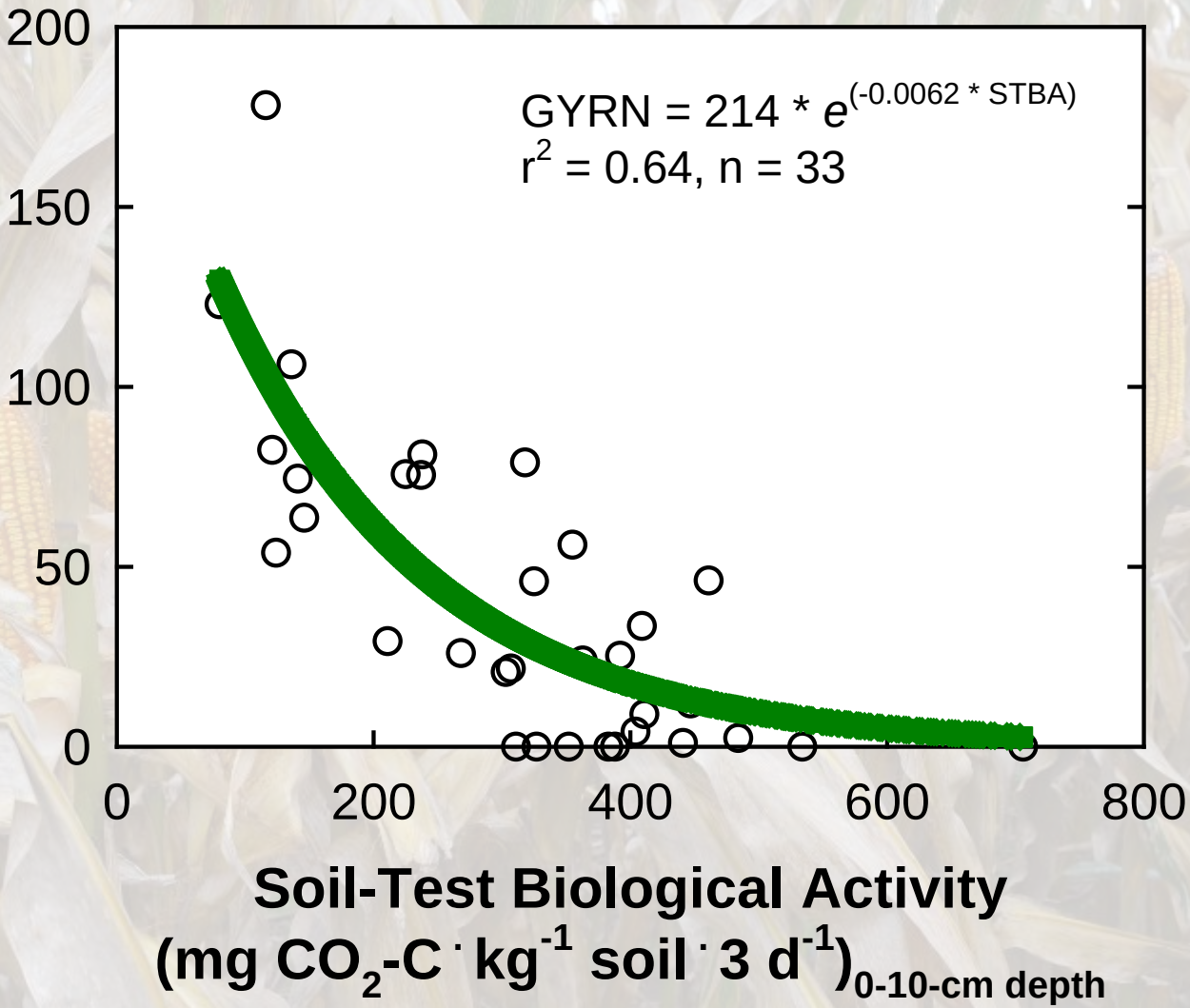
Franzluebbers (2017) Unpublished data

Yield data from across farms in NC and VA



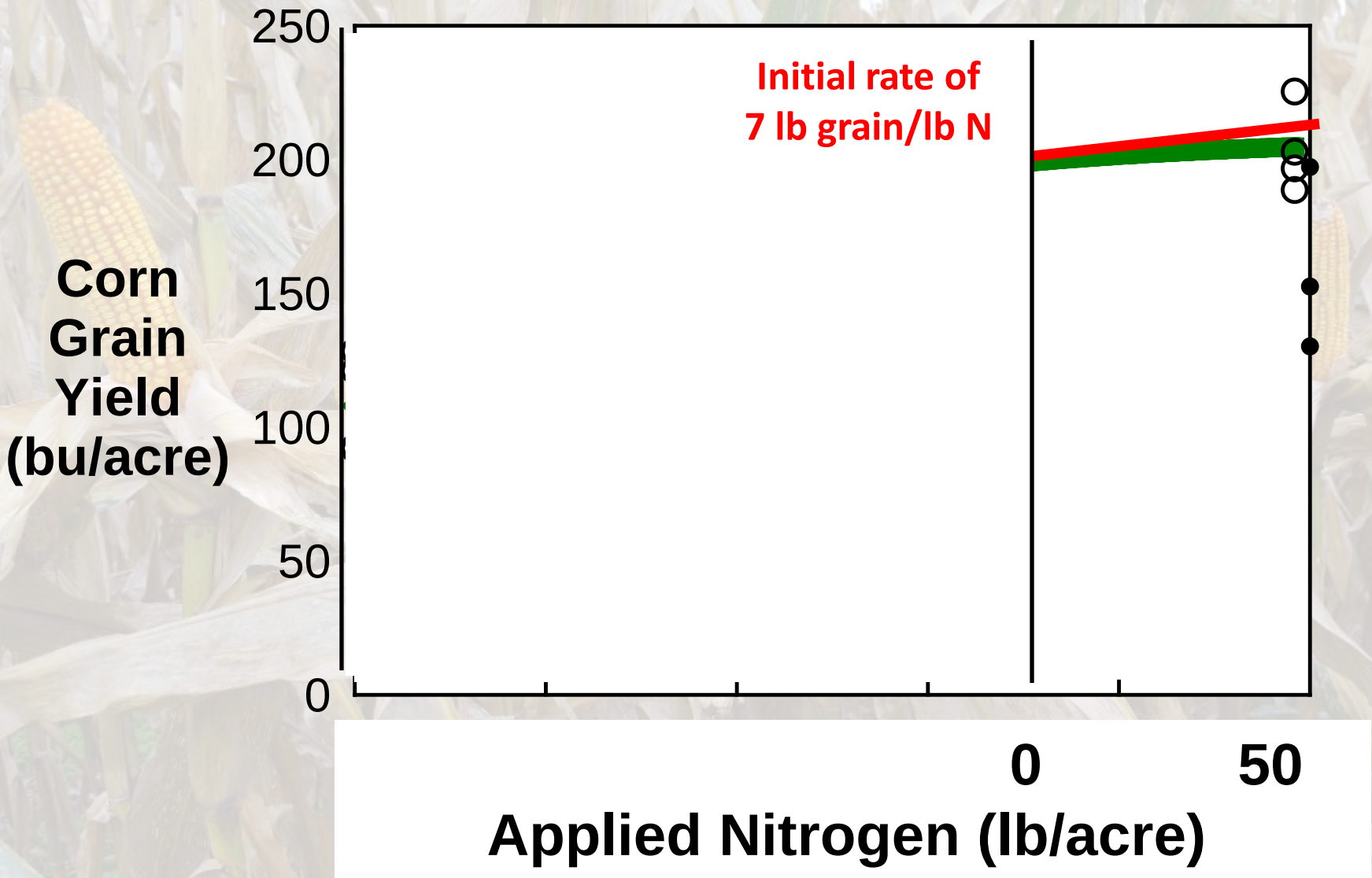
Total of 32 grain fields in NC + VA and 11 silage fields in VA

