The Potential for GHG Credits by Switching from AA to UAN and Using NIs

Dr. Bert Bock, TKI Crop Vitality Consultant

What's to Come For Ag Retail: Put The Future Into Focus

Doubling down on differentiators—what makes your ag retail business stand out and stand apart with the value it provides—helps focus on your strengths. Where an ag retailer's strengths cross paths with farmer needs is the sweet spot.

Note five escalating farmer needs:

- data management
- ecosystem services
- labor
- meeting supply chain demands
- risk management

TOPICS

- Importance of N_2O in GHG life-cycle footprint of corn
- Theory re alkaline N source (AA, urea, UAN) and NI impacts on N_2O
- Examples of reductions in N_2O via switching from AA to urea to UAN and using NI’s
- Potentials and limitations for monetizing N_2O-based GHG credits via converting AA users to UAN or UAN + NI

PERCENTAGE CONTRIBUTIONS TO IA CORN GRAIN GHG LCA

	lb CO_2e/bu	% of Grain Corn LCA
N	2.10	15.02
P	0.47	3.36
K	0.27	1.91
Lime	1.40	9.97
Herbicides	0.75	5.34
Insecticides	0.01	0.06
Seed	0.10	0.68
Gasoline	0.18	1.25
Diesel	0.85	6.10
LPG	0.61	4.39
Natural gas	0.00	0.00
Electricity	0.17	1.23
Depreciated capital	0.13	0.95
N_2O	6.96	49.74
Total	14.00	100.00

Non-
nutrient
related
~ 30%

Liska et al., 2009
Assumed SOC
at steady state,
Not irrigated

Sum of IPCC N_2O factors for fert. manure, and residue N = 1.8% of fert. N
Direct and indirect N_2O from fert. N = 1.1% of fert. N (IPCC tier-one factor)

CONVERTING N_2O EMISSIONS REDUCTION TO CARBON DIOXIDE EQUIVALENCY

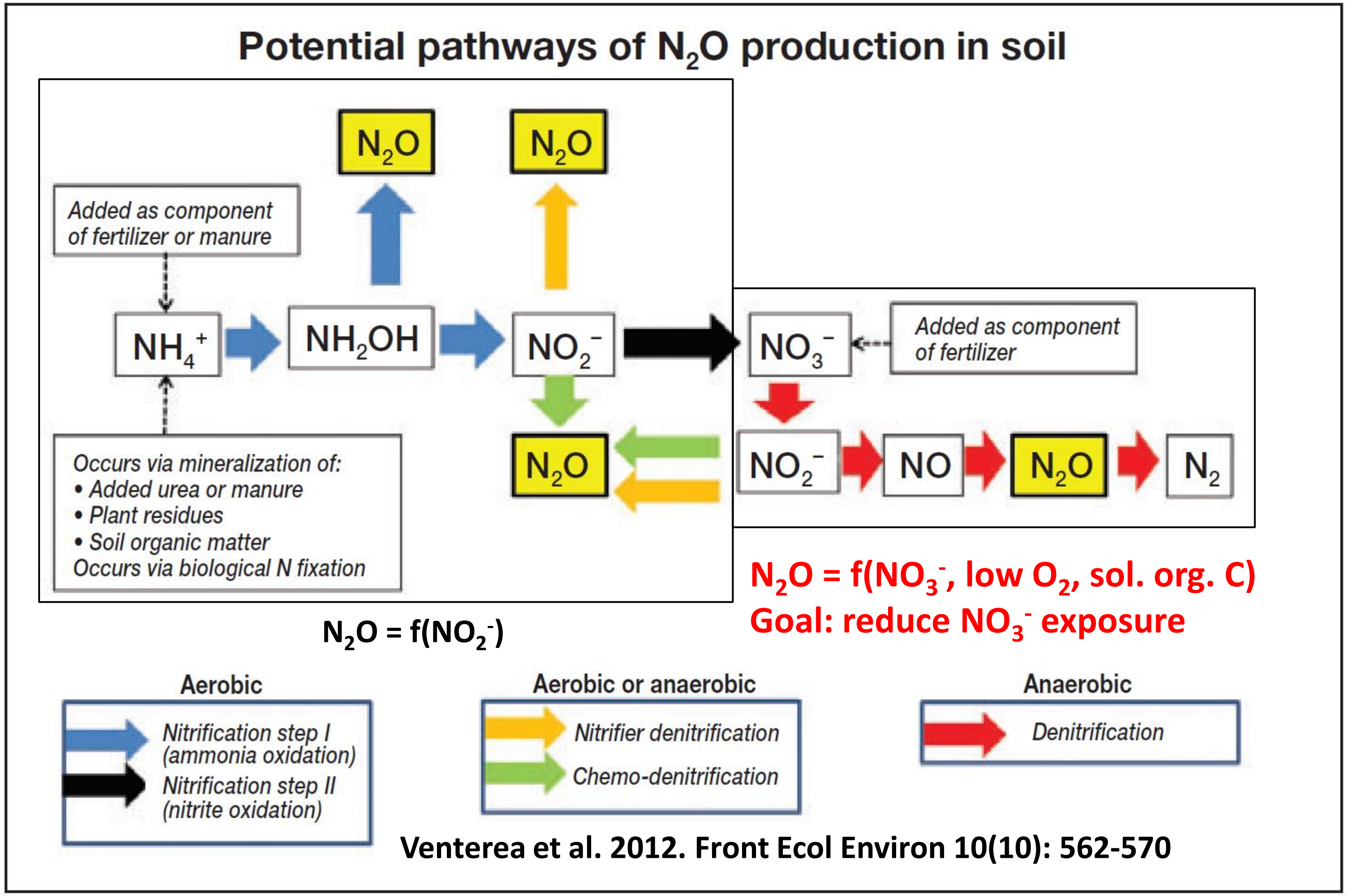
lb N_2O-N/ lb fert N	lb N_2O/ lb N_2O-N	lb CO_2 eq/ lb N_2O	lb CO_2 eq/ lb fert N	lb N/ Ac	lb CO_2eq/ Ac	tons Ceq/ Ac
0.03	1.57	298	14.05	180	2529	0.34

↑

Reduction in loss of fert. N
as N_2O-N by 3 percentage points

$/ ton CO_2eq
50.00
$/Ac
63.22

TRADITIONAL STORY—DENITRIFICATION MAIN SOURCE OF N_2O



Potential pathways of N_2O production in soil

Added as component of fertilizer or manure

NH_4^+ → NH_2OH → NO_2^- → NO_3^-

N_2O

N_2O

N_2O

Occurs via mineralization of:
- *Added urea or manure*
- *Plant residues*
- *Soil organic matter*

Occurs via biological N fixation

Added as component of fertilizer

NO_2^- → NO → N_2O → N_2

$N_2O = f(NO_2^-)$

$N_2O = f(NO_3^-$, low O_2, sol. org. C)

Goal: reduce NO_3^- exposure

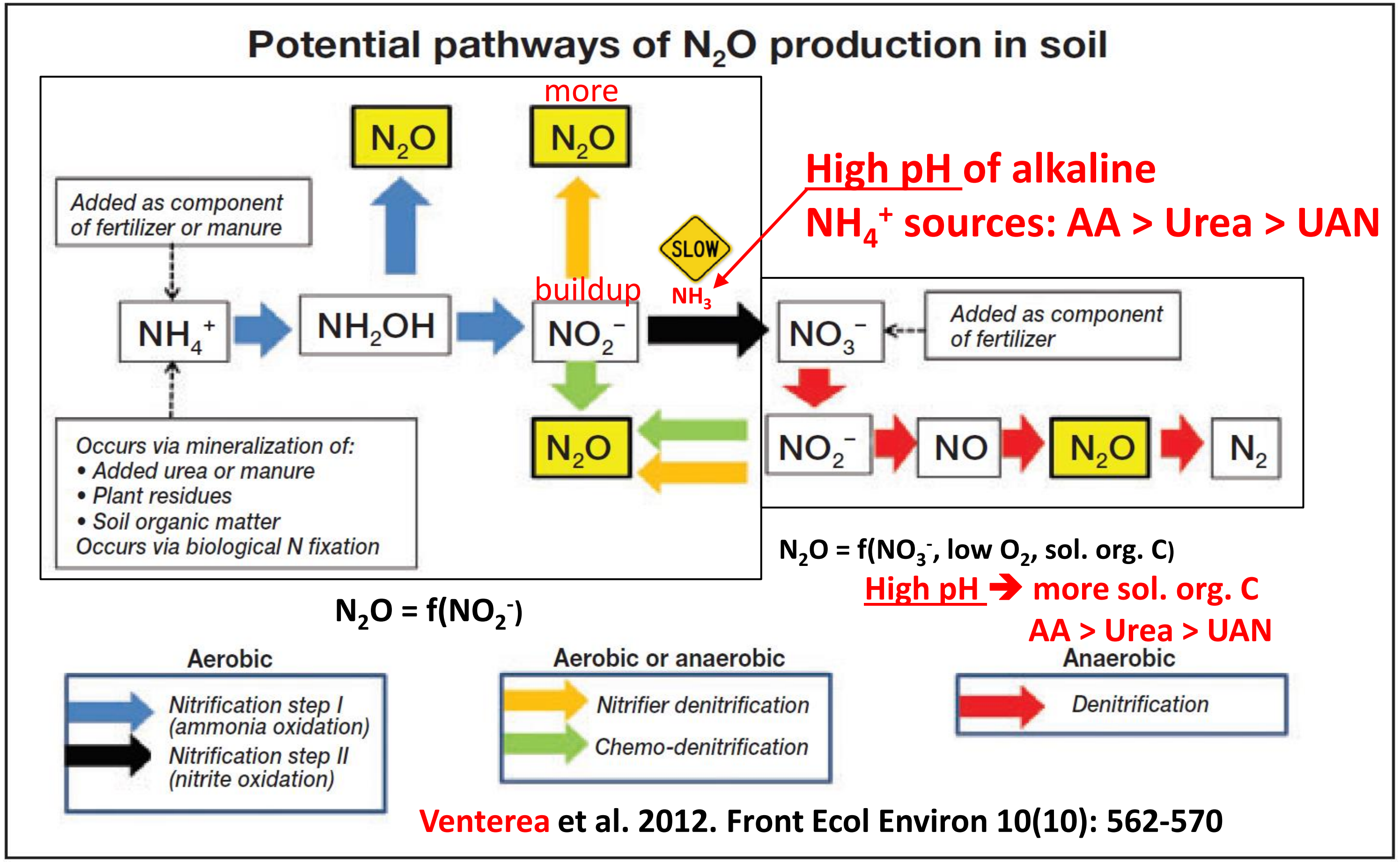
Aerobic
- 🟦 *Nitrification step I (ammonia oxidation)*
- ⬛ *Nitrification step II (nitrite oxidation)*

Aerobic or anaerobic
- 🟨 *Nitrifier denitrification*
- 🟩 *Chemo-denitrification*

Anaerobic
- 🟥 *Denitrification*

Venterea et al. 2012. Front Ecol Environ 10(10): 562-570

NONTRADITIONAL STORY WITH ALKALINE NH_4^+ SOURCES, ESPECIALLY BANDED



High pH of alkaline

NH_4^+ sources: AA > Urea > UAN

$N_2O = f(NO_3^-$, low O_2, sol. org. C)

High pH ➔ more sol. org. C

AA > Urea > UAN

$N_2O = f(NO_2^-)$

Venterea et al. 2012. Front Ecol Environ 10(10): 562-570

THE MISMATCH OF NITRIFICATION RATES

$$NH_4^+ \xrightarrow[AOB]{} \overset{\text{Buildup}}{NO_2^-} \xrightarrow[NOB]{NH_3} NO_3^-$$

NH_3 threshold, mg N/l[1] 10-150 0.1-1

[1] **Royal Society Advances. 2018. 8:31987-31995**

LESS MISMATCH OF NITRIFICATION RATES WITH NITRIFICATION INHIBITORS

Less Buildup

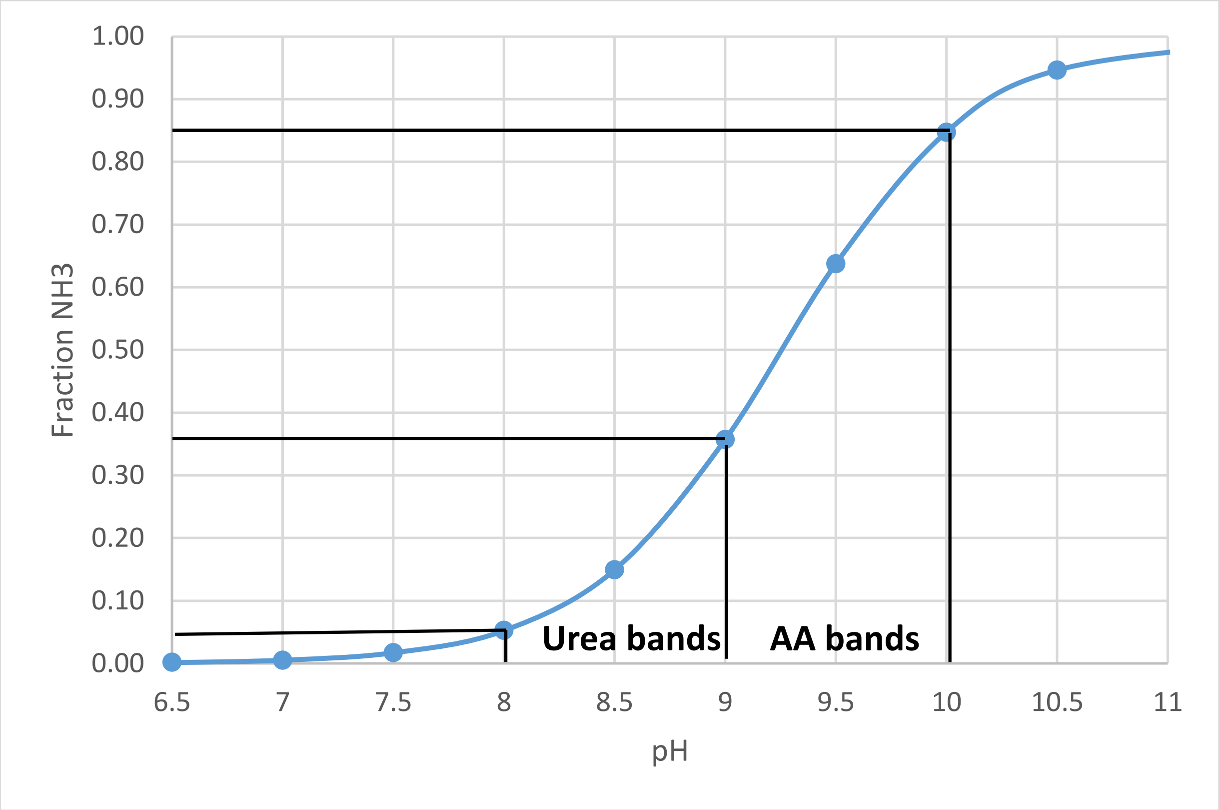
$$NH_4^+ \underset{AOB}{\overset{\mathbf{NI}}{\cancel{\rightarrow}}} NO_2^- \underset{NOB}{\overset{NH_3}{\rightarrow}} NO_3^-$$

