FINAL REPORT

Canola Agronomic Research Program (CARP)

Project Title: Optimal Source, Placement and Application Timing for Yield and Reduction of Greenhouse Gas Footprint for Canola Production on Light Texture Soils

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Introduction

Increasing atmospheric concentrations of greenhouse gases (GHG; CO_2, N_2O, CH_4) from human activity are resulting in warming (IPCC 2014). Agriculture accounts for 8.2% of GHG emissions in Canada with N_2O being a major contributor (54%, Environment Canada 2017). Despite emission reductions (1990-2015) by most economic sectors including livestock production, N_2O from agricultural soils is increasing (Environment Canada 2017). This is because of doubling in fertilizer use with reduced fallow, perennial conversion to annual crops, and higher N use by crops. Thus, N_2O emissions 1990-2015 have doubled! By international commitment, Canada is to reduce emissions 30% below 2005 levels by 2030. From field studies done by our lab, adoption of 4R Nutrient Stewardship practices of applying fertilizer N at the Right Rate, source, time and placement can reduce soil emissions in MB by 50% (Tenuta 2016). However, there are many opportunities for further reductions through fertilizer rate and emission reductions through better management of fall applied N, use of newly available enhanced efficiency fertilizer products, management of depth of N placement and utilization of in-season N application.

With increasing pressure to complete field operations in a timely manner and trend to using fertilizer custom applicators, a segment of growers in Western Canada are transitioning towards surface applications of granular urea; this represents a departure from the recommended practice of deep banding. Surface applications of fertilizer or manure increase the risk that nitrogen will be lost through NH_3 volatilization, which occurs when urea hydrolysis elevates pH levels and increases the concentration of gaseous NH_3 around granules. When fertilizer granules are deep banded (3” plus) or buried in the soil, gaseous NH_3 formed around urea granules can be interconverted to ammonium (NH_4^+), a non-volatile ion which subsequently absorbs to negatively charged soil particles. While deep banding is a superior technique with respect to protecting nitrogen fertilizer from gaseous losses via NH_3 volatilization or N_2O emissions, the placement technique does require additional horsepower, can slow field operations at seeding time, and may also have undesirable effects on seedbed quality and moisture content.

The current study builds on recent 4R N studies by our laboratory and others in the Prairies. In our previous studies with canola funded under the CARP program and KOCH, we found fall broadcast of urea with or without enhanced efficiency fertilizers (EEFs) resulted in less yield compared with spring broadcast application. The results with fall broadcast urea was based on only two site-years on clay soils in Red River Valley of Manitoba. We did have six site years of comparison of deep and shallow mid-row banding and broadcast urea with or without urease inhibitor (AgroTain containing NBPT) and urease and nitrification (SuperU containing NBPT and DCD) inhibitor. We found conventional band placement (3-4” deep) reduced N_2O emissions (Tenuta et al. 2023). However shallow banding (0.75-0”) increased N2O emissions. That study was done mostly on clay soil with only one soil of lighter texture, sandy loam. The lighter texture soil had the most ammonia loss with shallow placement. Deep placement on any of the soils had minimal NH_3 loss. SuperU shallow banded on the lighter texture soil did reduce NH_3 emissions by half. As soil texture is an important factor affecting fertilizer placement and timing effects on N_2O emissions from soils, further studies with more site-years and soil types are needed. The other important thing we learned from the study was N treatment effects on yield were evident at 70% applied N of recommendation. Thus, shorting canola by 30% of recommendation was able to show difference in N use efficiency between treatments. A recent trend in canola N fertilization that we did not examine was in-season application. Some growers are using top- or side-dressing of UAN at rosette stage to split N application between planting and the growing season (Adam Gurr, personal communication). It remains unclear if the common practice of subsurface banding in fall and the in-season application of fertilizer N used by some growers can help to reduce N_2O and NH_3 emissions while improving or maintaining canola yield.