Intensity of yield response to N fertilizer

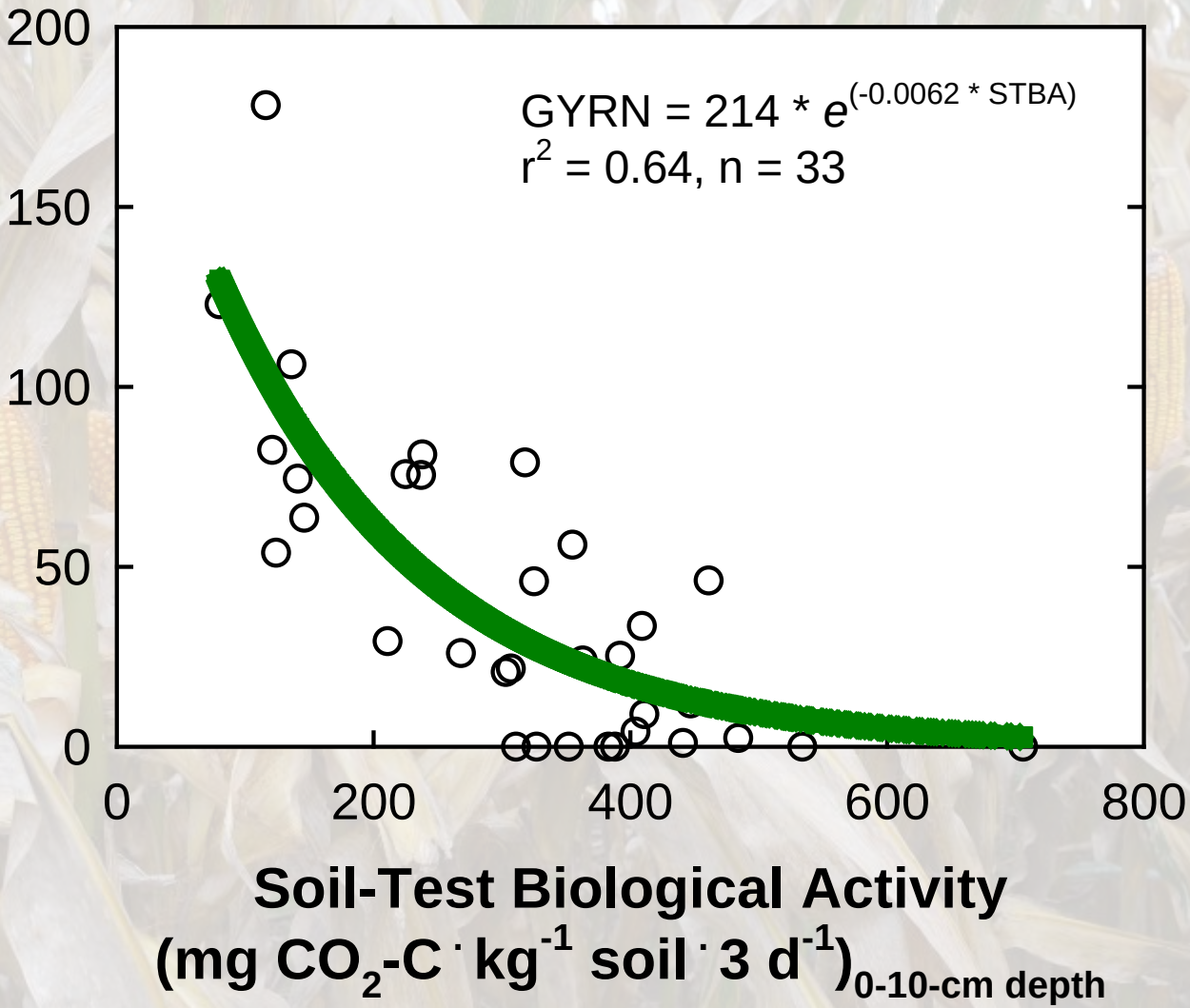


Total of 36 fields in NC + VA

Intensity of yield response to N fertilizer



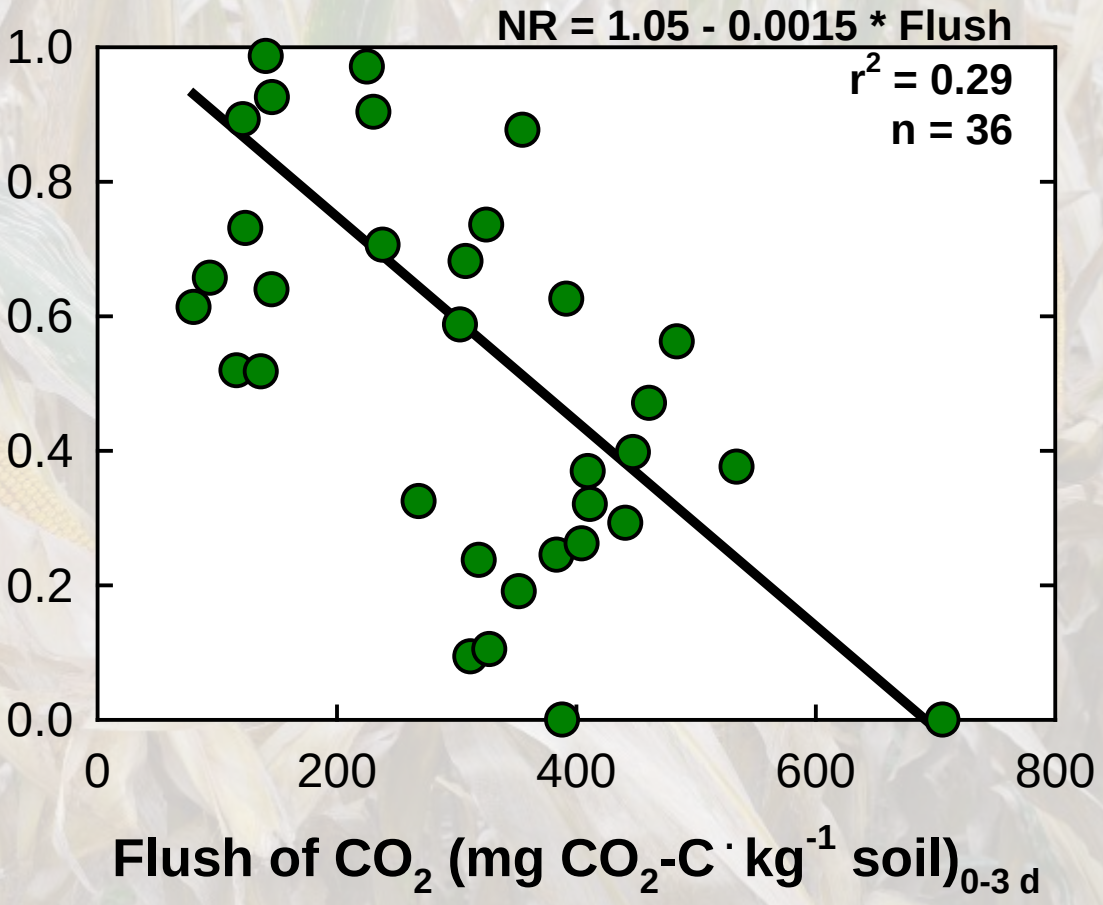
Intensity of yield response to N fertilizer



Total of 36 fields in NC + VA

Adjustment of N per bushel of grain…

Sidedress Nitrogen Required to Achieve Optimum Corn Grain Yield (lb N/bu grain)