NH_3 threshold, mg N/l[1/] 10-150 0.1-1

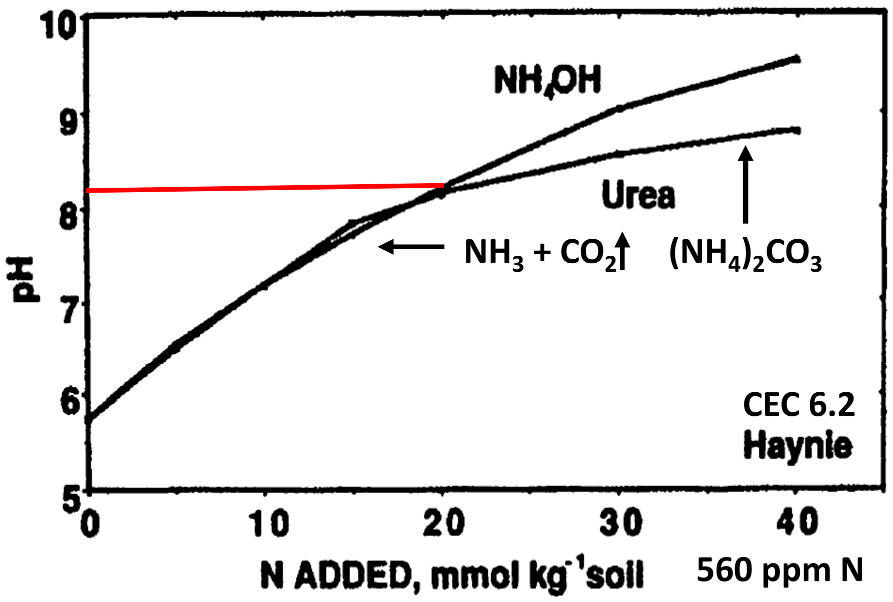
[1/] Royal Society Advances. 2018. 8:31987-31995

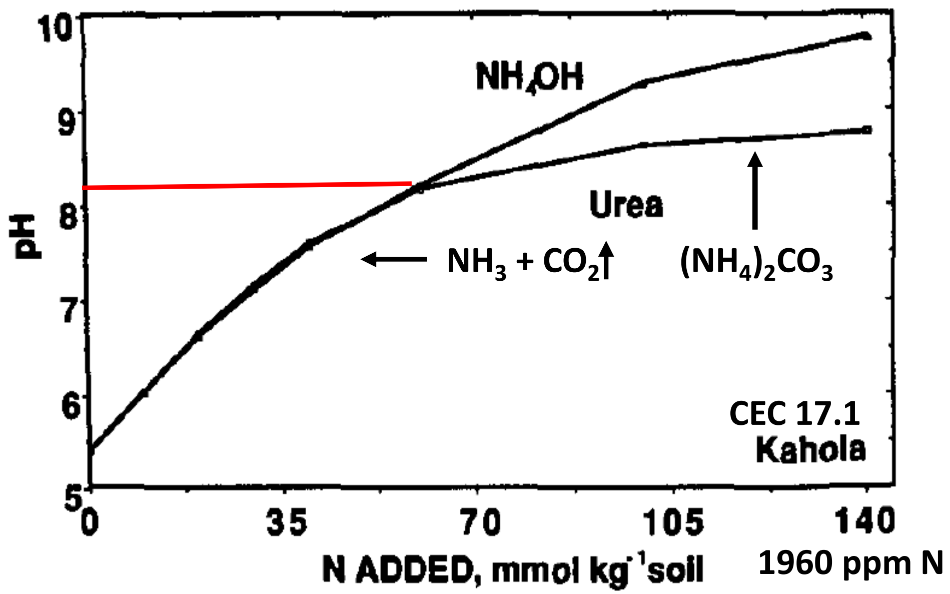
WHAT FACTORS DETERMINE PH AND AMOUNT OF NH_3, ESPECIALLY IN BANDS?

- Alkaline N Source—Anhydrous ammonia (NH_4OH) > Urea [$(NH_4)_2CO_3$]
  > UAN (½ urea N, ½ NH_4NO_3 N)
- Alkaline N Source Rate (concentration)
- Placement: degree alkaline NH_4^+ source is concentrated in a band
- Soil properties
  - pH buffering
  - CEC—NH_4^+ sorption



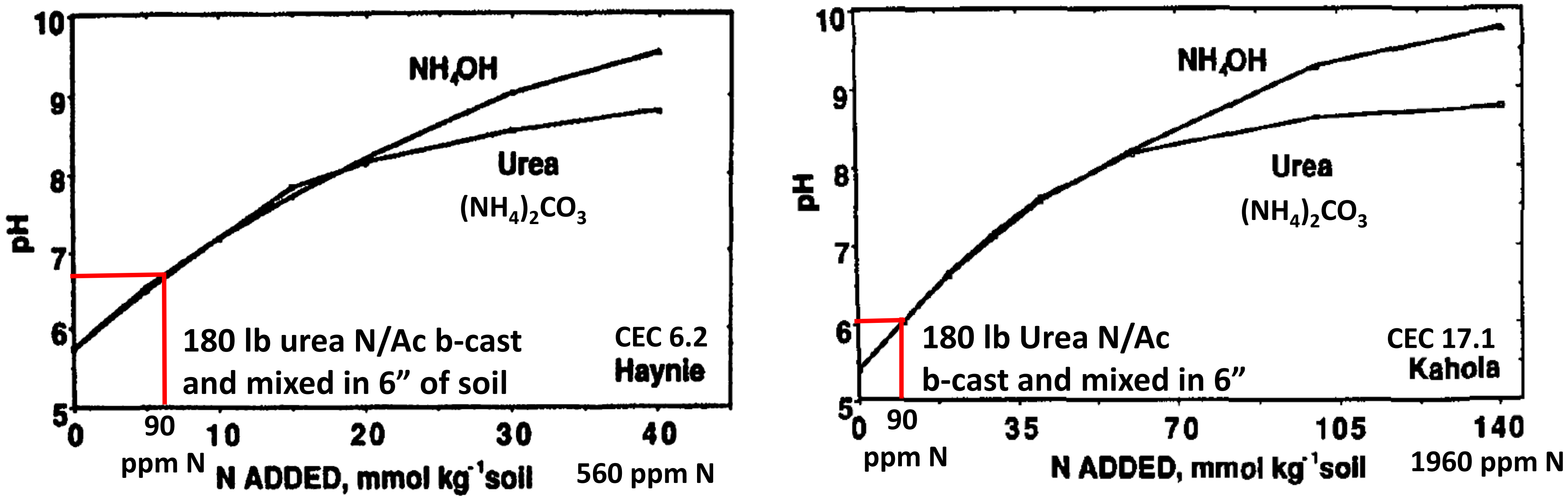
EFFECTS OF ALKALINE N SOURCE AND CONC., SOIL CEC ON SOIL PH





Kissel et al. 1988

BROADCAST/INCORP. RESULTS IN SMALL INCREASES IN SOIL PH



180 lb urea N/Ac b-cast and mixed in 6” of soil

180 lb Urea N/Ac b-cast and mixed in 6”

Kissel et al. 1988

WHAT ABOUT UAN SOLUTIONS (28 AND 32% N)?

- ½ of N from urea and ½ of N from ammonium nitrate
- Ammonium nitrate is not alkaline, doesn't increase pH
- Takes ~ 2 lb UAN N to give same pH increase as 1 lb urea N
- No NO_2^-, nitrification-based N_2O from nitrate (¼ of N)
- Bottom line: Expect less NO_2^-, nitrification-based N_2O from UAN than urea

  but

- The ¼ of N applied as nitrate is exposed to potential denitrification from time of application

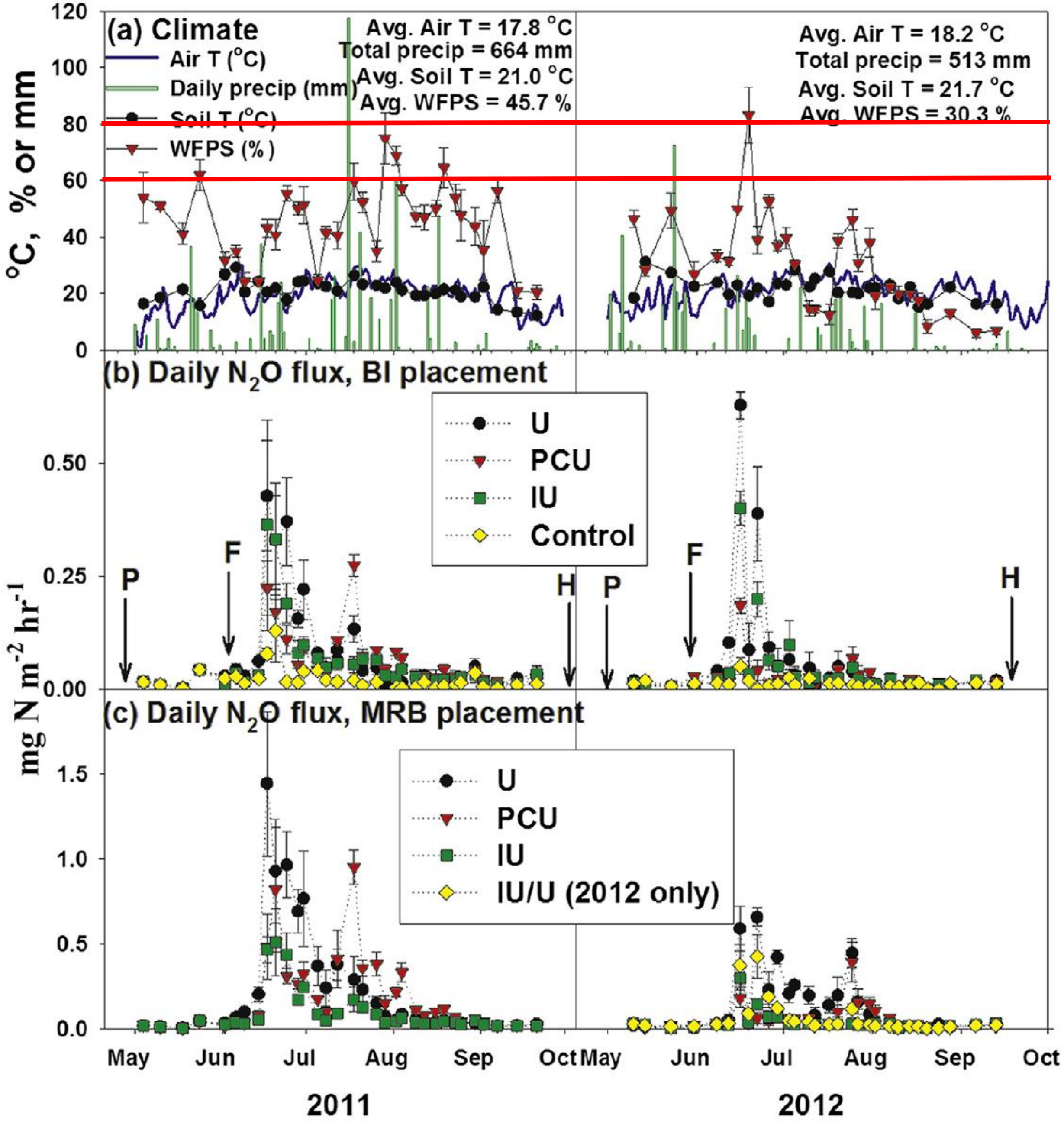
How do the last two bullets balance out?

Figure 5. Establishing N fertilizer treatments for a N_2O field experiment in research plots at the University of Minnesota, in St Paul. Urea containing nitrification and urease inhibitors (blue granules) is being applied in concentrated bands between rows of corn seedlings, for comparison with conventional urea.

