Nitrogen Fertilizer Management Effects on Soil Processes Affecting N_2O Production

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ASA-CSSA-SSSA Annual Meeting
18 October 2011, San Antonio

Funding:
-USDA-NIFA Air Quality Program
-ARS GRACEnet Project

Anhydrous ammonia application equipment:
-John Deere & Company

Objectives

Use findings from our recent studies to:

1. Examine how N Fertilizer Mgmt Practices influence underlying processes that control N_2O emissions

2. Discuss implications of findings with respect to improved N_2O emissions models and challenges for mitigation strategies.

Fertilizer management comparisons

Category	Number of peer-reviewed studies
Comparison of conventional fertilizer sources	
Anhydrous ammonia (AA) vs. other sources	3
Other conventional source comparisons	4
Timing of Application	
Single application vs. multiple split applications	2
Fall- vs. spring-applied fertilizer	2
Early spring vs. later application(s)	3
Physical Placement	
Anhydrous ammonia, placement depth	1
Other N source, placement depth	2
Broadcast vs. banding	2

1. To determine if specific management practices (other than reducing the N application rate) can be used to mitigate N_2O emissions.

2. To determine if the effectiveness of these practices depends on climate, soil, cropping system or other site-specific factors.

3. To develop quantitative relationships (e.g. emissions factors) that can be used to predict how a change in practice will affect N_2O emissions.

Fertilizer management comparisons

Management practices →

Soil & climate factors →

SOIL PROCESSES
Nitrification
Denitrification
N mineralization
N immobilization
Solubilization of DOC
etc

→ **N_2O**

-To better understand how mgmt practices & environmental factors interact to regulate fundamental soil processes

-To incorporate this understanding into improved models

USDA ARS

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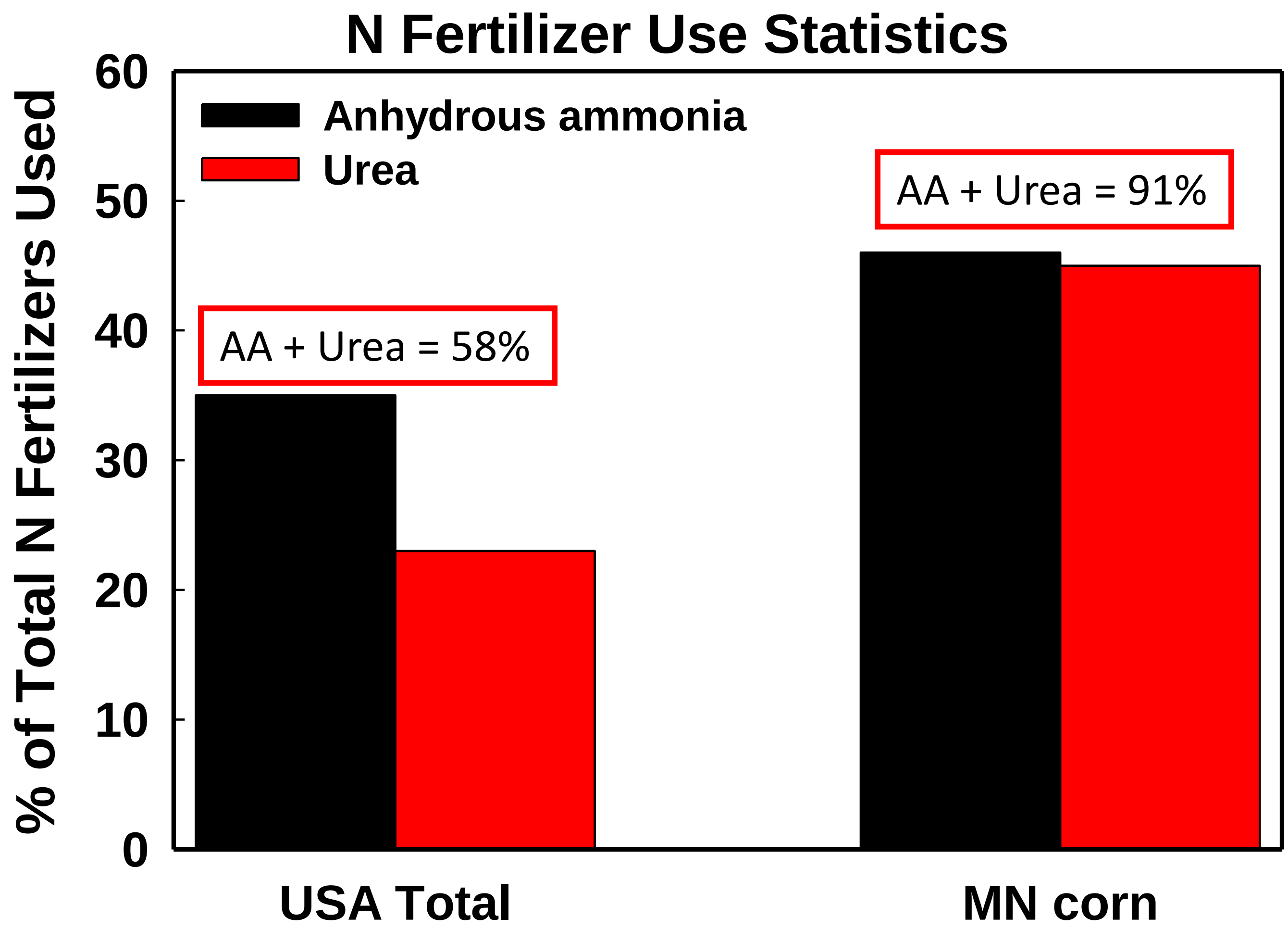
Broadcast vs. banding	**2**

1. **Compare AA and broadcast urea in a coarse textured soil used for irrigated corn production.**

2. **Examine effects of AA application depth.**

3. **Separate experiment in silt loam soil compare broadcast vs. band-applied urea.**

Anhydrous Ammonia (AA) and Urea



ERS, 2011 (2008 data)
http://www.ers.usda.gov/Data/FertilizerUse/

Survey data (2009 data)
Bierman et al. (In review)

Anhydrous Ammonia (AA) and Urea

Previous studies in Minnesota:

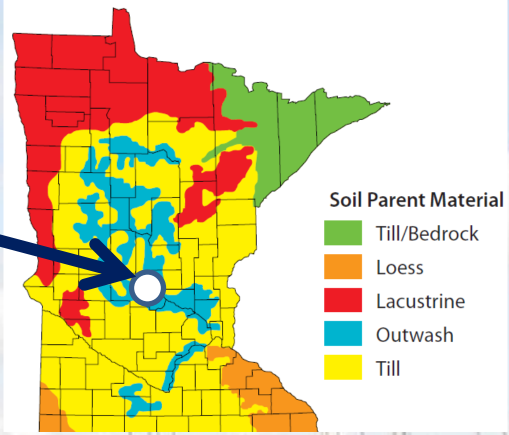
<u>Reduced N_2O emissions with broadcast urea compared to AA:</u>

- **Silt loam soil under varying tillage**
- **Silt loam soil with varying crop rotation**

Venterea et al. (2005; 2010)

Anhydrous Ammonia versus Urea: Two-year study in Irrigated Corn

Location	Parent material	Texture	Soil C	pH
Becker, MN	Outwash	Loamy sand	1.0%	5.0



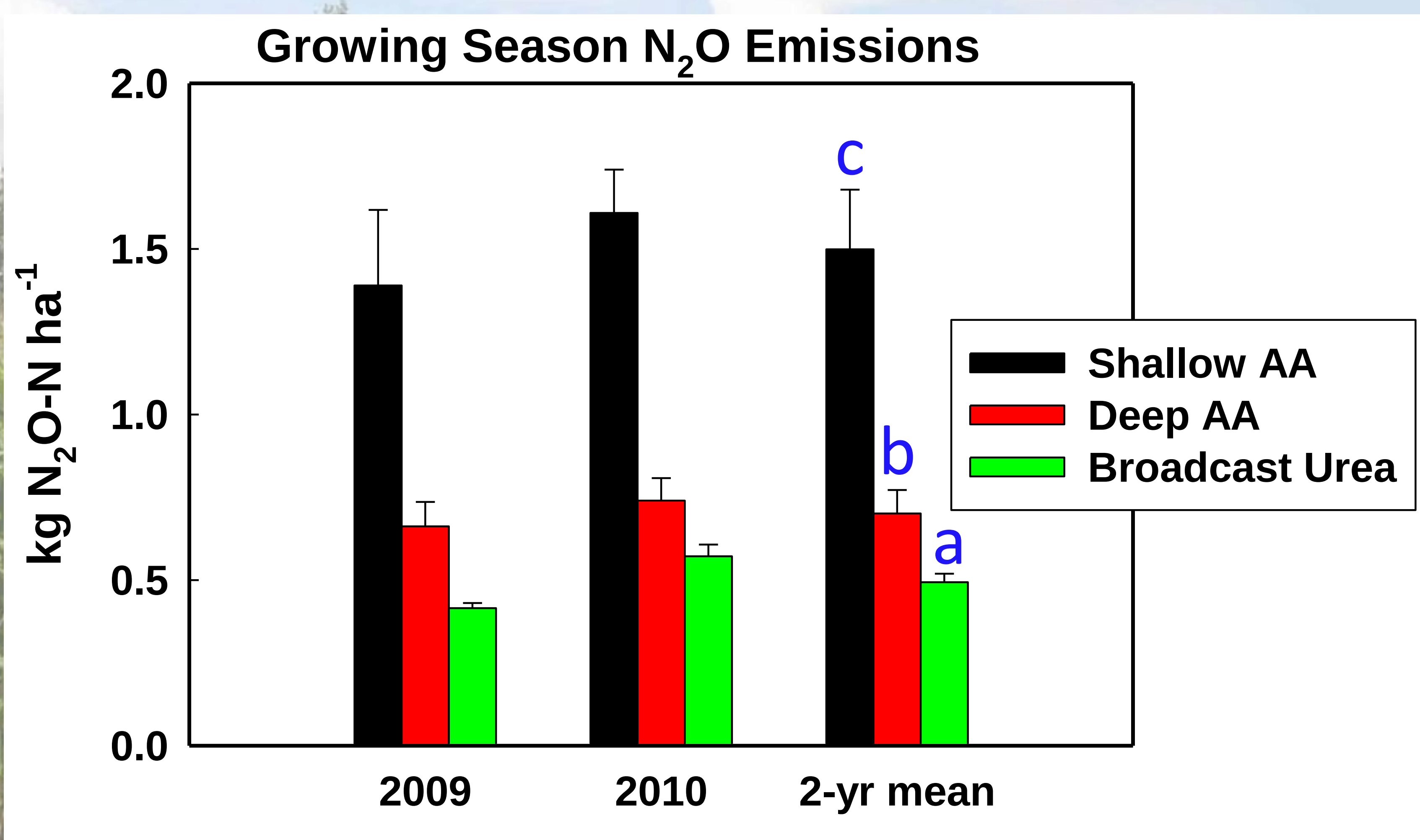
Source		Placement
1.	Urea	Broadcast and incorporated
2.	AA	Injected at approx. 20 cm depth
3.	AA	Injected at approx. 10 cm depth