Total of 36 fields in NC + VA

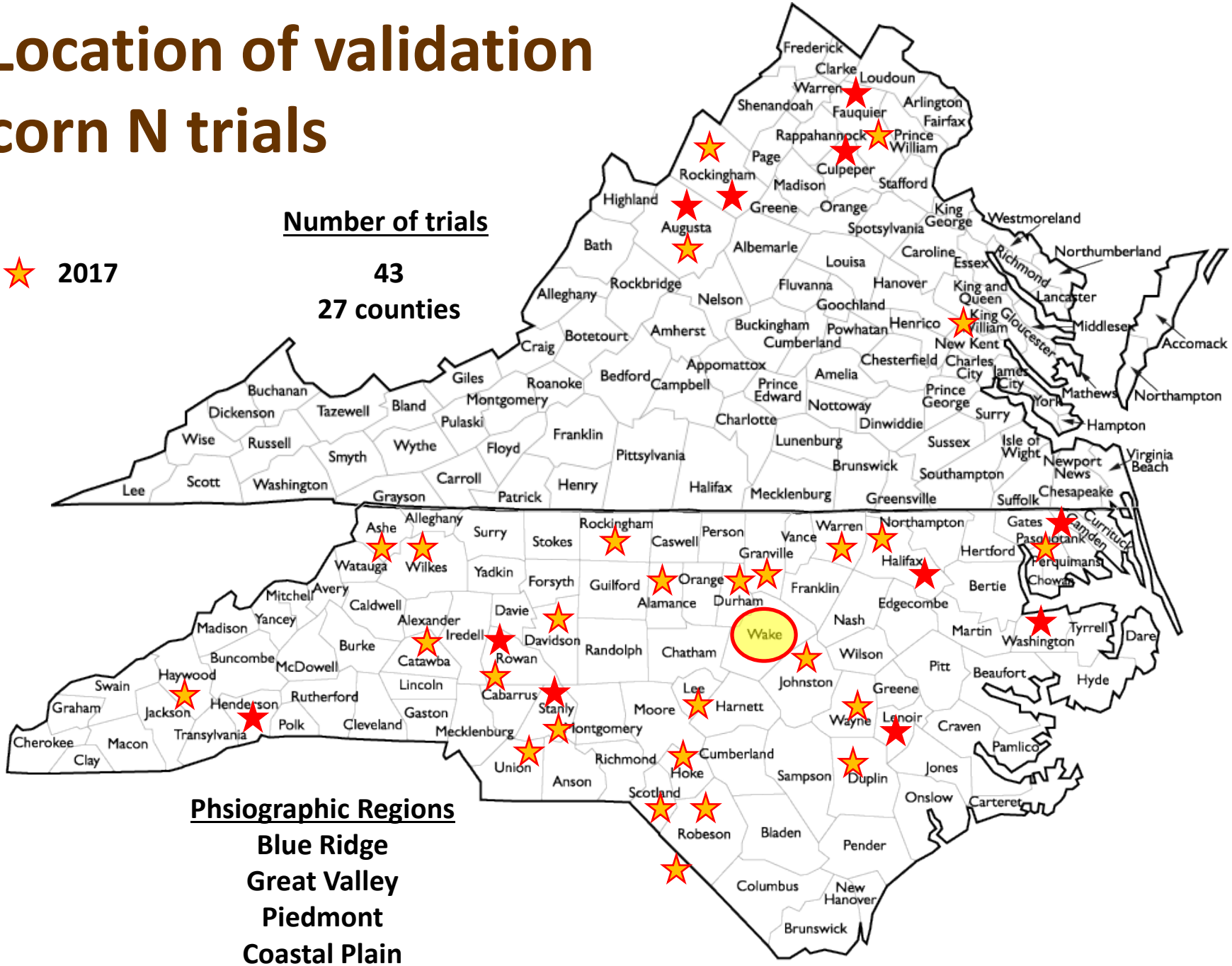
Location of validation corn N trials

★ 2017

Number of trials

43

27 counties



Phsiographic Regions

Blue Ridge

Great Valley

Piedmont

Coastal Plain

Testing this relationship against new trials

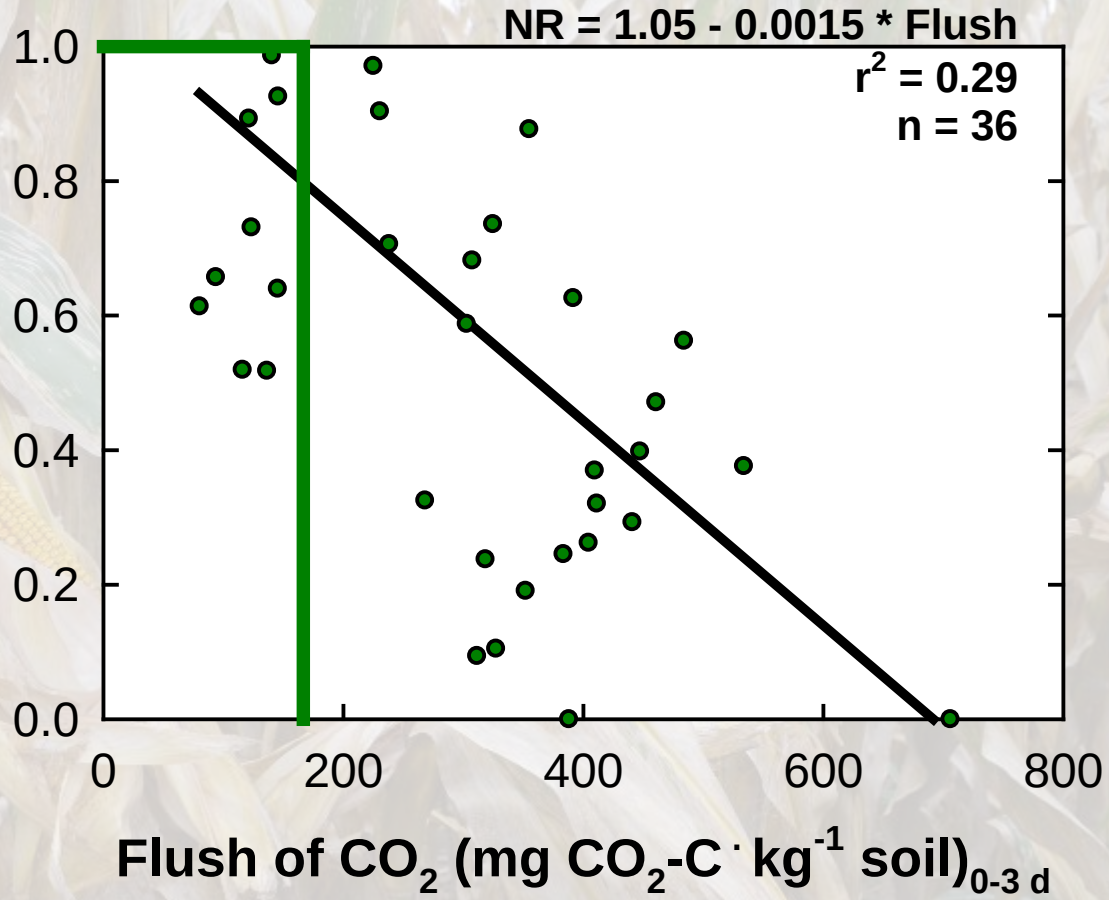
- 40 grain trials in NC and VA in 2017

Variable	All 40 trials	26 trials (>150 bu/a only)
Observed maximum yield (bu/a)	**174**	**167 – 248**
Soil-test biological activity (mg/kg/3d)	**229**	**123 – 323**
Nitrogen factor (lb N/bu grain)	**0.70**	**0.15 – 0.83**
