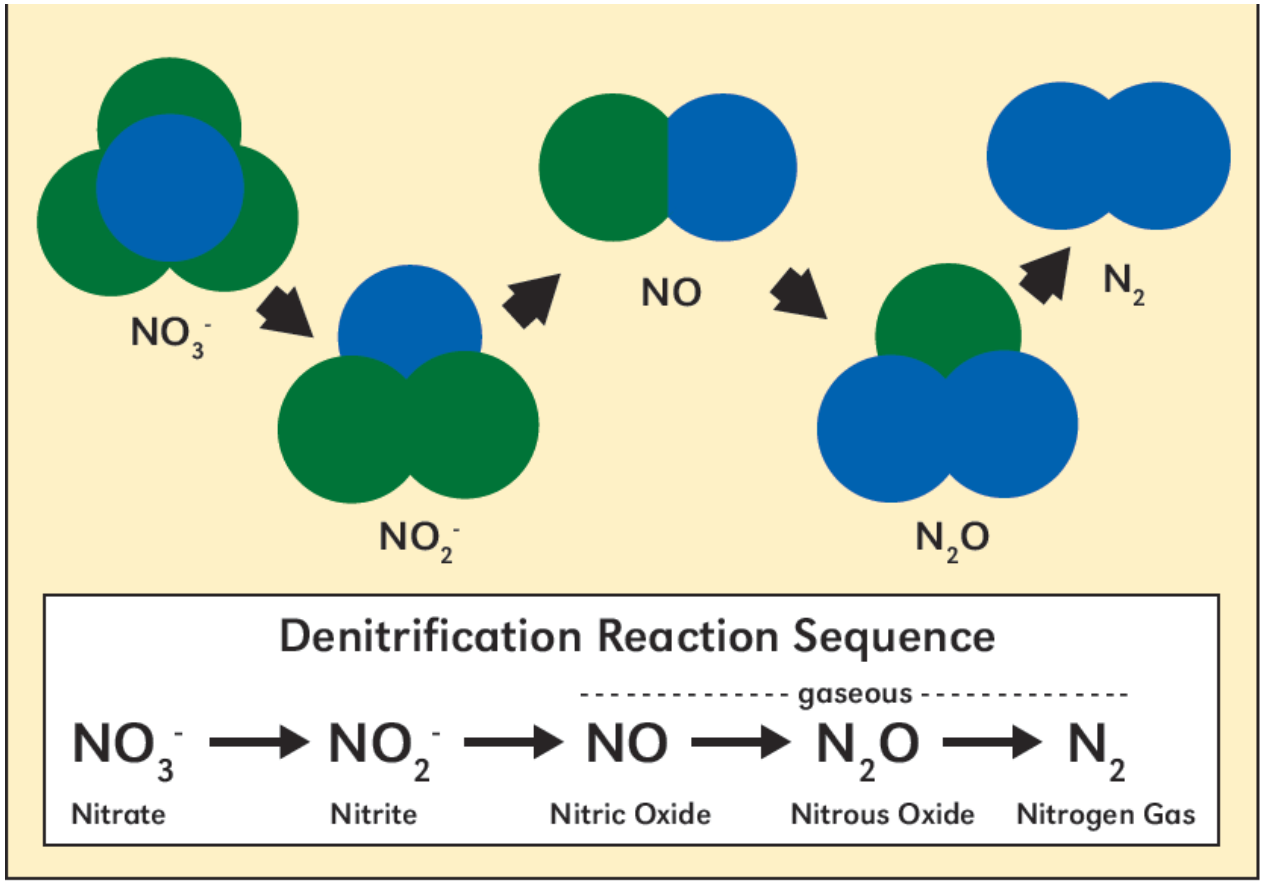
Denitrification- Causes and Solutions

Amit Chatterjee
Soil Science, NDSU

Denitrification- What is it?

