Clarifying What Enhanced Efficiency Nitrogen Fertilizers Are

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Agvise Seminar
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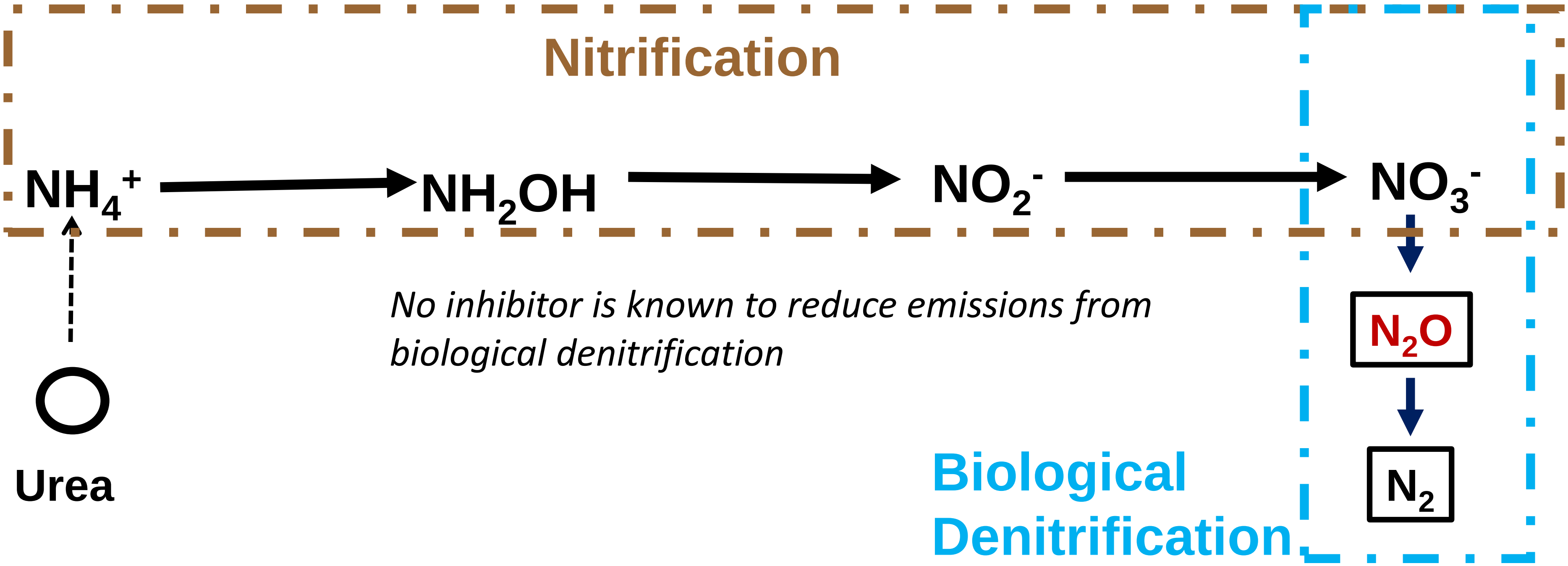
4R Senior Industrial Research Chair

University of Manitoba

Denitrification Producing Nitrous Oxide (N_2O)

Bacteria in soil do nitrification and denitrification

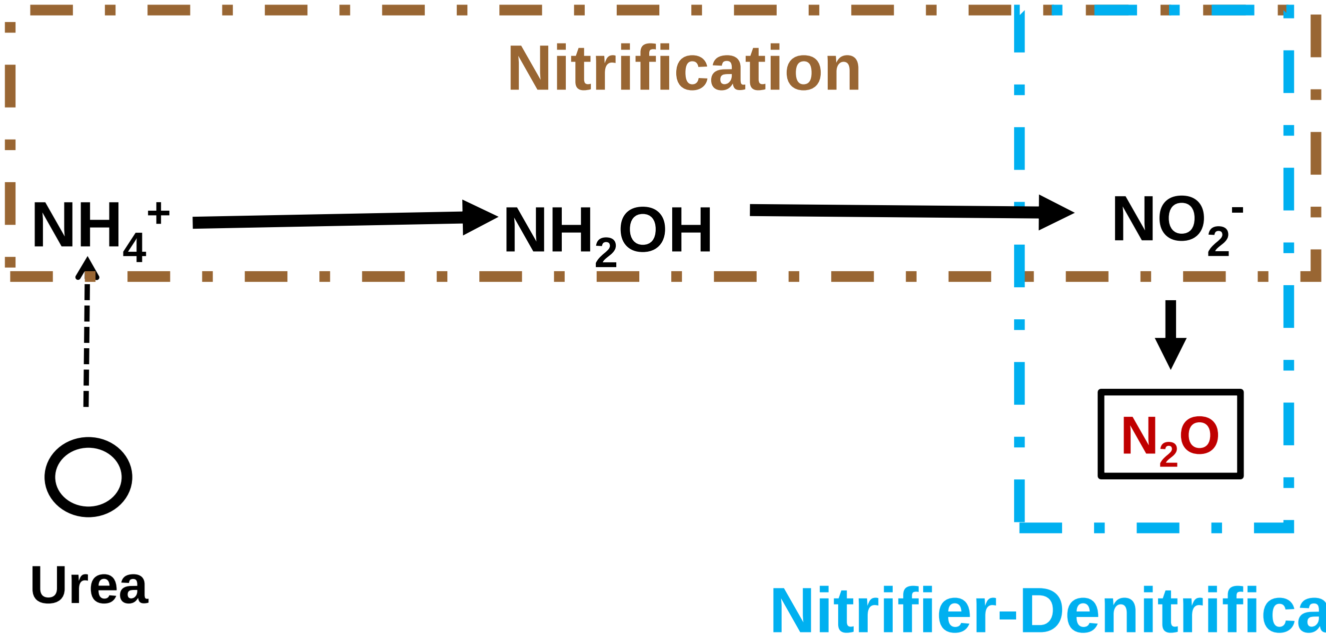


No inhibitor is known to reduce emissions from biological denitrification

In the Prairies, this process is the dominant source of N_2O emissions at thaw
Tenuta and Sparling (2010)

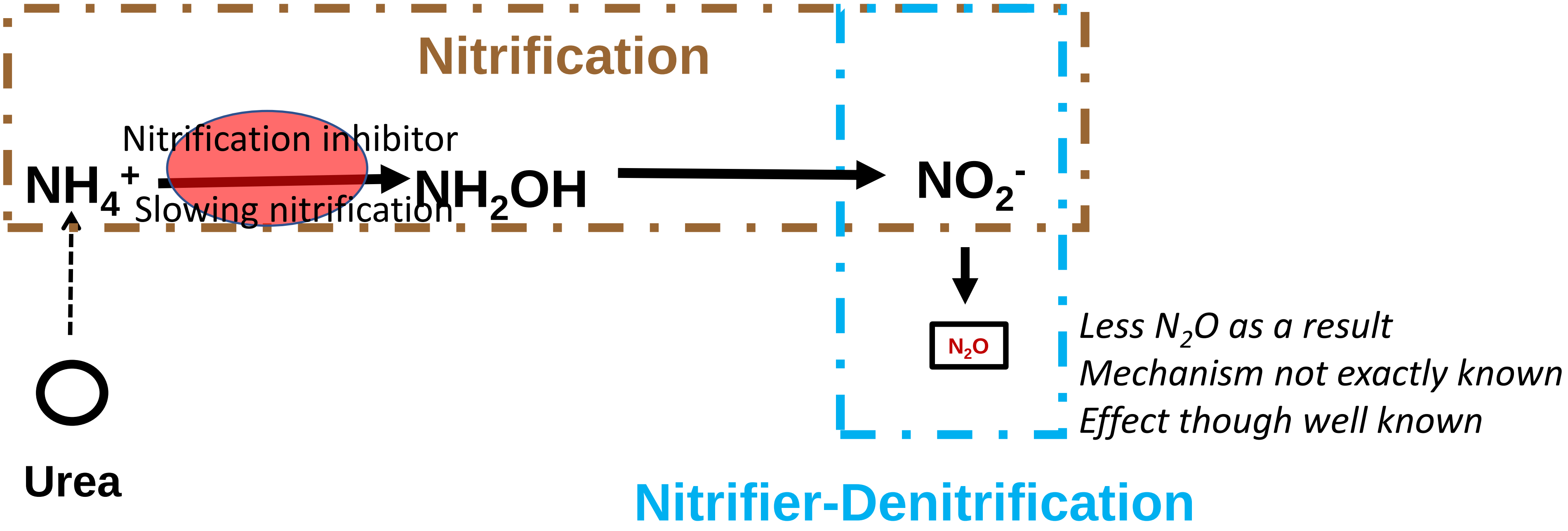
Nitrifier-Denitrification to Produce Nitrous Oxide (N_2O)

Nitrifying Bacteria nitrify ammonium to nitrite and then denitrify the nitrite to nitrous oxide under wet soil conditions (O_2 restriction)



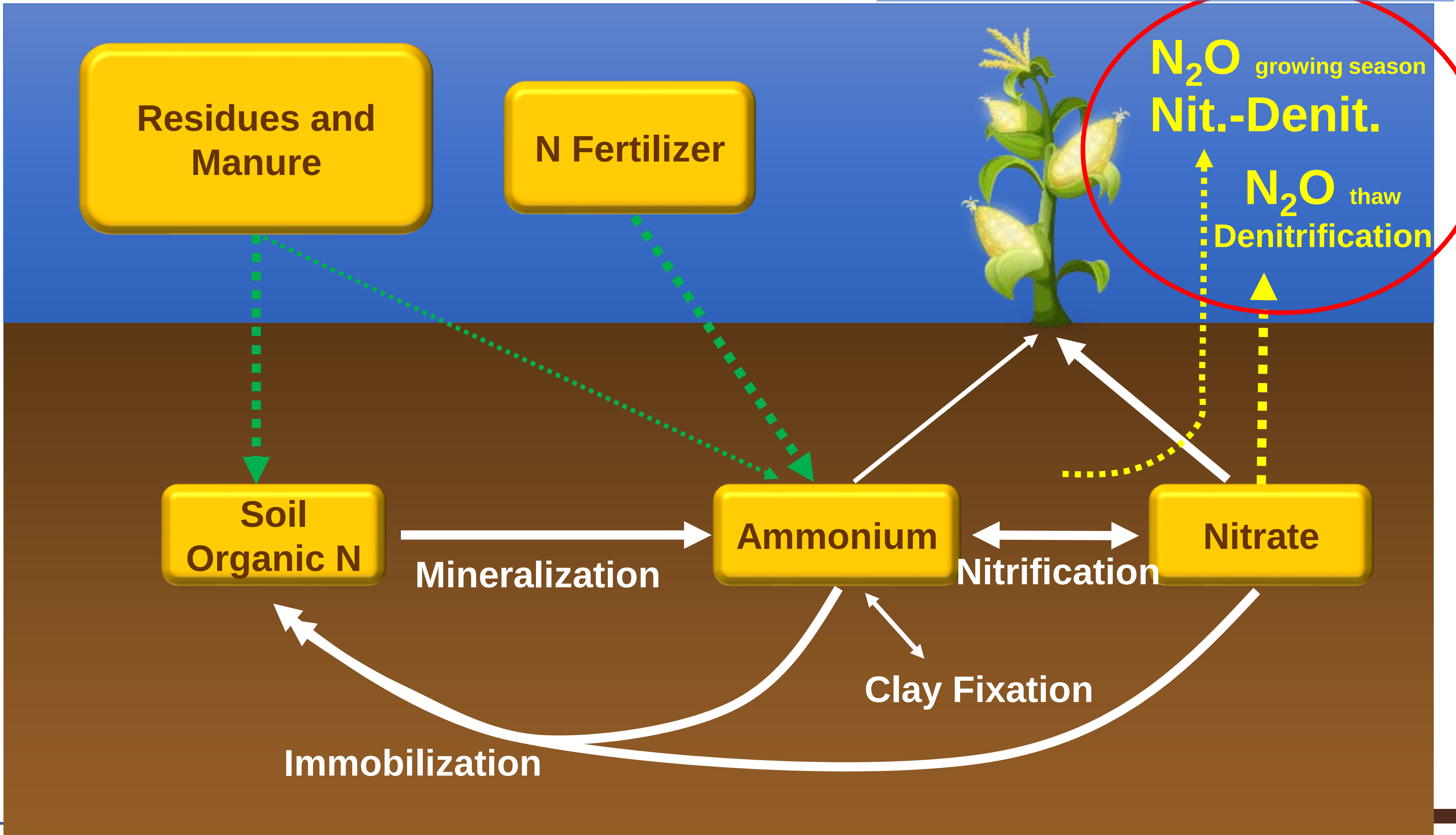
In the Prairies, this process is the dominant source of N_2O emissions other than at thaw (Runzika 2017, M.Sc. Thesis; multiple studies showing nitrification inhibitors reduce N_2O emissions from ammoniacal fertilizer N forms; Williamson (2011) Showing addition of ammoniacal fertilizer N but not nitrate at planting results in N_2O emissions)