Econ opt N fertilizer (lb N/a)	**105**	**34 – 164**
Standardized N recommend (lb N/a)	**191**	**184 – 263**
Yield with std N recommend (bu/a)	**171**	**167 – 248**
STBA-predicted N recomm (lb N/a)	**124**	**101 – 199**
STBA-predicted yield (bu/a)	**166**	**162 – 248**
Yield difference with STBA (bu/a)	**-5**	**-9 to +3**
Net return with STBA ($/a)	**+5.08**	**-10.88 to +56.34**

Greater economic return and less N applied/potentially lost

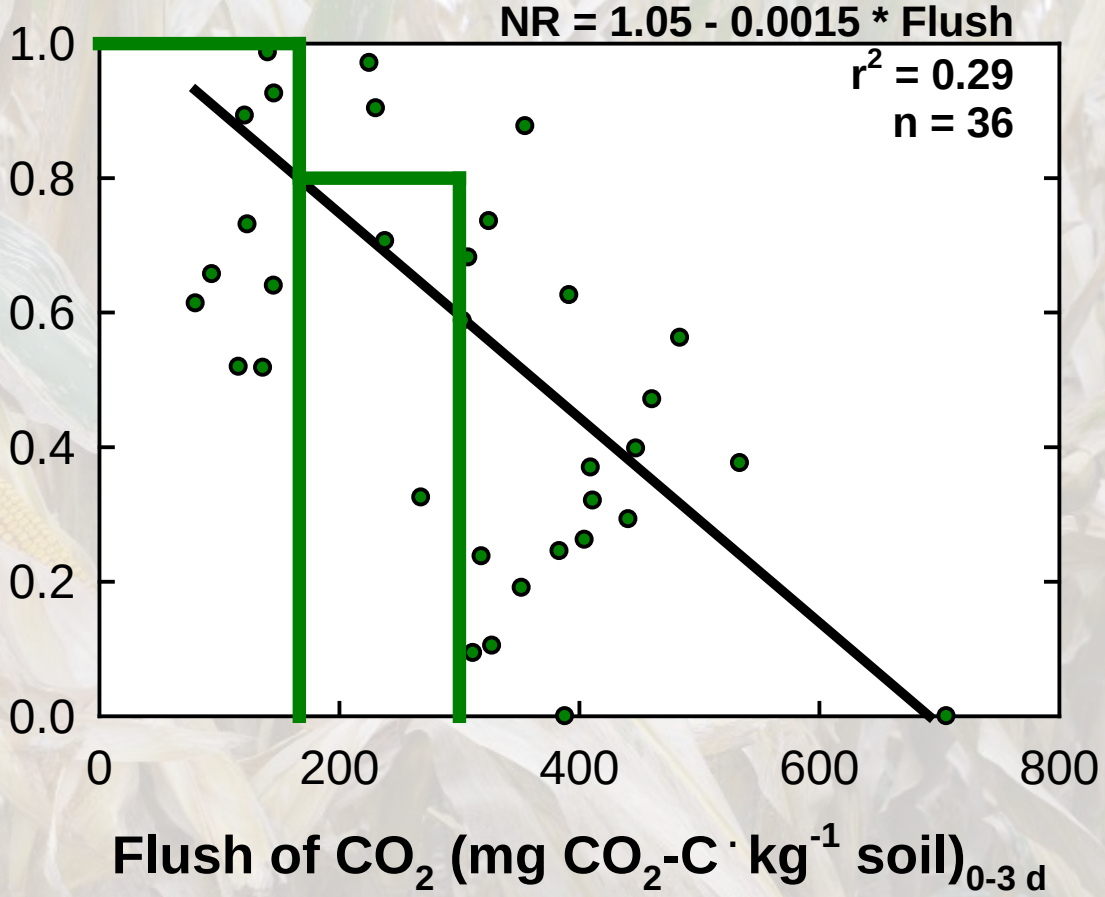
A potential N fertilizer recommendation framework