- Natural soil microbial process where nitrate (NO_3^-) is converted to nitrogen (N) gases (NO, N_2O and N_2)

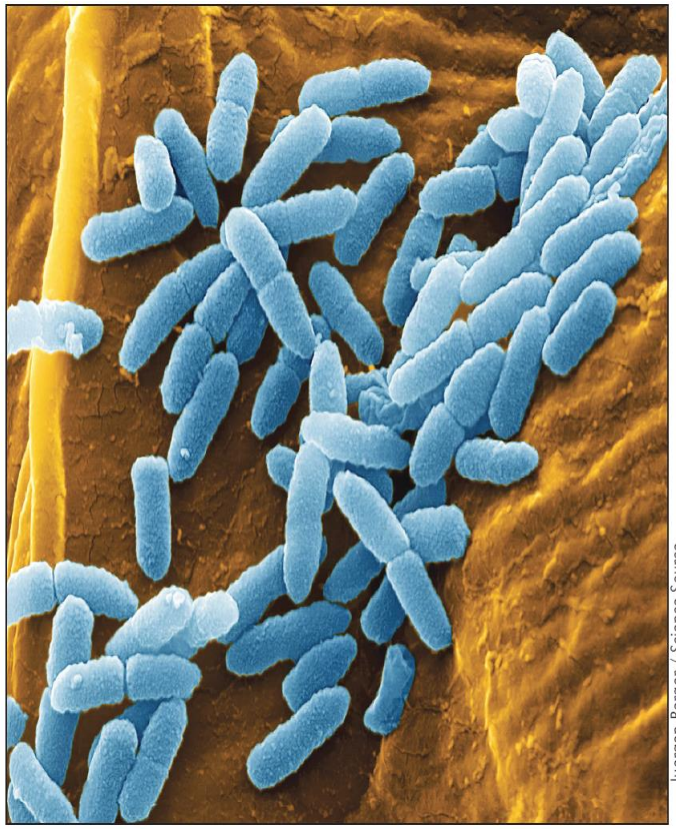


Denitrification- What is it?

- This loss of nitrate by denitrification has negative economic consequences for crop production since valuable N fertilizer is lost to the air