Maharjan and Venterea. 2013. Soil Biology & Biochemistry 66:229-238

2012: Very dry year
2011: Wetter year
(not excessively wet)

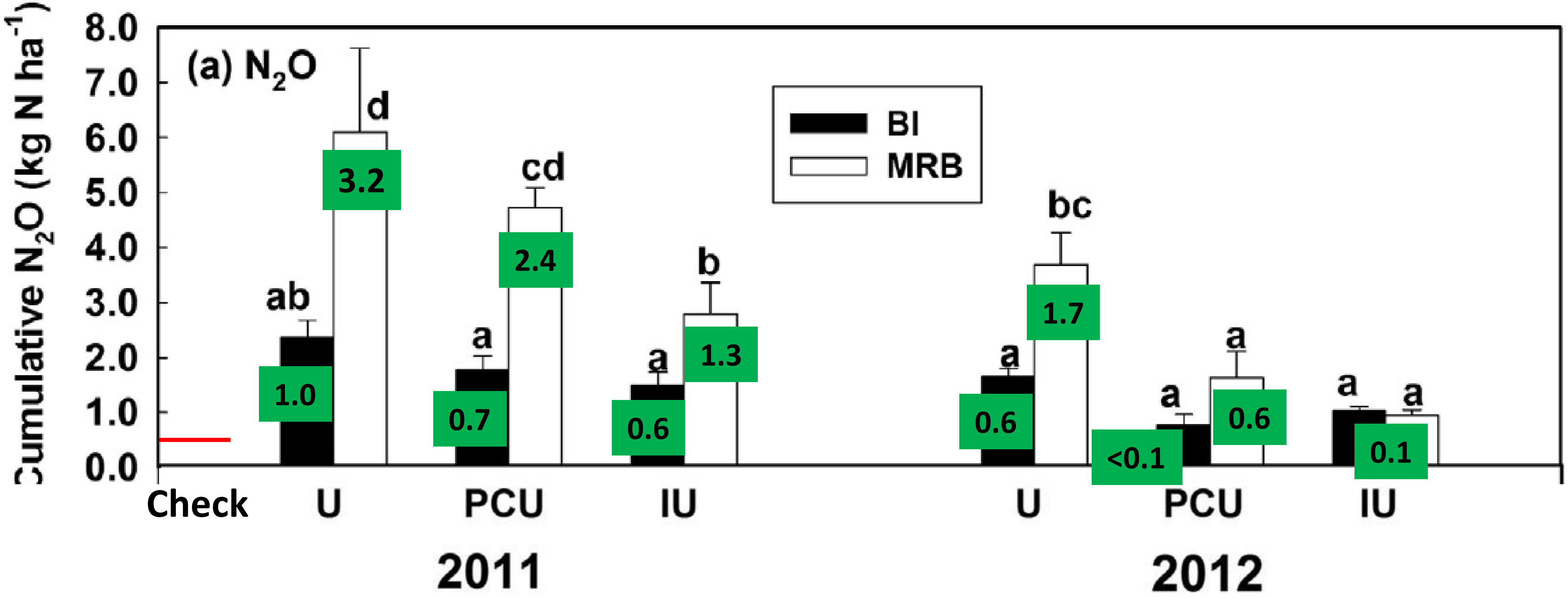
Urea, PCU, Inhibited Urea (IU)
(ESN) (Super U)
X
B-cast-Incorp, Mid-Row Band
(BI) (MRB)



Maharjan and Venterea. 2013. Soil Biology & Biochemistry 66:229-238

180 lb N/Ac

% of fert N lost as N_2O

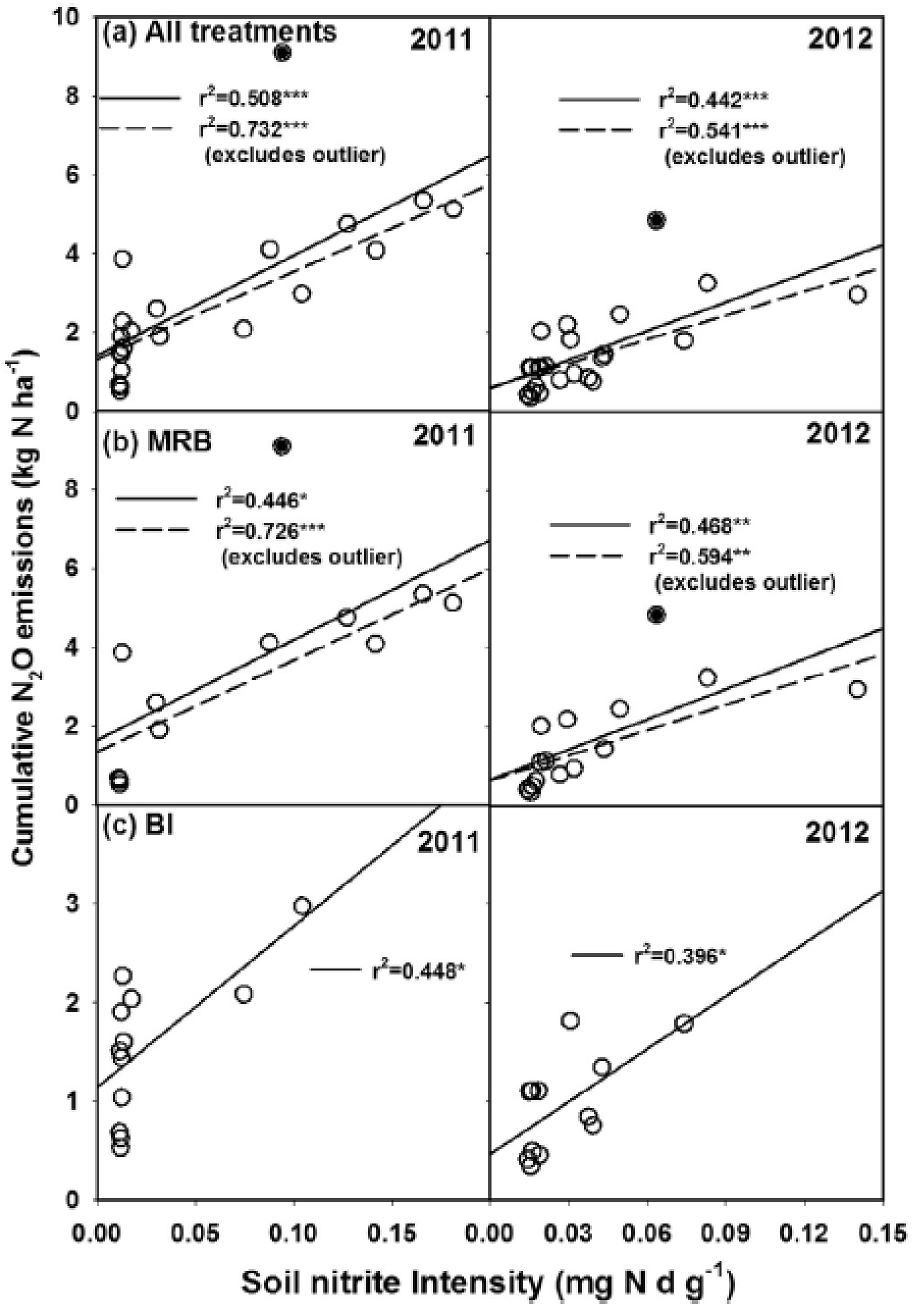


Wetter Year

Very Dry Year

Minnesota, Waukegon silt loam, 6.7% OM

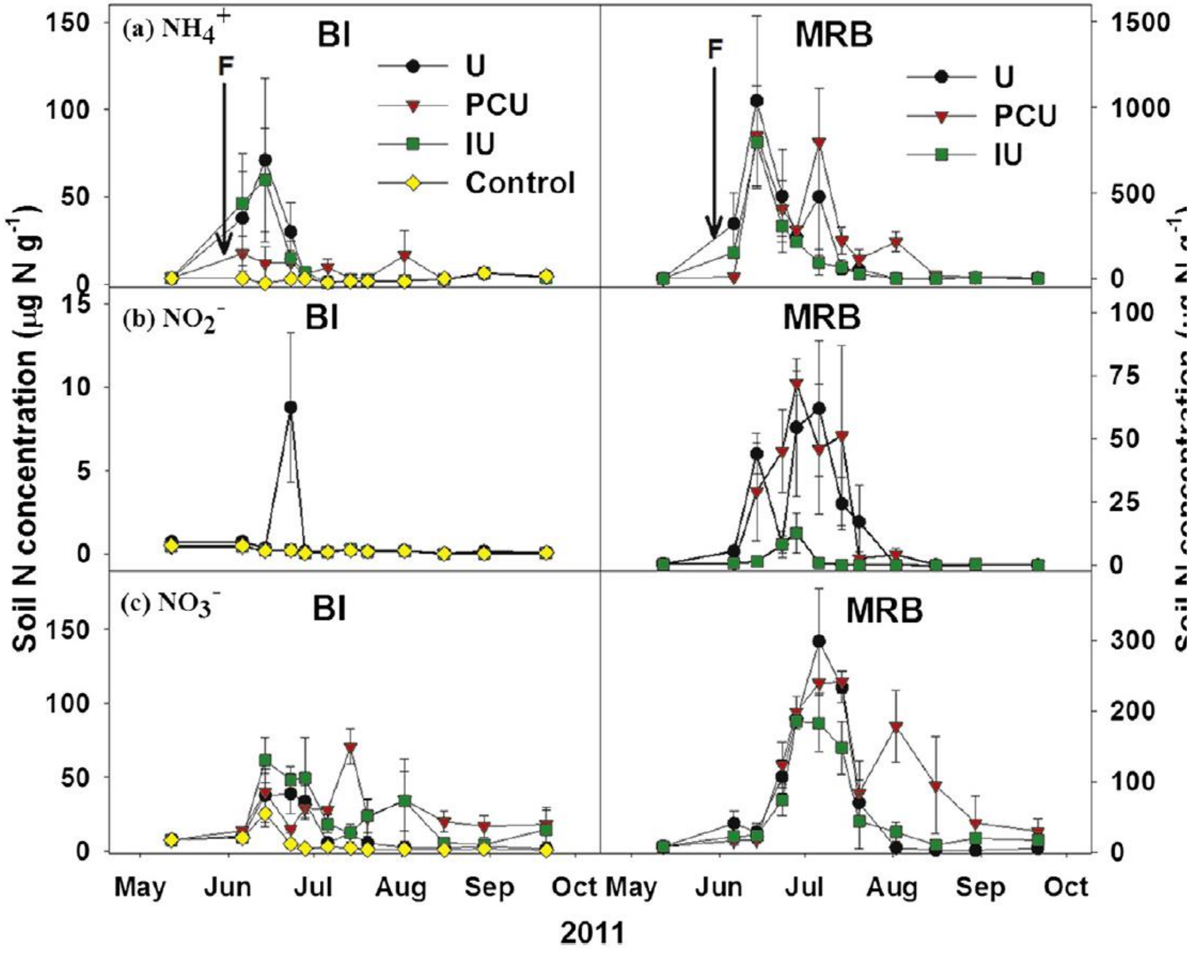
Maharjan and Venterea. 2013. Soil Biology & Biochemistry 66:229-238

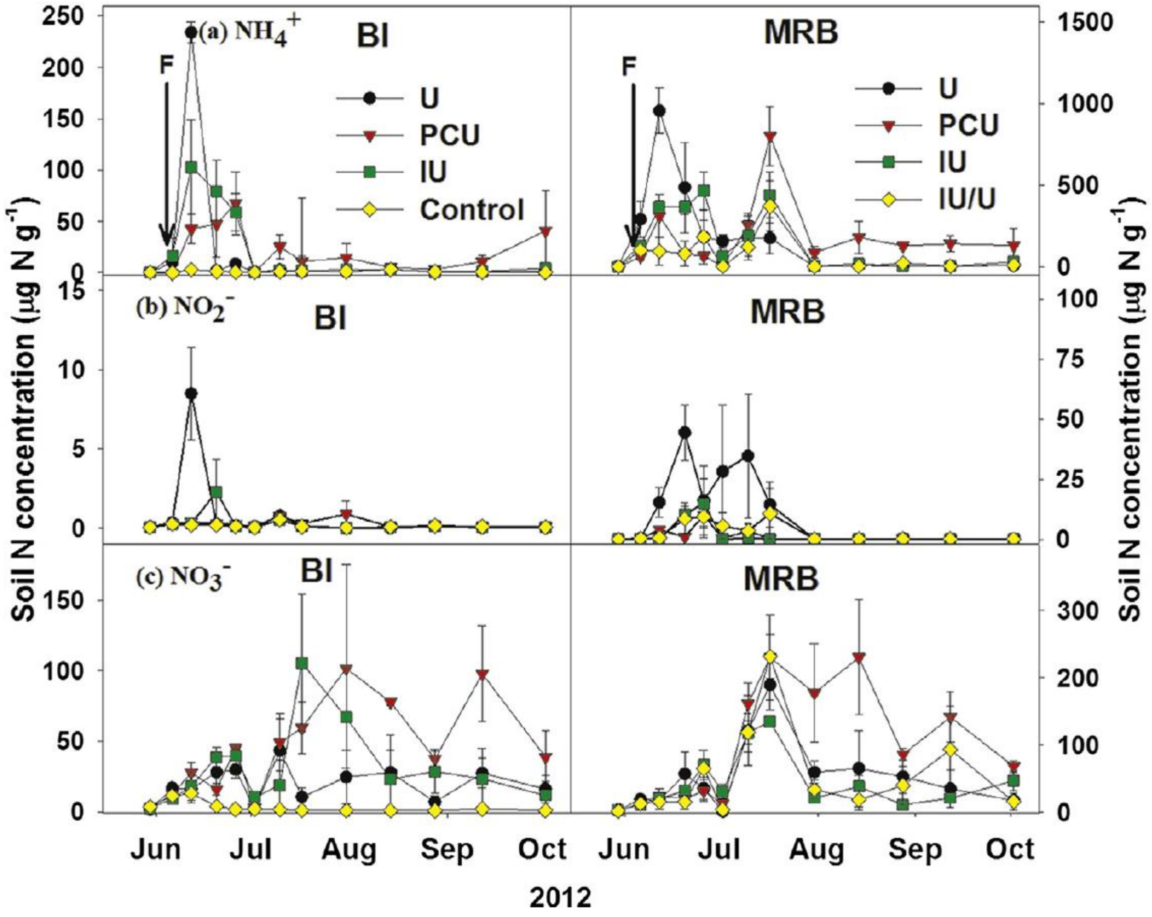


Maharjan and Venterea. 2013. Soil Biology & Biochemistry 66:229-238

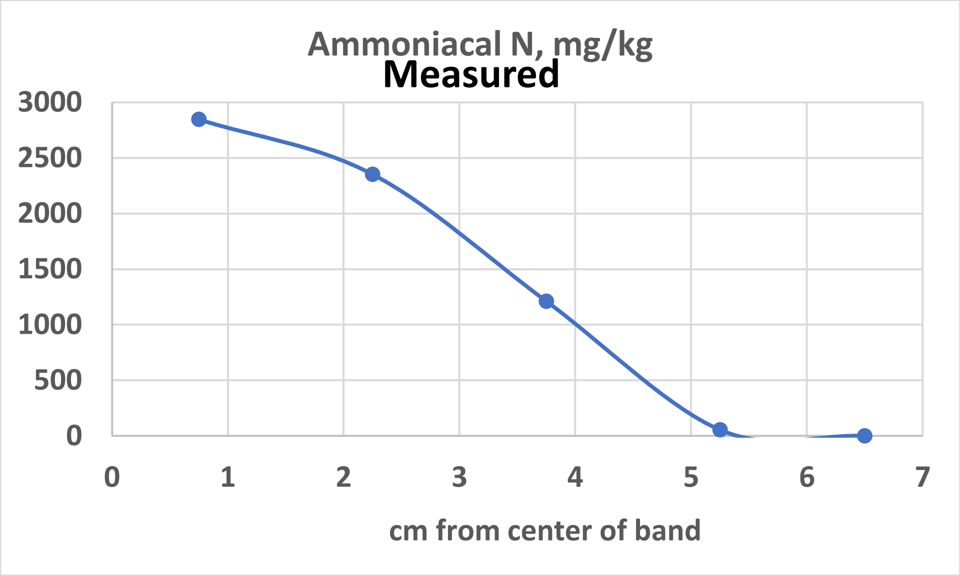
Nitrite Intensity Explains N Mgt. Effects on N_2O Emissions in Maize

