Soil Nitrogen Dynamics

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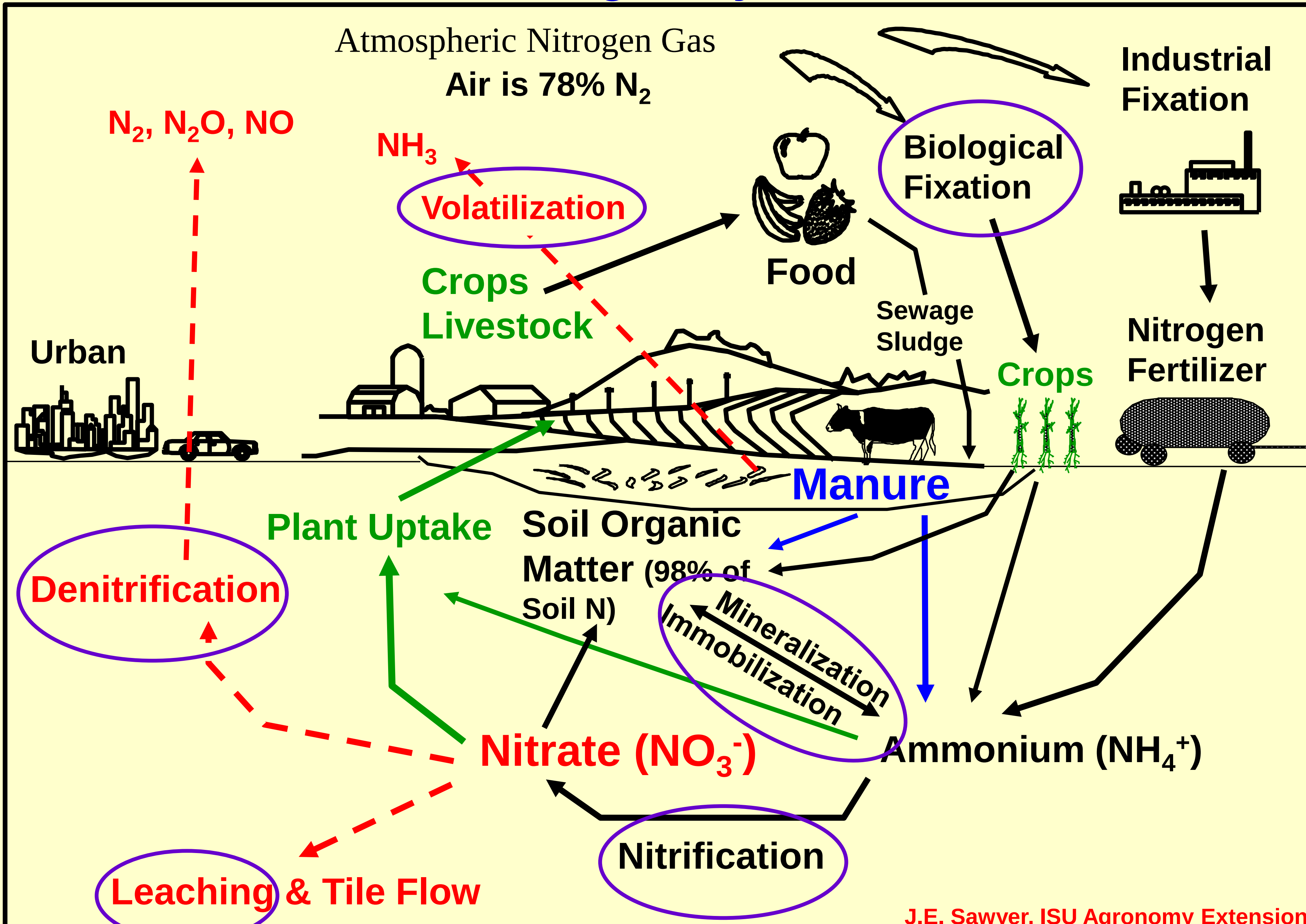
Nitrogen Cycle



Symbiotic N_2 Fixation

- Accomplished by bacteria (Rhizobium) that infect the roots of legumes
  - Alfalfa
  - Clover
  - Soybean
- Nitrogen fertilizer application not required for legume crop production