- Nitrous oxide (N_2O), a potent greenhouse gas that can remain in the air for over 100 years

Denitrification- Why does it occur?

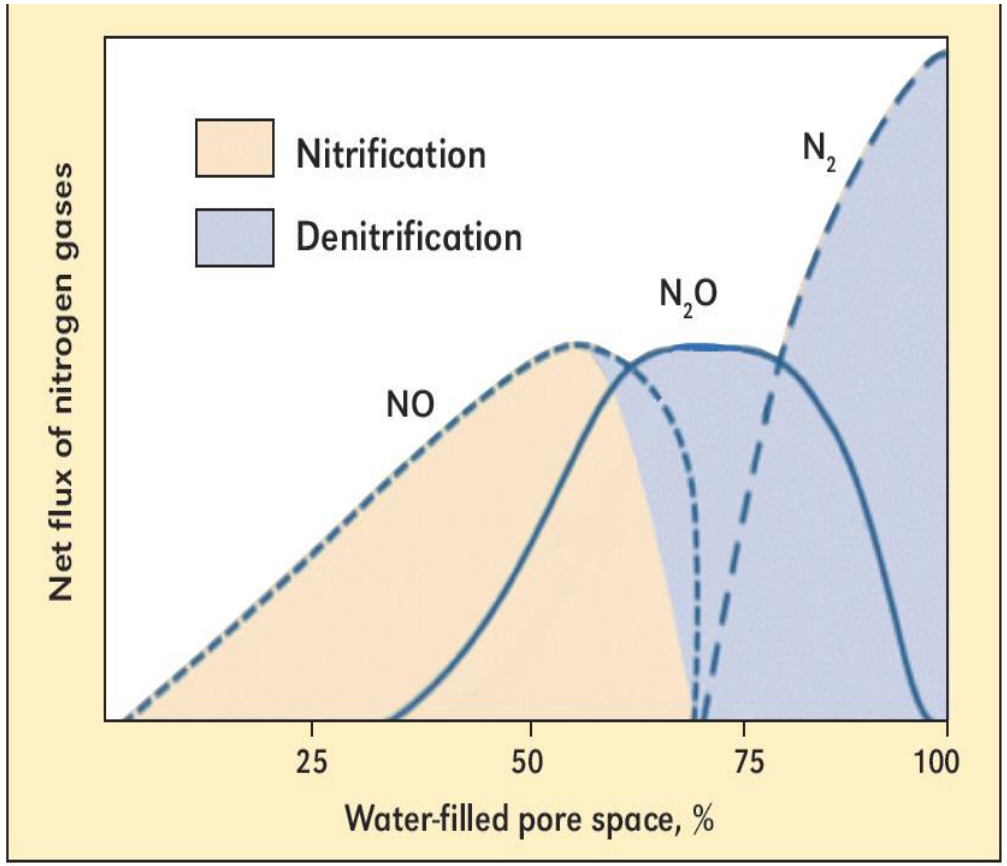
- When the oxygen (O_2) supply in soil becomes limited, a variety of bacteria use the oxygen in nitrate for respiration.
- Denitrification most commonly occurs in wet or waterlogged soils where the oxygen supply for respiration is restricted.