Nitrifier-Denitrification to Produce Nitrous Oxide (N_2O)



Direct Emission of N_2O

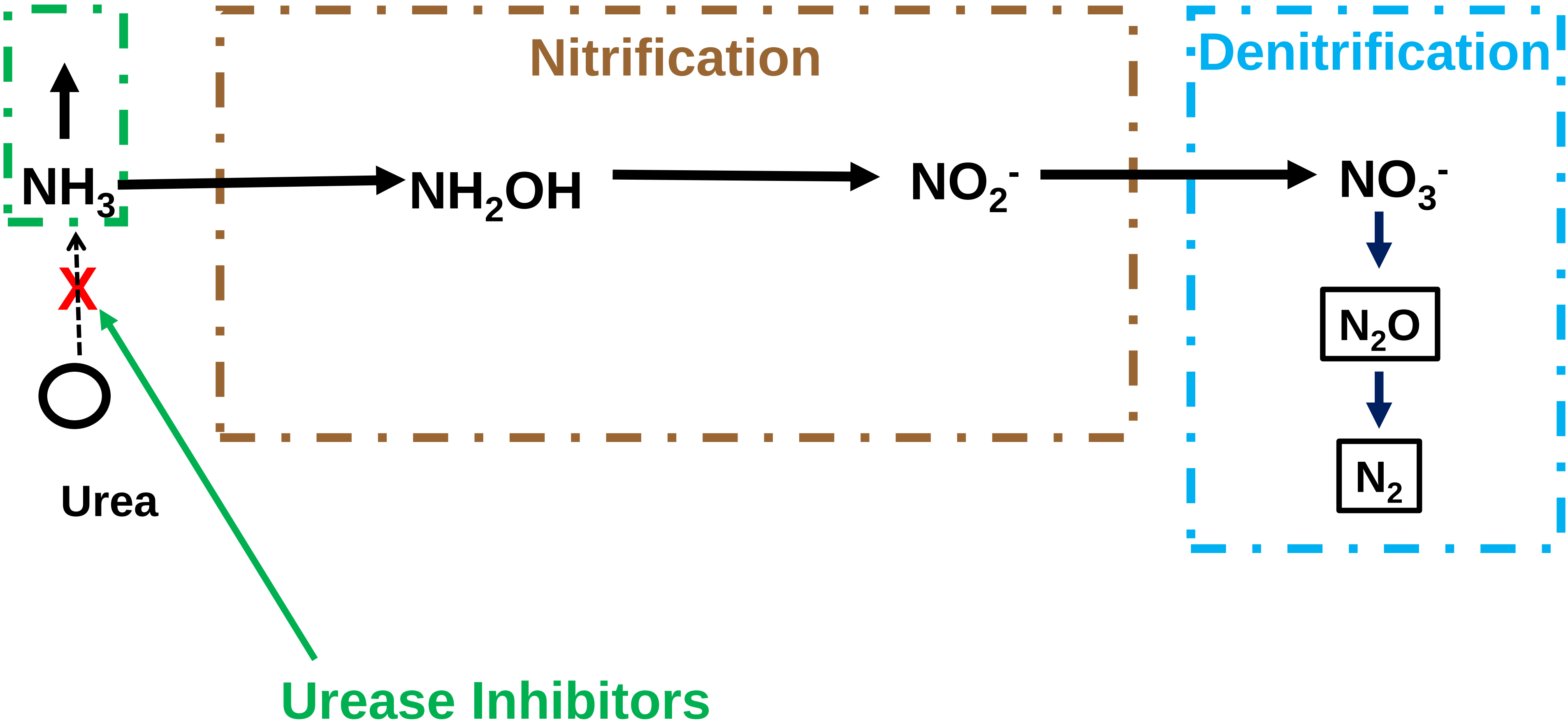
0.3 to 3% of fertilizer lost as Direct N_2O



Nitrification inhibitors reliably decrease N_2O emissions from ammoniacal sources of N because Direct Nitrifier-Denitrification emissions are reduced

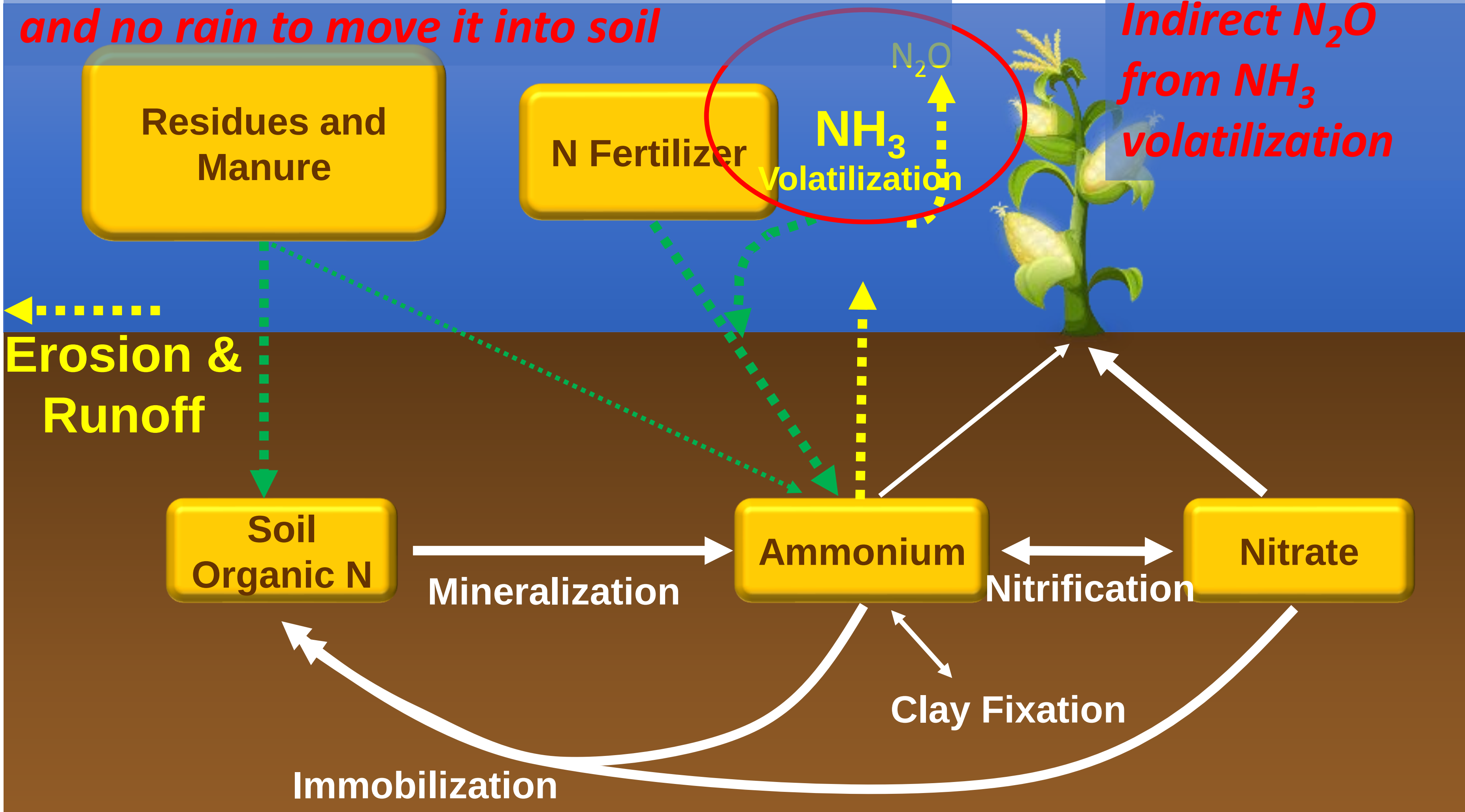
Urease Inhibitors

Reduces NH_3 Volatilization when urea remains at the soil surface



up to 20% fertilizer lost as NH_3 if urea left at surface and no rain to move it into soil