Our lab has evaluated the range of commercially available enhanced efficiency N products to reduce soil N_2O emissions in field trials (Asgedom et al. 2014, Gao et al. 2015, Gao et al. 2017, Tenuta et al. 2023 *in press*, Wood et al. 2023 *in press.*) and conclude that the control release product, ESN, and granular urea with nitrification inhibitors reduce N_2O emissions 30%. A research gap also exists in term of the effect of the new nitrification inhibitor from Eurochem (DMPSA) and used in products from Taurus Agriculture on N_2O emissions. A preliminary trial with DMPSA done by us in 2017 show DMPSA effective in inhibiting nitrification of granular urea and UAN when mid-row banded to a clay soil in the Red River Valley.

In general, an integrated BMP considering the "4R" components together is still lacking for canola production on Prairies. This project aims to determine the best combination of fertilizer source, placement and timing to maximize yield, improve fertilizer N use efficiency and reduce losses of N_2O and NH_3 on light texture soil, soils most prone to NH_3 loss.

Objectives

There are seven main objectives to this project aimed to improve nitrogen use efficiency of fertilizer for canola production. From this project canola growers will know which of the following practices perform better for yield and reduction of N loses on light texture soils:

- **Placement:** how does surface application of double inhibitor granular urea (SuperU) compare to shallow banding of granular urea and the recommended placement of deep banding of urea?
- **N Source for Shallow Banding:** is there an advantage in using SuperU or controlled release granular urea (ESN blend) compare to granular urea when shallow banding?
- **Nitrification Inhibition for Deep Banding:** is there an advantage to inhibiting nitrification (eNtrench, and new product, DMPSA) when deep banding granular urea?
- **Split Application:** is there an advantage to adding N at planting and in-season compared to just at planting?
- **Placement of In-season N:** does it matter if in-season N dressing of UAN is top-dressed by surface streaming or side-dressed by injection?
- **Inhibiting Ammonia Loss with Top-dressing:** is there a benefit of using an ammonia volatilization inhibitor to top-dress UAN? Does an ammonia volatilization inhibitor increase N_2O emissions?

Experimental Design and Activities

Field trials were established on commercial fields in Southern Manitoba starting the fall of 2018. Light texture soils of at least sandy loam will be used. Two sites were selected each year for three years giving a total of 6 site-years for the study. The trials were not sited on the same location between years to avoid growing canola on canola stubble. The trial sites are summarized in Table 1.

The sites had low residual levels of soil nitrate by being located on soybean stubble, this to increase likelihood of a response to fertility treatments. Plots were 3.25 by 7.9 m at each site for 36 treatments of test combinations of application timing (fall, spring, split with in-season), source (urea, SuperU, UAN with Agrotain, urea with eNtrench, urea with DMPSA, ESN/urea 70/30 blend), placement (surface, shallow and deep mid-row banded) and rate (100 of soil test recommendation). In addition a 0 N control was included. The nitrogen treatments are summarized in Table 2. The experimental design of each site was four blocks of completely randomized treatment plots within. A total of six trial sites were conducted with two sites being done in each of three years of the study.

Table 1. Details of trials sites in this study. Numbers associated with trial site names correspond to site mean labels in Table 4.

	2019 North (1)	**2019 South (2)**	**2020 Haywood (3)**	**2020 St. Claude (4)**	**2021 North (5)**	**2021 South (6)**
Legal	NW 5-10-7	NE 17-7-7	SE 27-8-6	NW 12-7-8	SE 20-9-7	NW 14-7-7
Texture	Sandy lacustrine with high water table/Sandy lacustrine over clay	Sandy lacustrine over clay	Sandy lacustrine over clay	Sandy lacustrine over clay/ sand deltaic deposits	Sandy lacustrine with high water table	Sandy lacustrine over clay/ sand deltaic deposits
Series	Lelant/ Almasippi	Almasippi	Almasippi	Almasippi/Long Plain	Lelant	Almasippi/Long Plain
kg N/ha	125	96	112	112	124	95
Dates						
Planting	27-May-2019	28-May-2019	26-May-2020	28-May-2020	18-May-2021	19-May-2021
Split	8-Jul-2019	8-Jul-2019	6-Jul-2020	6-Jul-2020	5-Jul-2021	30-Jun-2021
Harvest	24-Sep-2019	26-Sep-2019	28-Sep-2020	28-Sep-2020	31-Aug-2021	7-Sep-2021

Table 2. Nitrogen fertilizer source, timing and placement treatments used in this study. Rate (fraction) given where 1 is recommended rate of N addition based on soil test nitrate and yield goal.