B. Maharjan, R.T. Venterea / Soil Biology & Biochemistry 66 (2013) 229–238



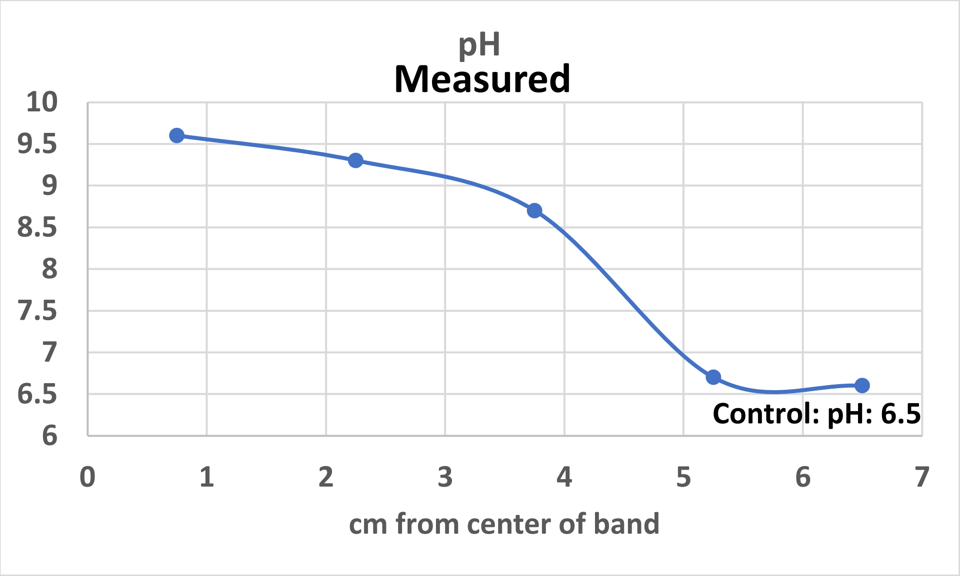


1 DAY AFTER 180 LB AA N/AC: DRUMMER SOIL, 3.0% ORGANIC C



Ammoniacal N, mg/kg

Measured

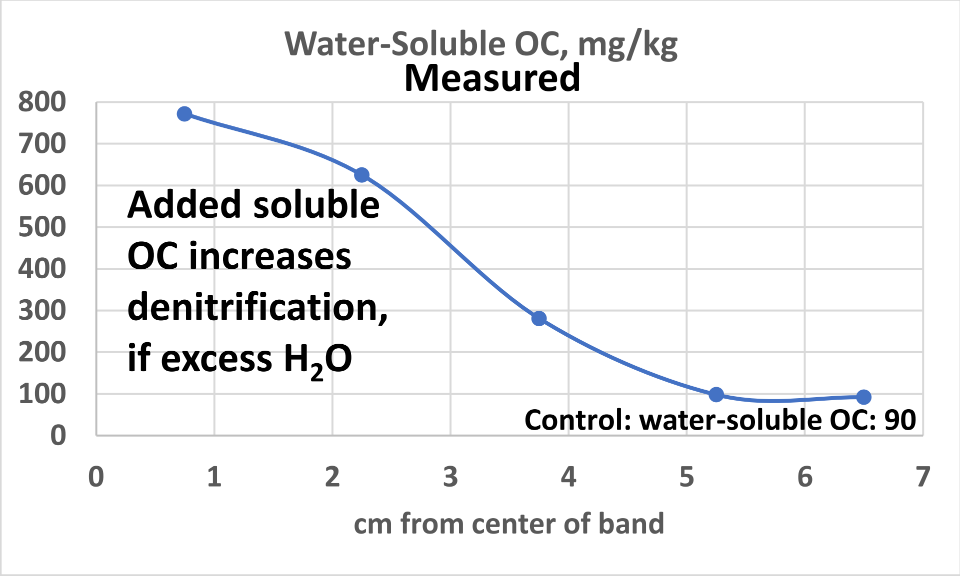


pH

Measured

Control: pH: 6.5

Norman et al., 1987



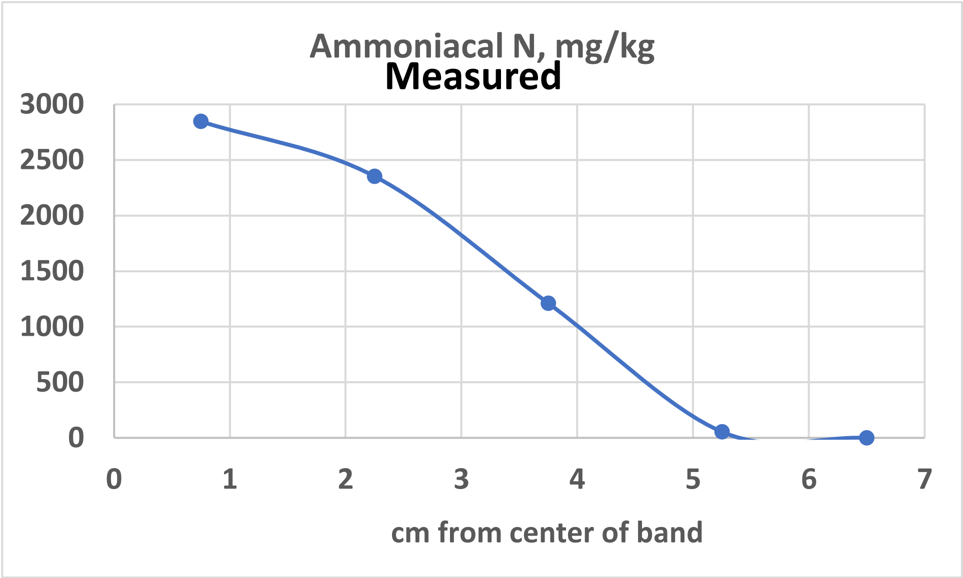
Water-Soluble OC, mg/kg

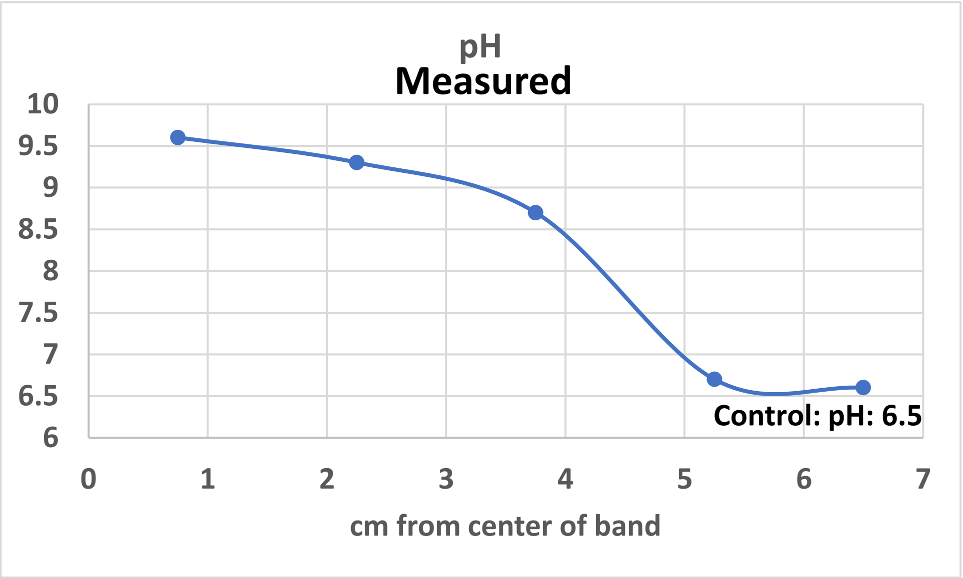
Measured

Added soluble OC increases denitrification, if excess H_2O

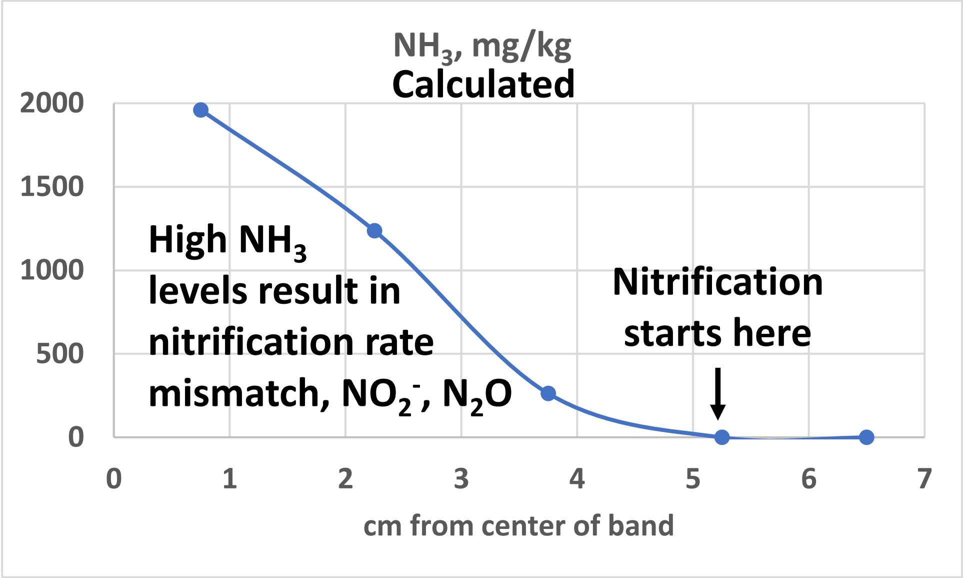
Control: water-soluble OC: 90

1 DAY AFTER 180 LB AA N/AC: DRUMMER SOIL, 3.0% ORGANIC C



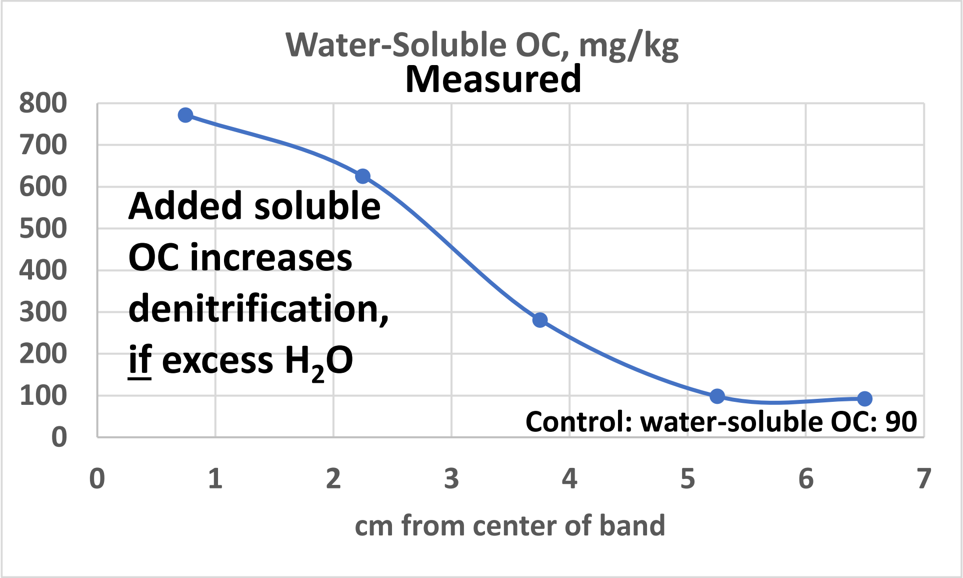


Control: pH: 6.5



High NH_3 levels result in nitrification rate mismatch, NO_2^-, N_2O

Nitrification starts here ↓

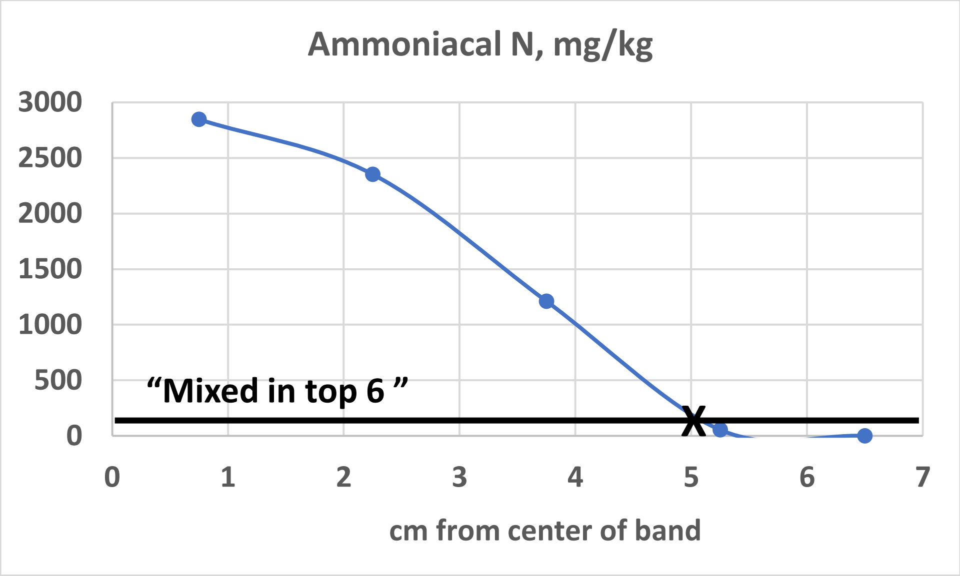


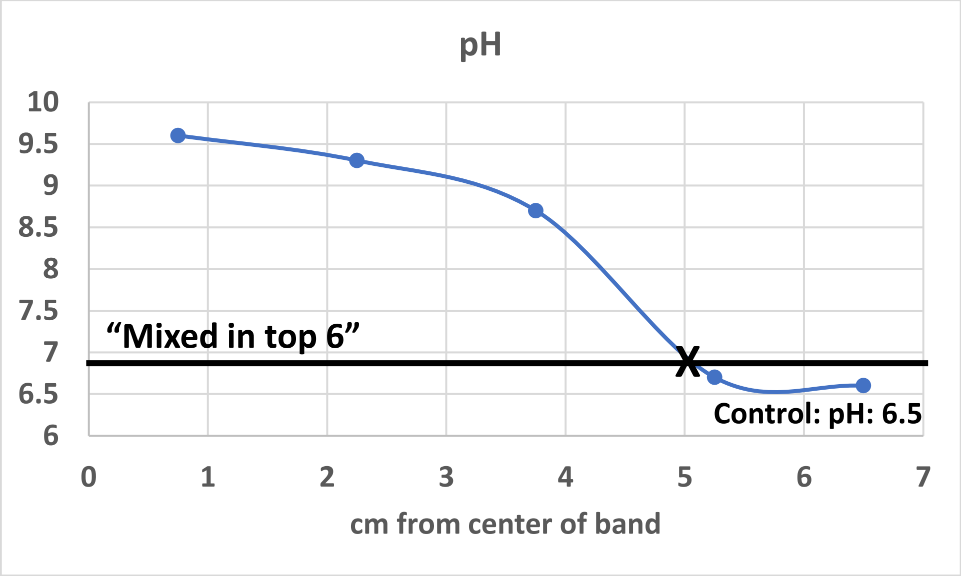