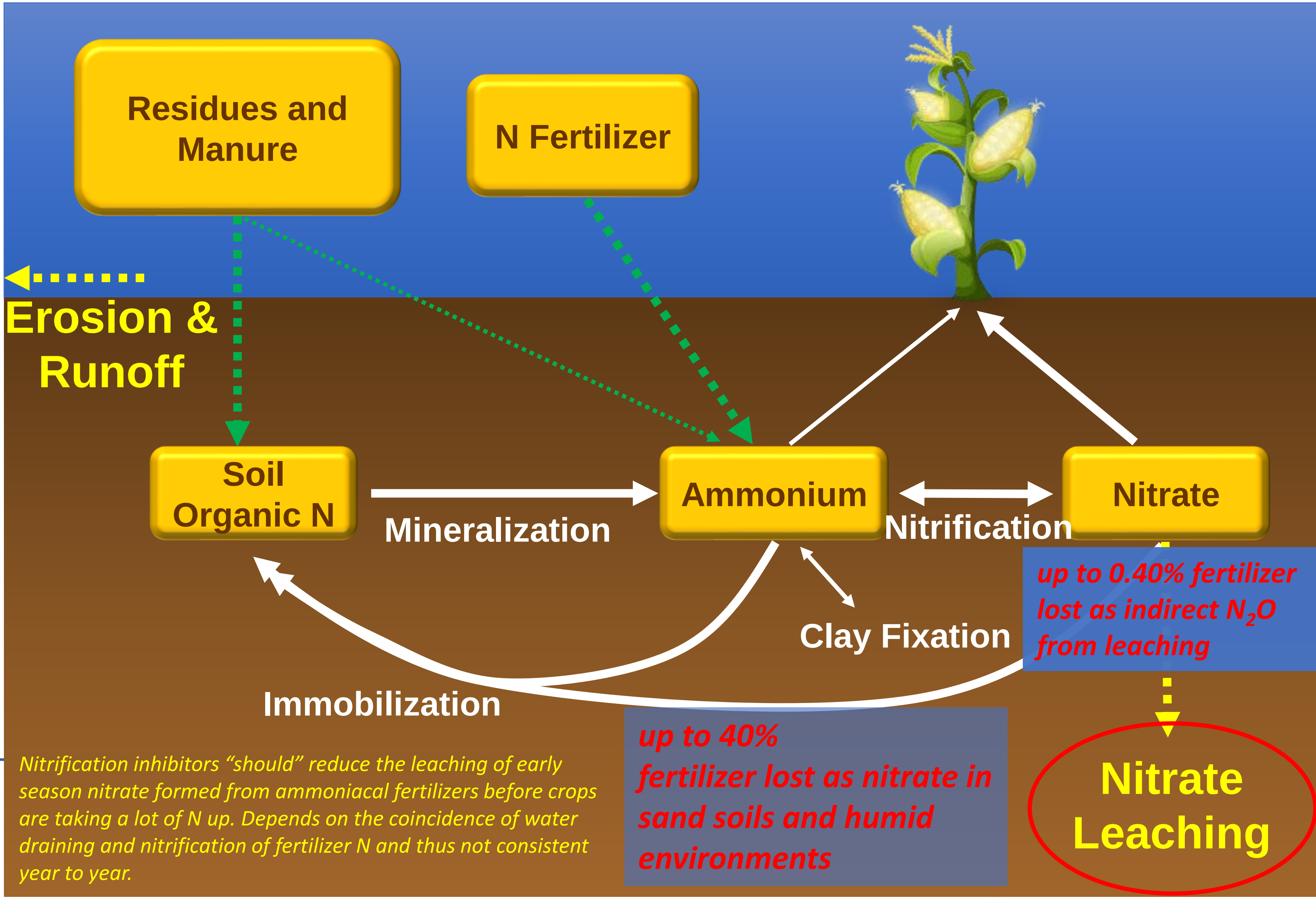
up to 0.2% fertilizer lost as Indirect N_2O from NH_3 volatilization



Indirect Losses of N_2O - Ammonia

Urease inhibitors reliably decrease NH_3 Losses from urea and thus lower indirect N_2O emissions from NH_3 volatilization. However, not many studies have quantified NH_3 losses in the Prairies

Indirect Loss of N_2O – Nitrate Leaching



Enhanced Efficiency (EEF) N Fertilizers

- **N Stabilizers**
  - Urease inhibitor
  - Nitrification inhibitor
  - Double (urease and nitrification) inhibitor

- **Controlled Release N**
  - Polymer Coated Urea

- **Slow Release**
  - Sulfur-coated Urea, Methylene Urea, Isobuylidene Diurea, Urea Formaldehyde, Urea Triazone

Some N Stabilizers in the Market

Urease inhibitor

Nitrolizer N, NITRAIN 2.0, ECLIPSE-N Nitrogen Stabilizer 26.7%, ANVOL, AGROTAIN, N-YIELD CX Nitrogen Stabilizer, Limus Nitrogen Management, ARM U

Nitrification inhibitor

N-Serve Nitrogen Stabilizer, eNtrench Nitrogen Stabiliser, ECLIPSE-D Nitrification Inhibitor Nitrogen Stabilizer, ENTEC, N-BOUND Nitrogen Stabilizer, DRIVE-N For Anhydrous Ammonia, CENTURO

Double inhibitor

SUPERU, ARM U Advanced Intelligent Nitrogen Stabilizer, NEON AIR, AGROTAIN PLUS SC, TRIBUNE, N Protect

Nitrification Inhibitor Compounds

- N-serve (50+ years old) [N-Serve, eNtrench]
- DCD (60+ years old) [SuperU, Agrotain Plus]
- DMPP (15+ years) [ArmU Advanced, Entec]
- DMPSA (3+ years, not available here) [none]
- Pronitridine (just available) [Centuro]

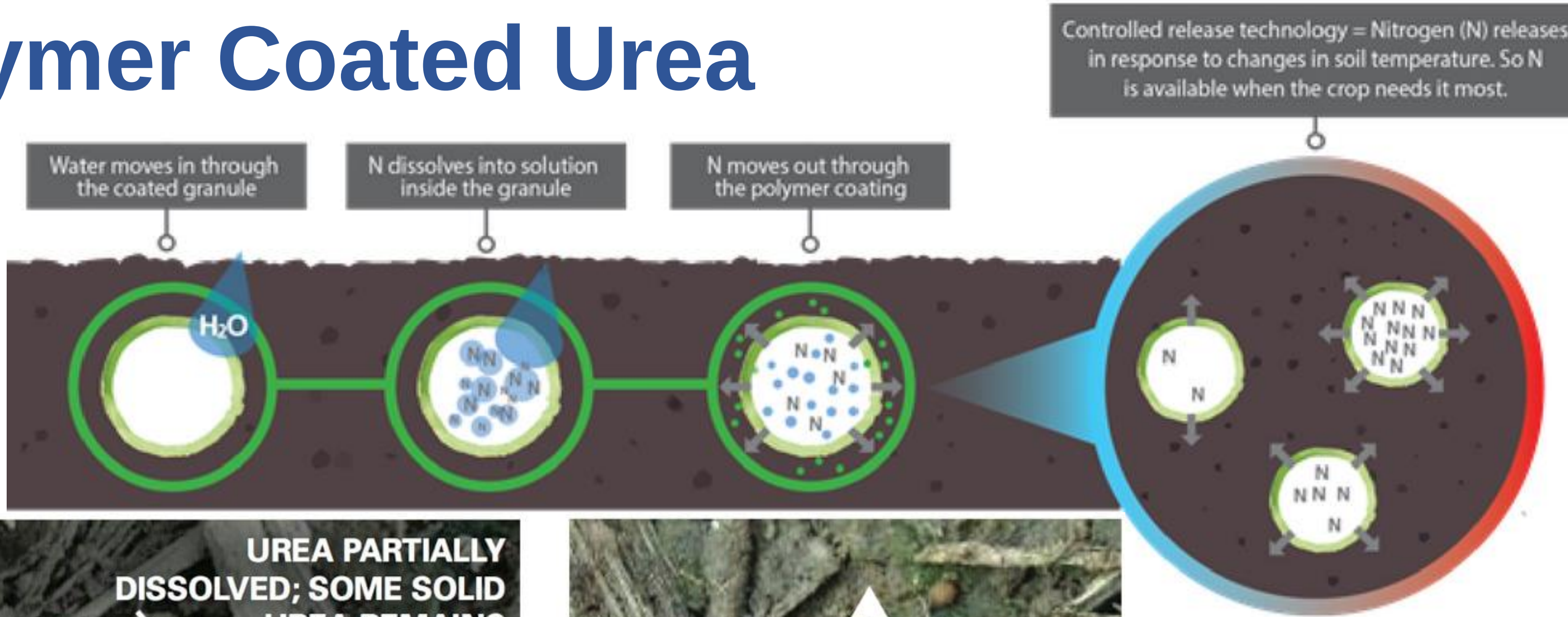
Urease Inhibitor Compounds

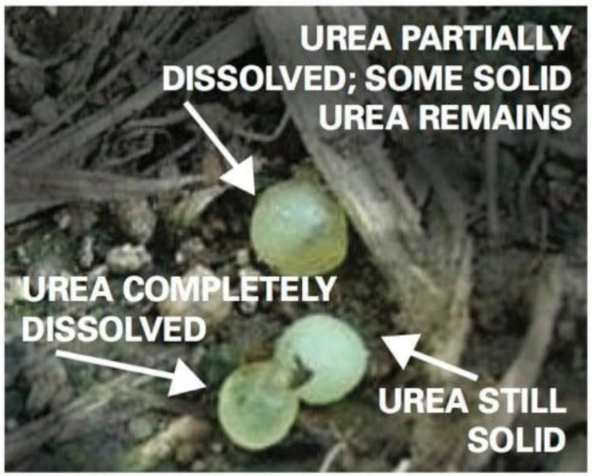
- NBPT (20+ years old) [Agrotain, eNtrench, Agrotain Plus]
- NPPT (5+ years) [Limus: not available here]
- Duromide (2+ years) [Anvol]

Polymer Coated Urea

- Polymeric resin coated fertilizer developed in 1960 by ADM Company – Osmocote and sold by Scotts Company
- Refined coating (Polyon) in 1991 by Purcell Technologies
- Developed for Hort industry
- ESN introduced for crops by Agrium 2003
- KOCH now holds patent for Polyon

Polymer Coated Urea





ESN SmartNitrog

PURYIELD
A PURSELL INNOVATION

- Blend 70 (polymer coated) : 30 (urea) ratio in RRV
- Place subsurface
- Place at planting or before
- Note ESN is 44% N and not 46% as urea is

- Provides good measure of urea seed safety

Many 4R Practices Significantly Reduce N_2O Emissions but Don't Change Yield

.

Management Practice	Site Years	N_2O Reduction %*	Yield Reduction %
Nitrification Inhibitors	22	32	1
Polymer Coated Urea (ESN)	21	27	increase 2
Deep Banding	16	3	1
N Fixing Legumes	15	61	NA
Split N Application	13	48	increase 3
Fall Application	7	increase 36	increase 1
Shallow Banding	6	increase 89	5
Cover Crops	4	1	
Organic Production	2	17	32

Summary of Field Studies by the 4R Chair Program from 2010-2021

Tenuta et al. 2023 Agron J (Canola)

Table 5. Growing season cumulative N_2O emissions (ΣN_2O_{GS}) as influenced by fertilizer treatments for the six site-years of this study. Urea$_{BI}$: broadcast-incorporated urea; Urea$_{SB}$: shallow-banded urea; Urea$_{DB}$: deep-banded urea; SuperU$_{BI}$: broadcast-incorporated SuperU; SuperU$_{SB}$: shallow-banded SuperU; SuperU$_{DB}$: deep-banded SuperU. Values are means ± 1 standard error and numbers of observations (n) are indicated.