An example of common soil bacteria (*Pseudomonas aeruginosa*) capable of denitrification

Denitrification- When does it occur?

- Denitrification proceeds rapidly when water-filled pore space in soil exceeds 60%.
- As the oxygen deficit increases, microbes tend to convert more of the nitrate to N2 gas



Soil moisture controls denitrification loss

Soil: Fargo-Ryan soil

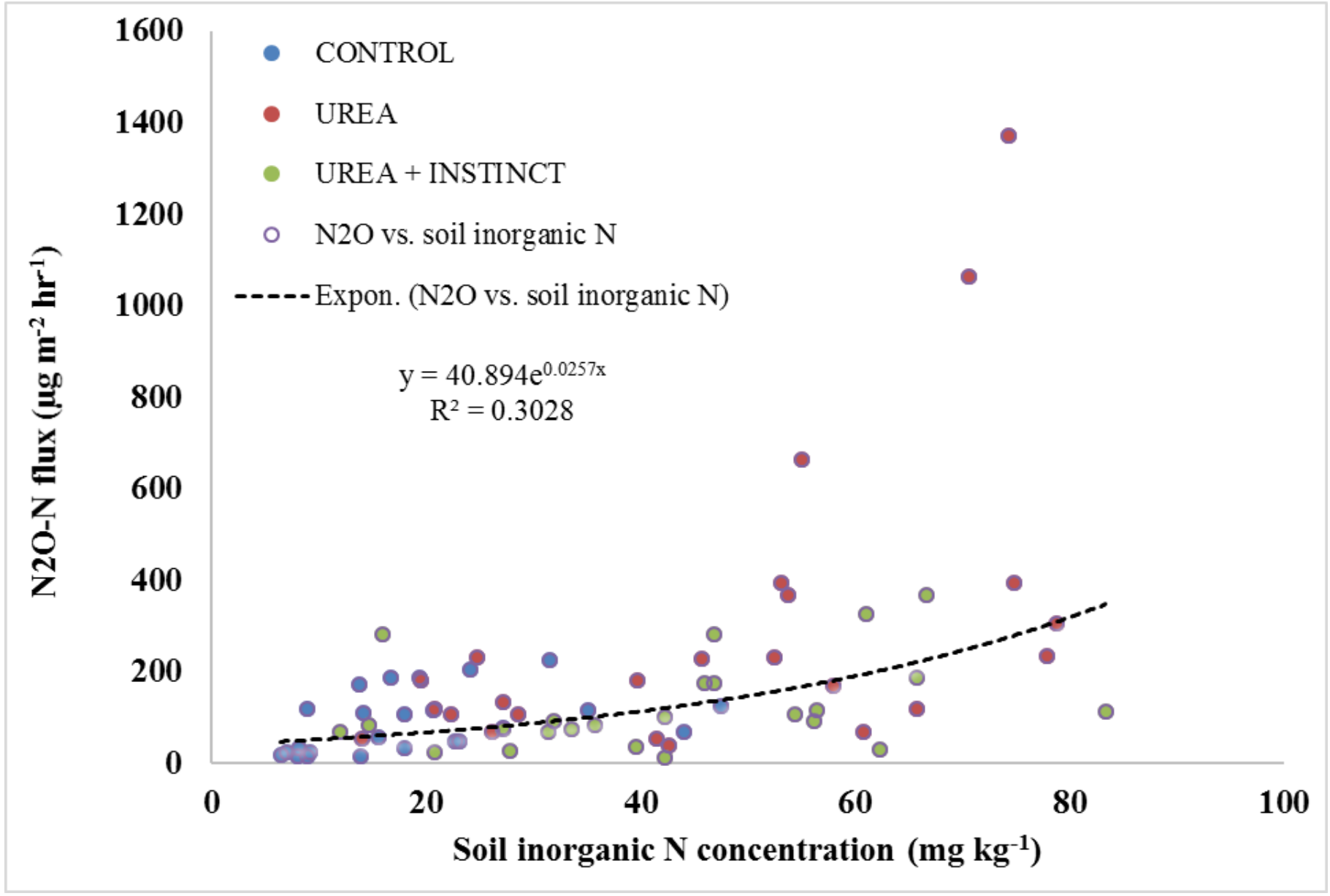
Treatment	30% WHC	60% WHC	80% WHC
	mg N_2O-N kg^{-1} soil over 140 days incubation		
Urea-N @135 lb N/ac	0.28^{B}	3.10^{A}	4.12^{C}
Urea-N @225 lb N/ac	0.56^{A}	3.92^{A}	16.0^{A}
Urea-N @135 lb N/ac + NP	0.07^{C}	1.13^{B}	8.99^{B}
Urea-N @225 lb N/ac + NP	0.12^{C}	1.52^{B}	12.8^{AB}