Sidedress Nitrogen Required to Achieve Optimum Corn Grain Yield (lb N/bu grain)



Preliminary analysis for recommendation domain

Sidedress Nitrogen Required to Achieve Optimum Corn Grain Yield (lb N/bu grain)



Preliminary analysis for recommendation domain

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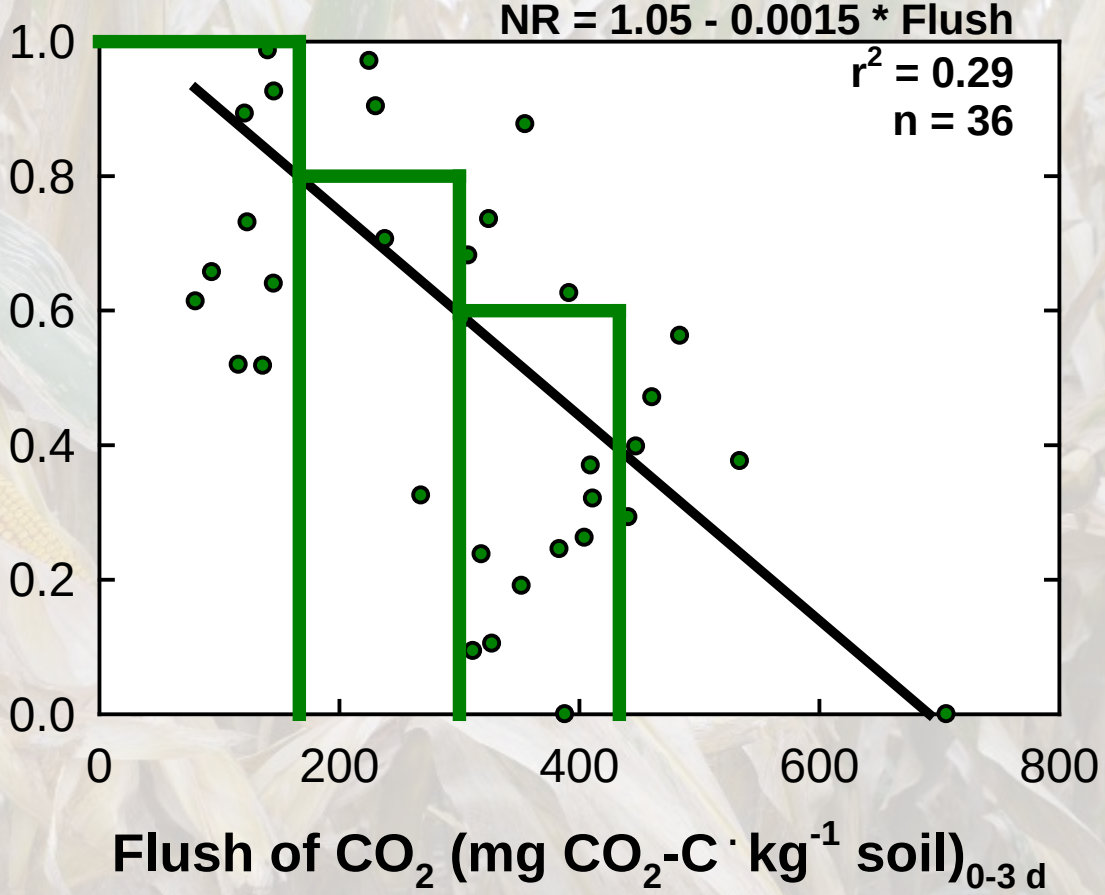