Treatments/Groups	ΣN_2O_{GS} (kg N ha^{-1})					
	Carman-2014	Kelburn-2014	Carman-2015	Oak Bluff-2015	Brunkild-2016	Domain-2016
Treatments						
Control (n=16)	0.12±0.02 d	0.14±0.03 d	0.28±0.05 c	0.05±0.01 c	0.06±0.02 d	0.08±0.03 c
Urea$_{BI}$ (n=16)	1.36±0.30 a	0.56±0.18 abc	1.18±0.32 bc	0.22±0.03 a	0.52±0.23 bc	0.67±0.16 b
Urea$_{SB}$ (n=16)	1.10±0.27 ab	0.72±0.18 a	3.72±0.85 a	0.19±0.03 ab	1.13±0.29 a	1.66±0.31 a
Urea$_{DB}$ (n=16)	0.93±0.18 abc	0.30±0.06 cd	1.57±0.55 b	0.16±0.04 ab	0.95±0.28 ab	1.32±0.25 a
SuperU$_{BI}$ (n=16)	0.80±0.13 bc	0.67±0.15 ab	0.87±0.13 bc	0.13±0.01 b	0.35±0.12 cd	0.55±0.13 bc
SuperU$_{SB}$ (n=16)	0.47±0.06 cd	0.56±0.12 abc	0.87±0.17 bc	0.14±0.03 b	0.66±0.15 abc	0.55±0.12 bc
SuperU$_{DB}$ (n=16)	0.44±0.05 cd	0.32±0.06 bcd	1.09±0.18 bc	0.13±0.02 b	0.66±0.17 abc	0.68±0.10 b
Groups						
N additions (n=96)	0.85±0.08	0.52±0.06	1.55±0.21	0.16±0.01	0.71±0.09	0.90±0.09
Urea (n=48)	1.13±0.15	0.53±0.09	2.16±0.38	0.19±0.02	0.87±0.16	1.22±0.15
SuperU (n=48)	0.57±0.06	0.52±0.07	0.94±0.09	0.13±0.01	0.56±0.09	0.59±0.07
BI (n=32)	1.08±0.17	0.61±0.11	1.03±0.17	0.17±0.02	0.44±0.13	0.61±0.10
Banded (n=64)	0.74±0.09	0.48±0.06	1.81±0.29	0.16±0.02	0.85±0.12	1.05±0.12
SB (n=32)	0.78±0.15	0.64±0.11	2.30±0.50	0.17±0.02	0.90±0.17	1.10±0.19
DB (n=32)	0.69±0.10	0.31±0.04	1.33±0.29	0.15±0.02	0.80±0.16	1.00±0.14
Contrasts						
Control vs. Others	<0.001	0.005	0.006	<0.001	0.003	<0.001
Urea vs. SuperU	<0.001	0.931	<0.001	0.013	0.065	<0.001
BI vs. Banded	0.028	0.209	0.031	0.433	0.020	0.006
BI vs. SB	0.100	0.816	0.003	0.735	0.025	0.007
BI vs. DB	0.030	0.017	0.465	0.308	0.073	0.034

Means within a column followed by the same lowercase letter are not significantly different at $P < 0.05$.

Urea incorporated

Urea shall banded

SuperU placements

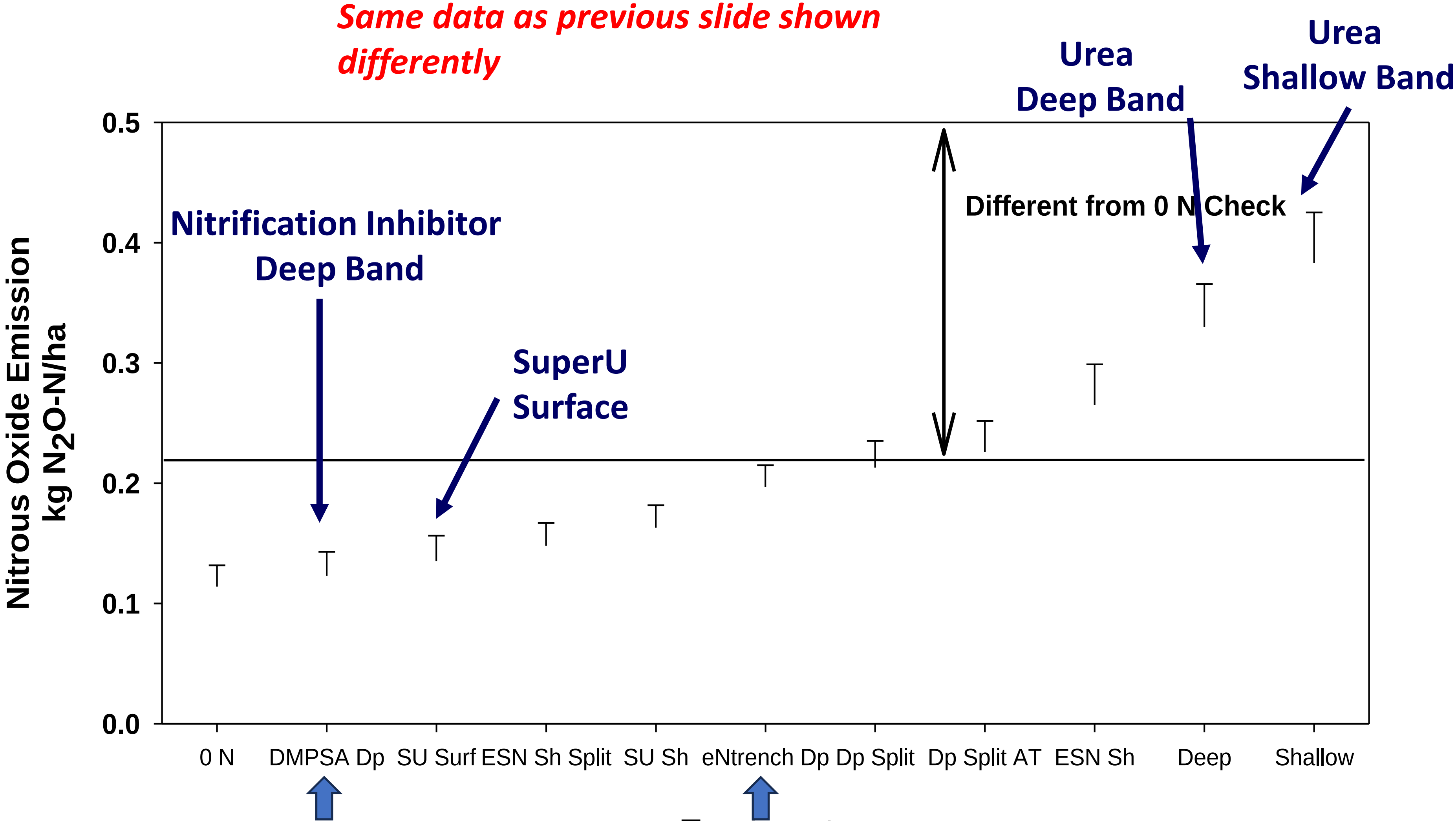
BI is deep thorough incorporation to 15 cm by roto-tilling
SB is shallow mid-row banded 10 cm from every second seed row and at 2.5 cm depth
DB is deep mid-row banded 10 cm from every second seed row and at a 7 cm depth

- Carman 2014 is sandy clay loam, Kelburn is clay, Carman 2015 is fine sand, Oak Bluff is clay, Brunkild is clay and Domain is clay

Evidence for Dual Inhibitor decreasing N_2O emissions regardless of placement method

Nitrification Inhibition Reduces N_2O (Canola)

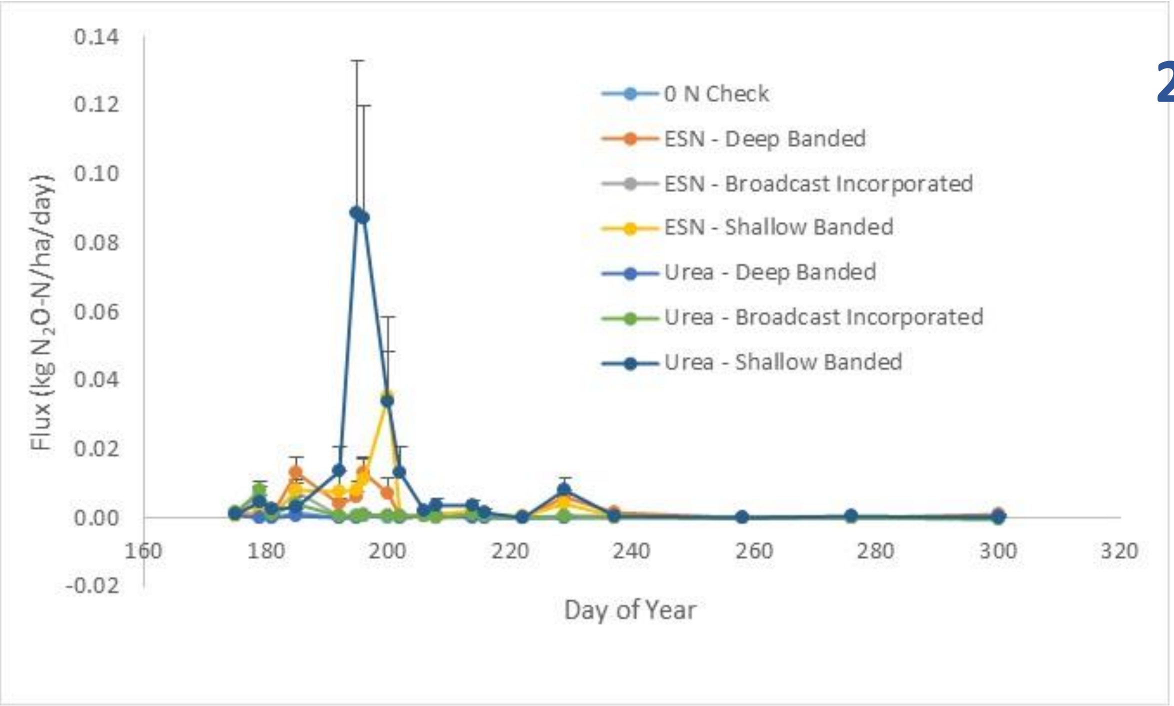
Same data as previous slide shown differently



Six Farm Trials with Canola

Tenuta et al. 2023. in preparation

Tenuta et al. 2 in prep (Canola)



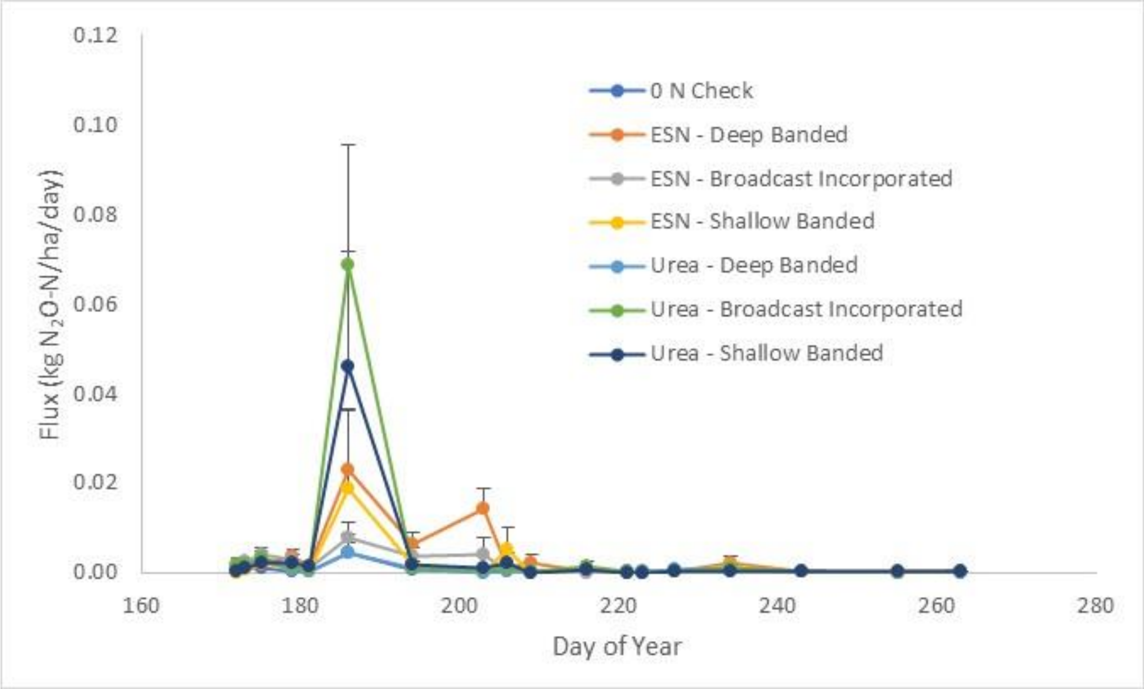
2022 Roseisle - Sandy

Evidence a single NI just as good if not better than subsurface band placement of Dual Inhibitor to decrease N_2O emissions