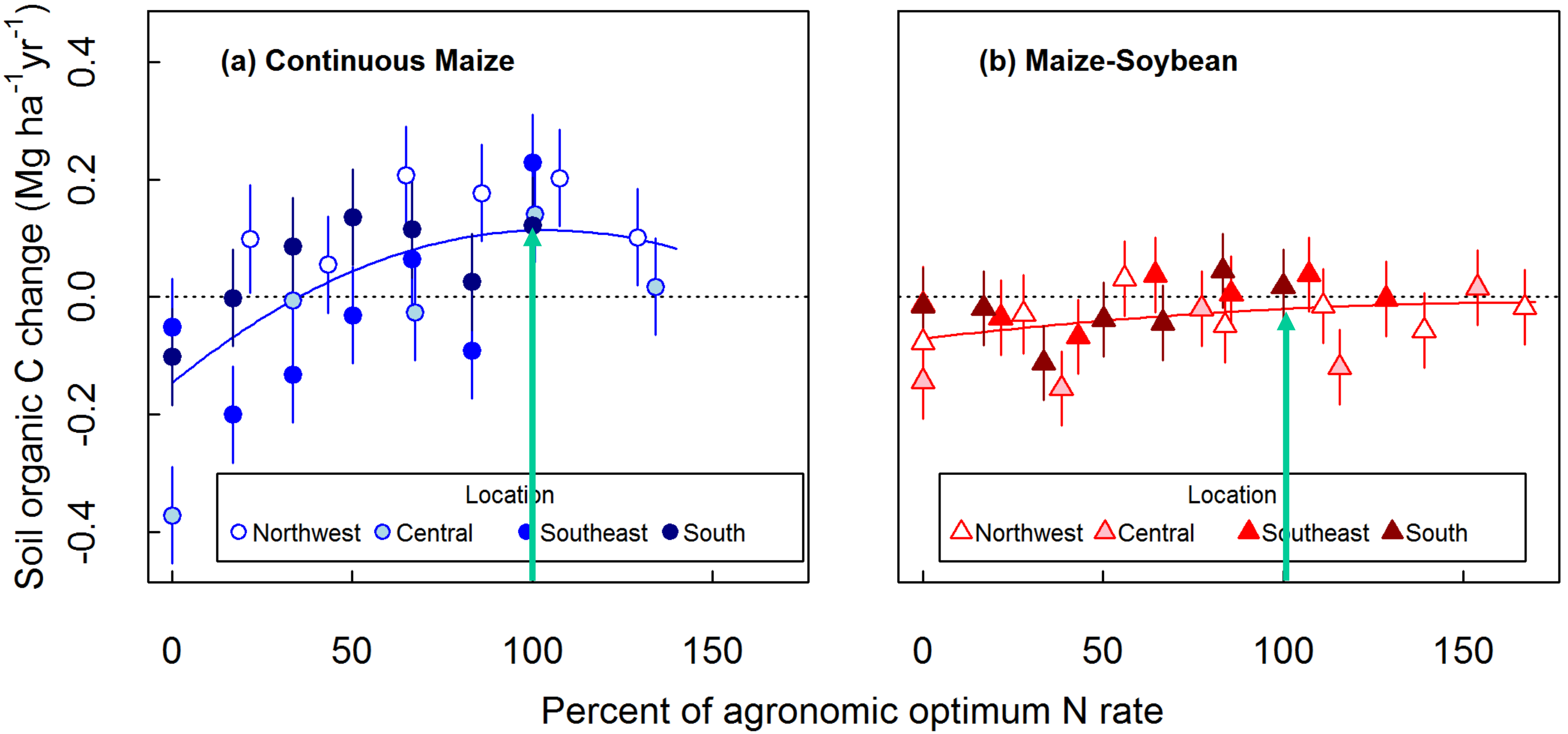
Symbiotic and Soil Derived N in Soybean

Loss or Gain of N from Soil

	Dry Matter	Total N	Symbiotic N	Soil N Export in Grain	Symbiotic N Return in Residue	Loss or Gain of N
	- - - - - - - - - - - - - - - - - -	- - -	- - - lb/acre	- - -	- - -	- - - - - - - - - - - - - - - - - -
Grain	2,100	152	61	91	---	---
Residue	3,400	40	16	---	16	---
Total	5,500	192	77	---	---	-75

40% of plant N from symbiosis (Source: Heichel and Barnes, 1984)

Nitrogen Application Needed to Maintain Soil Carbon with SC and CC



0.1 Mg C/ha/yr ≈ 90 lb C/acre/yr

Poffenbarger et al., 2017

Mineralization

- General process (microbial):
  1. Organic compounds $\longrightarrow$ NH_3
  2. $NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^-$
- Rate depends on:
  - Temperature and moisture
  - Carbon:Nitrogen (C:N) ratio of organic material
  - Aeration
  - Size of plant residue
  - pH
- Conditions favoring plant growth favor mineralization

Immobilization

- Incorporation of inorganic N into soil microbial biomass
- Favored by addition of carbon-rich crop residue (straw, corn stalks) to soil
- Very rapid in warm, moist soils

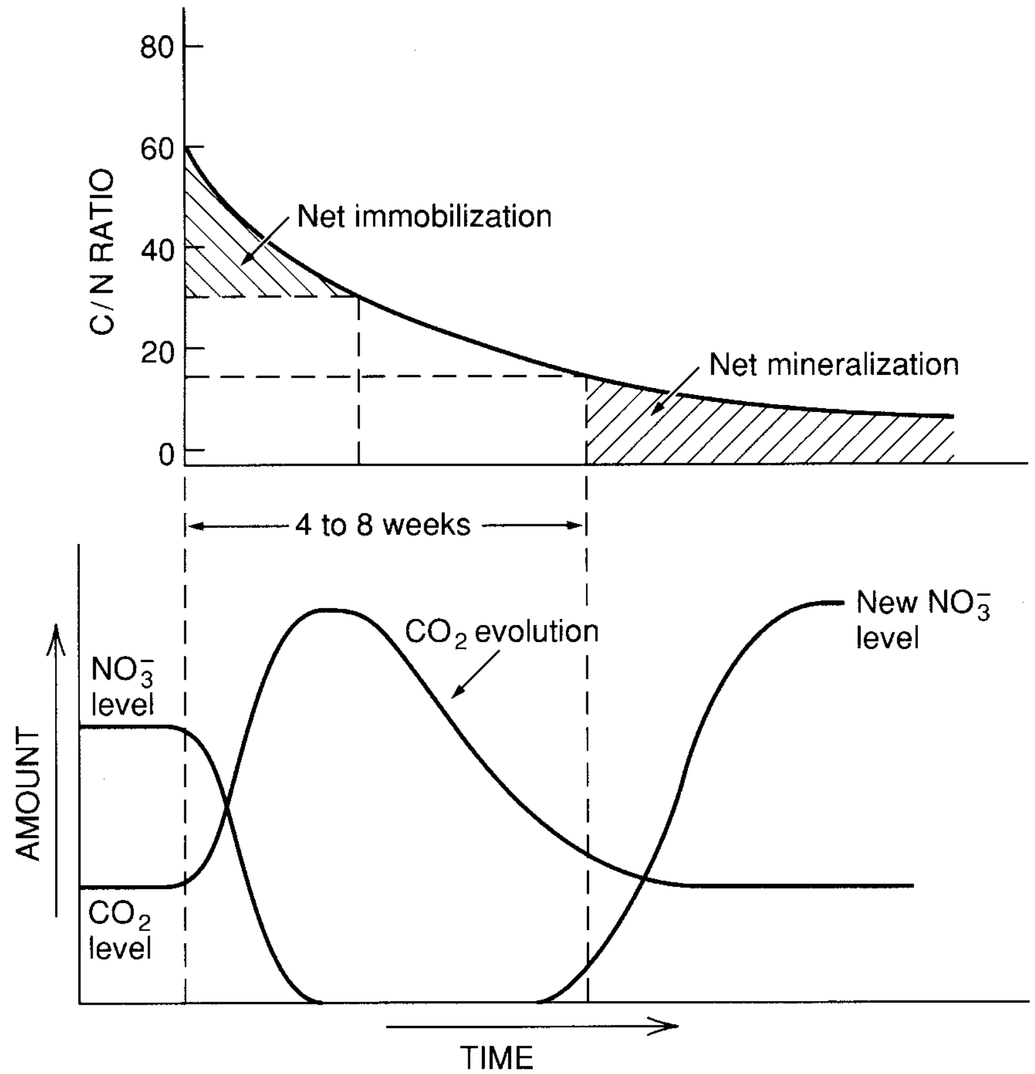


FIGURE 5.5 Changes in NO_3^- levels of soil during the decomposition of low-N crop residues. *Courtesy of B. R. Sabey, Univ. of Illinois.*