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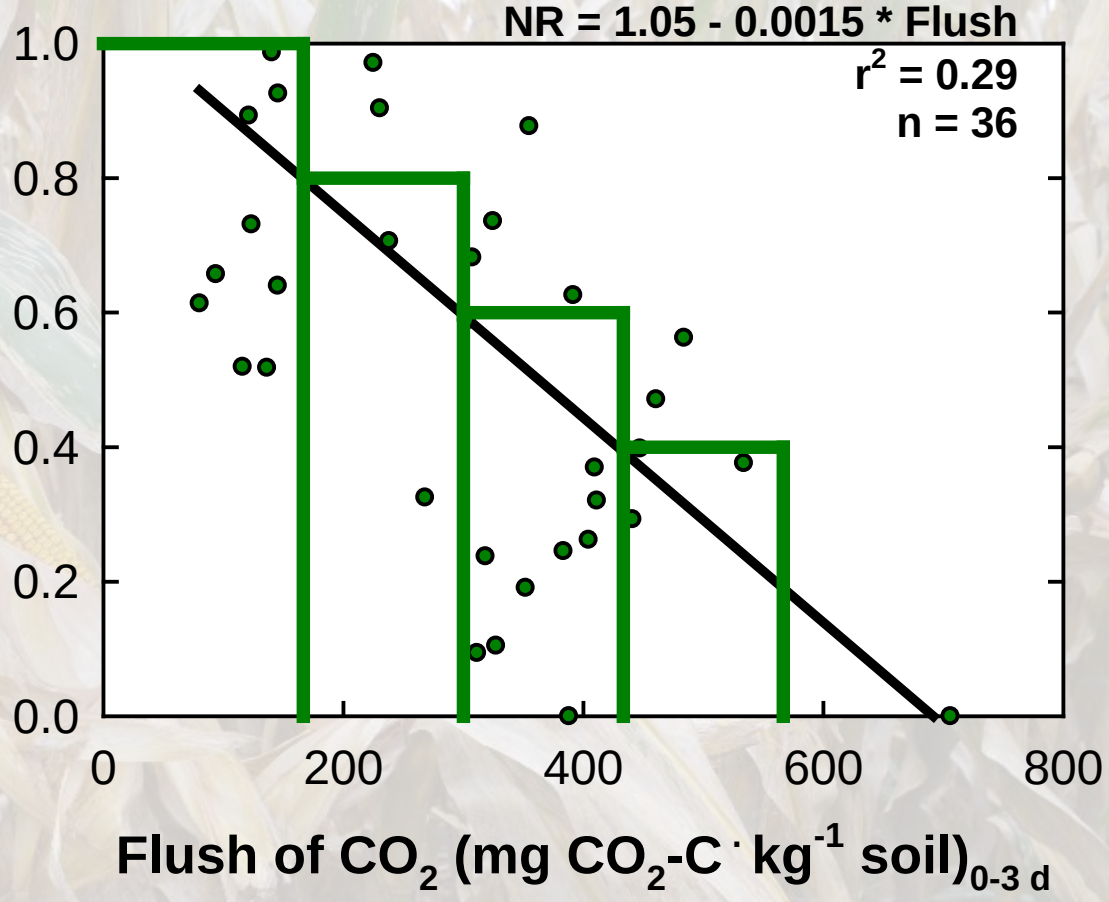