Mid-row banded 10 cm away from every second seed row and to a 4 cm depth

Emissions are whole year

Tenuta et al. 2 in prep (Canola)



2022 Glenlea - Clay

Evidence a single NI just as good if not better than subsurface band placement of Dual Inhibitor to decrease N_2O emissions

Mid-row banded 10 cm away from every second seed row and to a 4 cm depth

Emissions are whole year

Wood et al. Agron J (HRSW)

- Warren is clay loam, Glenlea is clay, Carman is clay loam, LaSalle is clay, Kelburn is clay and Ridge is loamy fine sand
- All fields except Kelburn are farmer fields. Kelburn is Richardson research farm
- Ridge 2017 had a dry post-planting period with low emissions
- ESN is a 70/30 ESN/granular urea blend
- Each mean of an N source treatment is the average of replicated fall and spring treatment plots (thus mean of 8 replicate plots per N source treatment)
- Single nitrification inhibitor (eNtrench) worked just as well as a double inhibitor product (SuperU)

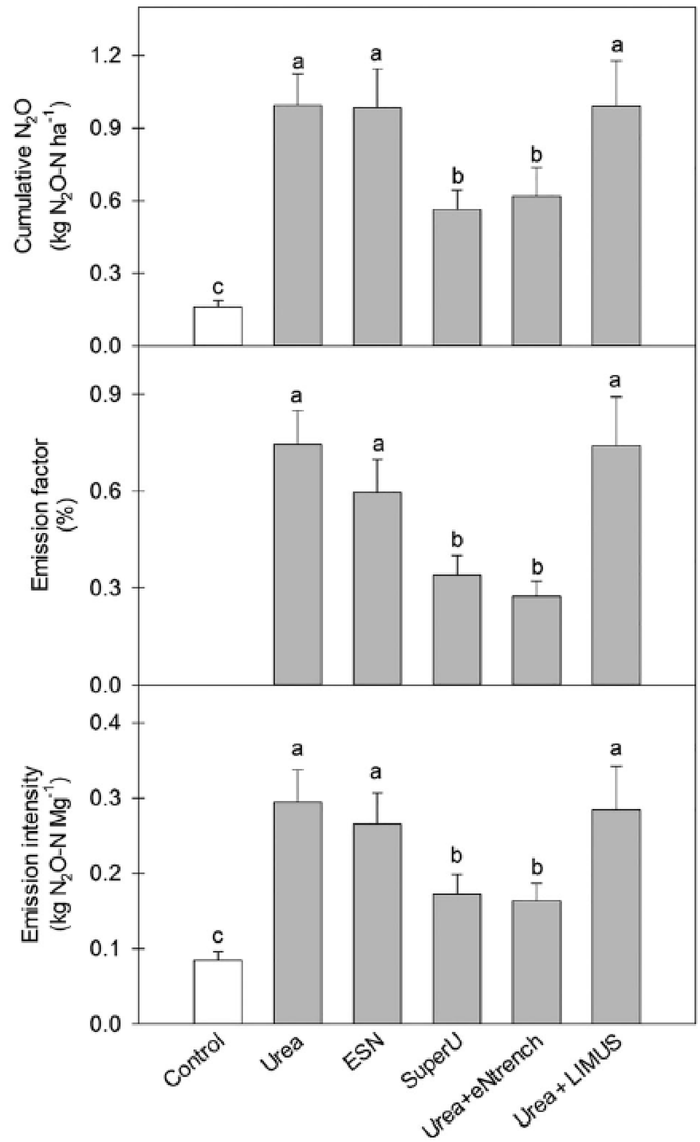


FIGURE 7 Mean cumulative N_2O emissions, applied-N scaled emission factor, and yield-scaled emission intensity of fertilizer treatments across fall and spring applications at all site-years. Different lowercase letters on the bar indicated significant differences at $p < 0.05$. Means +1 standard error are presented ($n = 48$). eNtrench, nitrification inhibitor; ESN, environmentally smart nitrogen; LIMUS, urease inhibitor; SuperU, nitrification and urease inhibitor.

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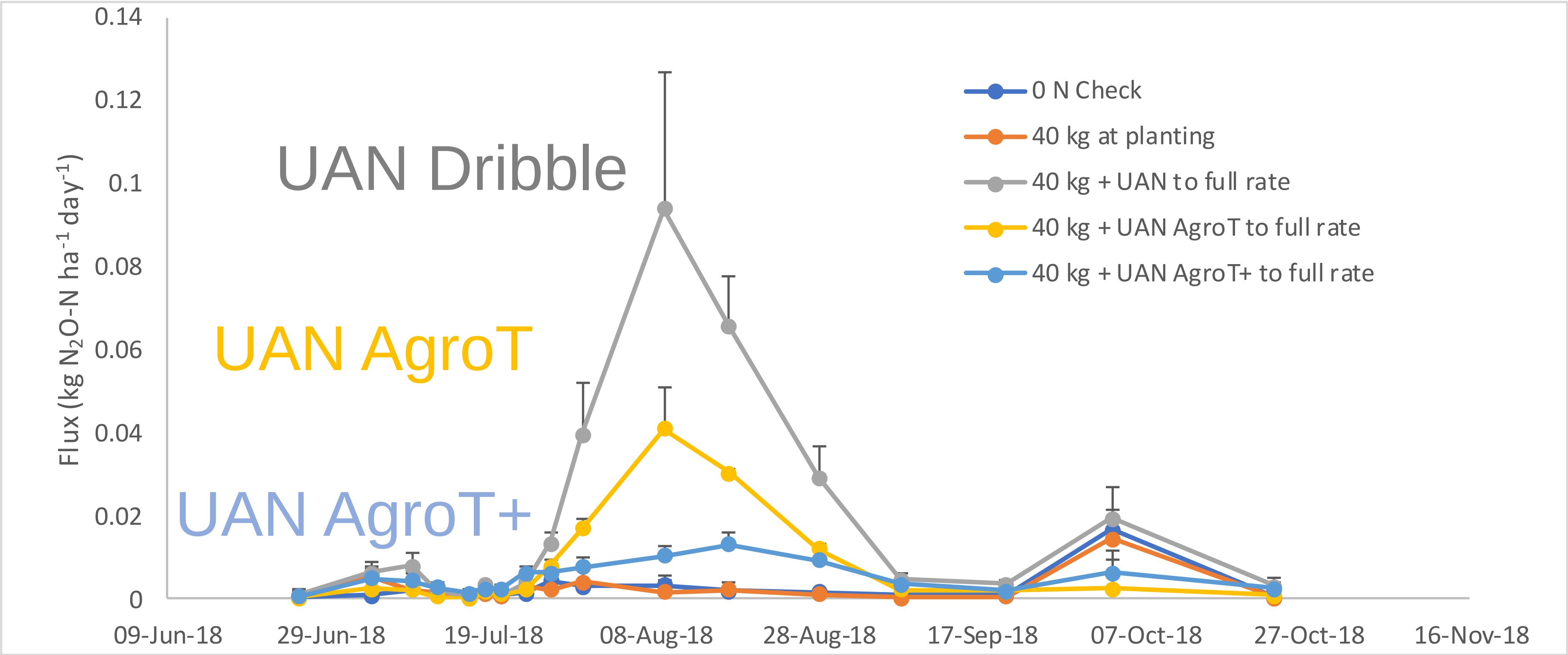
In-season UAN Dribble- Nitrous Oxide Losses (Canola)



Tenuta et al. in preparation

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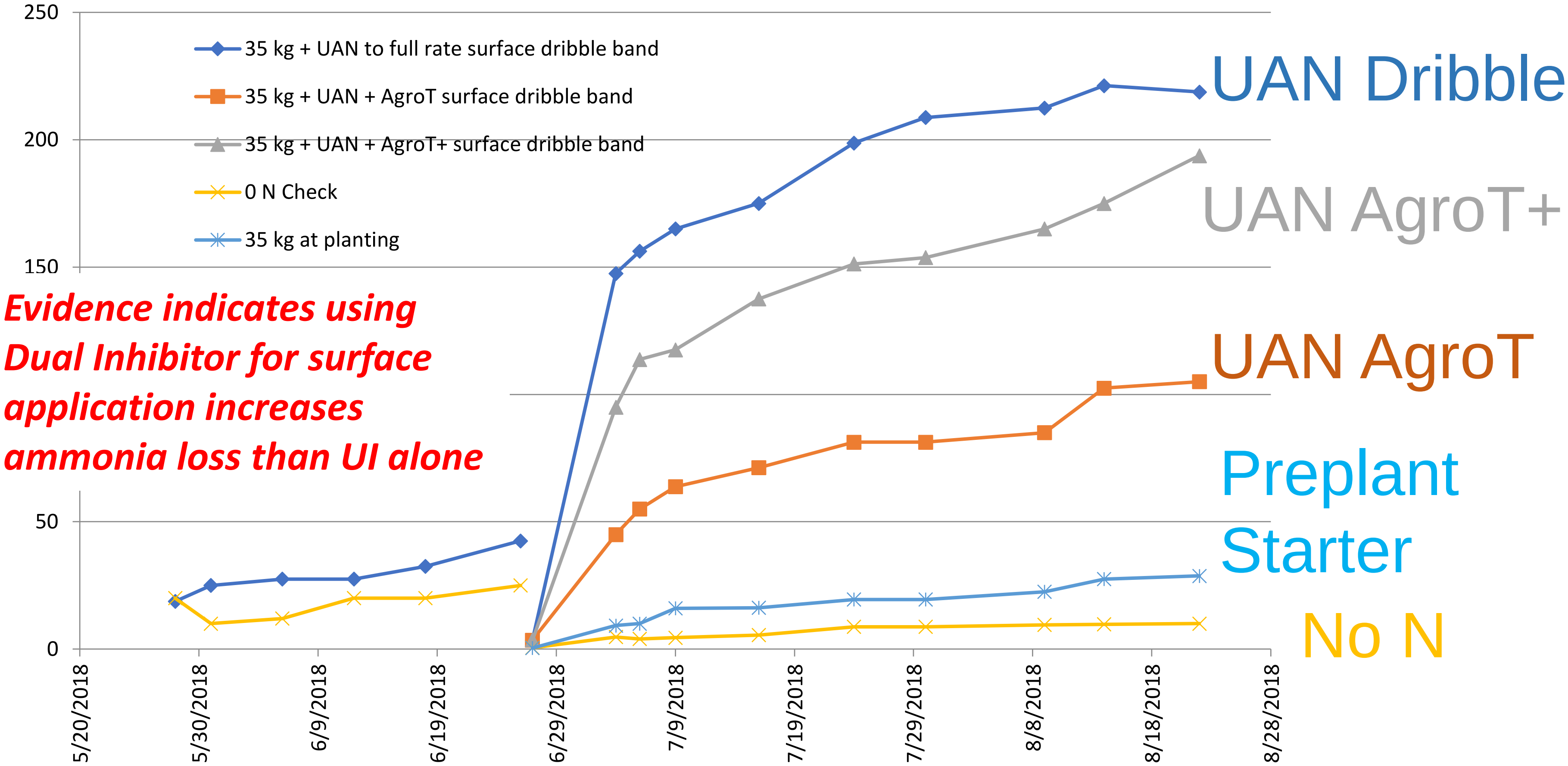
In-season UAN Dribble- Ammonia Losses (Manitoba) – Carman 2018 Corn