All sources applied in two split applications of 90 kg N ha^{-1} each:

50% prior to planting

50% as side dress 4-6 weeks after planting

Anhydrous Ammonia versus Urea:
Two-year study in Irrigated Corn



Fujinuma et al. JEQ (2011)

Anhydrous Ammonia (AA) and Urea

Reduced growing season N_2O emissions with broadcast urea:

	Percent reduction
• Silt loam soil under varying tillage (1 yr)	
•No till	50
•Biennial tillage	81
•Conventional tillage	79
• Silt loam soil with varying crop rotation (3 yr)	
•Continuous corn	57
•Corn/soybean	50
• Loamy sand with varying AA application depth (2 yr)	
•Shallow AA injection	29
•Deep AA injection	67

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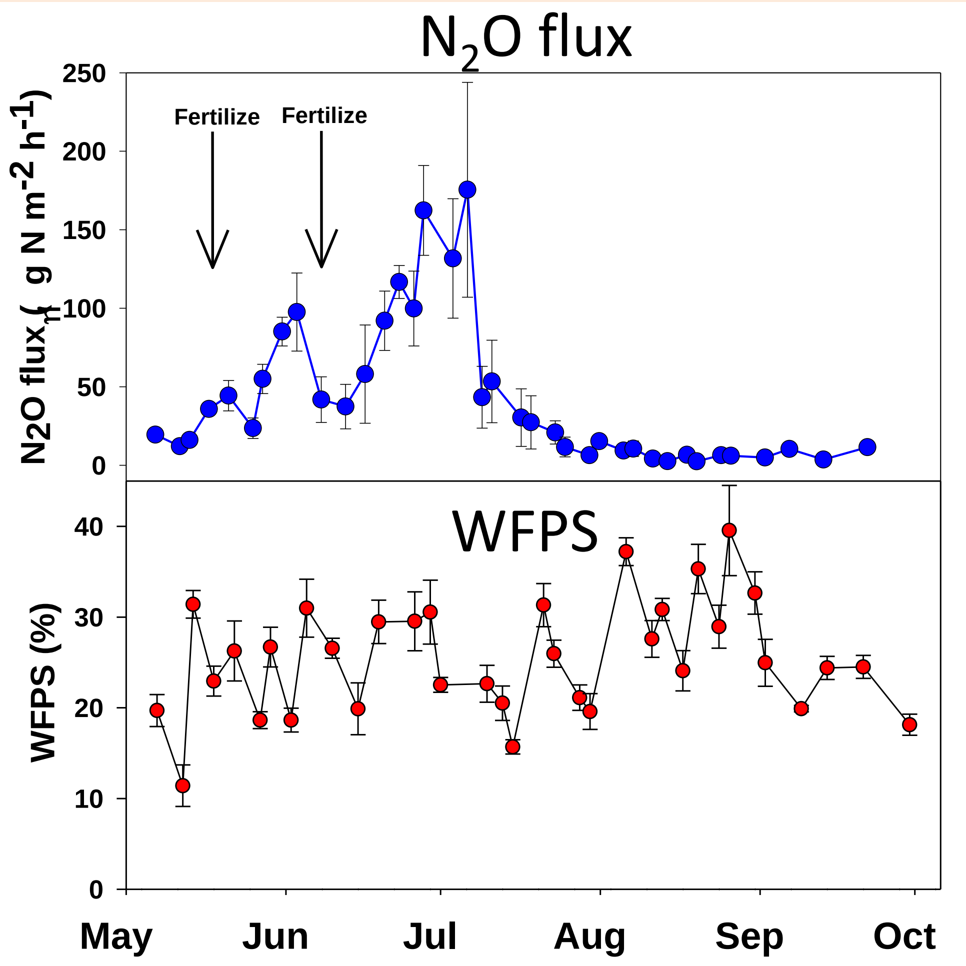
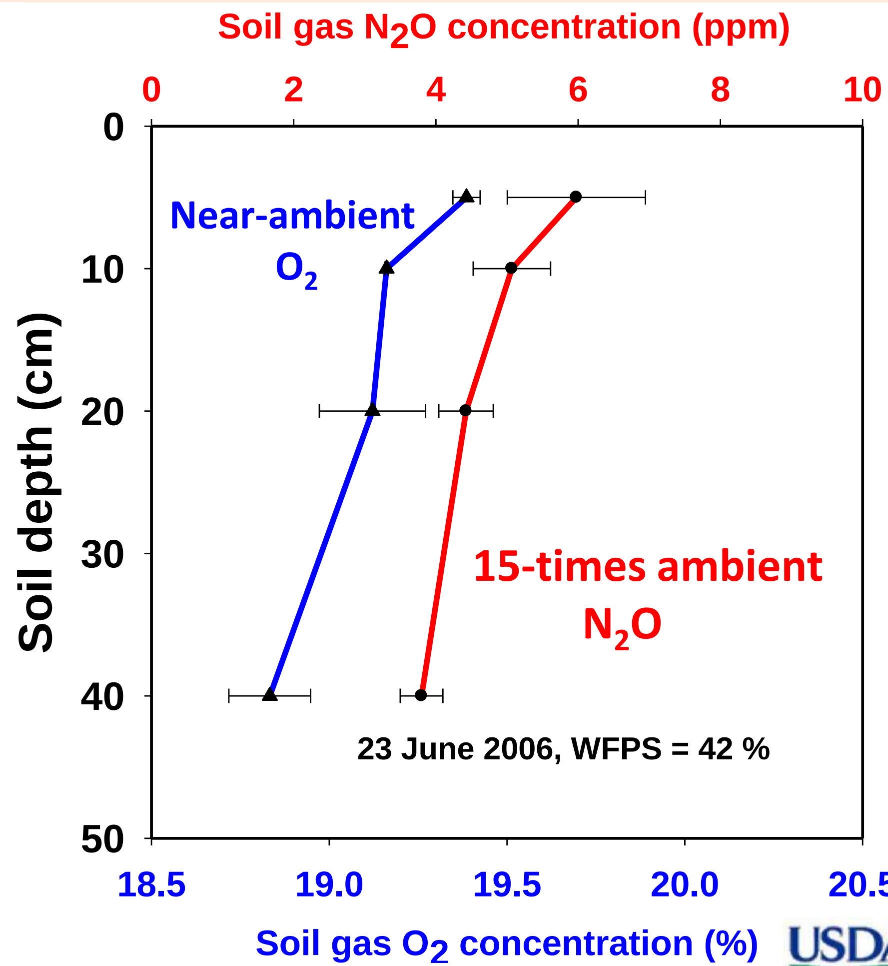
Why are N_2O emissions greater with Anhydrous Ammonia?

Peak N_2O fluxes occurred under aerobic conditions



Loamy sand, Becker, MN

Fujinuma et al. JEQ (2011)