Added soluble OC increases denitrification, <u>if</u> excess H_2O

Control: water-soluble OC: 90

Norman et al., 1987 + Bock

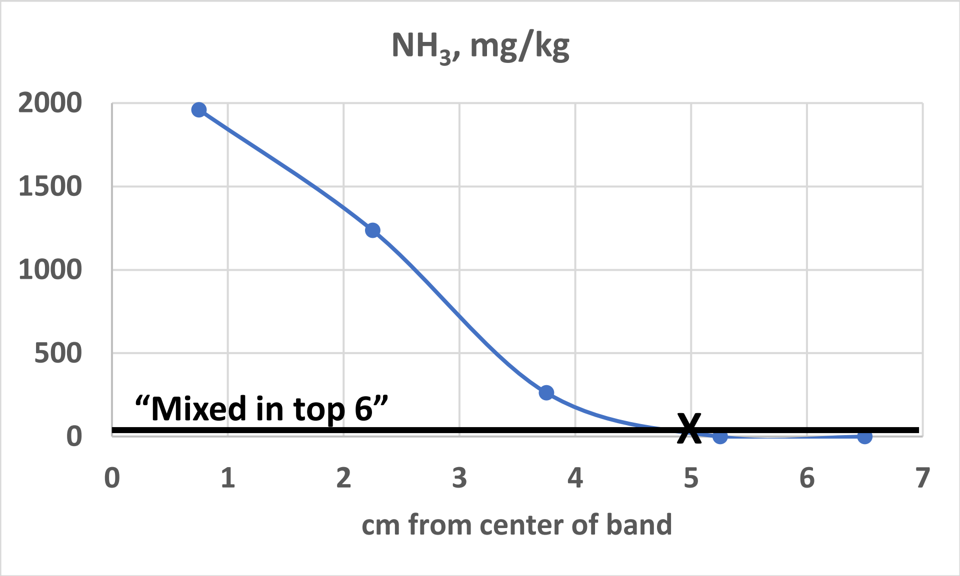
1 DAY AFTER 180 LB AA N/AC: DRUMMER SOIL, 3.0% ORGANIC C

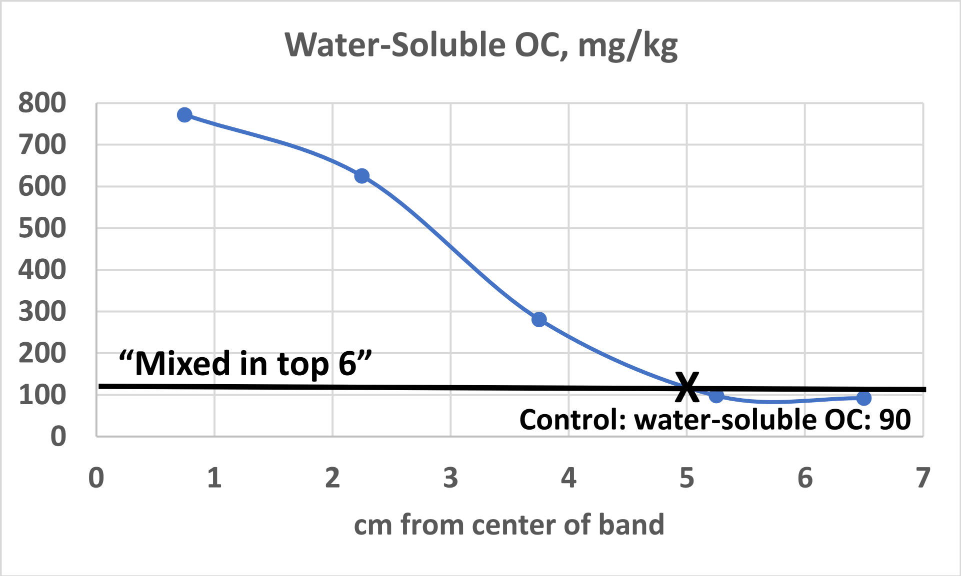

Ammoniacal N, mg/kg


pH

Control: pH: 6.5

Assumes no NH_4^+ on CEC

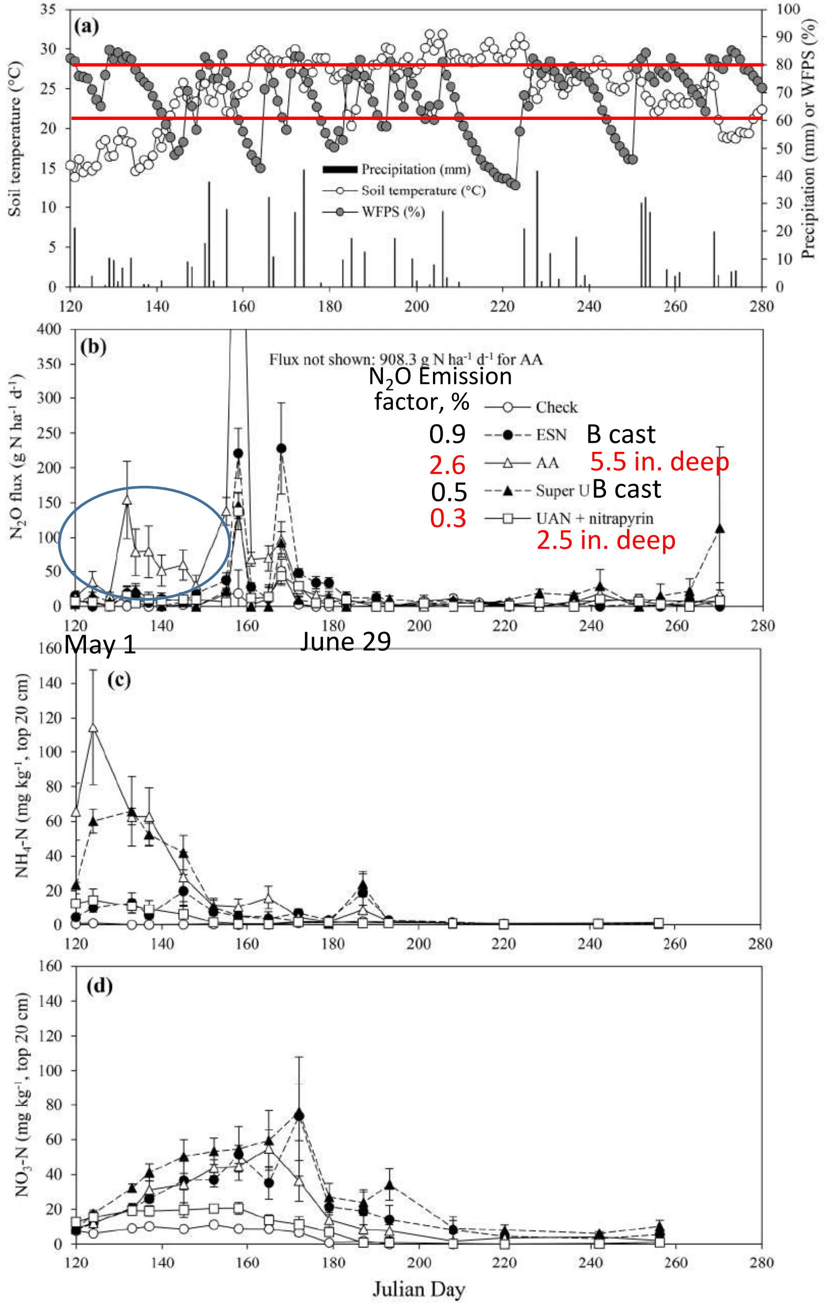

NH_3, mg/kg


Water-Soluble OC, mg/kg

Control: water-soluble OC: 90

Norman et al., 1987 + Bock

Urbana, IL
Drummer Silty Clay Loam, 12.5 CEC
2016
180 lb N/Ac



N_2O Emission factor, %

0.9 B cast

2.6 5.5 in. deep

0.5 B cast

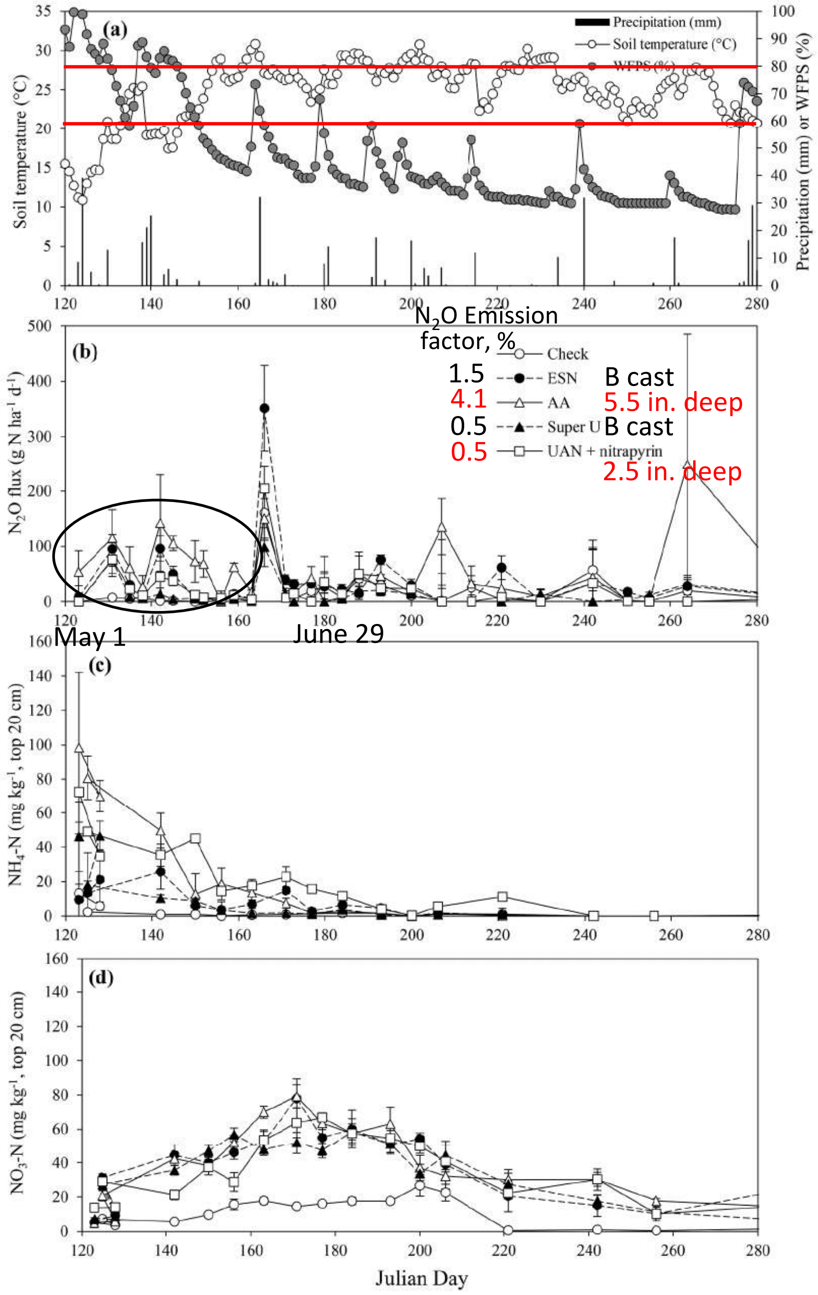
0.3 2.5 in. deep

May 1

June 29

Graham et al. (2018)
SSAJ 82: 1469-1481

Urbana, IL
Flanagan Silt Loam, CEC 15.7
2017
180 lb N/Ac



N$_2$O Emission factor, %
1.5 ESN B cast
4.1 AA 5.5 in. deep
0.5 Super U B cast
0.5 UAN + nitrapyrin 2.5 in. deep