Example Cornstalk Decomposition

Assume:

8,000 lb cornstalk residue per acre
At 40% C = 3,200 lb C in cornstalks
At 60:1 C:N ratio = 50 lb N in cornstalks
8:1 C:N of microbial population
(remaining residue material in soil)
75% of C used for energy and lost as CO_2

3,200 lb C x 0.75 = 2,400 lb C to atmosphere as CO_2
3,200 lb C – 2,400 lb C = 800 lb C remaining in soil
800 lb C ÷ 8 = 100 lb N in microbial tissue
50 lb N in cornstalks - 100 lb N in microbes = - 50 lb N

Therefore 50 lb N Immobilized

Soil Organic Matter N Mineralization
First Year of Cultivation

Assume:

5.0 % organic matter (OM) soil
4 % OM loss/year
Average 5% N in soil OM
2,000,000 lb soil in 6 2/3 inch depth

5.0% OM x 2,000,000 lb x 4% OM loss/yr x 5% N
= 200 lb N/acre

Produce ≅ 180+ bu/acre corn yield

5,000 lb N in AFS

Soil Organic Matter N Mineralization
After Many Years of Cultivation

Assume:

3.0 % organic matter (OM) soil
2 % OM loss/year
Average 5% N in soil OM
2,000,000 lb soil in 6 2/3 inch depth

3.0% OM x 2,000,000 lb x 2% OM loss/yr x 5% N
= 60 lb N/acre

Produce ≅ 50 bu/acre corn yield

3,000 lb N in AFS

Corn Yield Without N Application

Northern Research Farm, 1985-2001				
	N rate applied to corn, lb N/acre			
Crop	0	80	160	240
	- - - - - - - - - - bu/acre - - - - - - - - - -			
C-C	56	113	138	149
C-S	102	141	159	163
C-O-A-A	157	158	164	161
Oat underseeded with forage legume.				

First Year Corn After Forage Legume

First Year Corn N Need Following Forage Legume

State	Site Years	Responsive Sites	Optimum N Rate
			lb/acre
Iowa (Voss and Shrader, 1981)	11	0	0
Iowa (Morris et al., 1993)	29	6	25
Wisconsin (Bundy and Andraski, 1993)	24	0	0
Minnesota (Schmitt and Randall, 1994)	5	1	42
Illinois (Brown and Hoeft, 1997)	4	0	0
Pennsylvania (Fox and Piekielek, 1998)	2	0	0

Reasons for Reduced N Need When Corn Grown After Soybean Compared to Corn After Corn

- Greater net N mineralization from soil system
  - Less crop residue following soybean
  - Mineralization/Immobilization difference
    - More rapid soybean residue decomposition
    - Earlier fall residue to soil system
    - Higher quality residue (i.e. lower C:N ratio of some residue components)
  - Enhanced soil organic matter mineralization

Corn Stover Removal and Tillage Effect on Yield and N Fertilization in Continuous Corn

Effect of tillage and residue removal on corn grain yield and economic optimum N rate across sites, 2009-2011.

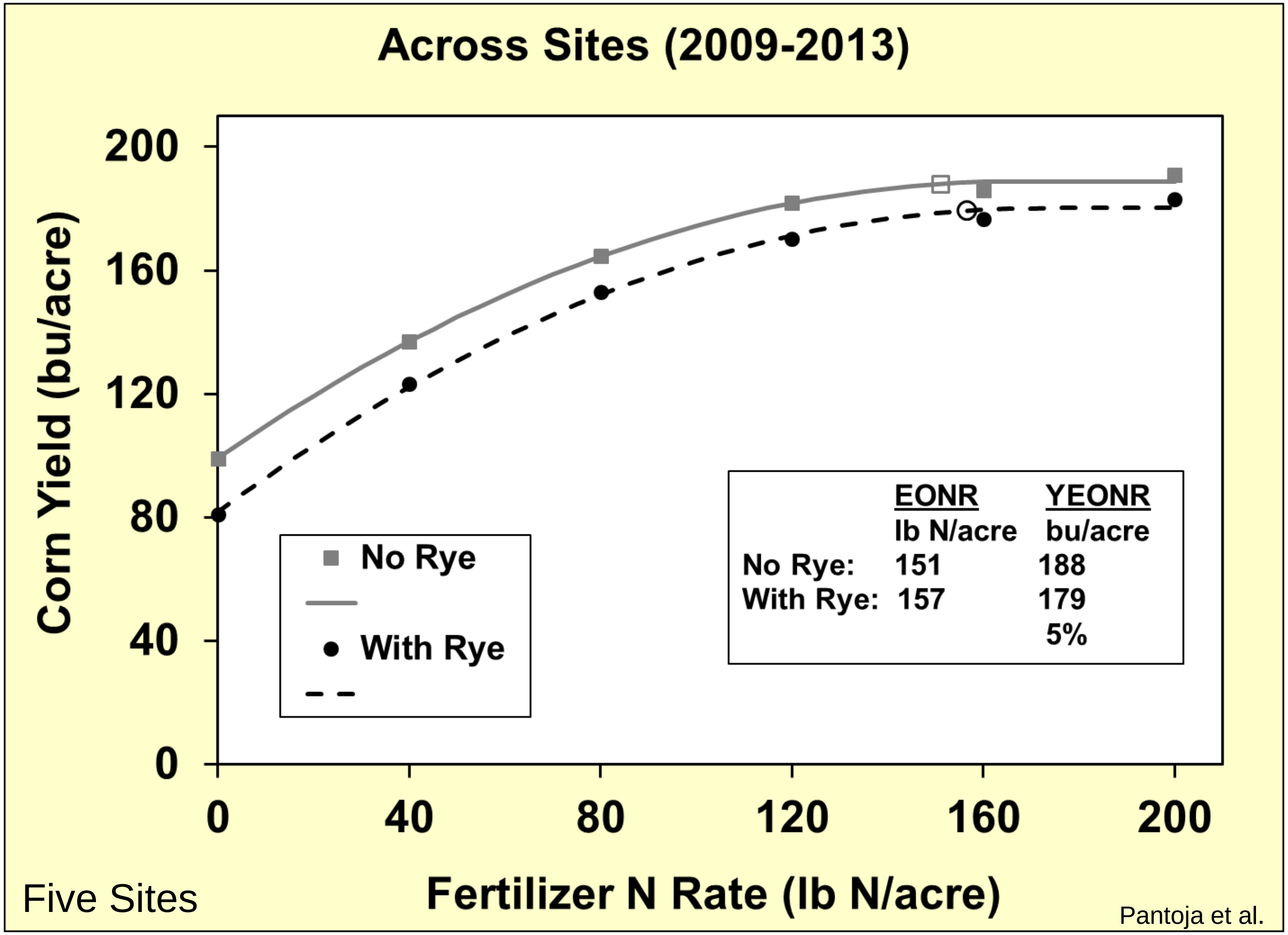
Residue	Chisel Plow		No-Tillage	
Removal	EONR	YEONR	EONR	YEONR
	lb N/acre	bu/acre	lb N/acre	bu/acre
None	228	179	227	162
50%	203	177	212	173
100%	185	181	189	170

EONR, economic optimum N rate; YEONR, yield at EONR.