Source: Awale and Chatterjee (2015) Soil moisture controls the denitrification loss of urea nitrogen from silty clay soil, Communications in Soil Sc. And Plant Anal. 46:2100-2110

Denitrification-How does it control?

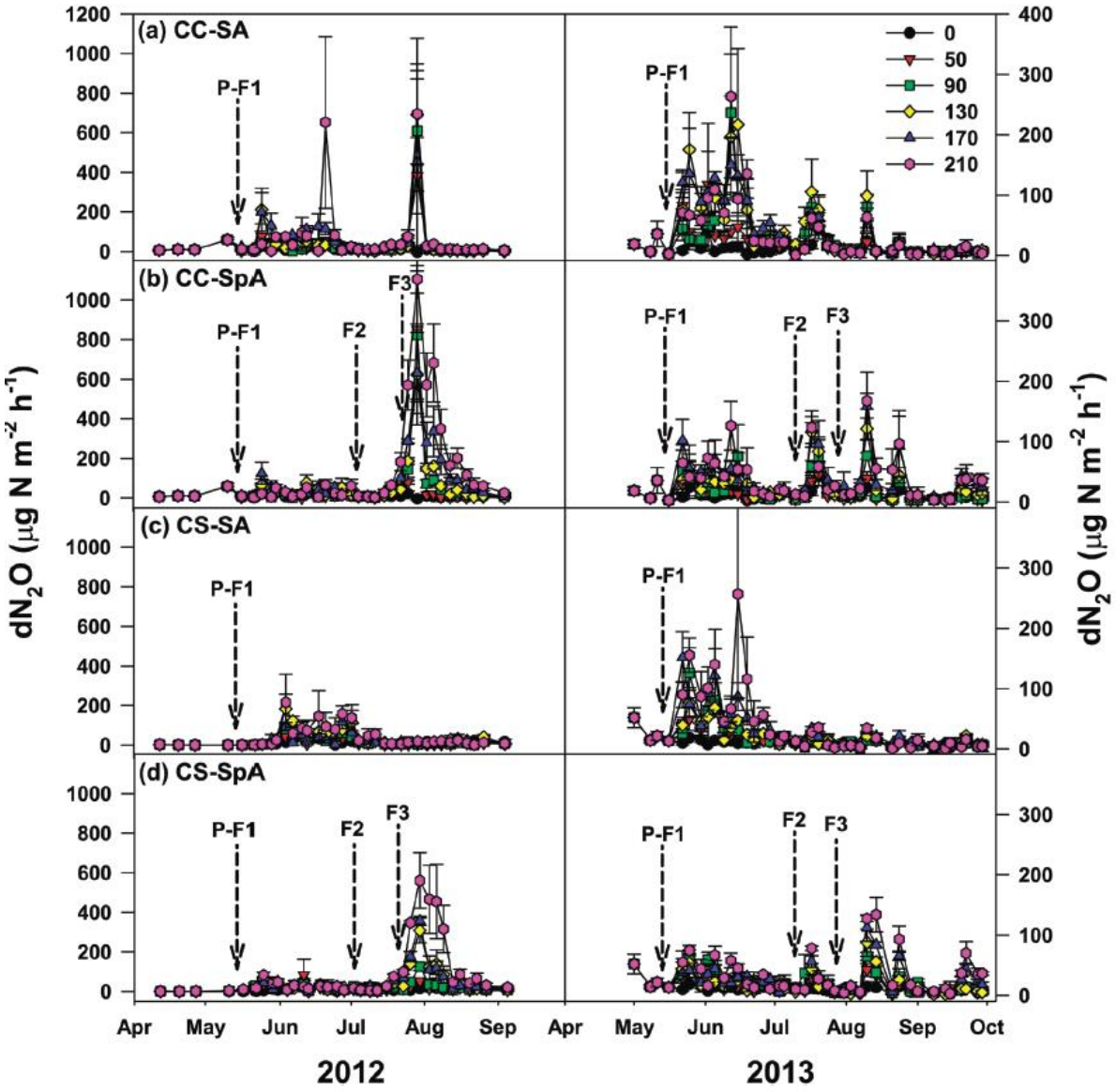
- Presence of nitrate- maintain a minimum concentration of nitrate needed to support healthy plant.
- This can be accomplished through split fertilizer applications, or the use of controlled-release N fertilizers
- Use of nitrification inhibitors temporarily restrict *Nitrosomonas* bacteria from converting ammonium to nitrate

Presence of soil nitrate-nitrogen showed a strong relationship with denitrification loss of N



Corn, 160 lb N/ac
Gardner, ND 2015

Split-N application and N_2O emissions



Rosemount (MN), silt loam, 2012-13, CC and CS rotation, single application (SA) at pre-plant and split (SpA) at planting, V6 and V14

SpA did not influence yield

Cumulative N_2O was 55% greater with SpA than SA in 2012

Prolonged dry period before the 2nd split followed by large rainfall events following the 3rd split

SpA increased cN_2O by 57% compared with SA when the maximum N rate was applied

Applying urea to coincide with periods of high crop N demand does not necessarily reduce and may increase N_2O emissions.

Source: Venterea and Coulter. 2015. Split application of urea does not decrease and may increase nitrous oxide emissions in rainfed corn. Agron. J. 107(1):337-348.