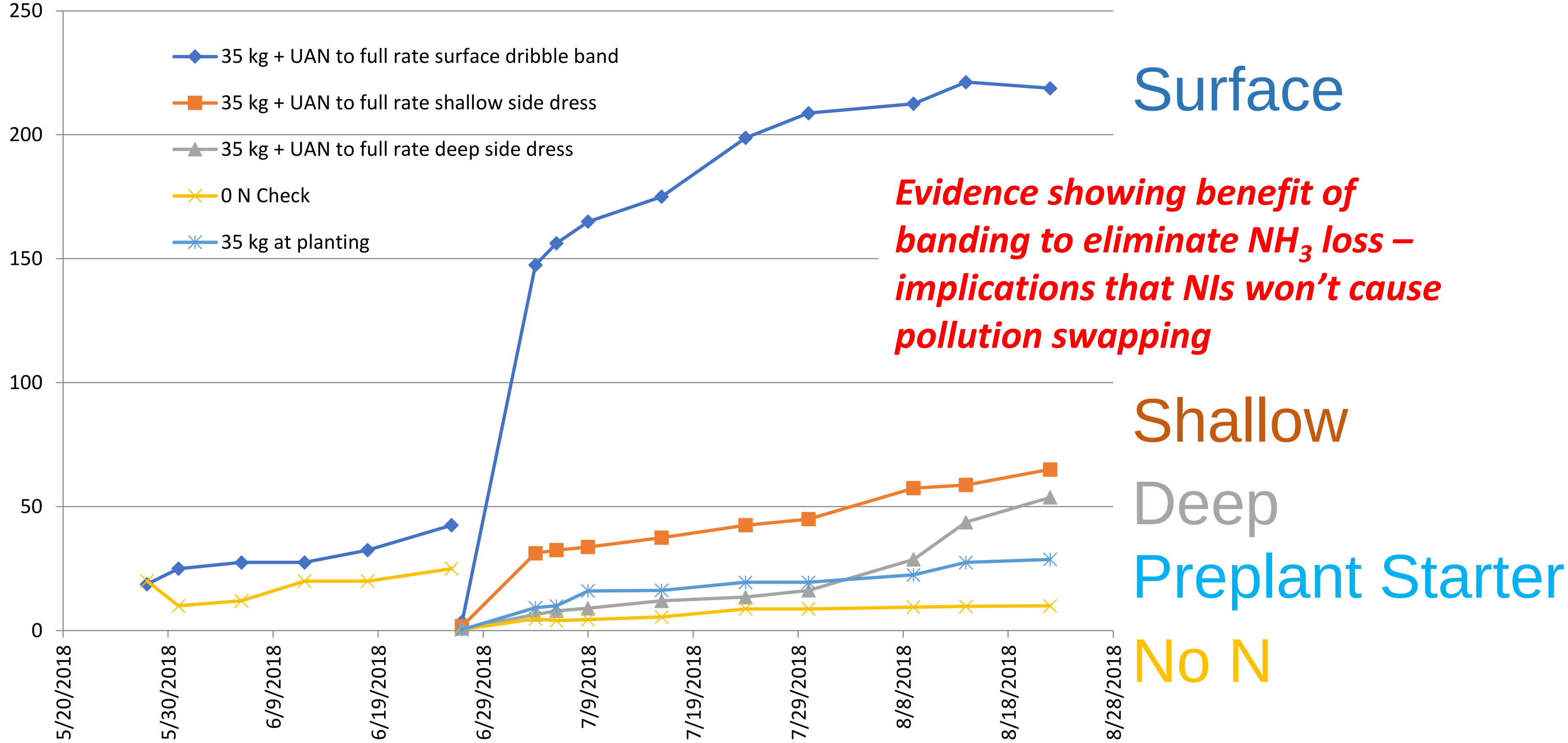
Tenuta et al. *in preparation*

An example of qualitative emissions of NH_3 using passive denuders and single urease inhibitor and double urease and nitrification inhibitor



- Urease inhibitor alone worked best to reduce ammonia volatilization of top-dress UAN dribbled at V4 stage
- No trend for "pollution swapping" (i.e., urease inhibitor reduced NH_3 loss but increased N_2O emissions) from Tenuta et al. *2023* and Tenuta et al. in prep

In-season UAN Dressing- Ammonia Losses (Manitoba)



- Subsurface placement works well to reduce volatilization losses

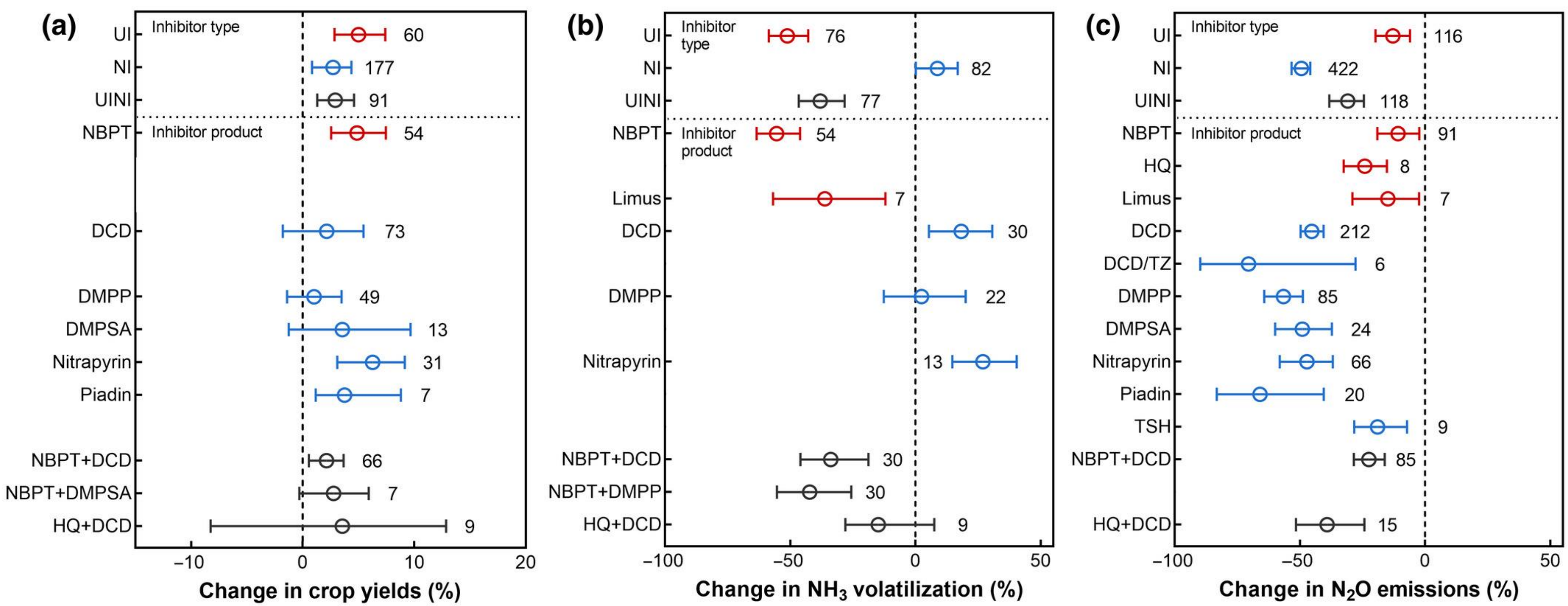
Tenuta et al. 2023 *in preparation*

Nitrification Inhibitors Work to Slow Nitrification but Yield Benefit not Clear

- Don’t know how to do field trials
- We do see inhibitors reduce nitrate appearance during the 2-3 weeks after application – *so they work as intended*
- We have a plethora of data showing nitrification inhibitors work to reduce N_2O emissions – *so they do work to inhibit nitrification*

Nitrification Inhibitors Haven’t had big Effect on Yields Elsewhere

- Global meta-analysis of studies showed nitrification inhibitors to increase yield about 2.5%
- Statistical effect of treatment to increase yield 2.5% in a study is very difficult



Fan et al. 2022 Global Change Biology

Break Even Point (BEP) Analysis for Grain Corn

Paying for EEFs Requires More Yield, Less N Added, C Market Payment, or $ Incentives

Corn $7/bu
Assume rate 180 lb N/ac

Product	$/lb N	$/ac	bu BEP	lb N/ac BEP	Morden N$_2$O Credit $/CO$_2$tonne BEP	Windsor N$_2$O Credit $/CO$_2$tonne BEP
Urea (46-0-0)	1.41	254		180		
Urease Urea (46-0-0)	1.49	268	2	170	NA	NA
Double Inhibitor Urea (46-0-0)	1.54	277	3	165	300	50
Polymer Coated Urea (44-0-0)	1.61	290	5	158	600	NA

30% N Reductions is 126 lb N/ac

Tenuta, M. current analysis

OFCAF Program
$75,000 to Dual Inhibitors and PCU

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We Haven't Used Nitrification Inhibitors in High N Loss Conditions

- For yield to increase, N losses must limit productivity
- We have been using the products for fall, spring and in-season application
- Fall application do see reduced N availability but nitrification inhibitors have not protected N sufficiently long – more studies needed
- Haven't had high enough moisture conditions following planting to leach applied N where benefit of nitrification inhibitors would be seen

How to Use?