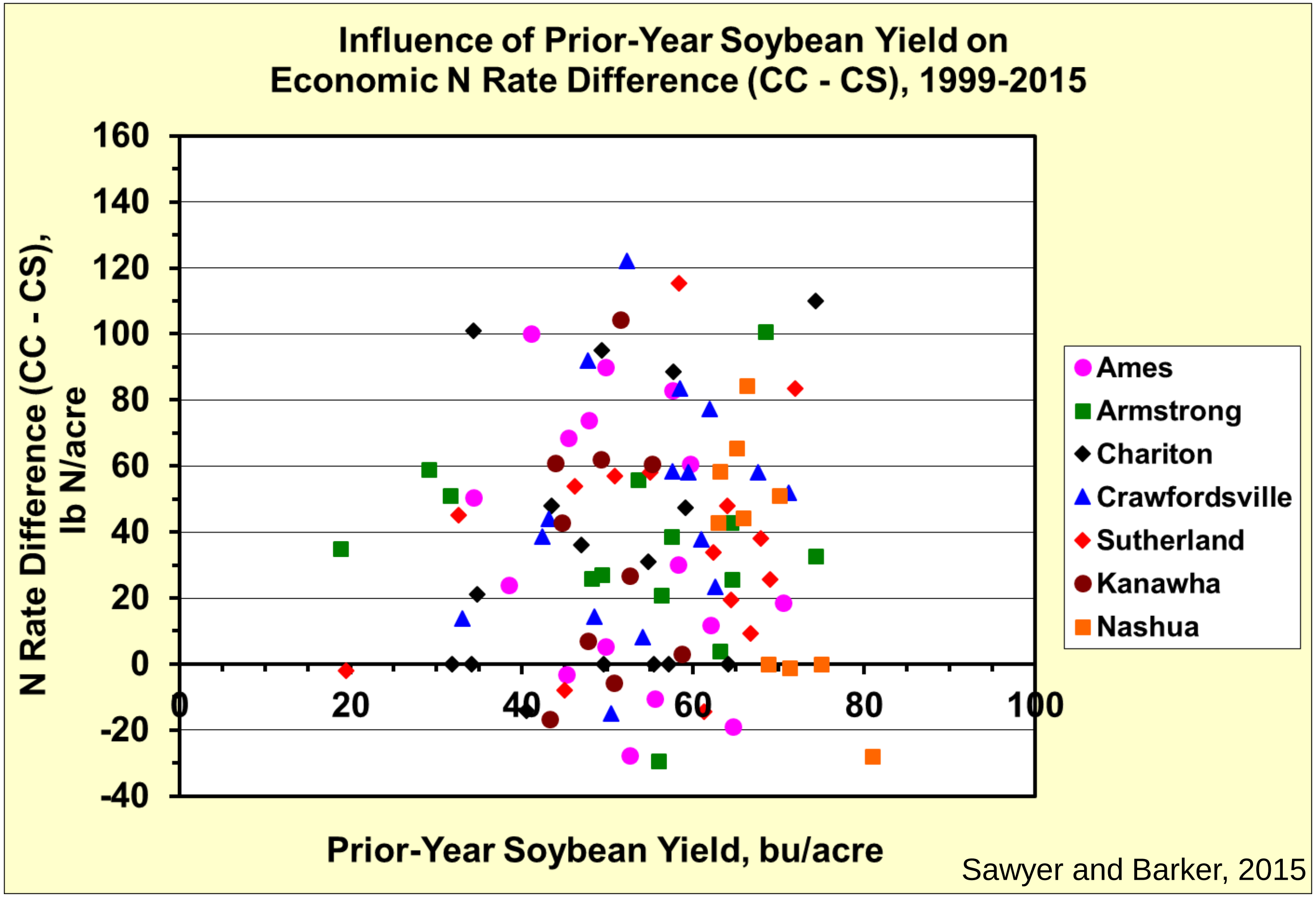
EONR and YEONR at 0.10 N:corn grain price ratio.

J. Pantoja et al., Iowa State University

Winter Rye Cover Crop Effect on N Fertilization (Soybean-Corn Rotation)