May 1
June 29

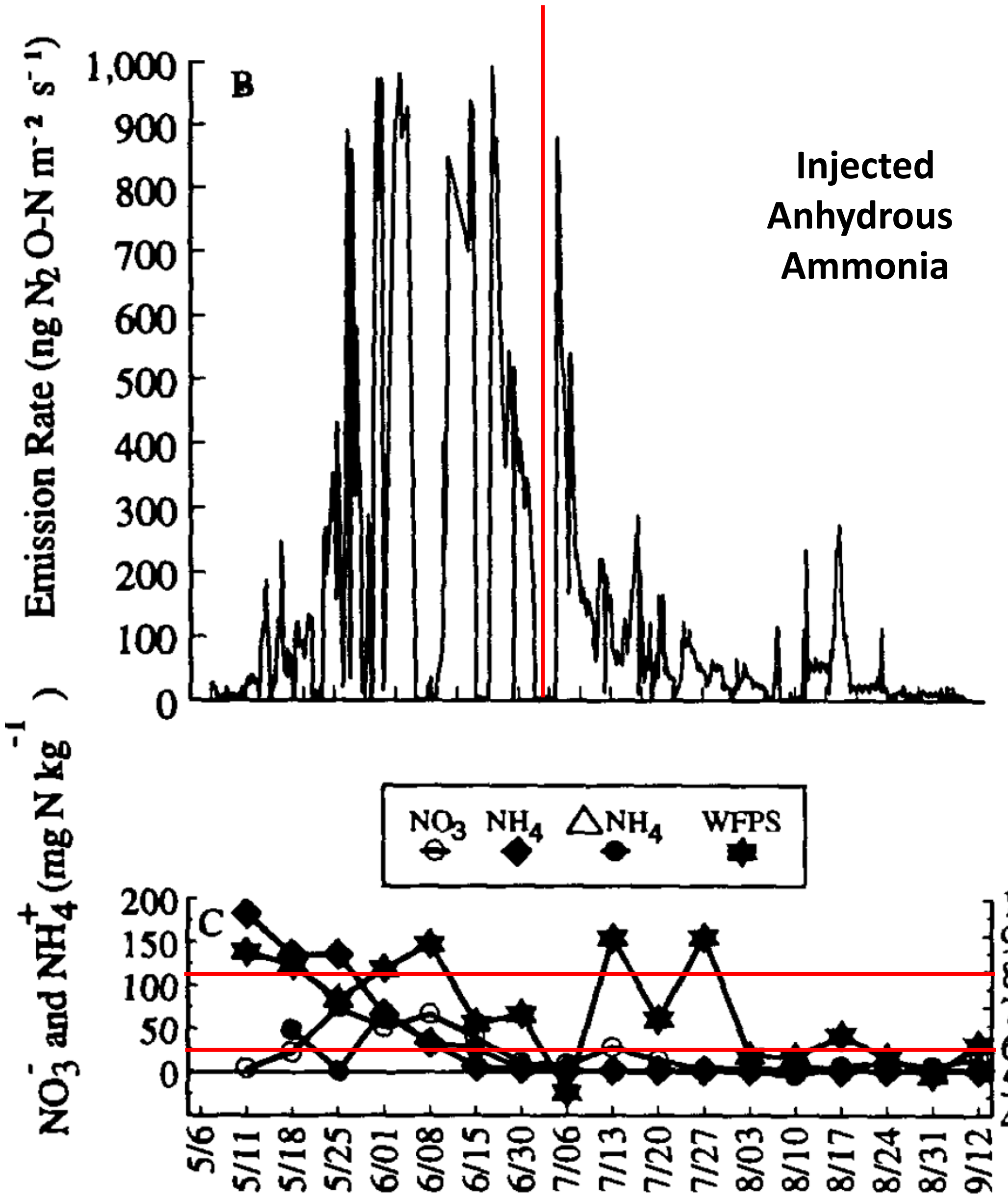
Graham et al. (2018)
SSAJ 82: 1469-1481

INJECTED AA VS. INJECTED UREA SOLUTION, 170 KG N/HA[1/]

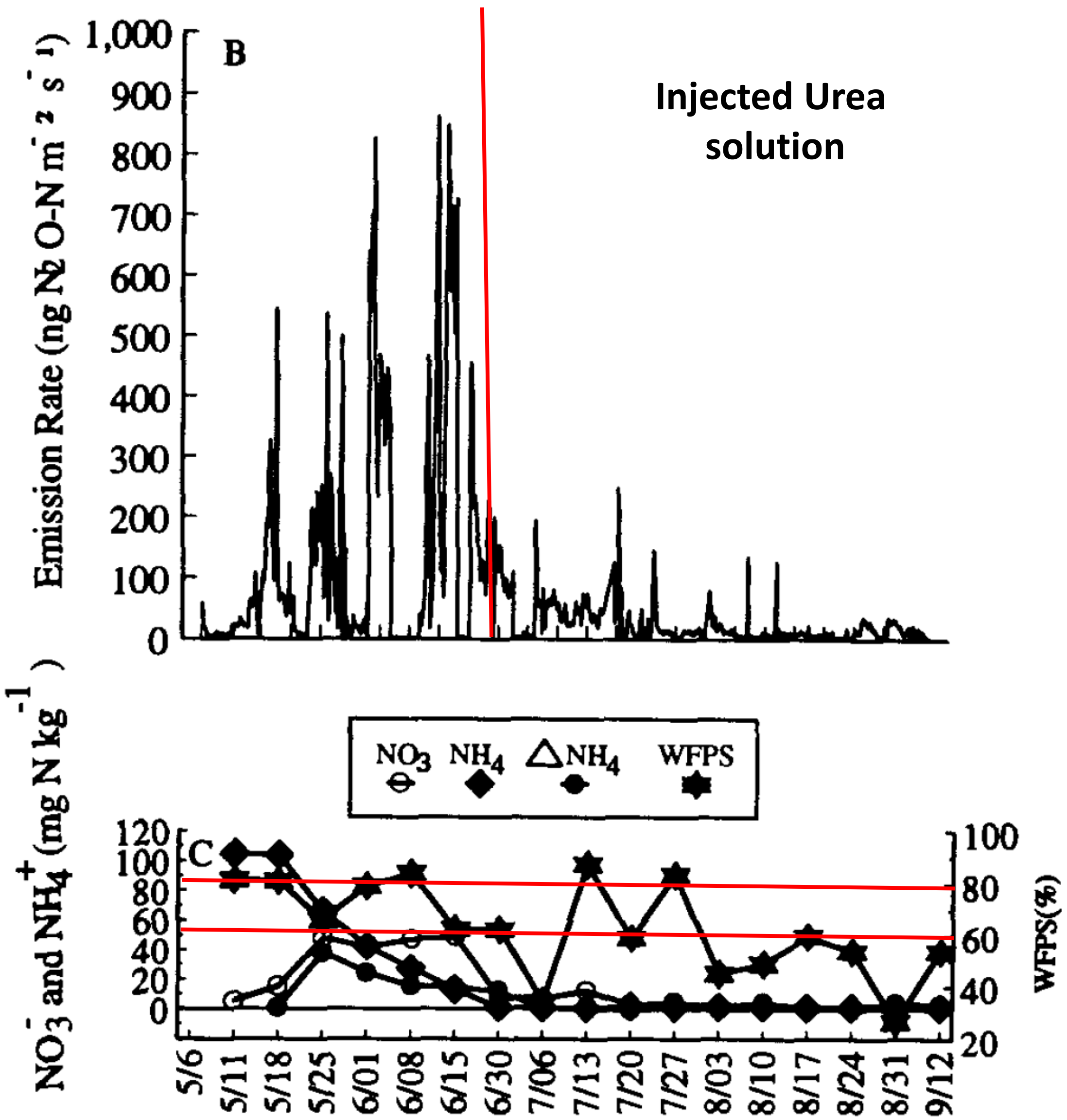
N Source	Actual	Net due to fert	N_2O Emission
	kg N_2O-N/ha		factor, %
Control	1.43		
Injected AA	13.77	12.33	7.3
Injected Urea soln. (18 % N)	7.78	6.34	3.8

[1] No-till corn, West Tennessee, Lexington silt loam, 1.7% OM, 7.9 CEC
N_2O measured every 3 hours for 129 days

Thornton et al. (1994)

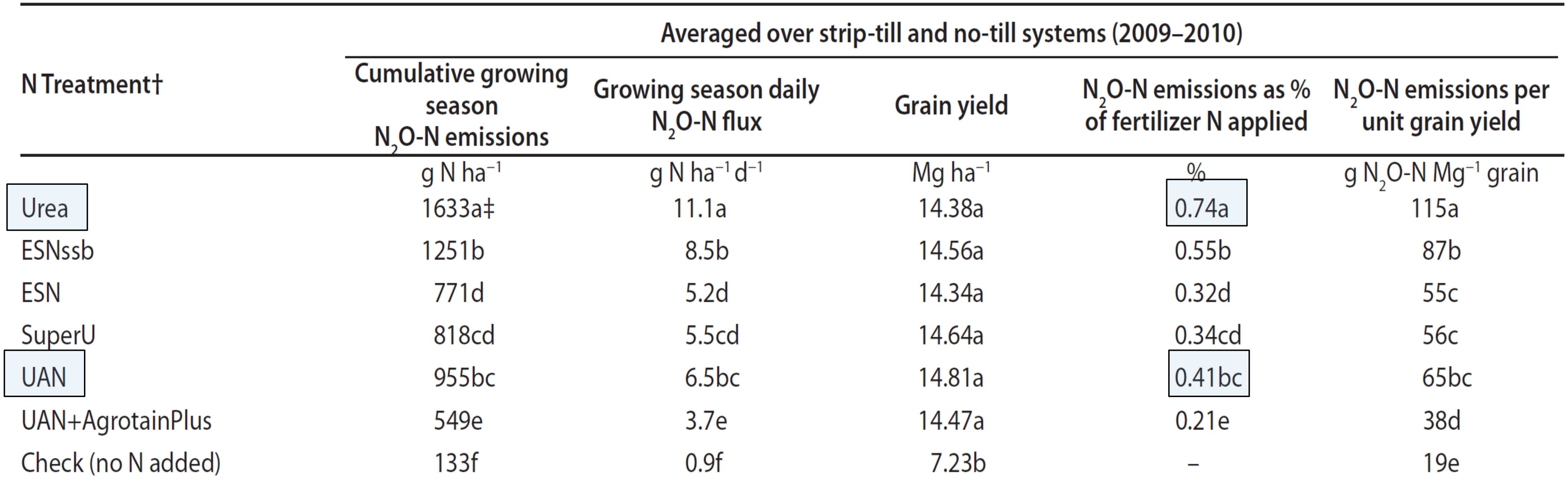


Injected Anhydrous Ammonia



Injected Urea solution

SURFACE BANDED N SOURCES (5-7 CM BAND WIDTH) AND WATERED IN (16-19 MM) NEXT DAY, 180 LB N/AC

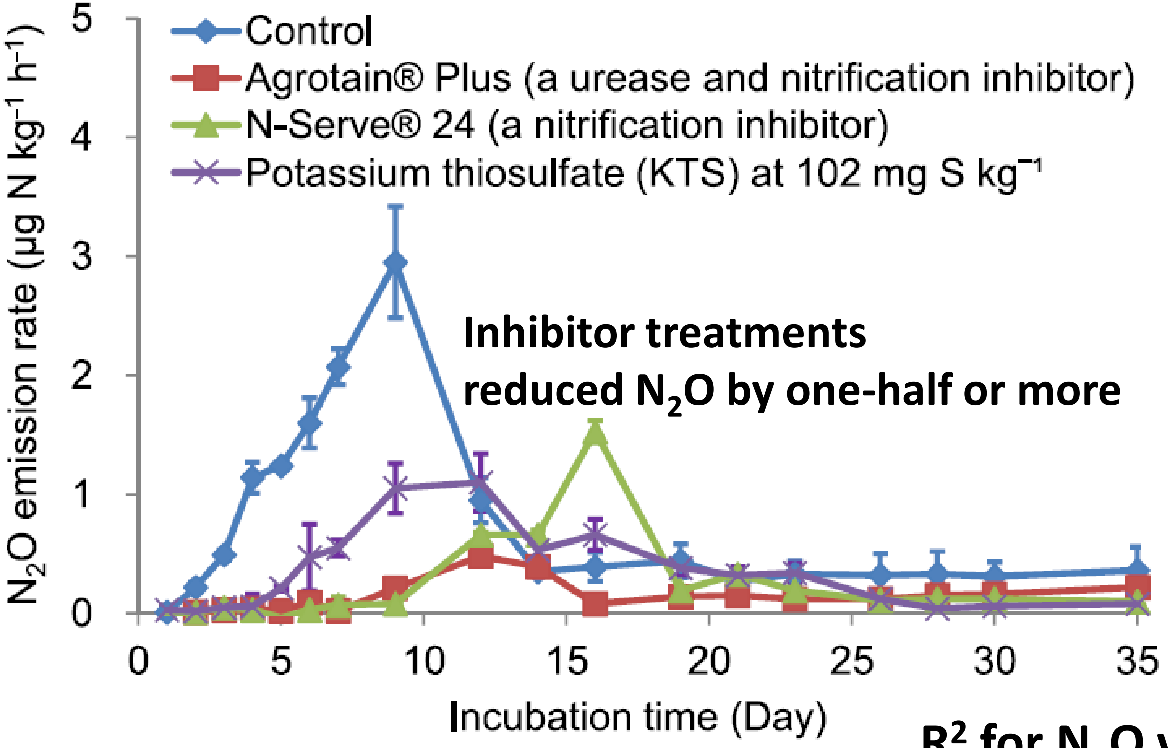


N Treatment†	Averaged over strip-till and no-till systems (2009–2010)				
	Cumulative growing season N_2O-N emissions	Growing season daily N_2O-N flux	Grain yield	N_2O-N emissions as % of fertilizer N applied	N_2O-N emissions per unit grain yield
	g N ha^{-1}	g N ha^{-1} d^{-1}	Mg ha^{-1}	%	g N_2O-N Mg^{-1} grain
Urea	1633a‡	11.1a	14.38a	0.74a	115a
ESNssb	1251b	8.5b	14.56a	0.55b	87b
ESN	771d	5.2d	14.34a	0.32d	55c
SuperU	818cd	5.5cd	14.64a	0.34cd	56c
UAN	955bc	6.5bc	14.81a	0.41bc	65bc
UAN+AgrotainPlus	549e	3.7e	14.47a	0.21e	38d
Check (no N added)	133f	0.9f	7.23b	–	19e