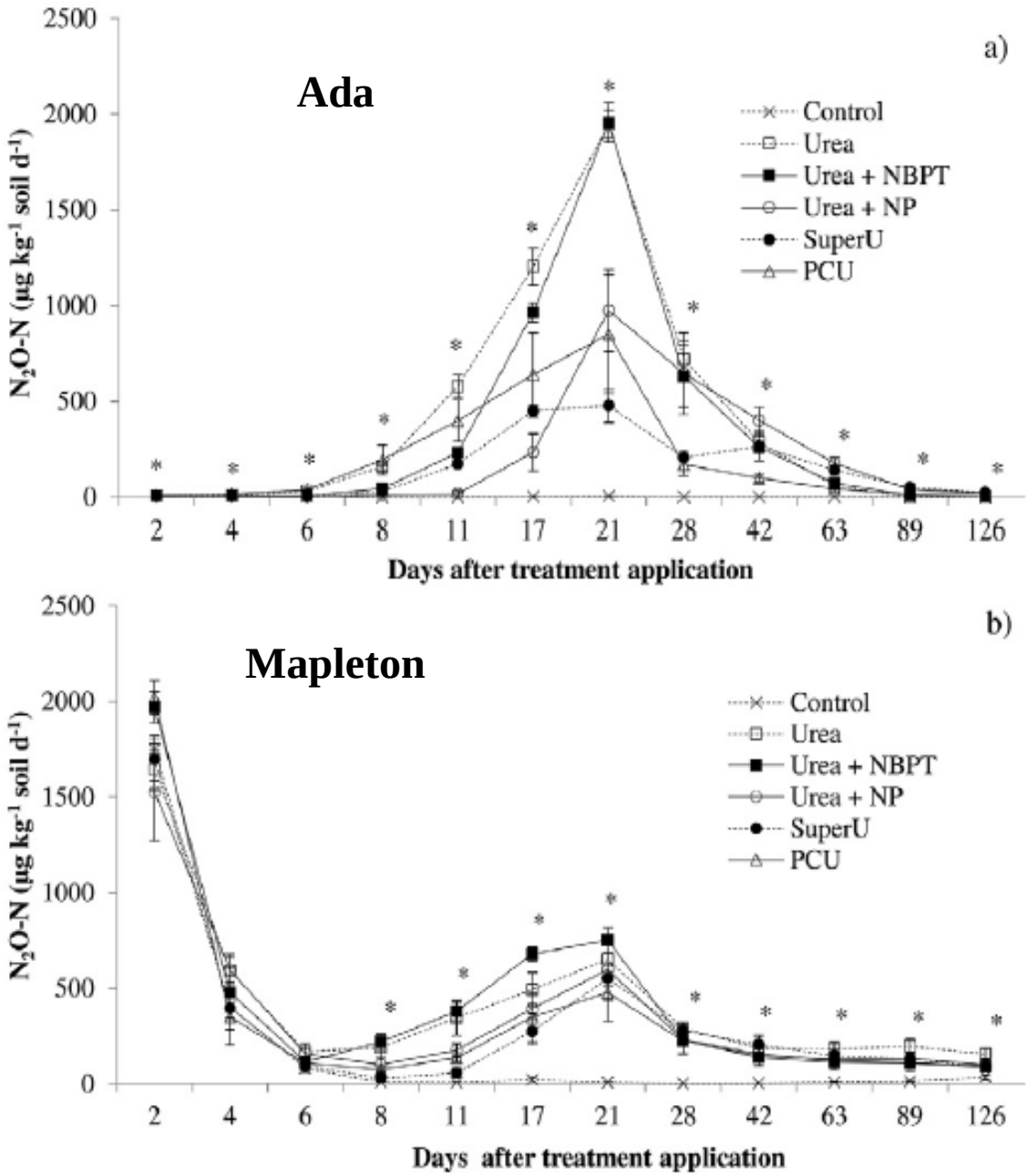
Nitrous oxide emissions from anhydrous ammonia, urea and polymer-coated urea (ESN) in Illinois corn field

	Corn grain yield (Bu/ac)				N_2O-N kg N/ha			
	2009	2010	2011	Mean	2009	2010	2011	Mean
Check	53^{C}	59^{C}	61^{C}	58B	1.20	2.21^{C}	1.06	1.49C
AA	126^{AB}	160^{AB}	136^{B}	140^{A}	3.55	16.89^{A}	3.99	8.14^{A}
ESN	117^{B}	170^{A}	160^{A}	149^{A}	1.23	9.77^{B}	3.84	4.95^{B}
Urea	135^{A}	147^{B}	152^{AB}	145^{A}	0.97	14.07^{A}	3.63	6.22^{AB}
Mean	108	134	127		1.74	10.73	3.13	