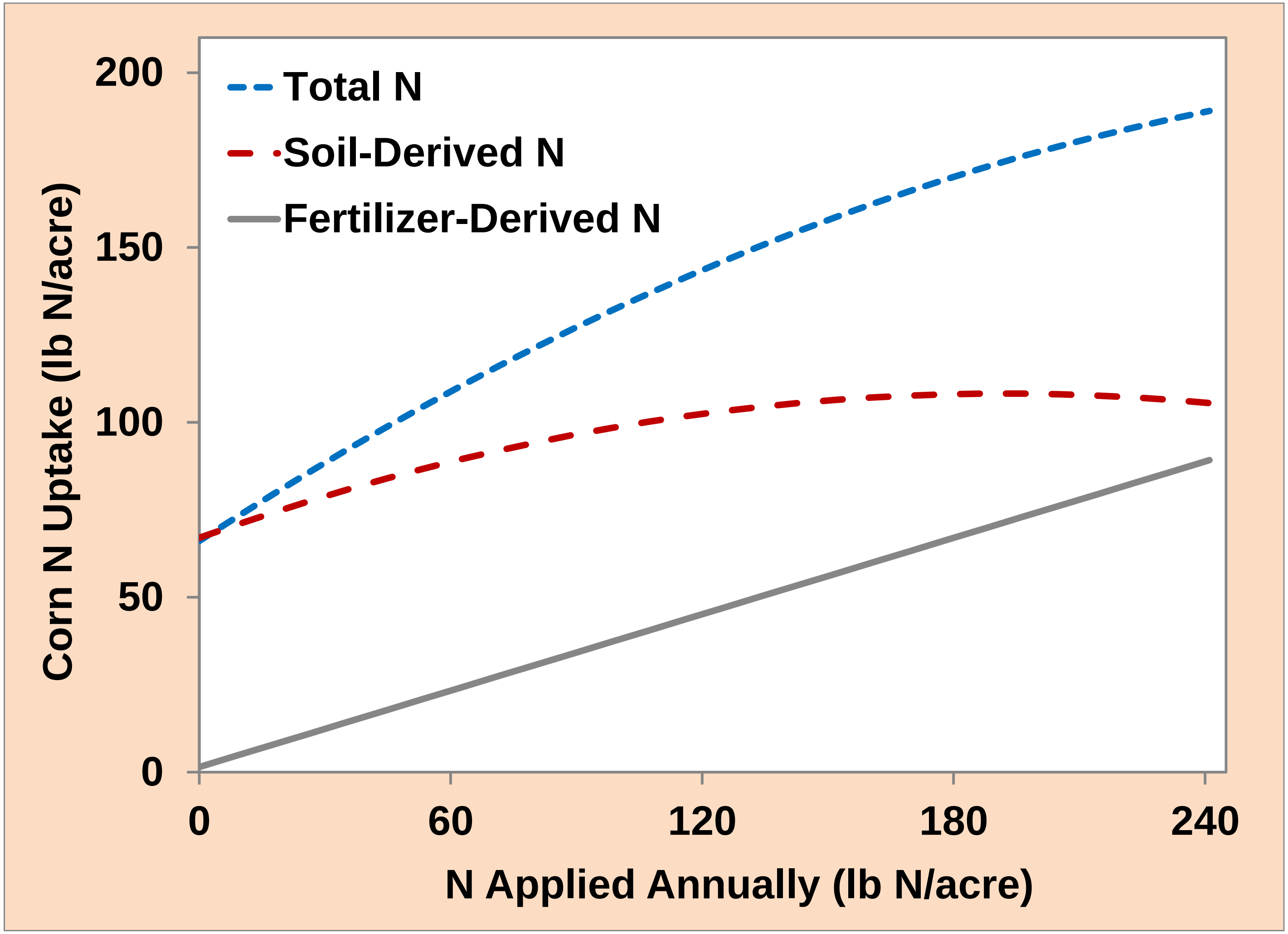


Prior-Year Soybean Yield vs. Next Year Difference in EONR for CC and SC



Corn N Uptake From Soil and Fertilizer

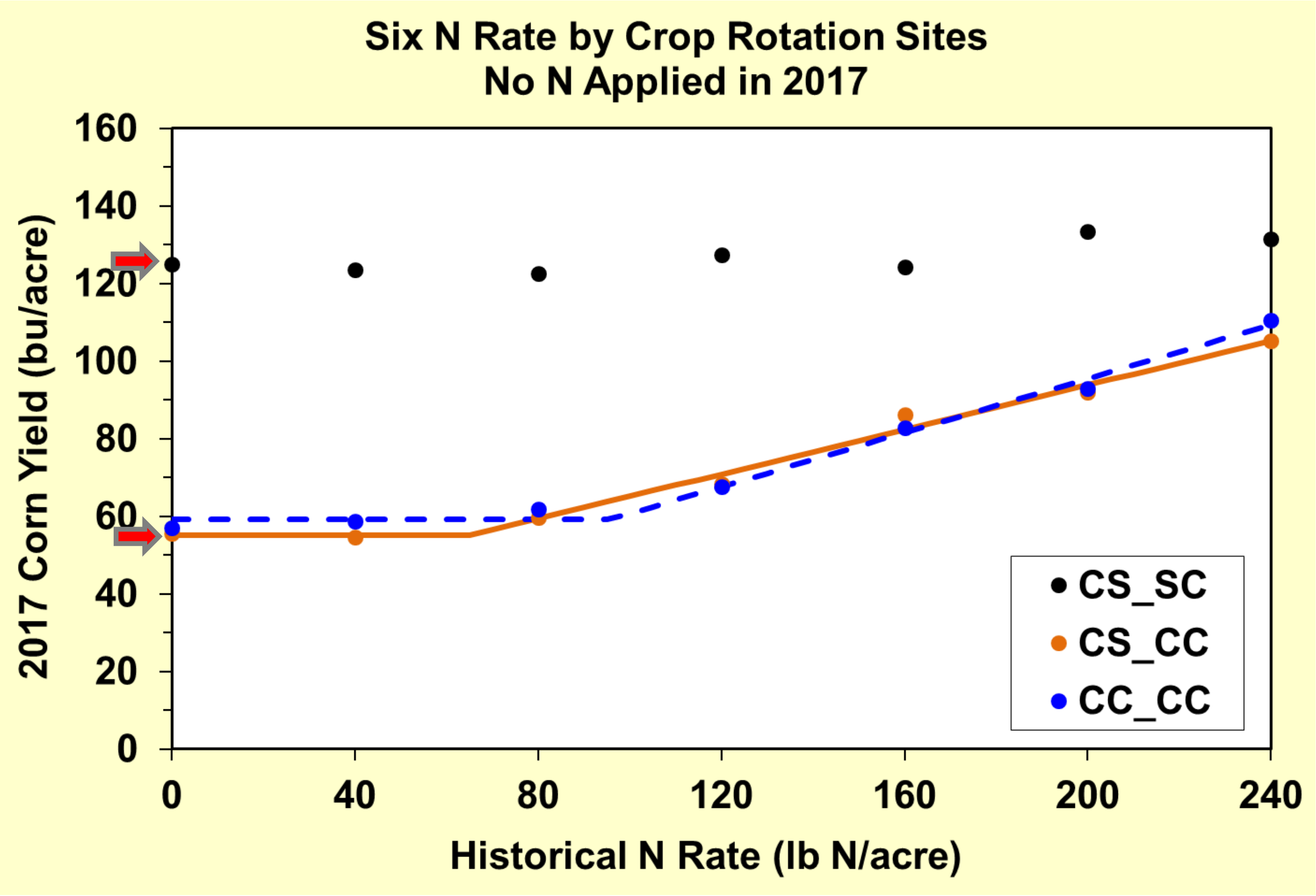
Stevens et al. (2005) Univ. of Illinois



Variation in Mineralization Example

	Crop Uptake	Crop Available	Additional Need	Fertilizer Rate
Assume:	- - - - - - - - - - -	lb N/acre	- - - - - - - - - -	
3.5% soil organic matter (OM)				
50% fertilizer N uptake efficiency				
200 bu/acre corn crop	200			
100 lb N crop residue (50% release)		50		
Precipitation		10		
Good Growing Conditions:				
3% OM N release		70		
Total crop available N		130		
Supplemental N need			70	
Fertilizer N application rate				**140**
25% Less OM mineralization:				
Organic matter N release		50		
Total crop available N		110		
Supplemental N need			90	
Fertilizer N application rate				**180**
25% Greater OM mineralization:				
Organic matter N release		90		
Total crop available N		150		
Supplemental N need			50	
Fertilizer N application rate				**100**