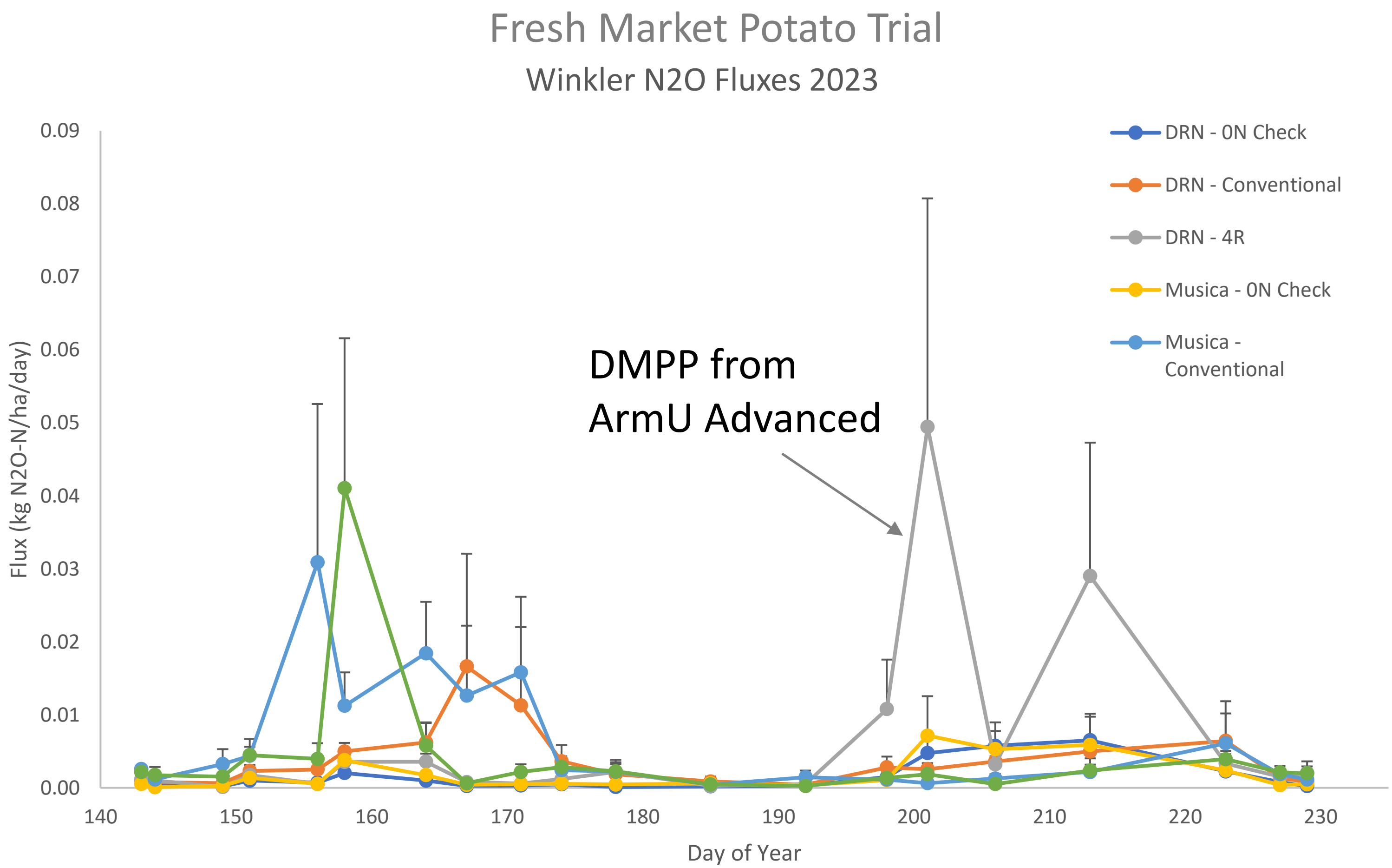
- For urea remaining at the soil surface, use a single urease inhibitor
- Subsurface band place N fertilizers 3” or more deep
- Use single nitrification inhibitor when N fertilizers are subsurface placed (incorporated or banded)
- Doesn’t hurt to use dual inhibitor when N fertilizers are subsurfaced placed (may be benefit of urease inhibitor with urea for seed safety)
- There is an advantage of dual inhibitor products treated in manufacturing – they flow better for application than dual inhibitor or single inhibitor treated at the retailer or on-farm
- Consider reducing N rates when using EEFs (10%)
- Break even for yield on EEF cost is 3-6 bu/acre

How to Use?

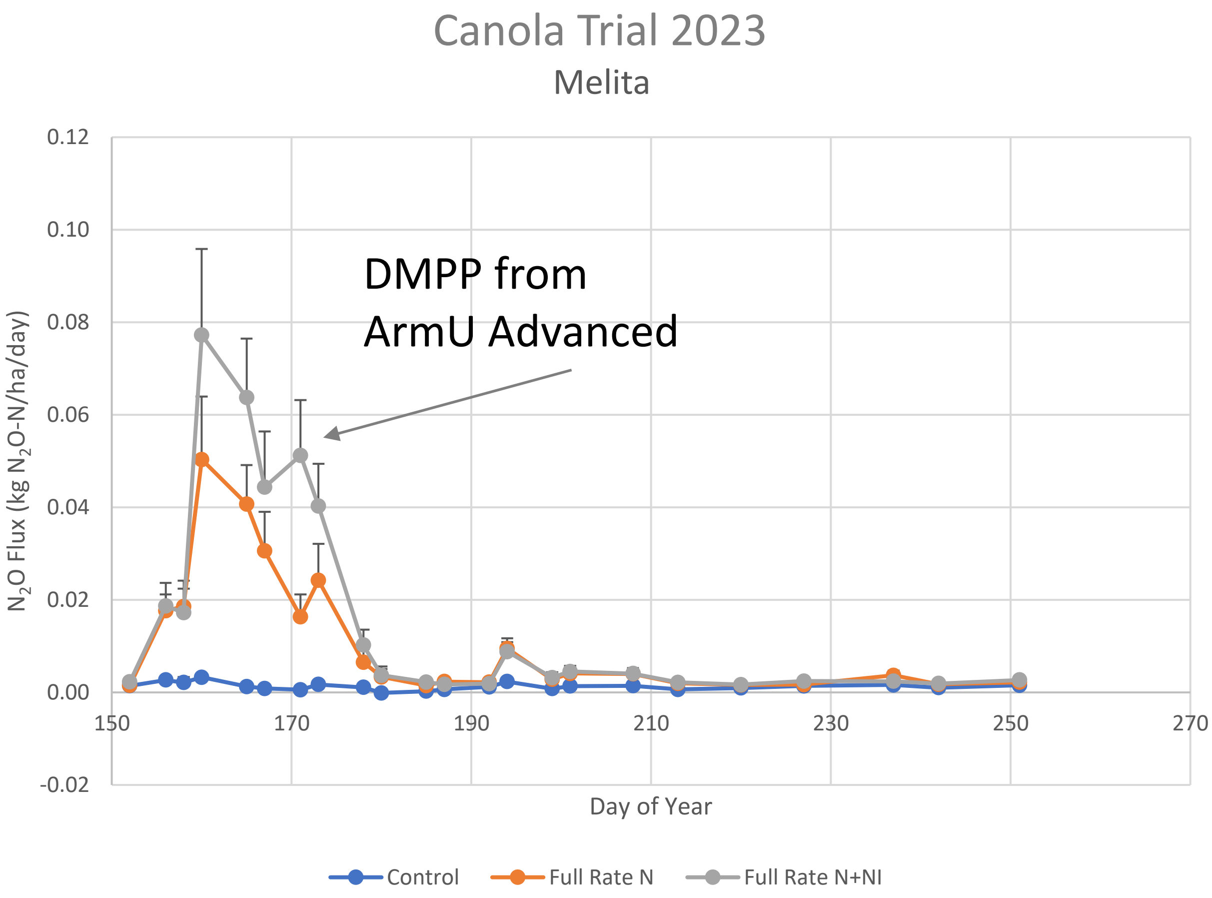
- PCU urea has increased seed safety
- PCU has increased convenience
- Don’t leave PCU at soil surface
- Blend PCU with urea
- Don’t use PCU mid-season

But

- Starting to examine newer nitrification products
- Performance of these not clear



DMPP from ArmU Advanced



Silverwinds (2020-21) Fall Applied Anhydrous

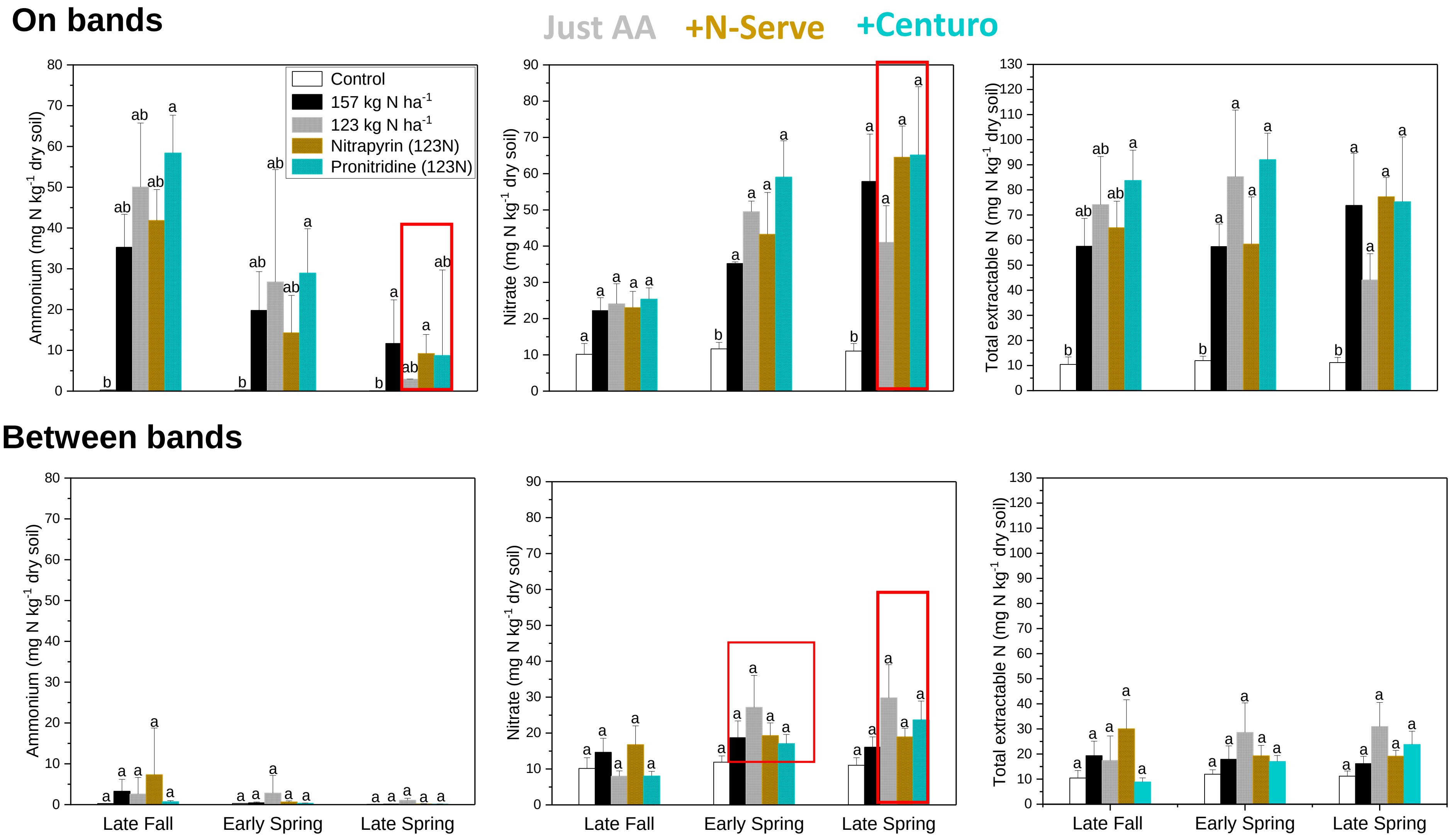
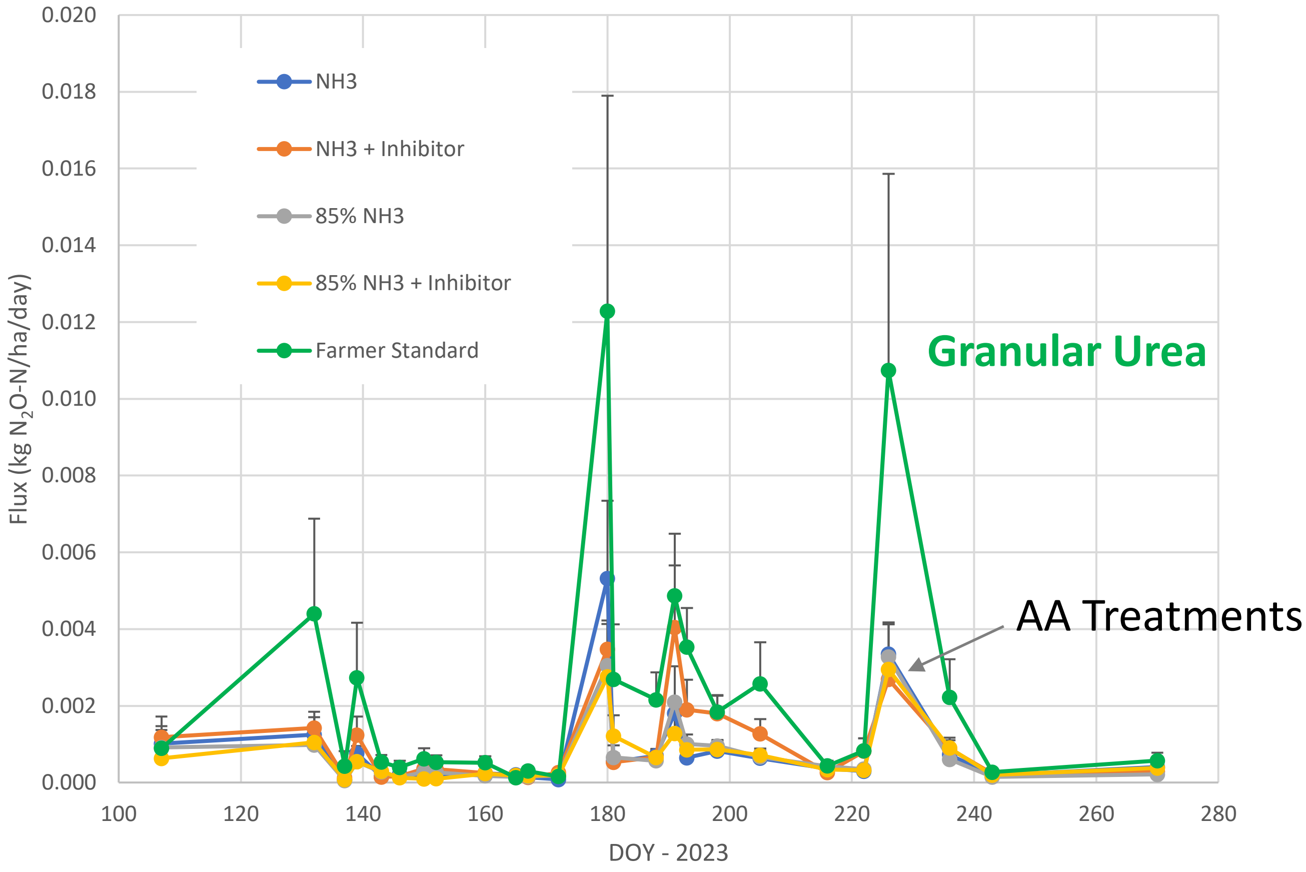