Source: Fenandez et al. (2015) J. Environ. Qual. 44:415-422 Continuous corn, 2009-2011, silt-loam, 160 lb N/ac

Performance of Enhanced Efficiency Fertilizers depends on soil texture

126 days of incubation @60% WHC	Ada, MN (Sandy loam)	Mapleton, ND (Fargo silty clay)
200 lb N/ac	mg N_2O-N kg^{-1} soil	
Urea	27.3^{a}	30.6^{a}
Urea+NBPT	24.0^{ab}	25.1^{a}
Urea+Nitrapyrin	20.9^{bc}	22.2^{a}
SuperU	15.4^{cd}	22.5^{a}
ESN	13.5^{d}	22.4^{a}

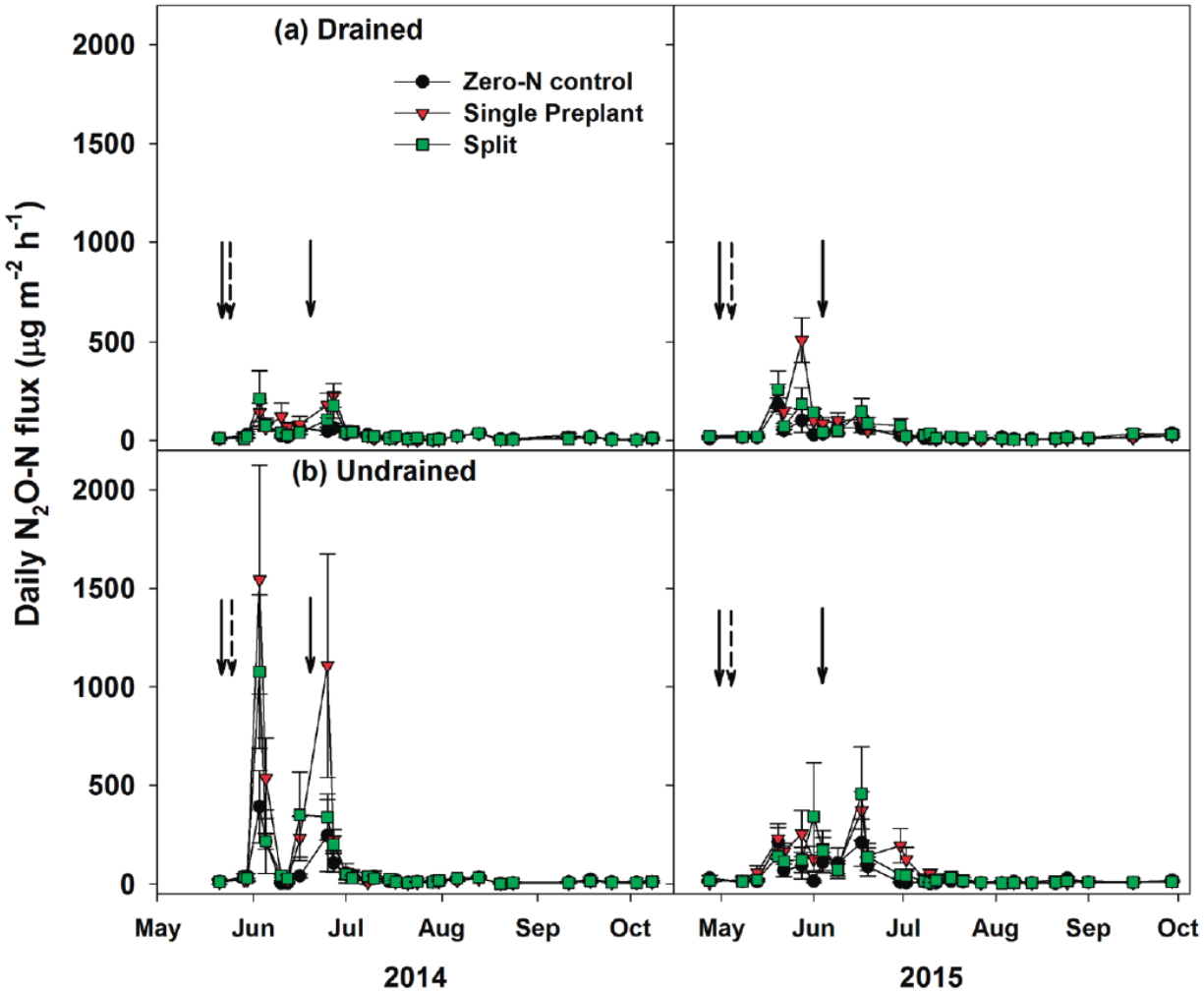


Source: Awale & Chatterjee (2016) Agron. J. 109:1-11

Denitrification-How does it controlled?

- Temperature- Denitrification is most rapid at temperatures between 80° and 100° F.
- Soil Wetness- triggers denitrification. Nitrogen gases can begin to appear as soon as 15 minutes after saturation. At higher moisture N_2 tends to be major product than N_2O.

Drainage and N management influences nitrous oxide emissions



Location: Wells, MN, silty clay loam, tile spacing-30 ft, tile depth 4ft, corn-soybean, preplant-120 lb N/ac, split-40 lb N/ac at planting and 80 lb N/ac with NBPT at V4

	Corn yield	N_2O-N kg/ha
Year	Bu/ac	
2014	170	1.84
2015	176	1.82
Drainage		
Drained(D)	184^{A}	1.29^{B}
Undrained (UD)	160^{B}	2.36^{A}
N mgmt.		
Control	138^{B}	1.17^{C}
Pre-plant	195^{A}	2.48^{A}
Split	186^{A}	1.84^{B}

Source: Fernandez et al. 2016. Corn nitrogen management influences nitrous oxide emissions in drained and undrained soils. JEQ 45:1847-1855

Denitrification-How does it controlled?

- Soluble organic carbon supplies energy for denitrifying bacteria