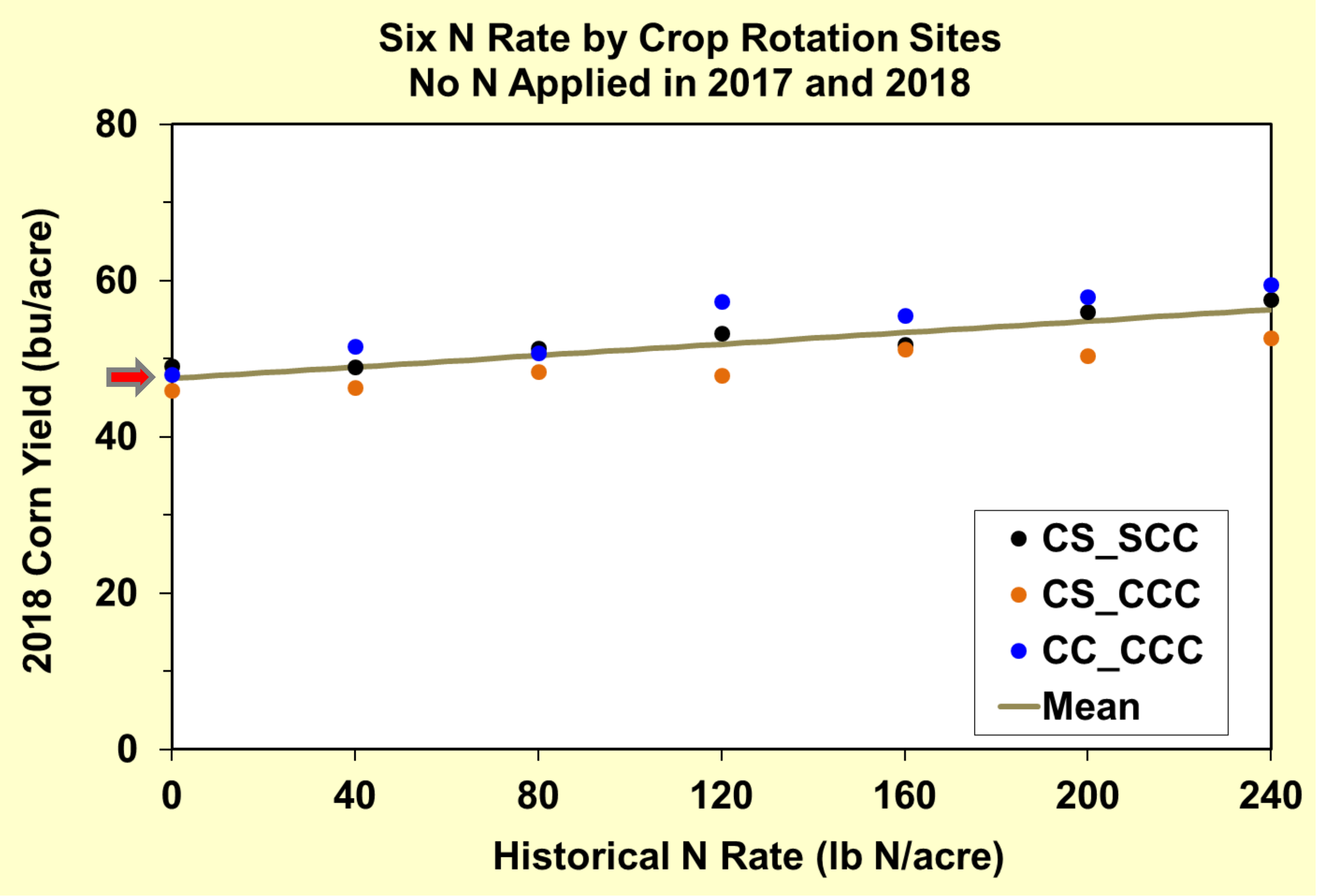
Residual Effect of Historical N Application



Sawyer et al.

After 11 to 17 years of N rate applications.

Residual Effect of Historical N Application



Sawyer et al.

After 11 to 17 years of N rate applications.