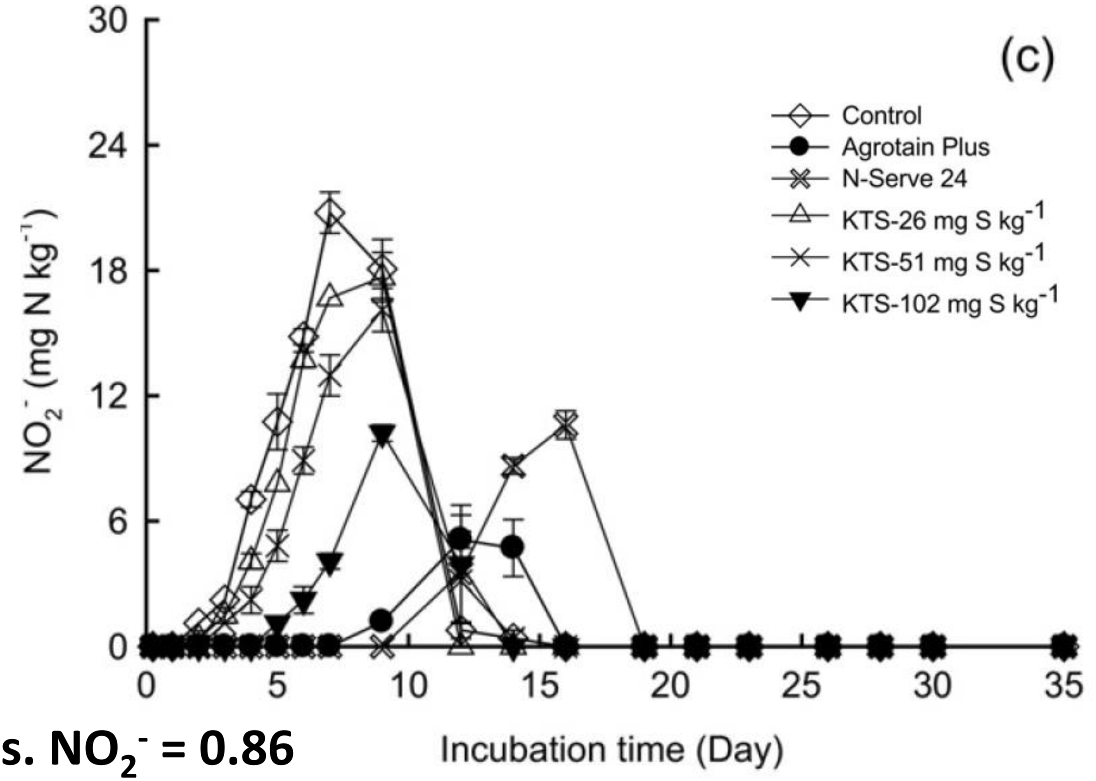
Fort Collins clay loam, 1.25% organic C (2.15% OM)

Halvorson et al. 2011 and 2012. JEQ

150 PPM UAN-N, NOT BANDED, 10% MOISTURE (W/W), LAB

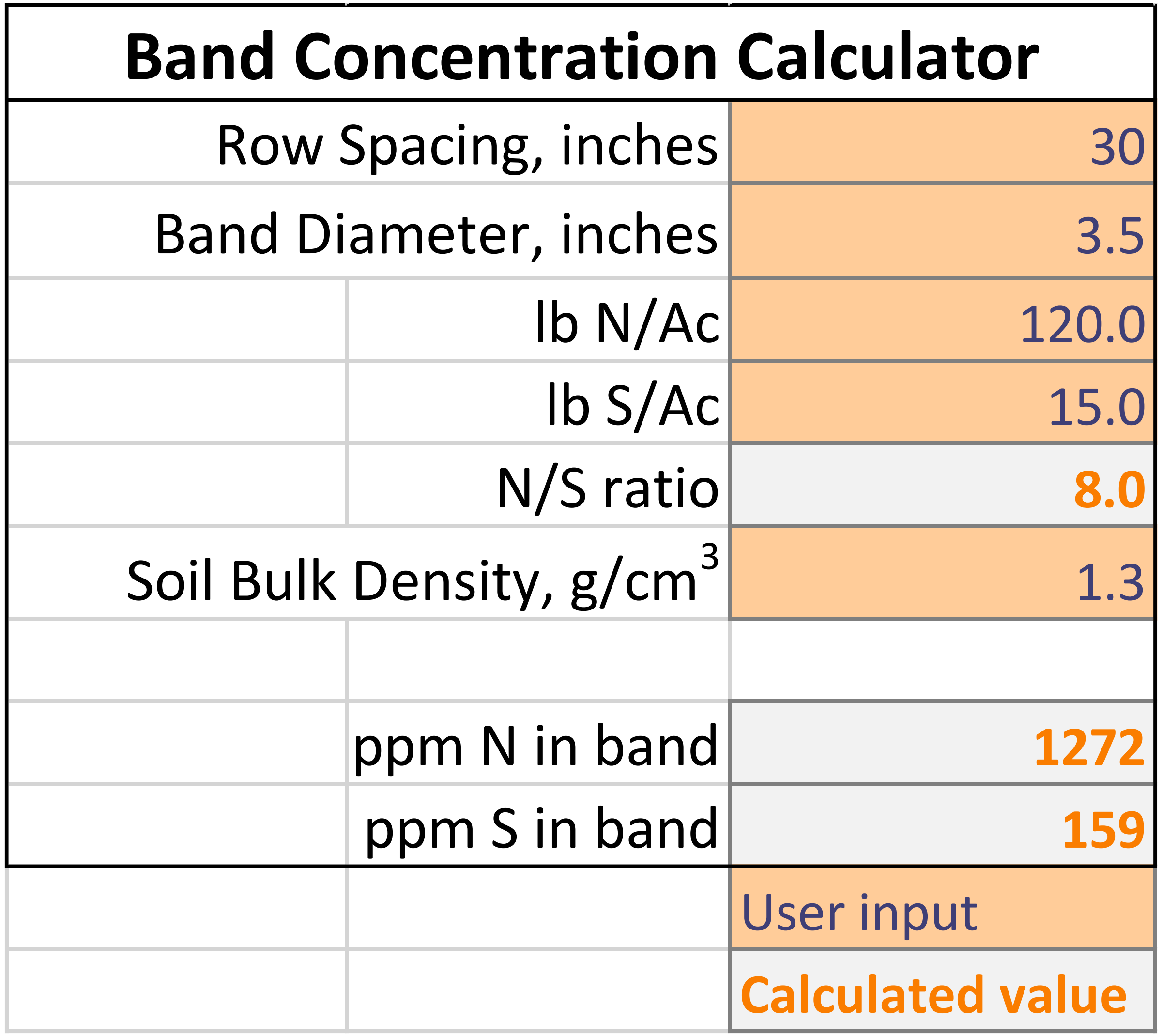


Inhibitor treatments reduced N_2O by one-half or more



R^2 for N_2O vs. NO_2^- = 0.86

Cai et al. (2017)



Band Concentration Calculator

Row Spacing, inches	30
Band Diameter, inches	3.5
lb N/Ac	120.0
lb S/Ac	15.0
N/S ratio	**8.0**
Soil Bulk Density, g/cm^3	1.3
ppm N in band	**1272**
ppm S in band	**159**
	User input
	Calculated value

CONCLUSIONS

- Large effects of alkaline NH_4^+ source and placement on NO_2^-, nitrification-based N_2O: AA > Urea > UAN; **Injected AA >>>> broadcast UAN + NI**
  - NH_3 concentration is the key driver
  - Importance overlooked by many, including prevailing mechanistic models
  - Virtually a given; effects don't require high moisture/low oxygen and available carbon source
    - Implies relatively consistent opportunity for GHG credits by lowering N_2O
- In contrast, denitrification-based N_2O requires excess soil moisture that is highly variable ➔crapshoot
- Primary factors affecting NH_3 concentration in alkaline NH_4^+ source bands
  - N rate
  - Alkaline NH_4^+ source: Ammonia > Urea > UAN
  - Higher in soils with lower CEC (lower NH_4^+ sorption, pH buffering)
  - NIs slow first step of nitrification and reduce NO_2^- buildup and N_2O

Proposing simple soil measurements and calculations to reflect these factors re N_2O

CONCLUSIONS CONTINUED

- The high pH in alkaline NH_4^+ bands solubilizes soil OM and increases denitrification-based N_2O, if both NO_3^- and high soil moisture are present
  - AA > Urea > UAN
  - Proposing index as starting point for predicting this effect
- Assuming improved prediction tools, excellent potential for GHG credits based on managing banded alkaline NH_4^+ sources
  - **Potential especially large via replacing AA with UAN or UAN + NI**

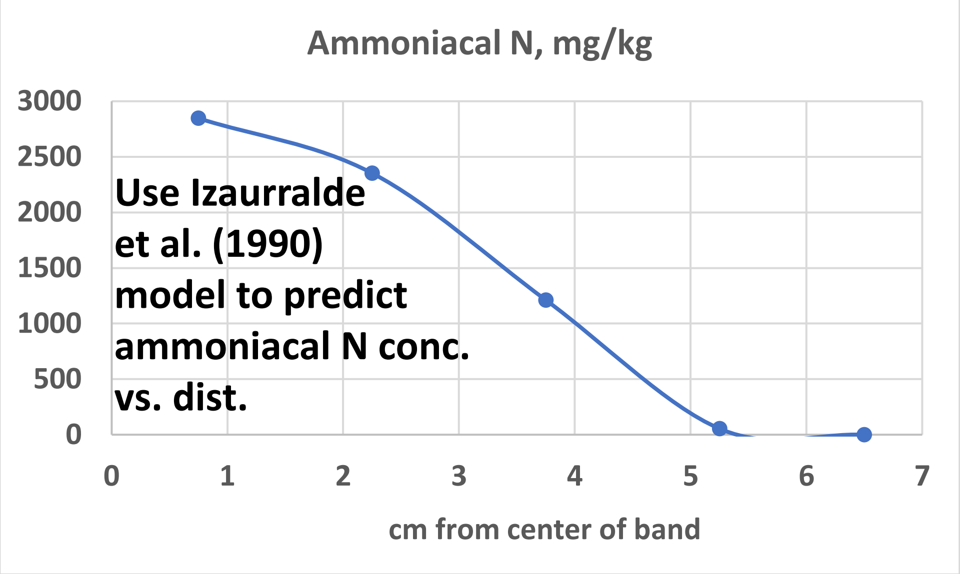
HOW DOES POTENTIAL FOR MONETIZING REDUCTIONS IN N_2O STACK UP?