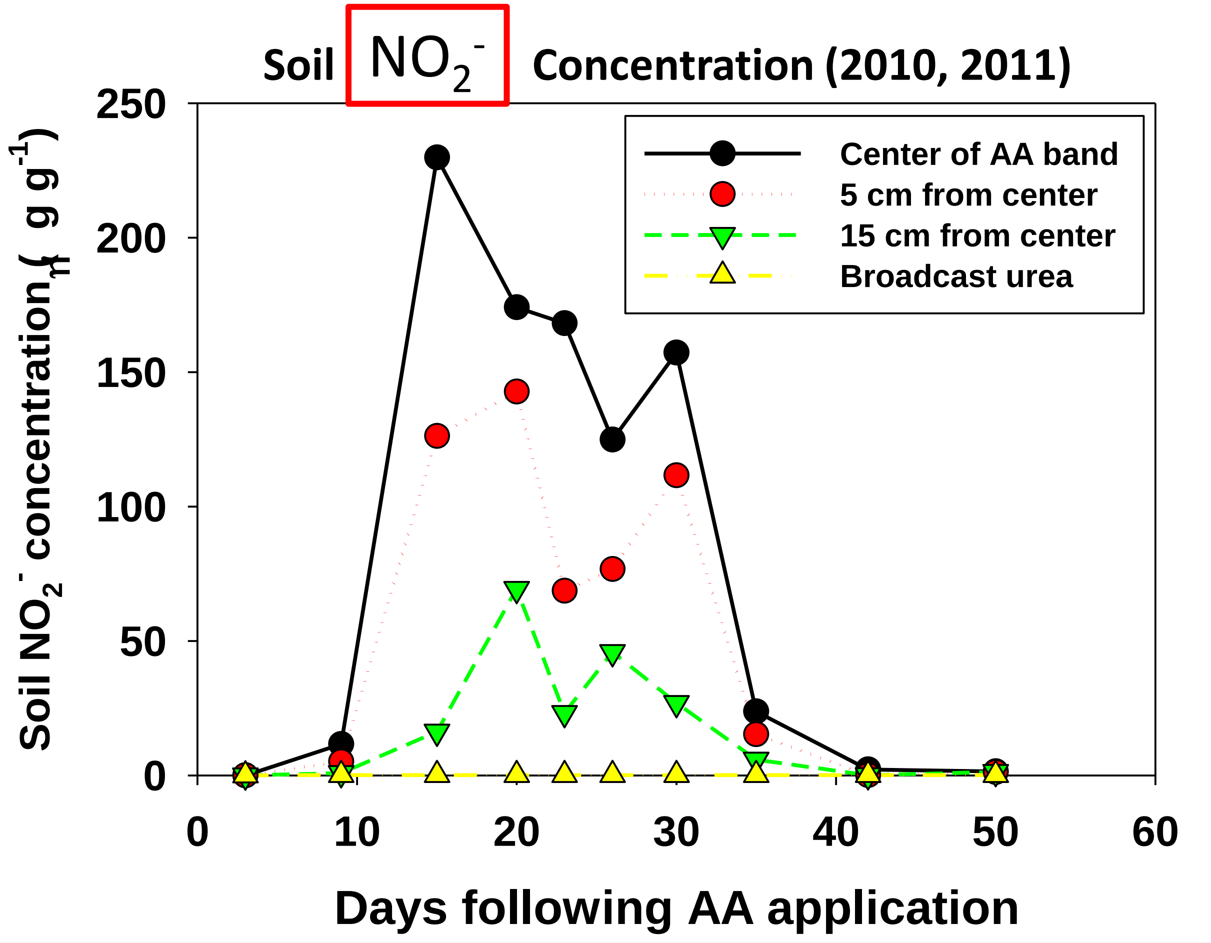


Silt-loam soil, Rosemount, MN

Unpublished data

Why are N_2O emissions greater with Anhydrous Ammonia?

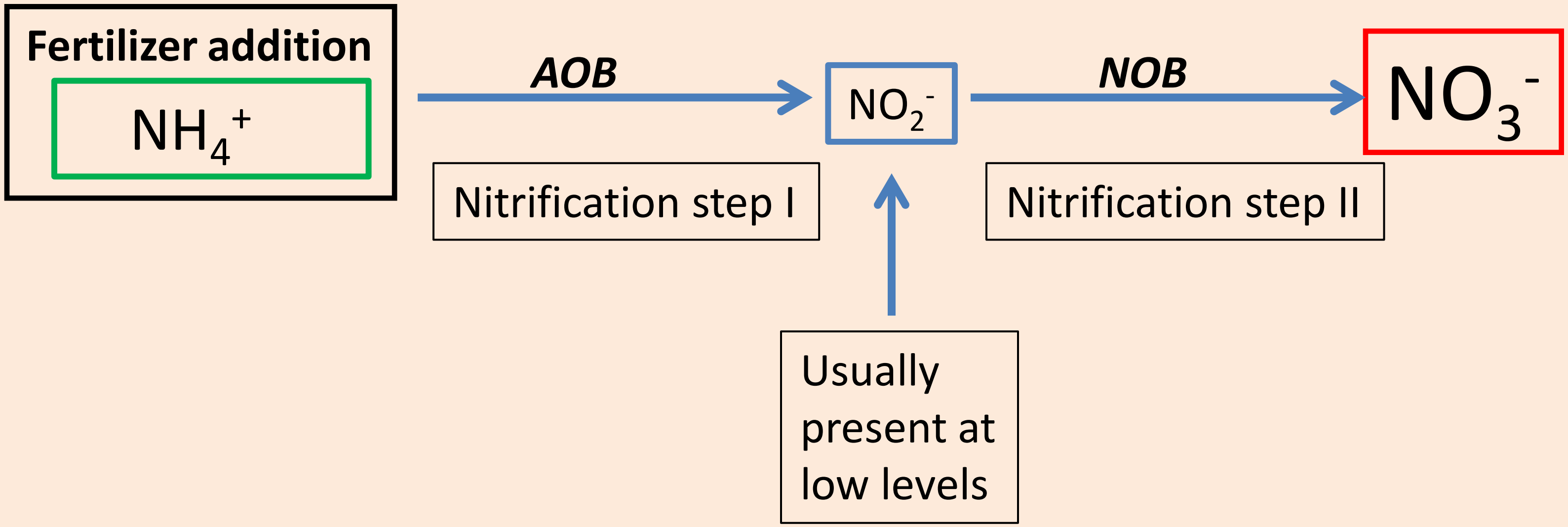
NO_2^- accumulates in soil when AA is applied



Fujinuma, Maharjan & Venterea (Unpublished)

Why are N_2O emissions greater with Anhydrous Ammonia?

Decoupling of the two steps of nitrification



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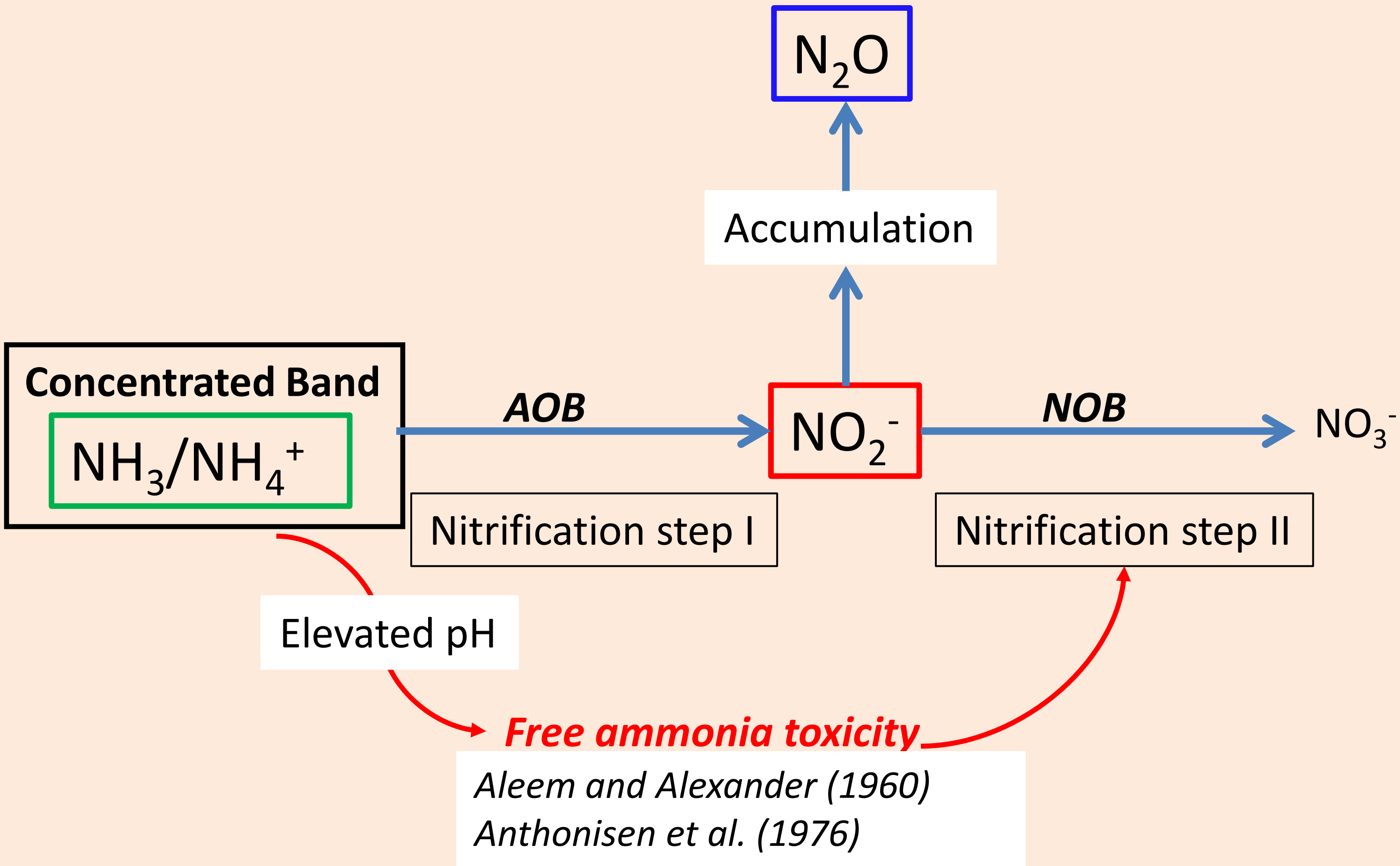
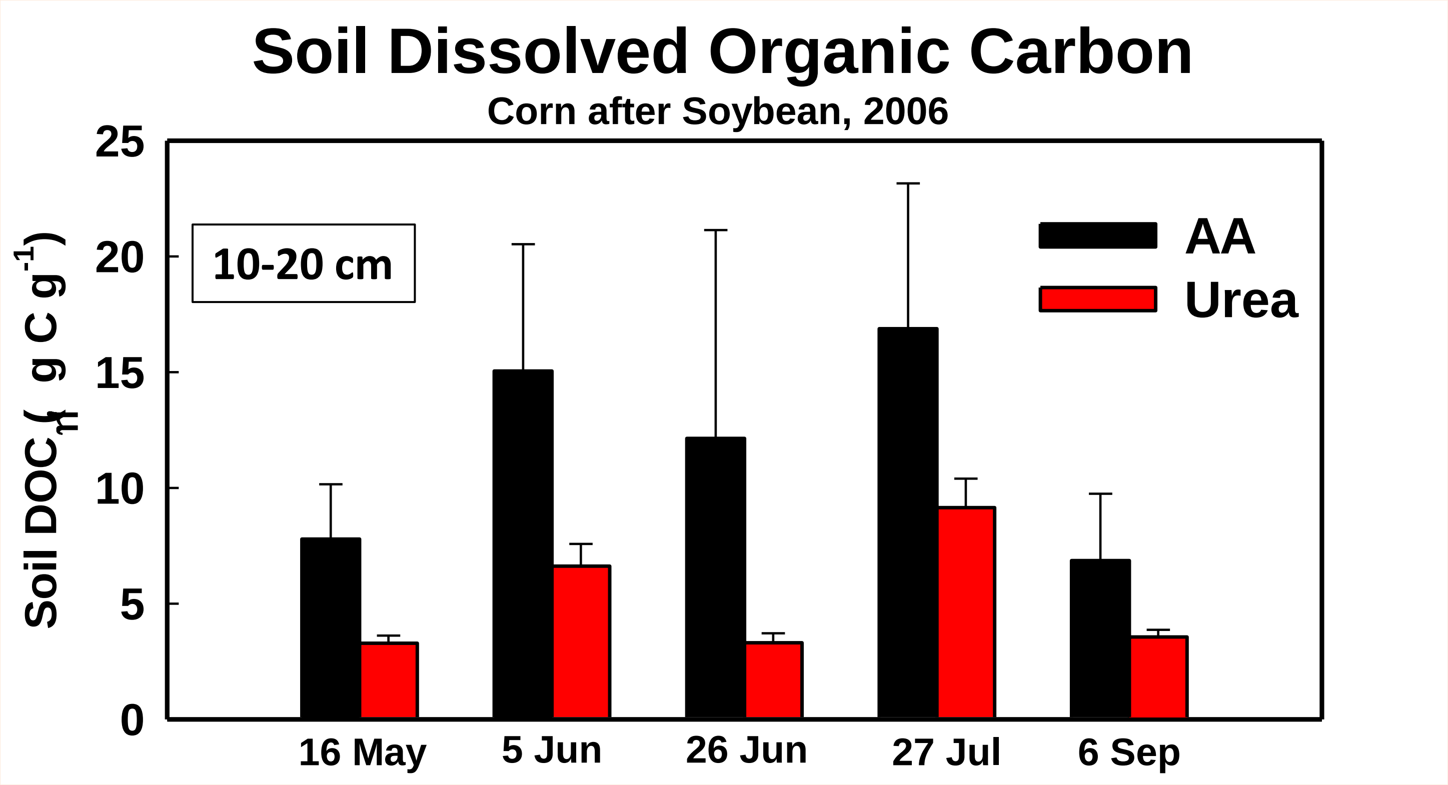