Fig. 1 Effect of nitrification inhibitors (N-Serve and Centuro) on soil (0-30 cm) ammonium (NH_4^+-N), nitrate (NO_3^--N), and total extractable nitrogen (NH_4^+-N + NO_3^--N) concentrations in the NH_3 banded and between the banded rows (15 cm away from the bands) on different sampling times at Silverwinds (2020-2021). Means with different letters within a sampling time are significantly different ($P < 0.05$) according to Tukey's multiple comparison procedure. Error bars indicate standard errors of the means (n=4). (Late Fall = Nov-07, Early Spring = Apr 27, Late Spring = May 12).

Fall AA with Centuro – Sperling Grain Corn



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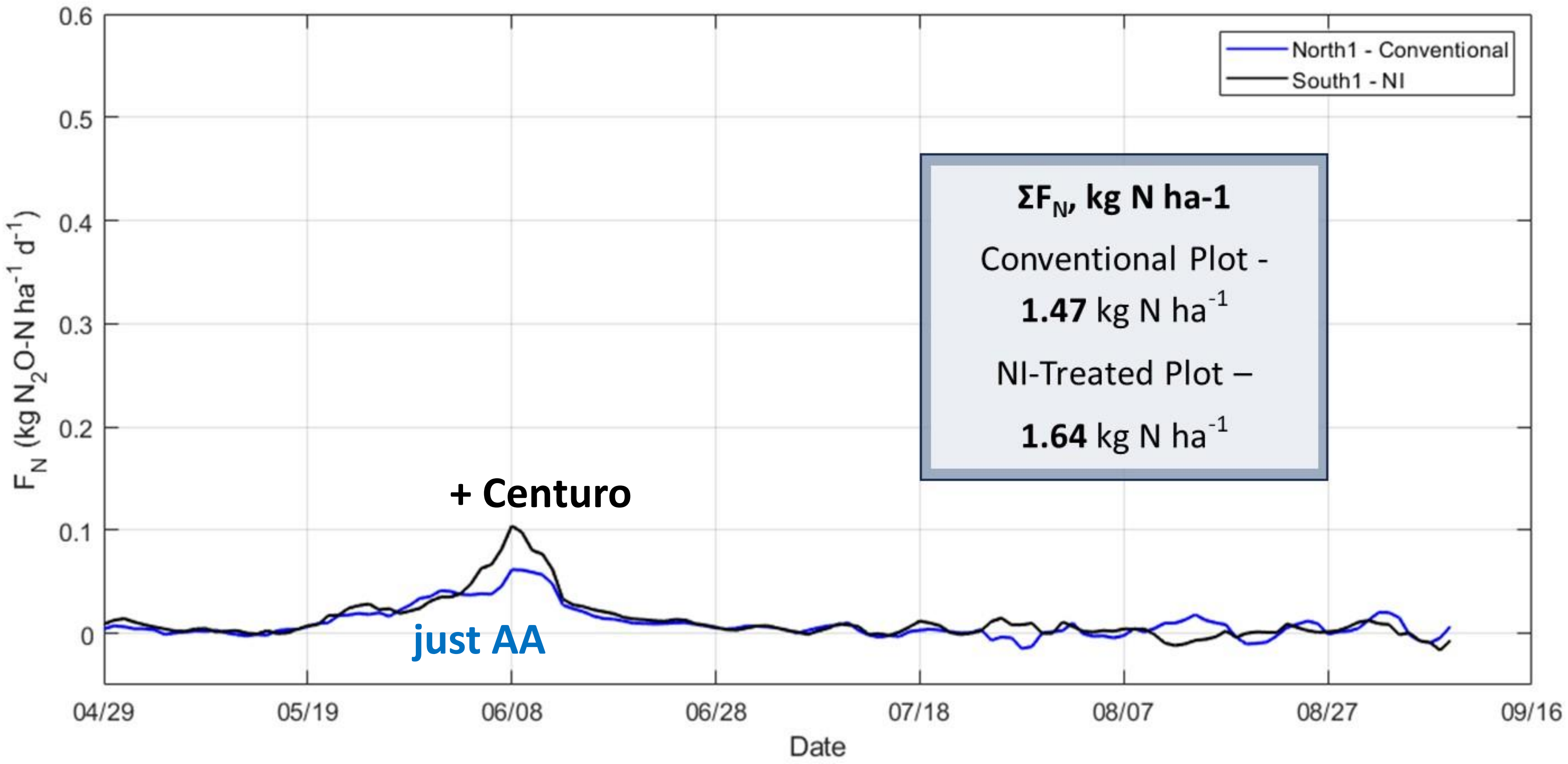
Spring Applied Centuro – Clearwater Grain Corn



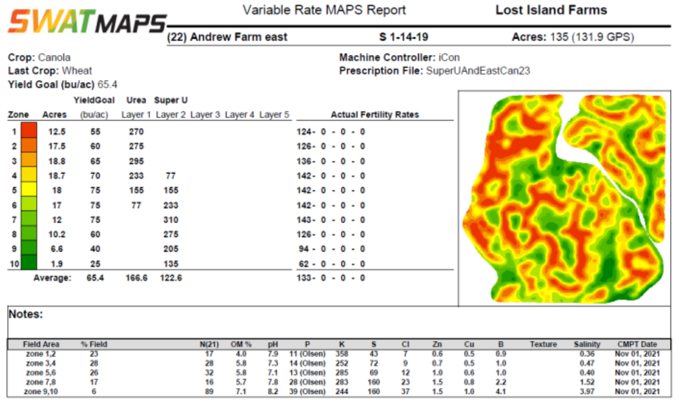
Why Are We Seeing Some Newer Products Not Working?

- I believe it comes down to concentration of the active nitrification inhibitor ingredient
- Concentrations of nitrification inhibitor can vary 50X between products on the market
- Inhibitors applied based on field area and not N rate are more likely to be successful in inhibiting nitrification

Precision 4R
Variable N Rate and Variable N Source

Field with Variable Topography

Identify N Management Zones and Prescription Map



SWATMAPS Variable Rate MAPS Report — Lost Island Farms

(22) Andrew Farm east — S 1-14-19 — Acres: 135 (131.9 GPS)

Crop: Canola
Last Crop: Wheat
Yield Goal (bu/ac) 65.4

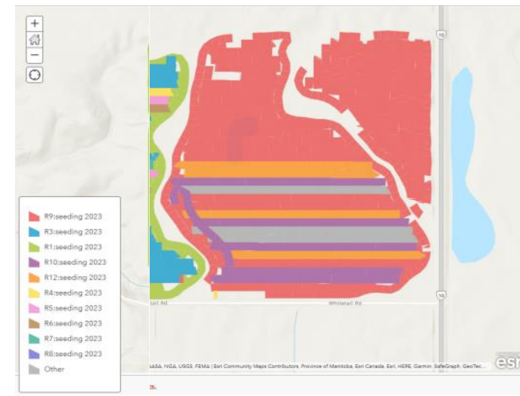
Machine Controller: iCon
Prescription File: SuperUAndEastCan23

Zone	Acres	YieldGoal (bu/ac)	Urea Layer 1	Super U Layer 2	Layer 3	Layer 4	Layer 5	Actual Fertility Rates
1	12.5	55	270					124- 0 - 0 - 0
2	17.5	60	275					126- 0 - 0 - 0
3	18.8	65	295					136- 0 - 0 - 0
4	18.7	70	233	77				142- 0 - 0 - 0
5	18	75	155	155				142- 0 - 0 - 0
6	17	75	77	233				142- 0 - 0 - 0
7	12	75		310				143- 0 - 0 - 0
8	10.2	60		275				126- 0 - 0 - 0
9	6.6	40		205				94 - 0 - 0 - 0
10	1.9	25		135				62 - 0 - 0 - 0
Average:		65.4	166.6	122.6				133- 0 - 0 - 0

Notes:

Field Area	% Field	N(21)	OM %	pH	P	K	S	Cl	Zn	Cu	B	Texture	Salinity	CMPT Date
zone 1,2	23	17	4.0	7.9	11 (Olsen)	358	43	7	0.6	0.5	0.9		0.36	Nov 01, 2021
zone 3,4	28	28	5.8	7.3	14 (Olsen)	252	72	9	0.7	0.5	1.0		0.47	Nov 01, 2021
zone 5,6	26	32	5.8	7.1	13 (Olsen)	285	69	12	1.0	0.6	1.0		0.40	Nov 01, 2021
zone 7,8	17	16	5.7	7.8	28 (Olsen)	283	160	23	1.5	0.8	2.2		1.52	Nov 01, 2021
zone 9,10	6	89	7.1	8.2	39 (Olsen)	244	160	37	1.5	1.0	4.1		3.97	Nov 01, 2021

Farmer Conducts Experimental Strips



Overlay Test Strips and Zones and Sample

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