- Most of agricultural GHG credit attention on increasing soil carbon sequestration
  - Diminishing returns after a few years
  - Reversed if revert back to previous system
  - Early adopter problem re additionality
- Reduced N_2O
  - One and done—can’t reverse a decreased loss
  - No diminishing returns over years
  - Good long-term potential
  - No early adopter problem re switching from AA to UAN + NI
  - Easier to switch N sources than tillage system
  - Option for stacking reduced N_2O and soil C sequestration GHG credits
- Prediction of GHG reductions is challenging for both soil carbon sequestration and N_2O
  - Looking for GHG credit modeling and monetization partners

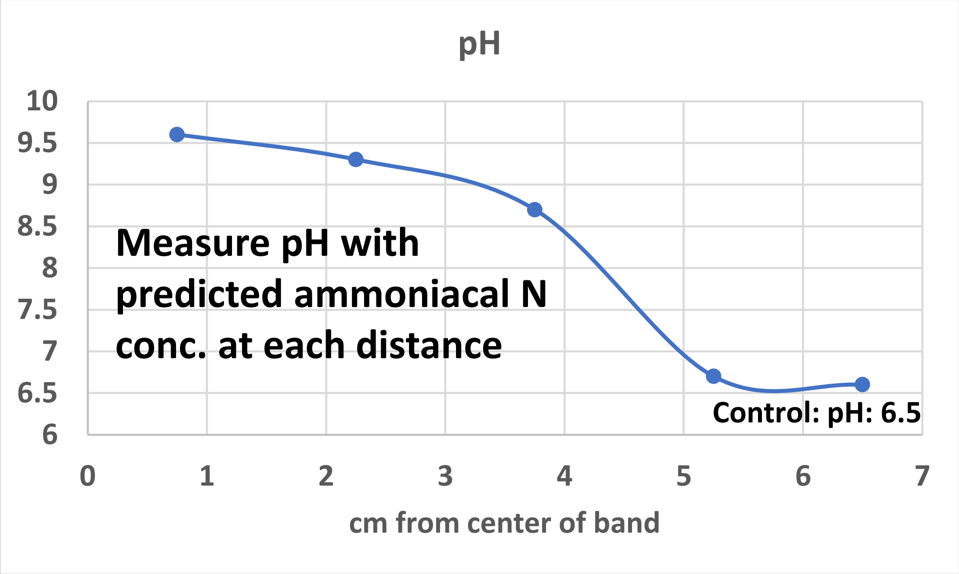
MECHANISTIC MODELS BASED ON TRADITIONAL STORY

- Structured to predict rates of nitrification and denitrification
- But, assume constant percent of N lost as N_2O via nitrification
  - Expert N: 0.5%
  - Century (now DAYCENT): 2%
  - DNDC: formula with max. of 0.06% at water saturation
- **Don't reflect important soil chemistry aspects of alkaline NH_4^+ source bands that affect pH, NH_3 levels , NO_2^- buildup, solubilized OC, and resulting N_2O**
- Proposing relatively simple soil measurements and calculations hypothesized to improve N_2O predictions
  - Starting inputs for mechanistic models
  - Support empirical approaches

PROPOSED SIMPLE SOIL MEASUREMENTS AND CALCULATIONS: DRUMMER SOIL E.G.



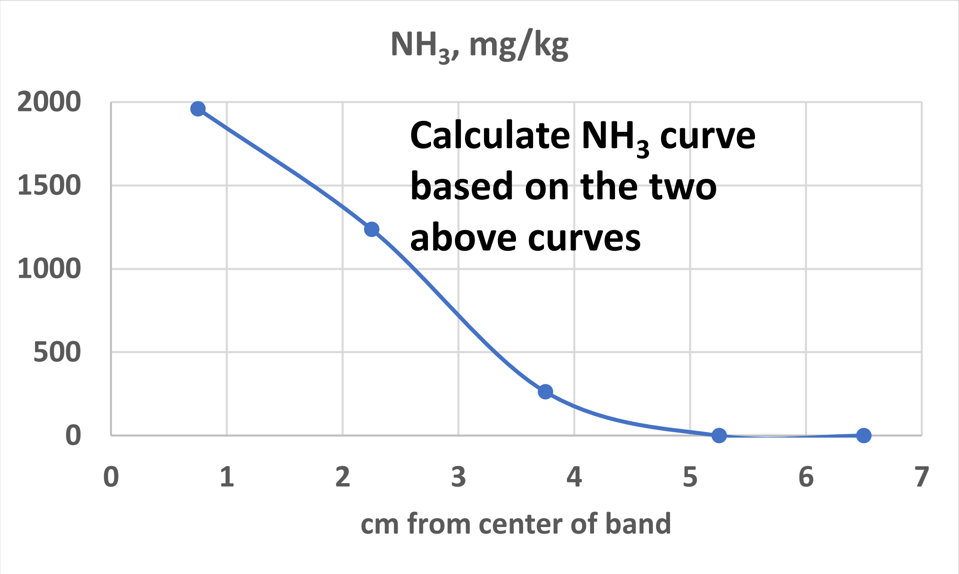
Use Izaurralde et al. (1990) model to predict ammoniacal N conc. vs. dist.



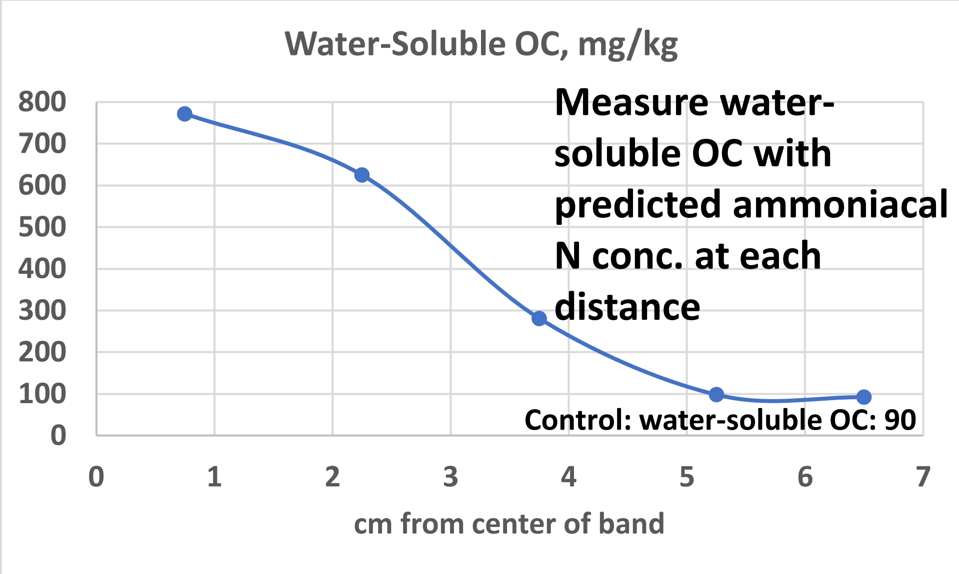
Measure pH with predicted ammoniacal N conc. at each distance

Control: pH: 6.5

Norman et al., 1987 + Bock



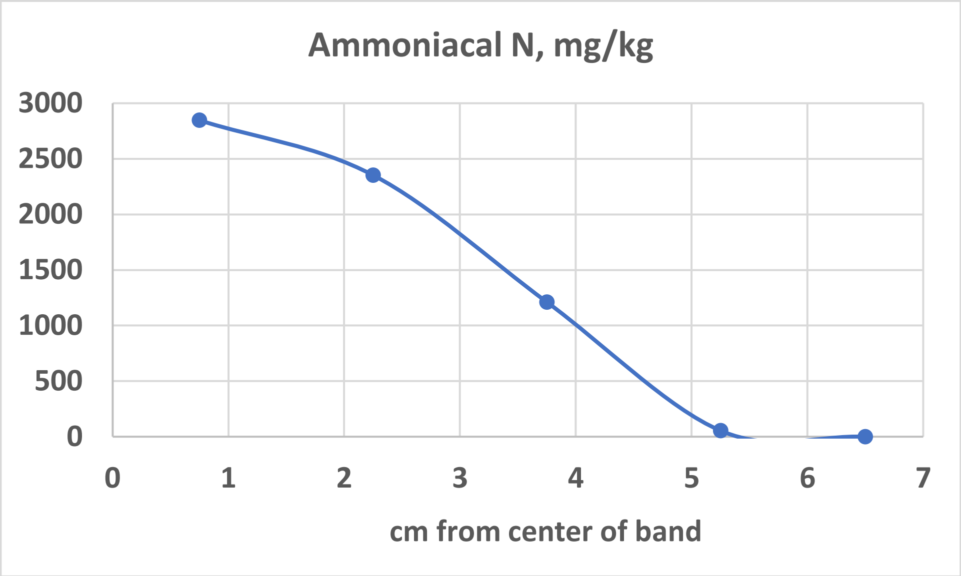
Calculate NH_3 curve based on the two above curves

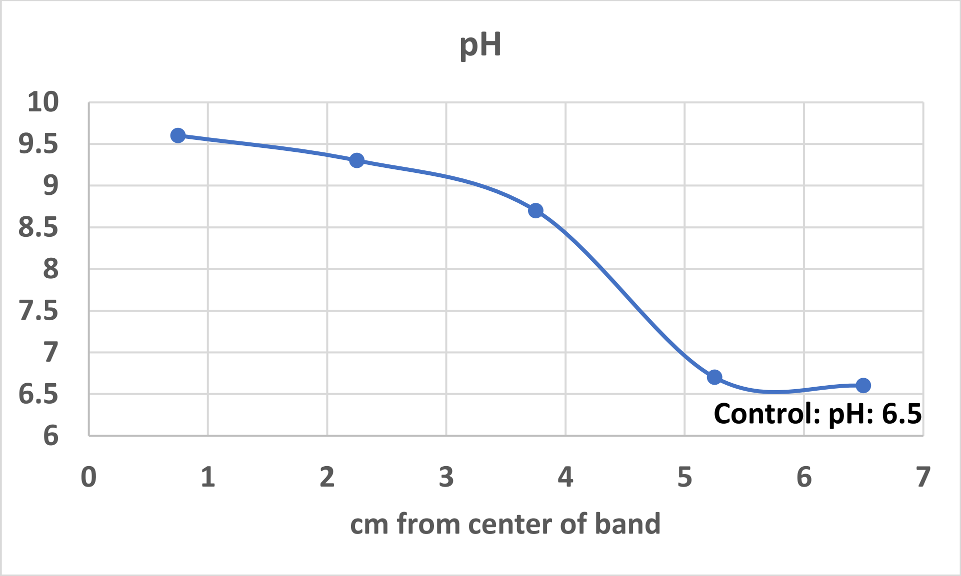


Measure water-soluble OC with predicted ammoniacal N conc. at each distance

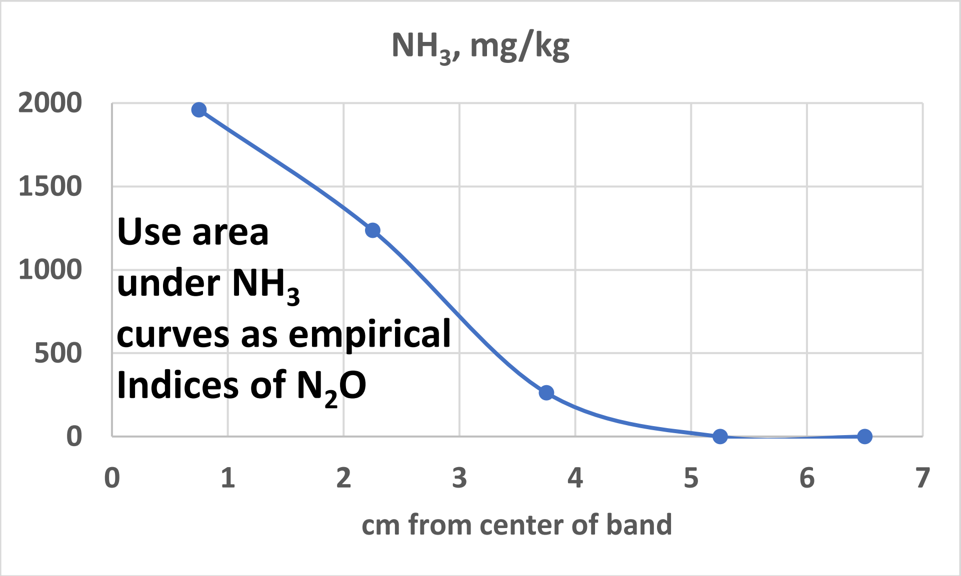
Control: water-soluble OC: 90

PROPOSED SIMPLE SOIL MEASUREMENTS AND CALCULATIONS: DRUMMER SOIL E.G.

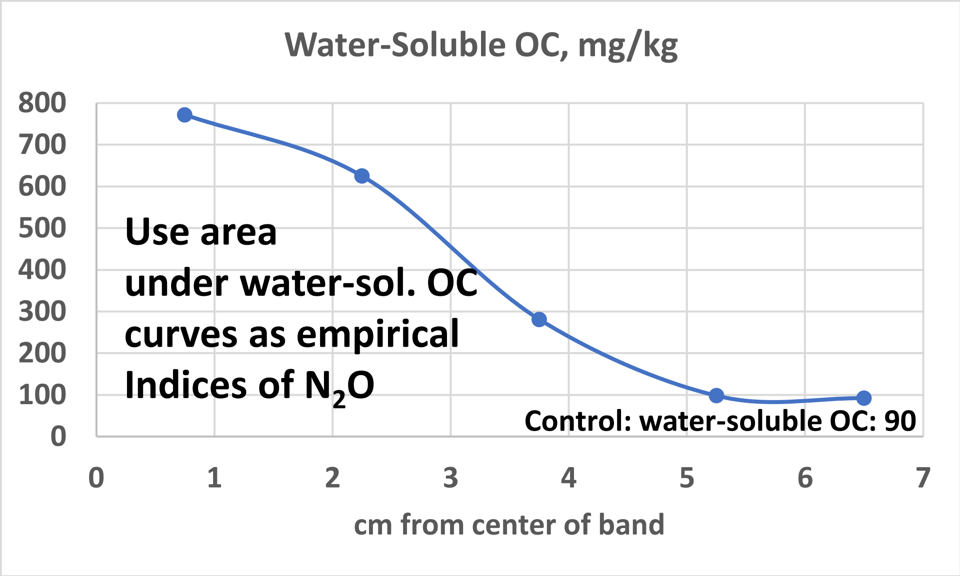

Ammoniacal N, mg/kg


pH

Control: pH: 6.5


NH_3, mg/kg

Use area under NH_3 curves as empirical Indices of N_2O


Water-Soluble OC, mg/kg

Use area under water-sol. OC curves as empirical Indices of N_2O

Control: water-soluble OC: 90

Norman et al., 1987 + Bock

CONCLUSION

EXCELLENT POTENTIAL FOR THE FLUID FERTILIZER INDUSTRY AND CUSTOMERS TO IMPROVE BOTTOM LINE AND AG SUSTAINABILITY BASED ON GHG CREDITS FOR SWITCHING FROM AA TO UAN + NI