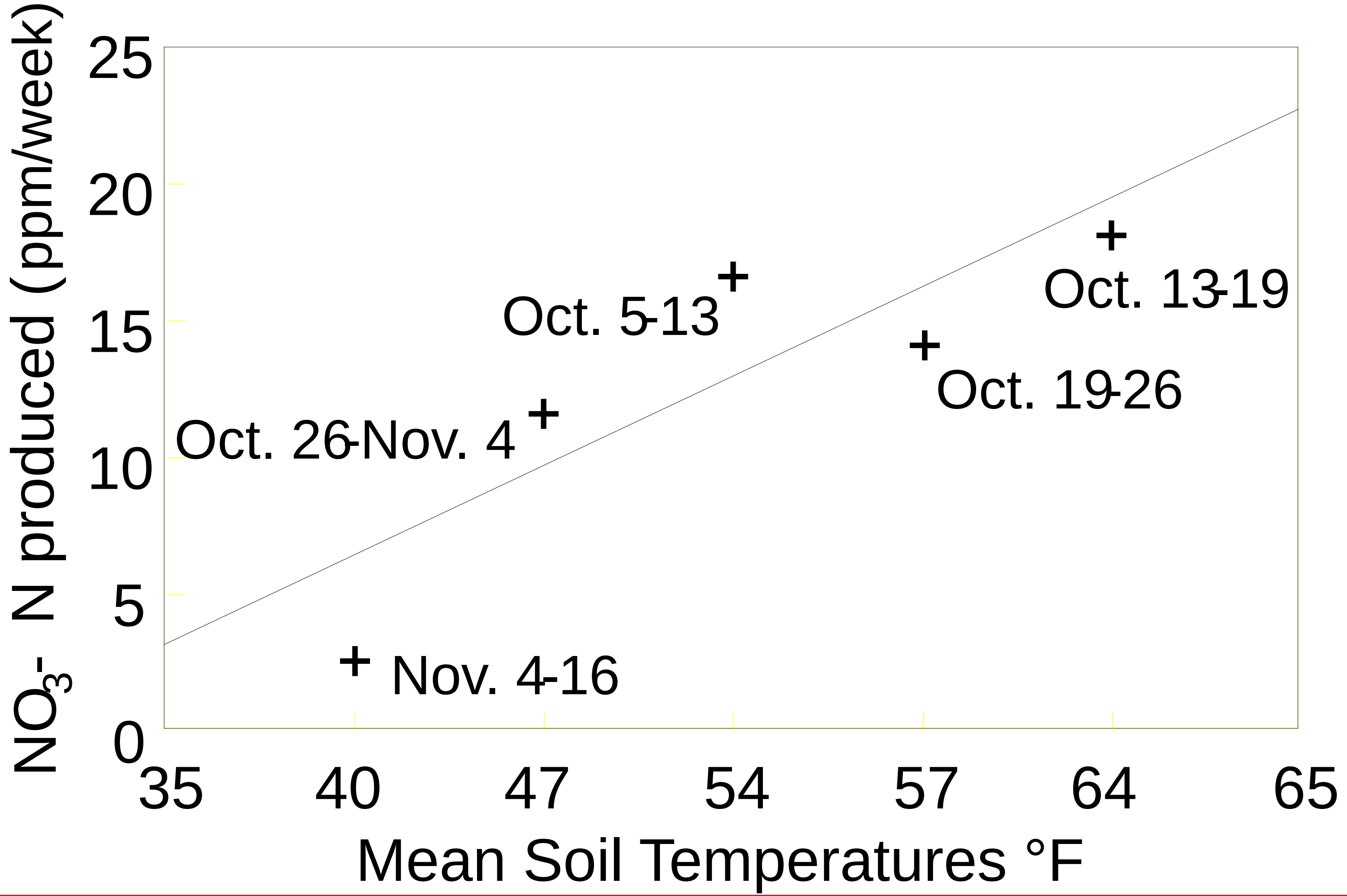
Nitrification

- NH_4^+ ⟶ NO_2^- (Nitrite)
  Nitrosomonas
- NO_2^- ⟶ NO_3^- (Nitrate)
  Nitrobacter
- Nitrification inhibitor designed to reduce biological conversion of NH_4^+ to NO_2^-

Nitrification

- Optimum temperature is 86 - 95 °F
  - Rate slows at temperatures below 50° F and is essentially zero if the soil is frozen
- Soil pH
  - Increases with increasing pH
  - Optimum at pH 8.5
  - Nitrobacter sensitive to alkaline conditions and free ammonia
- Soil moisture
  - Highest at field capacity

Influence of Temperature on Nitrification in Field Soils



Application Time and Nitrapyrin Impact on Ammonium Remaining from Anhydrous Ammonia Application

Application	Nitrapyrin	Sample Date 12/8	4/2	5/3
		% NH_4-N Remaining		
Nov. 7 (> 50 °F)	No	39	19	3
	Yes	63	28	17
Nov. 18 (< 50 °F)	No	40	33	7
	Yes	57	58	26

Urbana, IL.   J. E. Sawyer

Influence of Temperature on Persistence of N-Serve

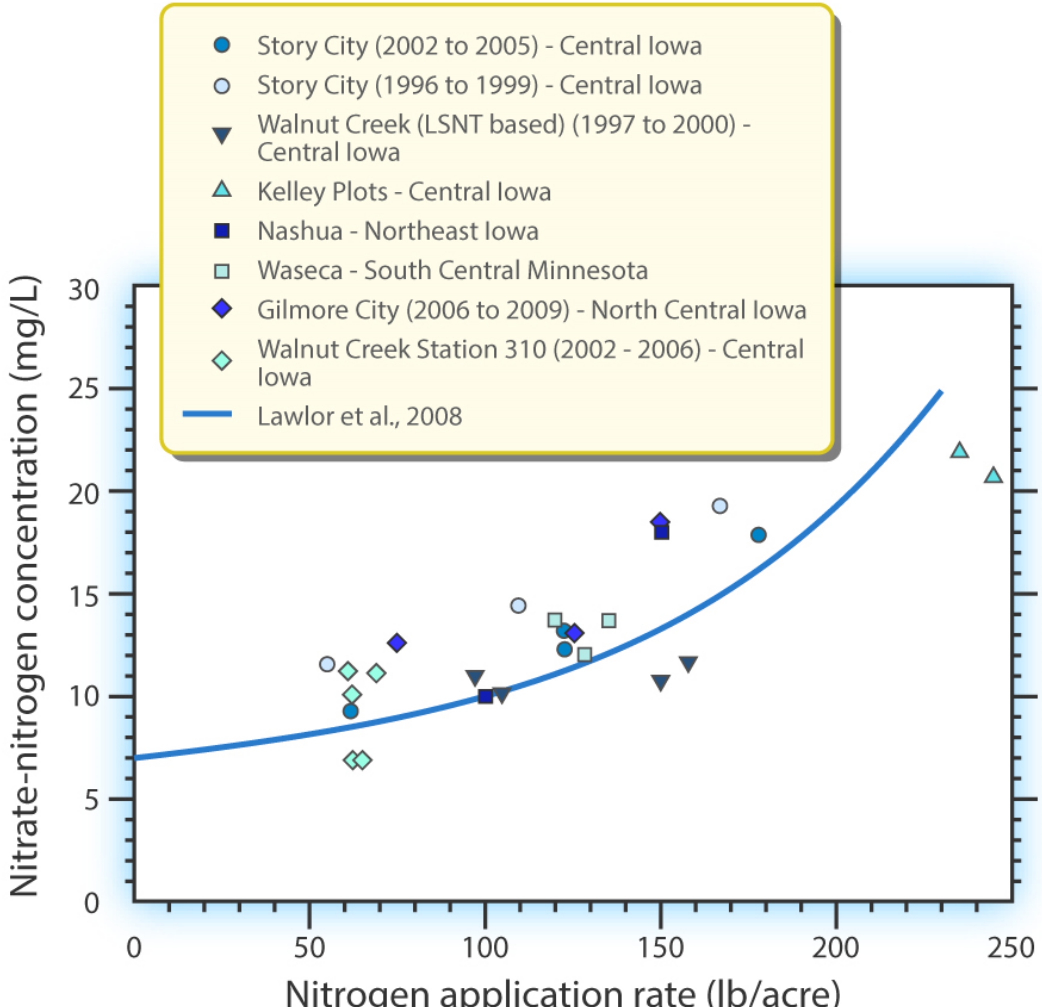
	Temperature	N-Serve Half Life, days	
	^{o}F	sicl soil	sil soil
Touchton (IL)	40	92	22
	55	70	< 7
	70	20	< 7
		solution	
Bremner (IA)	40	> 320	
	70	14	
	86	4	