Why are N_2O emissions greater with Anhydrous Ammonia?

Release of dissolved organic carbon from SOM



Venterea et al. SSSAJ (2010)

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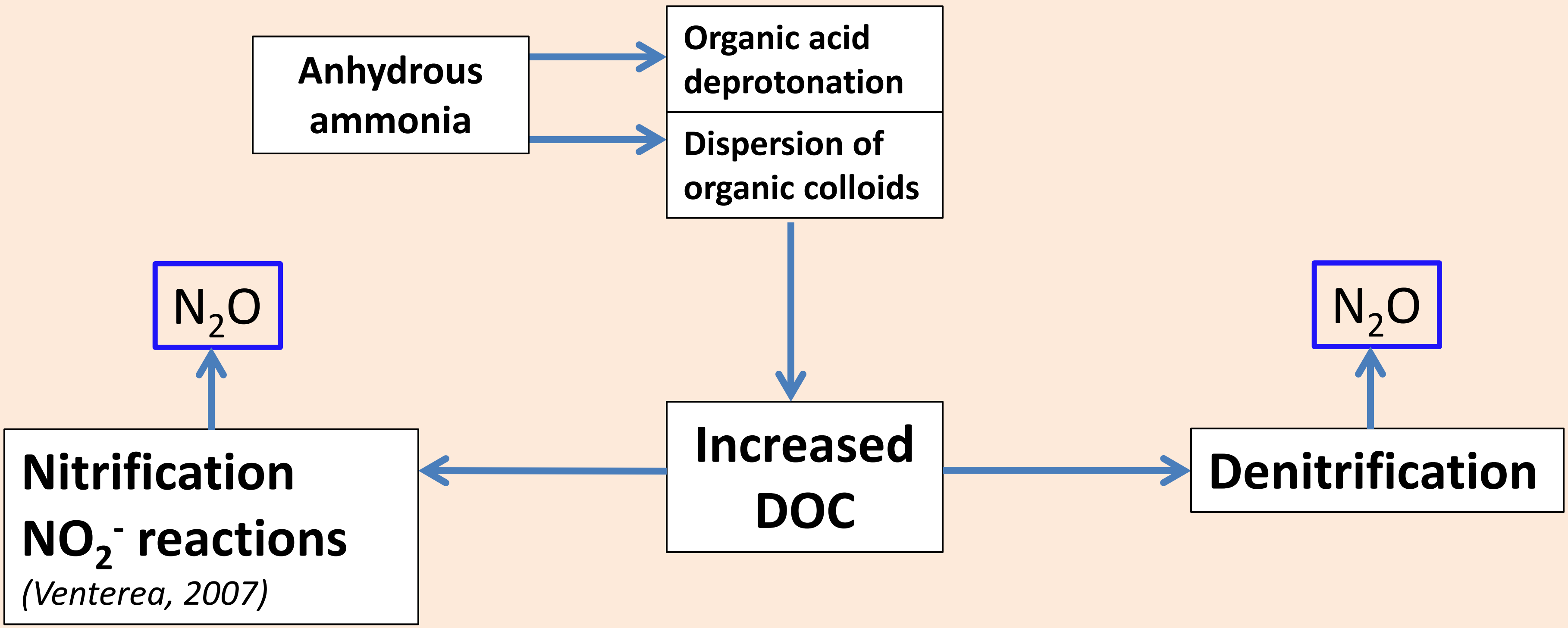
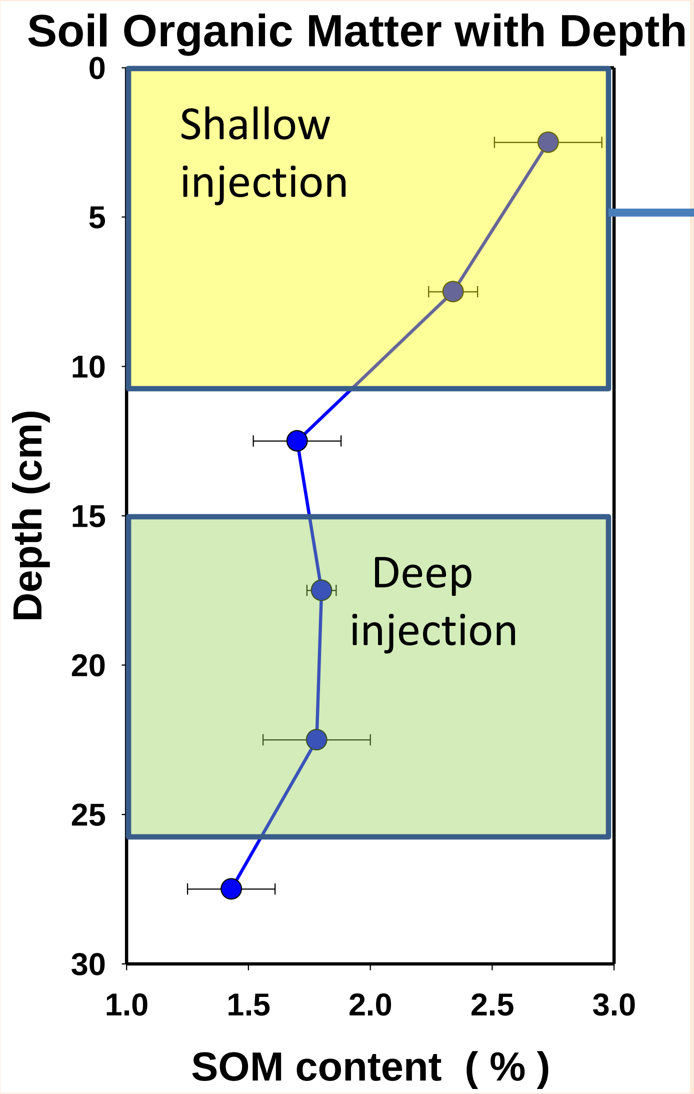


Tomasiewicz and Henry (1985)
Myers and Thien (1988)
Norman et al. (1988)
Clay et al. (1995)

Why are N_2O emissions greater with Shallow Anhydrous Ammonia?

Release of dissolved organic carbon from SOM



HYPOTHESIS:
More DOC released with shallow injection due to higher SOM at shallower depth?