- Denitrification is enhanced in soils with a ready supply of organic carbon such as manure, compost, cover crops or crop residues
- Soils that go through a prolonged dry period followed by rainfall or irrigation typically have a burst of soluble carbon that can support a spike in denitrification
- Waterlogging also stimulates the release of soluble C into the soil that may support rapid denitrification

Rye Cover Crop Effects on N_2O emissions in Central Iowa

Soil type: silty clay loam and Nicollet loam; duration: 2004-13 rotation: corn-soybean

	Grain yield (Bu/ac)		kg N_2O-N ha^{-1} yr^{-1}	
	Rye	No rye	Rye	No rye
Corn	199	201	7.80	7.22
Soybean	45.0	47.1	4.42	3.66

Source: Parkin et al. 2016. Rye cover crop effects on direct and indirect nitrous oxide emissions, Soil Sci. Soc. Am. J. 80:1551-1559

Fertilizer and tillage management impact on denitrification

	Corn yield (Bu/ac)	N_2O-N kg ha^{-1} yr^{-1}
Conventional tillage	168	4.94^{ab}
No-till	165	3.79^{ab}
No-till, cover crop	138	5.02^{a}
No-till, split N	157	3.87^{ab}
Precision tillage*	155	2.38^{c}

Location: Lafayette, IN, Corn-Soybean, silt-loam, 2003-2007, *Kinze planters (martin row cleaners-keeton seed firmer-Martin spader wheels-dagger chain); Source: Smith et al. (2011). Soil Sci. Am. J. 75:1070-1082

Conclusion

- Denitrification loss of N occurs when soils have (i) high nitrate concentration, (ii) ready supply of carbon and (iii) water filled pore space above 60%
- Denitrification can be reduced with split application and/or with additions of nitrification inhibitors or slow-release N fertilizers
- No consistent effect of cover crop and tillage on denitrification

Questions?