	At Planting				**In Season**			
Treatment	Rate (fraction)	Source	Timing	Placement	Rate (fraction)	Source	Timing	Placement
SuperU Surface	1	SuperU	Spring	Surface Broadcast				
Shallow	1	Urea	Spring	Shallow MRB				
ESN Shallow	1	ESN: urea	Spring	Shallow MRB				
SuperU Shallow	1	SuperU	Spring	Shallow MRB				
Urea Deep	1	Urea	Spring	Deep MRB				
DMPSA Deep	1	DMPSA Urea	Spring	Deep MRB				
eNtrench Deep	1	eNtrench Urea	Spring	Deep MRB				
Deep Split	0.6	Urea	Spring	Deep MRB	0.4	UAN	Rosette	Streamed
Deep Split AgroTain	0.6	Urea	Spring	Deep MRB	0.4	UAN w/agroT	Rosette	Streamed
ESN Shallow Split	0.6	ESN: urea	Spring	Shallow MRB	0.4	UAN	Rosette	Streamed
0 N	0	No N						

To simplify interpretation of N2O emission results, treatments are considered as four treatment groups. For each group the SuperU Surface at planting and 0N Control serve as reference treatments, the former for a BMP when subsurface application is not possible and the 0N Control for background emissions levels. The groupings are as follows:

- *Placement and Split Group-* Urea Shallow, Urea Deep and Split application. Testing effect of mid-row band depth and split application of urea.
- *Source Group-* ESN Shallow, Urea Shallow and SuperU Shallow. Testing effect of a controlled release and dual inhibited urea product on reducing emissions from shallow mid-row banding.
- *Deep Source Group-* DMPSA Deep, Urea Deep and eNtrench Deep. Testing effect of nitrification inhibition alone on the conventional banding depth of urea.
- *Split Group-* Deep Split urea, Deep Split Agrotain and ESN Shallow Split. Testing the effect of splitting N application between at planting and rosette stage and effect of urease inhibitor of rosette-streamed UAN and ESN blend at planting followed by rosette-streamed UAN.

Agronomics

For surface placement, the SuperU fertilizer was applied to the soil surface by hand. Band treatments were applied mid-row using a Bourgault Mid Row disk-style Bander (Bourgault Industries Ltd., St. Brieux, SK) on 40 cm rows and either 2-2.5 cm (shallow) or 7.5-10 cm (deep) depth. Granular urea, SuperU and ESN fertilizer products were obtained from local farm suppliers just before applications to insure all are representative of what growers use (SuperU has a shelf life and ESN needs to be put through the commercial product handling stream to be effective). ESN was blended with granular urea in a 70/30 ratio according to manufacturer recommendation (Ray Dowbenko, personal communication). The nitrification inhibitors were mixed with granular urea just prior to use according to product label for eNtrench and manufacturer recommendation for DMPSA as it is not yet commercially available in Canada (Dr. Nils Berger of EuroChem, personal communication).

InVigor L140P treated seed was grown at all sites. Seeding was 5.6 kg ha^{-1} on 20 cm rows using two passes of a plot-scale (1.6 m wide) air-seeder (5000HD, Flexi-Coil Ltd., Saskatoon, SK) with tine openers and rubber wheel packing system. Seeding depth was 1.3 cm. Triple superphosphate (0–46–0) was applied at 13.5 kg P ha^{-1} with the seed. The sites were managed in a direct-seeding and fertilizer application with no tillage operation except for the surface application of SuperU that was done manually. Herbicides (including glufosinate as an option) and flea beetle control was achieved by using treated seed and spraying as needed.