→ N_2O

HYPOTHESIS:
More microbial activity and nitrification at shallower depth

Fujinuma et al. JEQ (2011)

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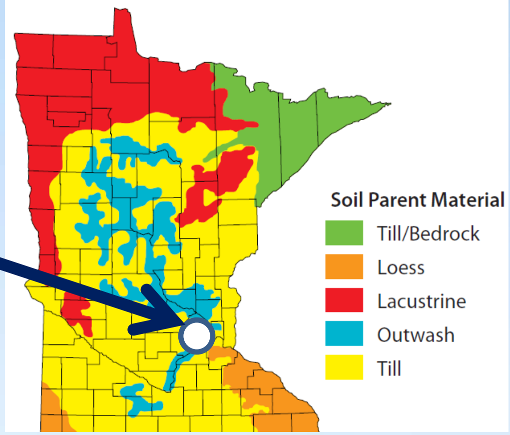
Banded Versus Broadcast Urea: Ongoing study in Rainfed Corn

Location	Parent material	Texture	Soil C	pH
St. Paul, MN	Till	Silt loam	2.0%	6.0

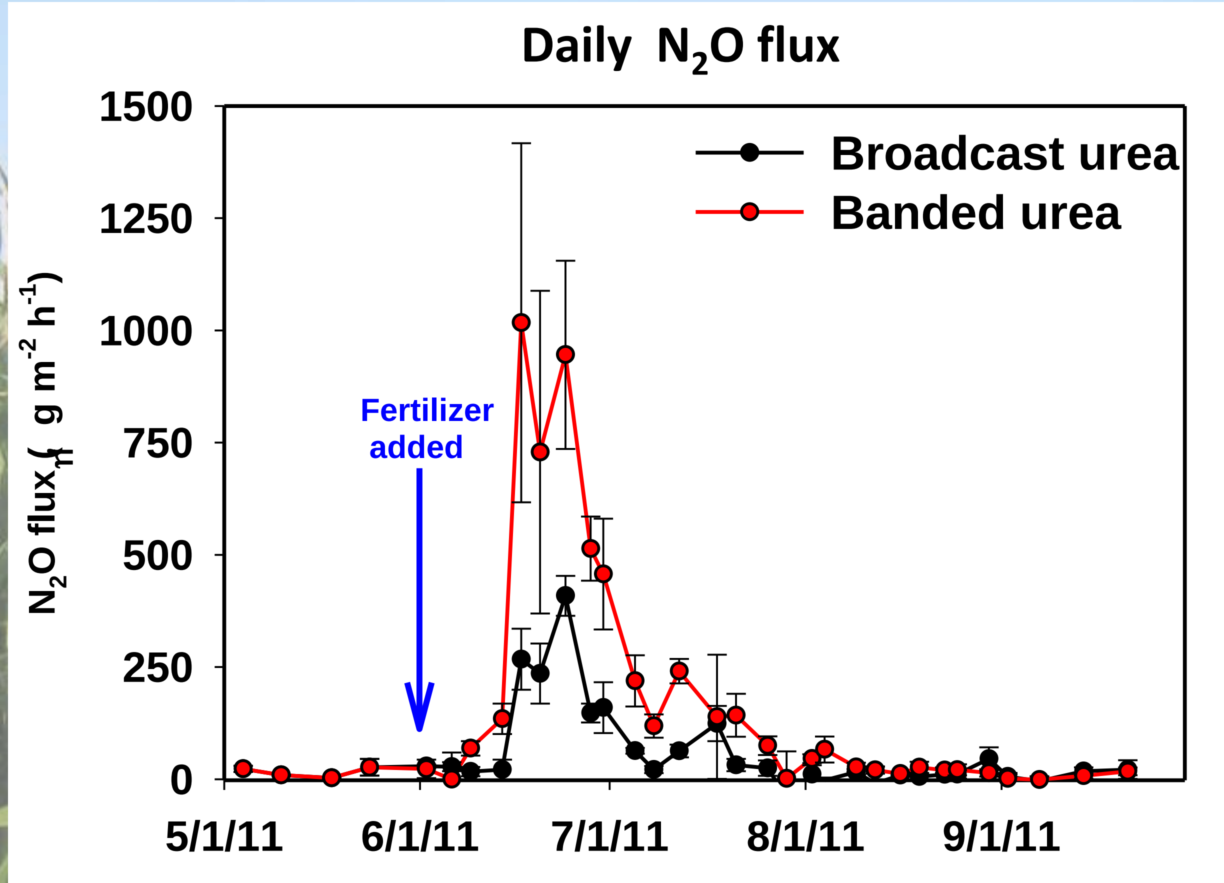


Goal: Isolate effects of physical placement from chemical formulation

Source	Placement
1. Urea	Broadcast and incorporated
2. Urea	Subsurface band (5 cm deep, 5 cm wide)

Both treatments applied post-emergence in single application of 150 kg N ha^{-1}

Banded Versus Broadcast Urea: Ongoing study in Rainfed Corn



Growing season total emissions

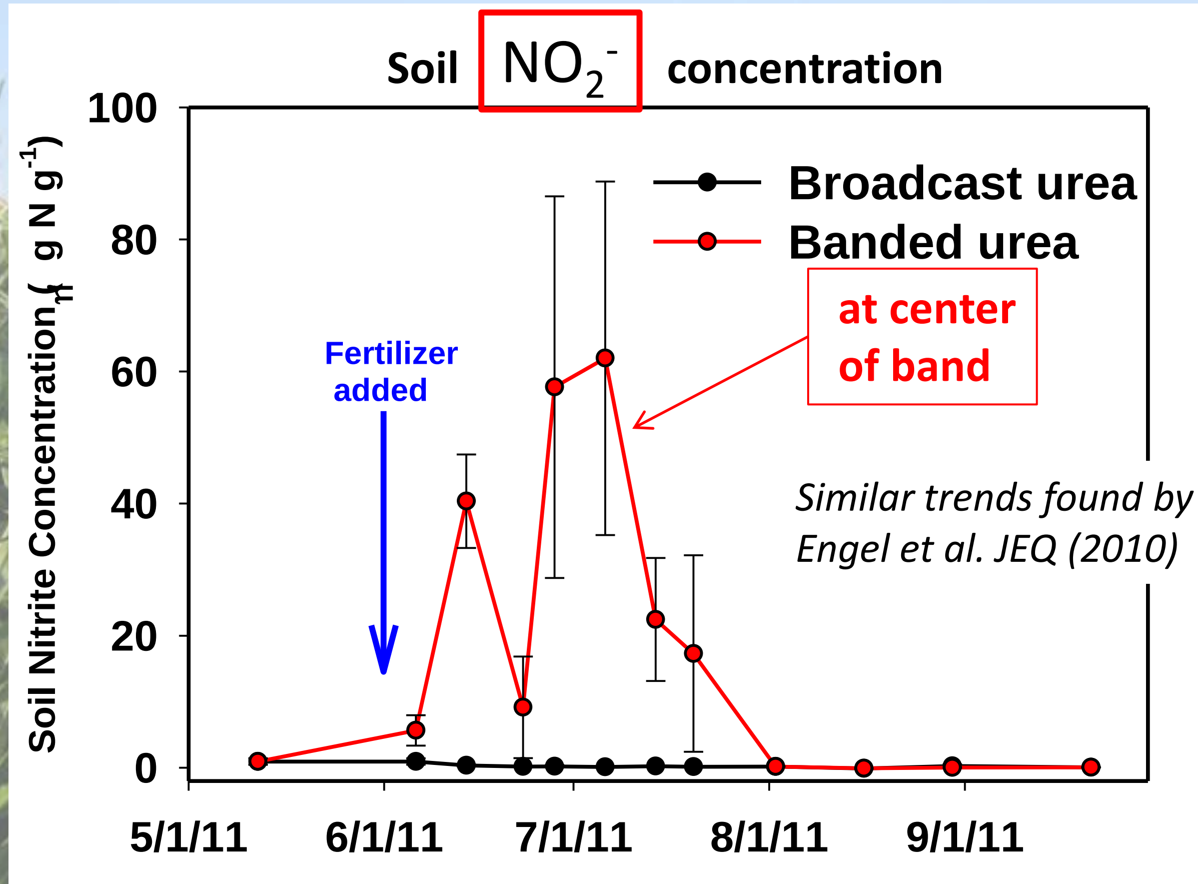
Banded 4.2 kg N ha^{-1}

Broadcast 1.7 kg N ha^{-1} (60 % reduction)

Maharjan et al. (Unpublished)

Why are N_2O emissions greater with Banded Urea?

NO_2^- accumulates in soil with banded urea



Similar trends found by Engel et al. JEQ (2010)

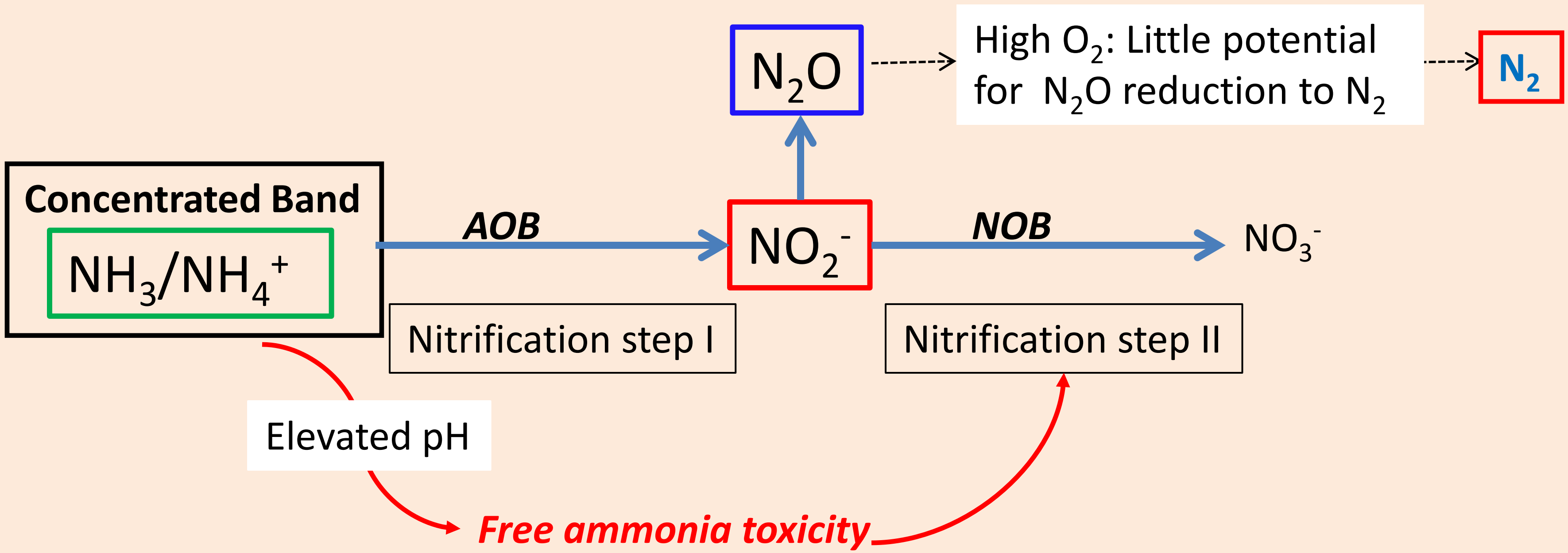
Maharjan et al. (Unpublished)

Why are N_2O emissions greater with AA and Banded Urea ?