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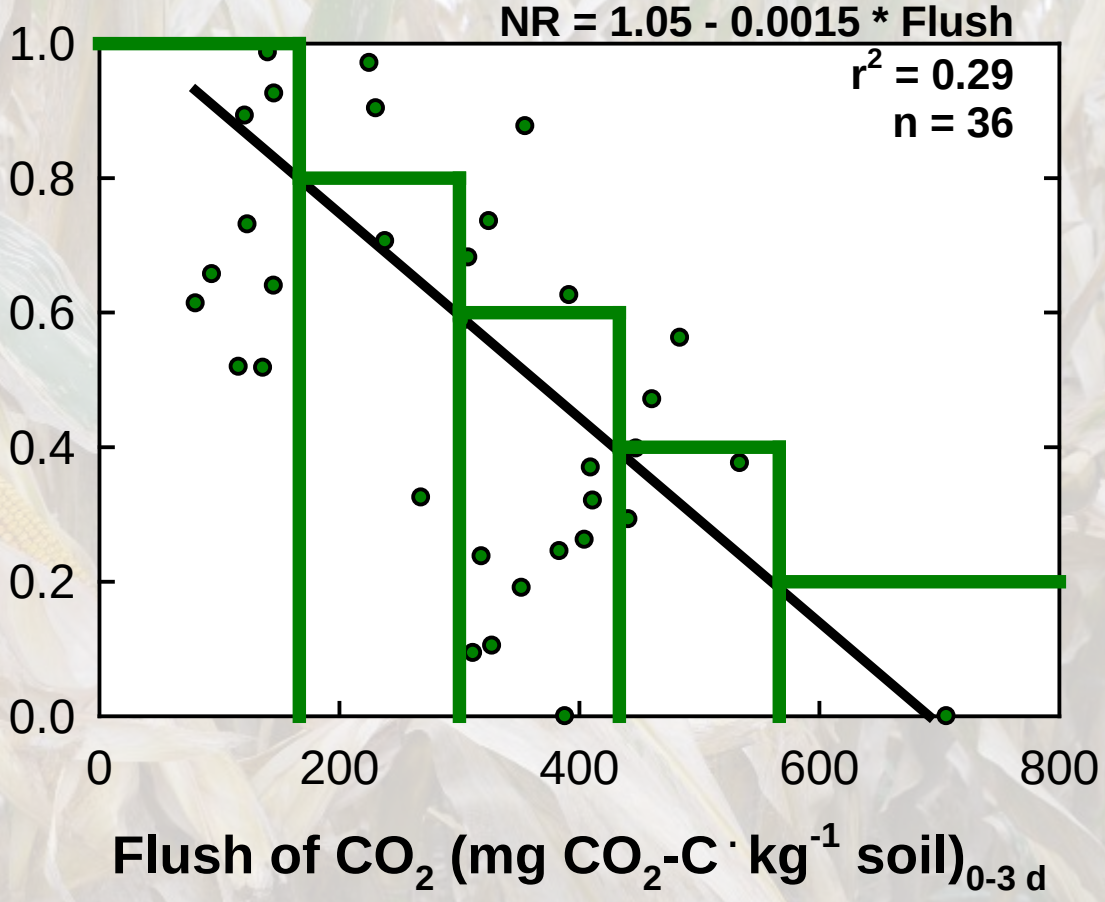
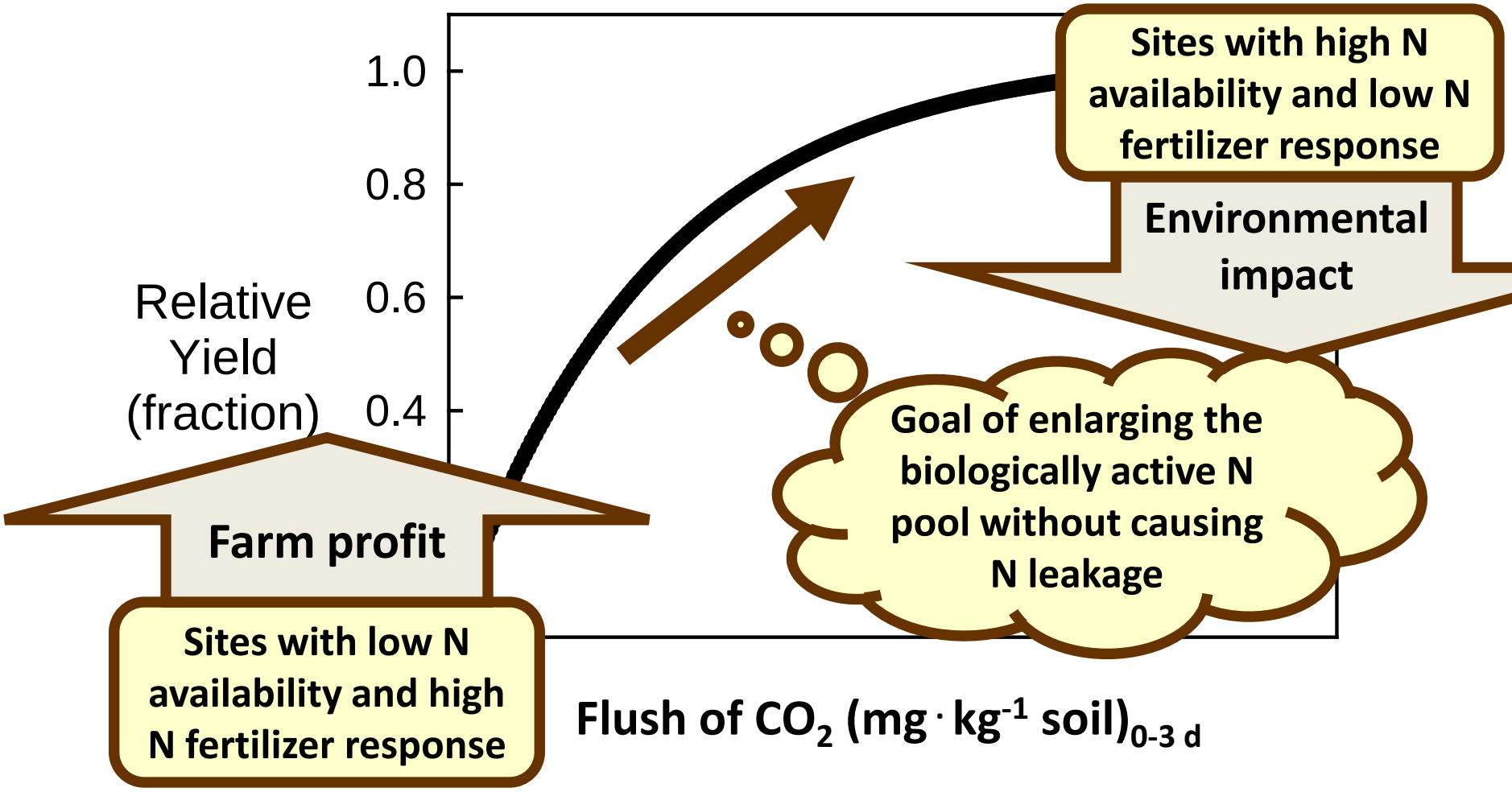


The flush of CO_2 as a predictive soil test



A working hypothesis…

Incubating soil in sealed jar with alkali to absorb CO_2

Components

- **1-L canning jar with lid**
- **Two 60-mL graduated bottles with 50 g soil wetted to 50% WFPS (***)**
- **One 30-mL screw-cap vial containing 10 mL of 1 *M* NaOH to absorb CO_2**
- **One 25-mL vial containing 10 mL water to maintain humidity**

***

- ✓ **One bottle pre-incubated for 10 days prior to $CHCl_3$ fumigation to estimate soil microbial biomass C**
- ✓ **One bottle incubated for 24 days to determine cumulative C and N mineralization**

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Agricultural & Environmental Letters

Research Letter

Should Soil Testing Services Measure Soil Biological Activity?

Alan J. Franzluebbers*

- ✓ **Soil biological activity is a key indicator for productivity and environmental quality**
- ✓ **The flush of CO_2 possesses many qualities of a robust soil test**
  - ➢ **Rapid**
  - ➢ **Inexpensive**
  - ➢ **Reproducible**
  - ➢ **Suitable for a wide range of soils**
  - ➢ **Correlating to nutrient needs of crops**

Thanks!

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