- Chemical hydrolysis is dominant degradation
- Effect of temperature on degradation rate is approximately parallel nitrification activity

Leaching

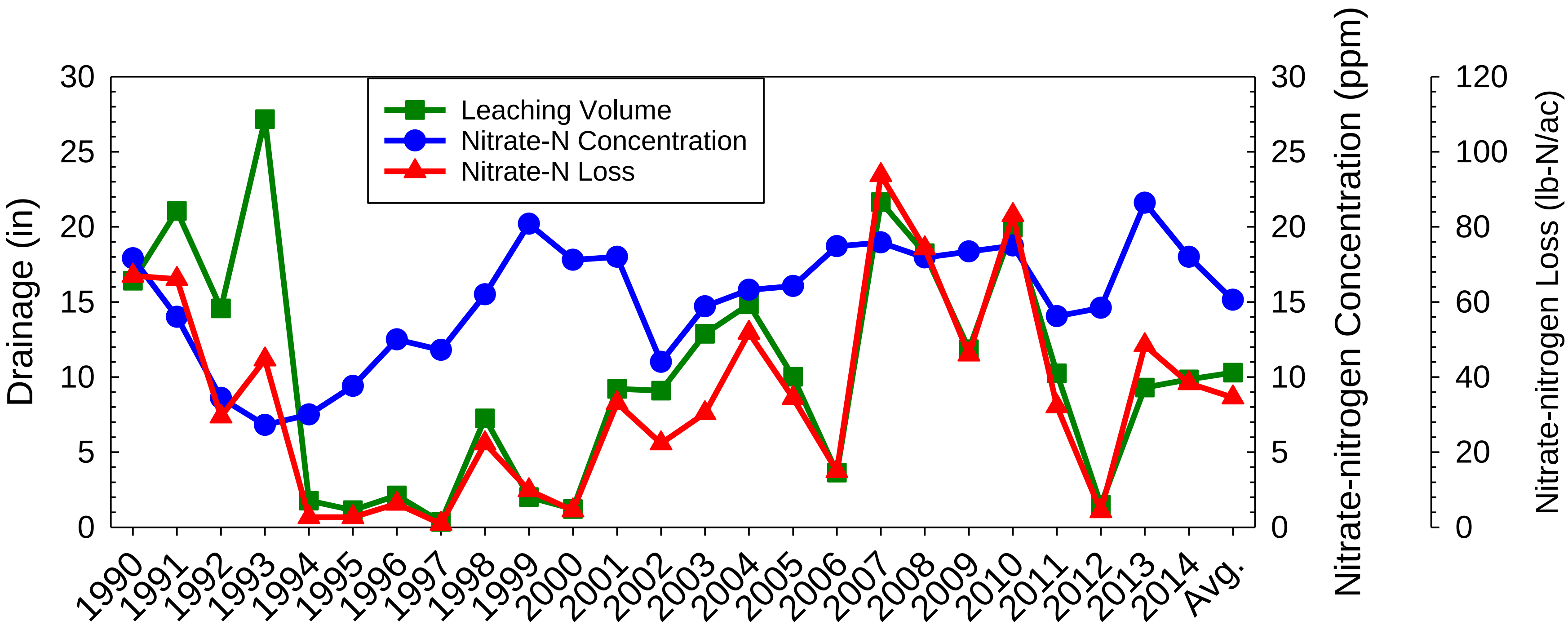
- Nitrate moves freely in soil with water
- Losses of nitrate can be rapid
- A high percent of nitrate lost through tile lines occurs in spring rainfall events
- Nitrate in tile flow comes from soil-derived nitrate and applied N

Nitrogen Rate Effect on Nitrate Losses in Tile Drainage (Iowa)



Iowa Nutrient Reduction Strategy

Influence of Precipitation/Leaching Volume on Nitrate-N In Tile Drainage



Combined Corn-Soybean System – Same N management – Early Spring Sidedress at 150-160 lb-N/acre. Helmers et al. Iowa State University.

Denitrification

- Biological conversion of nitrate to N gases
- Occurs when the soil pores are saturated

$$NO_3^- \longrightarrow NO_2^- \longrightarrow N_2O \longrightarrow N_2$$

Air quality issue with N_2O

Small amount per acre but greenhouse gas

Conditions That Favor Denitrification

- Anaerobic conditions (saturated soil)
- Suitable temperature
  - Rate increases > 50º F
- Decomposable organic material
- Suitable pH
  - > 5.5
- Presence of denitrifying bacteria

Rate of Denitrification Per Day in a Webster Soil As Affected by Temperature [a]

	N loss per day in lb/acre	
Temp in °F	Surface 0-6”	27-36”
37	0.3	0
50	3.3	0.8
63	8.3	1.2
75	12.3	3.2

[a] Treated at rate of 400 lb N/acre and incubated for 5 days under waterlogged conditions.

2 to 4% nitrate-N loss per day (55 to 75+ °F soil temperature)

Urea Volatilization

Urea hydrolysis

Urease inhibitor designed to "inactivate" urease enzyme

1. $(NH_2)_2CO + 2H_2O = (NH_4)_2CO_3$
   Urea — Urease — Ammonium Carbamate

2. $(NH_4)_2CO_3 + 2H^+ = 2NH_4^+ + CO_2\uparrow + H_2O$
   Ammonium

3. $NH_4^+ + OH^- = NH_3\uparrow + H_2O$
   Hydroxyl — Ammonia

pH increase as a result of hydrolysis

at pH 7.0, 0.6% as NH_3 -- at pH 9, 37% NH_3

Volatilization

- Field conditions increasing urea hydrolysis and NH_3 loss
  - No rainfall/incorporation after application
  - High crop residue on soil surface
  - High soil pH (alkaline soils)
  - High temperatures
  - Moist to drying soils
  - Low soil clay and organic matter (low buffer and ability to absorb ammonium)

Volatilization

- Field conditions decreasing urea hydrolysis and NH_3 loss
  - 0.25 to 0.5 inch rainfall within 1-2 days after application
  - Surface temperatures below 50º F
  - Surface soil pH < 7.0
  - Dry soil surface
  - Low crop residue on soil surface
  - High buffer capacity soil

Questions?