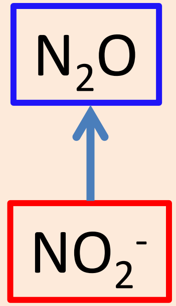
Can these processes be accurately modeled and predicted?

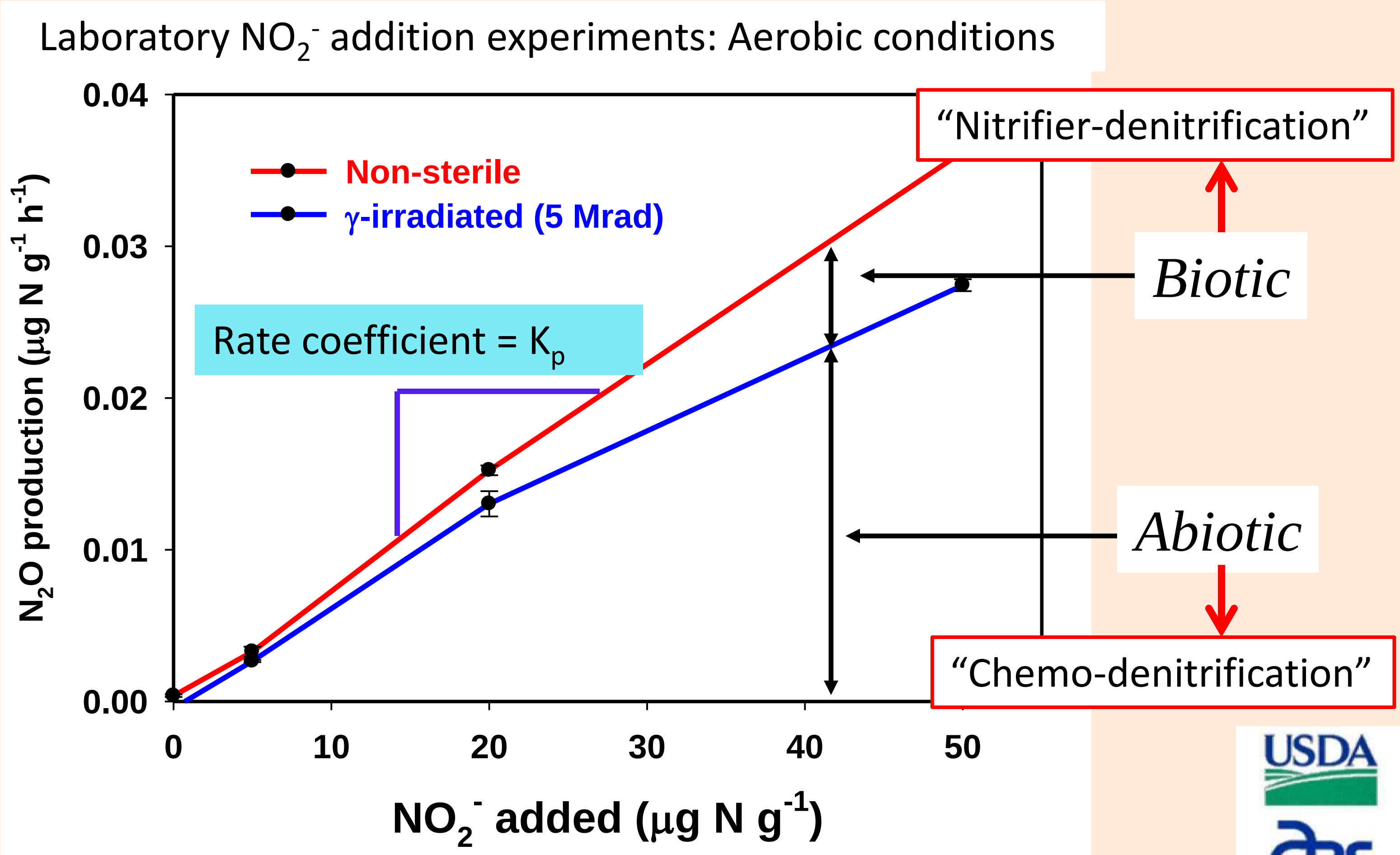
1. Predicting the accumulation of soil NO_2^-

2. Predicting N_2O emissions when the NO_2^- concentration is known



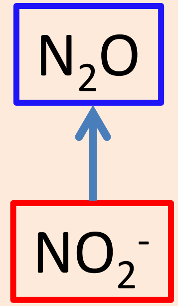
Predicting N_2O emissions when the NO_2^- concentration is known





Venterea (2007)

Predicting N_2O emissions when the NO_2^- concentration is known

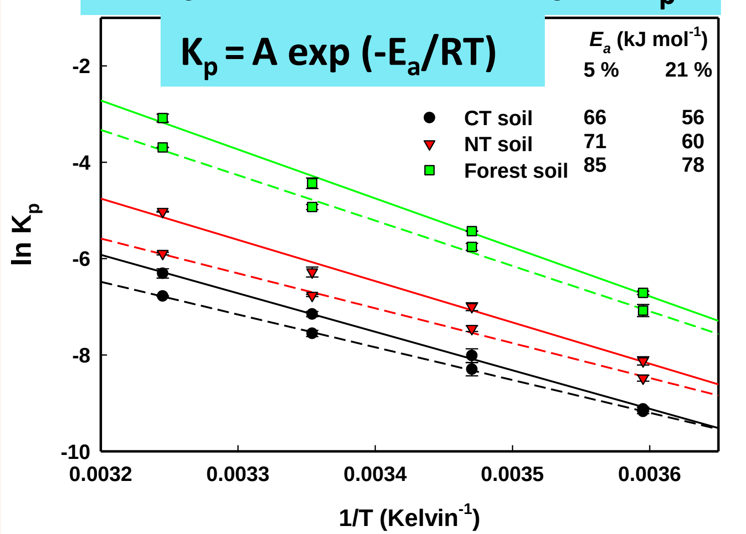


First-order model

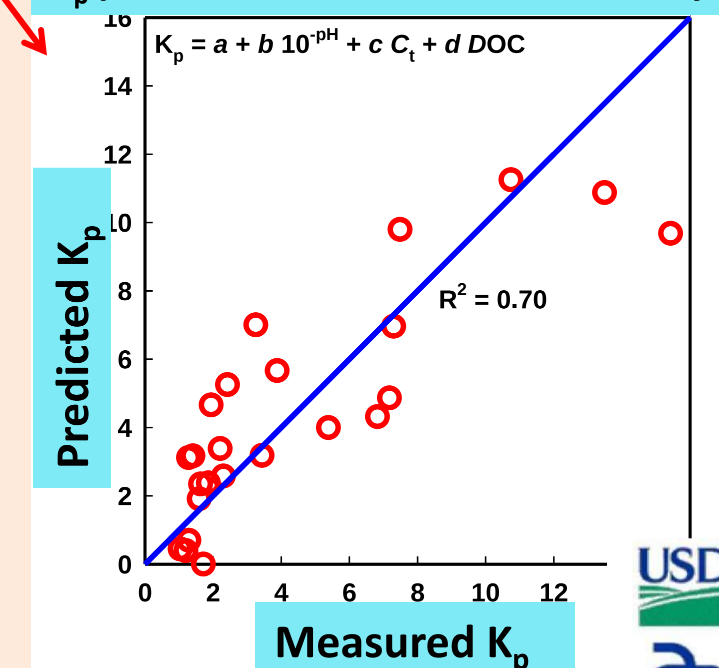
N_2O Production Rate = K_p [NO_2^-]

Temperature Sensitivity of K_p

$K_p = A \exp(-E_a/RT)$



K_p pos. correlated: SOM, DOC, acidity

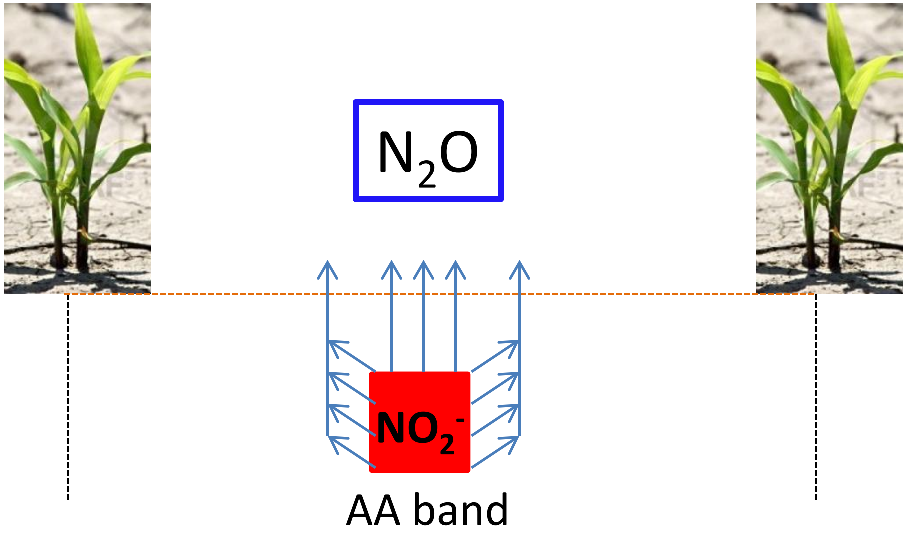


Venterea (2007)

Predicting N_2O emissions when the NO_2^- concentration is known

Complications for modeling:

1. Vertical and lateral non-uniformity of the soil NO_2^- distribution due to banding
2. Two-dimensional gas diffusion

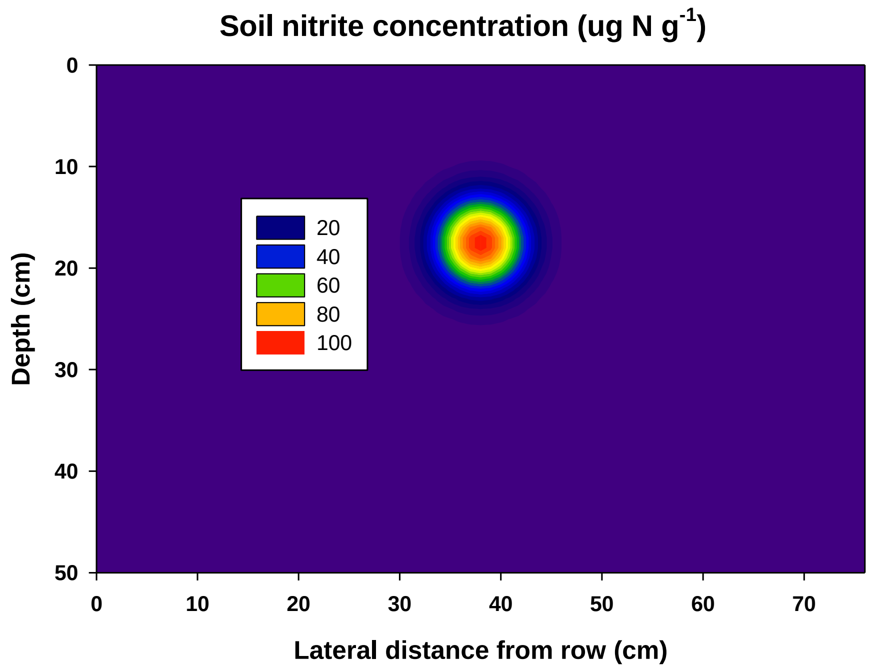


Predicting N_2O emissions when the NO_2^- concentration is known

Complications for modeling:

1. Vertical and lateral non-uniformity of the soil NO_2^- distribution due to banding
2. Two-dimensional gas diffusion

1. Assumed a 2-D Gaussian distribution of NO_2^- concentration that varied with time using spatial and temporal interpolation of measured NO_2^- data (spoonfed):



Used as model input: Example of input data for a given point in time.

Fujinuma & Venterea (Unpublished)

Predicting N_2O emissions when the NO_2^- concentration is known

Complications for modeling:

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2. Two-dimensional gas diffusion

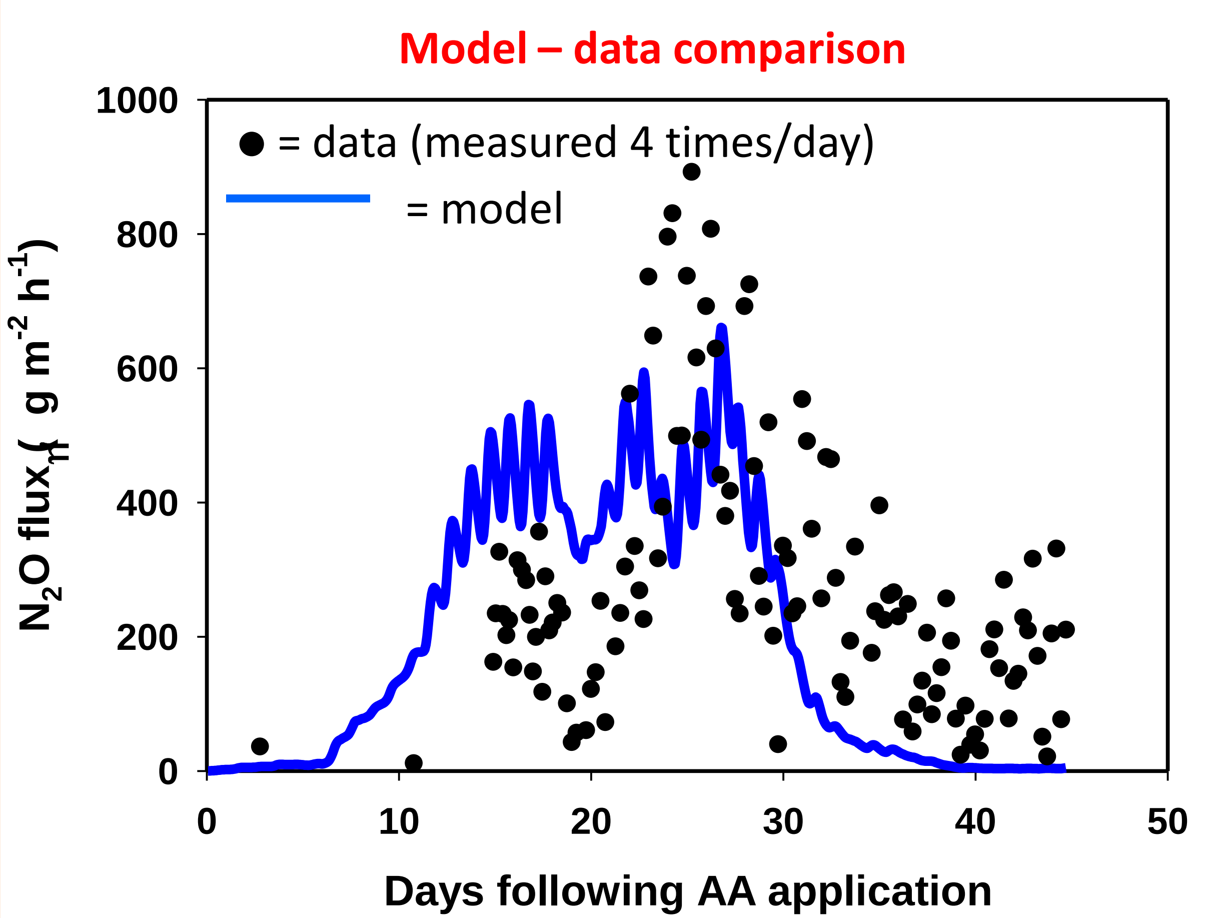
2. Used 2-D diffusion model to describe N_2O transport:

$$R\frac{\partial C}{\partial t} = \frac{\partial}{\partial z}\left(D\frac{\partial C}{\partial z}\right) + \frac{\partial}{\partial y}\left(D\frac{\partial C}{\partial y}\right) + K_p(T)[NO_2^-]$$

Solved numerically using finite difference methods to predict surface emissions:

Measured temperature & water content used as inputs for parameter estimation.

Predicting N_2O emissions when the NO_2^- concentration is known



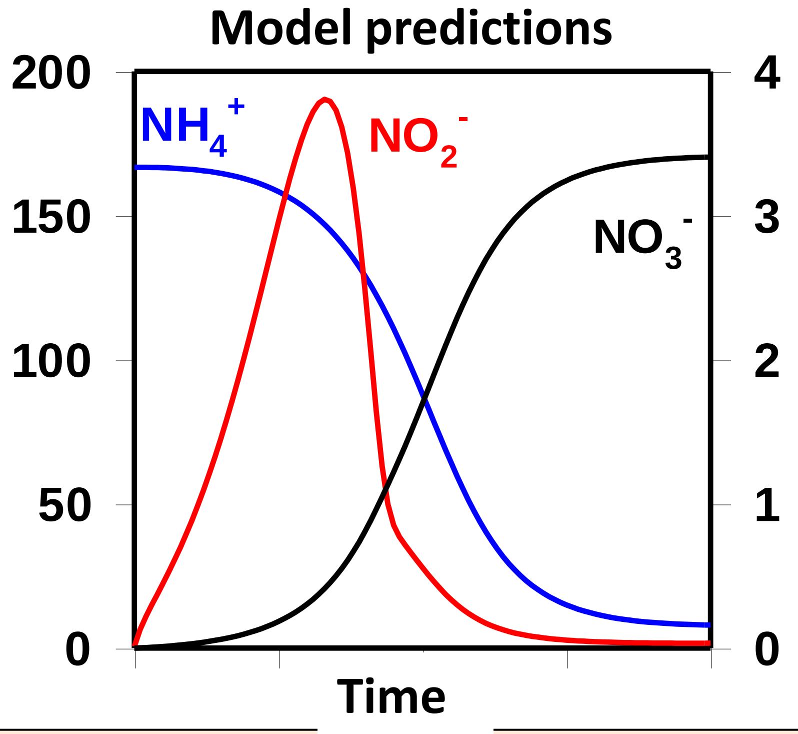
Assumed: No N_2O produced from denitrification
No N_2O consumption by denitrification

Not predicting NO_2^-

Fujinuma & Venterea (Unpublished)

Predicting the accumulation of soil NO_2^-

1. To make a useful model, we need better understanding of factors that promote nitrite accumulation; under what conditions it occurs and to what extent.
2. We have working two-step nitrification model, but we're guessing at the parameters and kinetics - trying to fill those in with some experiments.
3. Detailed model useful primarily as research tool. Practical predictive model might need to be simplified.



Venterea & Rolston, 2000.

Implications and Complications

1. Transient nitrite accumulation can be an important process; more work needed to determine under what conditions.

2. Majority of data show that a banding application of N fertilizer (AA or urea) will increase N_2O emissions.

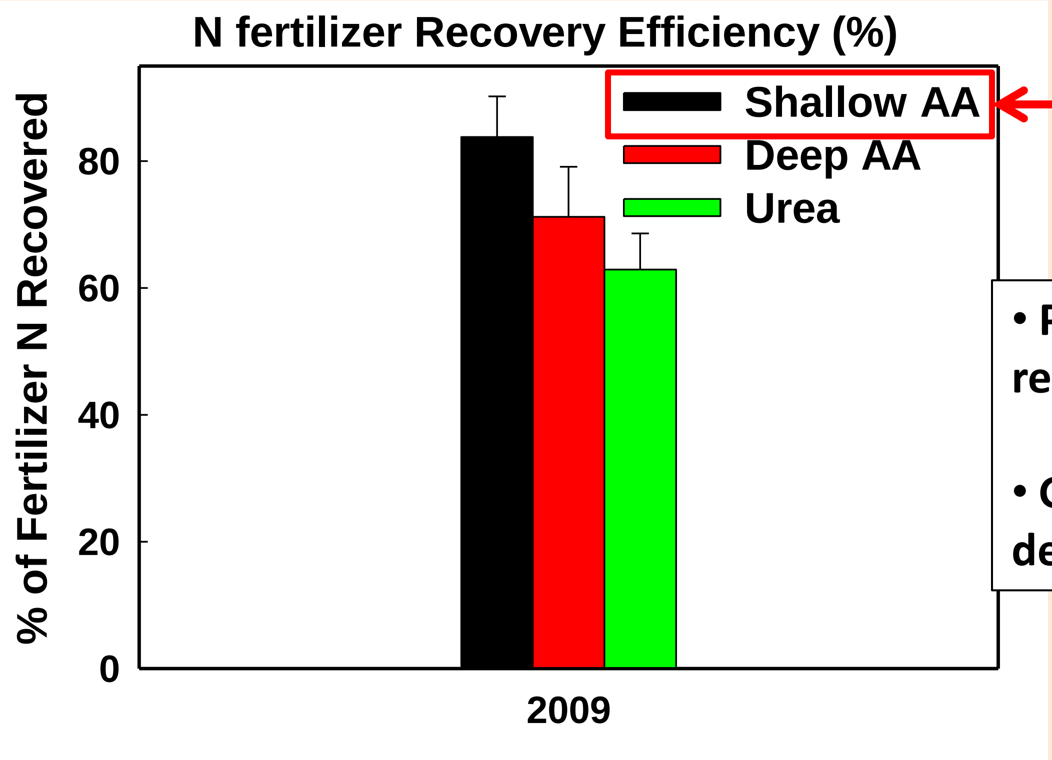
3. Banding can increase Nitrogen Use Efficiency by:

   -Improving root access to N
   -Decreasing fertilizer-soil contact, N immobilization & volatilization
   -Slowing overall nitrification rate and decrease nitrate leaching
   (e.g., Malhi et al. 2001; Yadvinder-Singh et al. 1994)

Trade-off between N_2O emissions and NUE ?

Implications and Complications

3. Trade-off between N_2O emissions and NUE ?



Greatest N_2O emissions and Greatest NUE

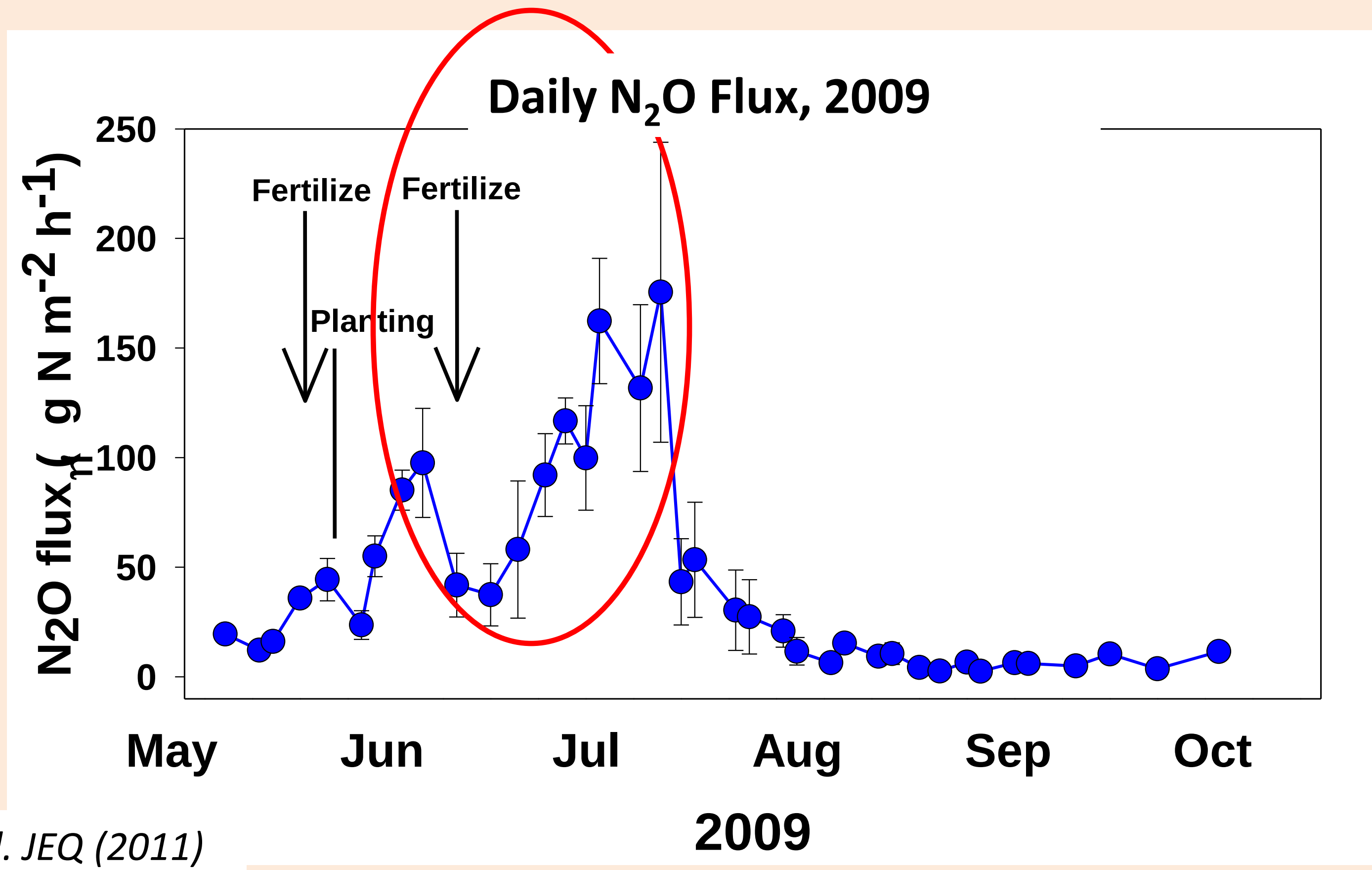
- Possible because N_2O represents small % of N applied.
- Greater root density at shallow depths in sandy irrigated soil.

Fujinuma et al. JEQ (2011)

Implications and Complications

3. Trade-off between N_2O emissions and NUE ?

- Even though N applied weeks after planting, large N_2O response observed.
- May have been less nitrate produced/leached, and more N uptake.
- But the 1st step of nitrification still can proceed rapidly to generate nitrite and N_2O



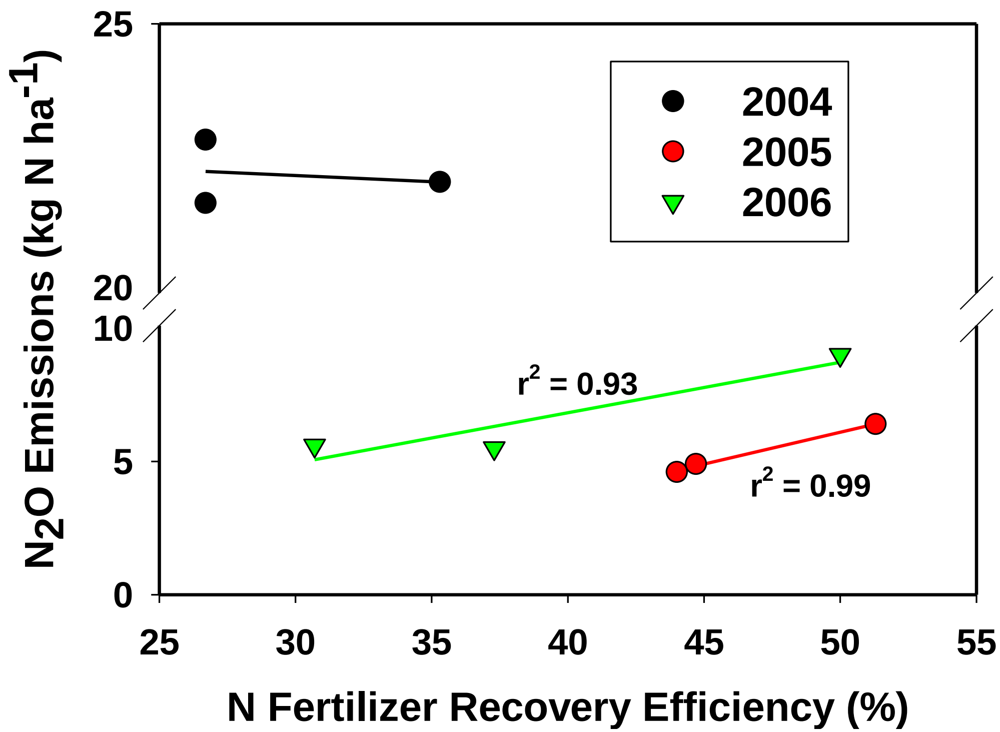
Fujinuma et al. JEQ (2011)

Implications and Complications

3. Trade-off between N_2O emissions and NUE ?

- **Comparison of 3 banded fertilizer sources *(UAN, CAN, AqA)***
- **Nitrate losses may have been reduced, but both N_2O emissions and NUE were greater.**

Positive correlation between N_2O Emissions and NUE



Gagnon & Ziadi, Argon. J. (2010)
Gagnon et al. Soil Sci. Soc. Am. J. (2011)

Implications and Complications

4. Improving NUE is absolutely important; in all cases will help to reduce indirect N_2O emissions and other environmental impacts. And in some cases reduce decreased direct N_2O emissions.

5. But to develop improved mitigation strategies and models of direct N_2O emissions, we need better understanding of short-term microbial and chemical responses to N fertilizer additions.

Models (of whatever type) need to account for:

- Factors affecting nitrite accumulation.
- Chemical N_2O production (chemo-denitrification); can be responsible for more than 50% of the N_2O production.
- Vertical stratification of microbial & chemical processes.