Top-dressing occured at rosette stage at late evening using a stream bar (Needham AG Technologies, Calhoun, KY) with 40 cm spacing. Side-dressing was done with the Bourgault Mid Row disk-style Bander and liquid kit at 40 cm spacing.

Greenhouse Gas Monitoring

Immediately following seeding, spring application treatments were intensively monitored for greenhouse gas emissions (N_2O) using the static-vented chamber method and ammonia (NH_3) volatilization losses using dosimeter tubes. For emission of nitrous oxide (N_2O) in particular, sampling crews of 2-3 people travelled to each of the field sites ~ 30 sampling days between seeding and harvest. The intensive sampling of greenhouse gases and subsequent analysis of samples by gas chromatography in the Soil Ecology Laboratory was necessary to capture the spatial and temporal variability in N_2O emissions driven by environmental variables such as soil moisture and temperature.

Nitrous oxide emission sampling was mostly done between 0900 and 1100 h at each sampling date as this time is usual in between the daily minimum and maximum air temperature. Two-piece chambers consisted of (i) a rectangular collar (0.15 m high by 0.45 m long by 0.20 m wide) and (ii) a lid (0.45 m long by 0.20 m wide) with an internal vent tube to equilibrate pressure and temperature. The width of the chamber corresponded to the width between the canola rows. Collars were inserted 5 cm into the soil and left open throughout the experiment, except during gas collection periods. Collars were removed temporarily for field operations as needed. Two collars were deployed in each plot between separate plant rows, one over the band row and one where no band row. For sampling, lids placed on collars and 20-mL gas samples collected through a rubber septum at regular intervals (0, 20, 40, and 60 min) using syringes (Becton-Dickinson, Franklin Lakes, NJ) and subsequently transferred to 12-mL thrice helium-flushed pre-evacuated to 0.04 MPa, screw cap glass vials (Labco Exetainer, High Wycombe, UK). A layer of all-purpose Silicon II was applied to vial tops. Two 20-mL vials containing known concentrations of N_2O were prepared in the laboratory prior and brought to the field site, and handled in the same manner as other gas samples to confirm sample integrity during sampling and storage. All vials were transported back to the laboratory for analysis. Concentrations of N_2O in gas samples were determined using a gas chromatograph equipped with an electron capture detector (Varian CP-3800, Bruker Daltonics LTD., Milton, ON) and a Combi- PAL robotic sample introduction system (CombiPal, Zwingen, Switzerland). The chromatograph was calibrated using dilutions of pure N2O gas (Welders Supply, Winnipeg, MB). Analysis of a sample set was either repeated or the gas chromatograph column reconditioned and calibration redone if check vials were off by more than 5% of expected concentration. The minimum detection limit of the gas chromatography system was 0.01 mL N_2O L^{-1}. The N_2O emission rates (ng N m^{-2} min^{-1}) were calculated using the HMR package (Pedersen, 2011) implemented with the R language. The package recommends application of one of three regression approaches to estimate emission from the accumulation of N_2O during chamber deployment. A nonlinear model (Pedersen et al., 2010) is recommended if the rate of accumulation of N_2O decreases with time. A linear model is recommended if the rate of N_2O accumulation is consistent with time. An emission of zero is recommended in the absence of a clear trend in gas concentration with time. In the current study, outlier concentration data were not removed or negative emissions forced to zero.

Extractable Soil Nitrogen and Weather Monitoring

At each site, soil samples were collected on six occasions during the growing season. For each plot, 10 3.8-cm-diam. soil core samples (0–15 cm), consisting of five on-band and five between-band samples were collected and composited to one sample. Samples were stored at 4°C overnight and the next day mixed by hand to break large aggregates and then extracted with 2 M KCl and analyzed colorimetrically within 3 d for NH_4^+ using the Berthelot reaction, NO_2^- by azo dye formation from reaction with sulfanilamide and N-naphthylethylene-diamine dihydochloride, and NO_3^- by reduction using Cu–Cd to NO_2^- before azo dye formation using a Technicon Autoanalyzer II system. The concentration of NO_3^- (mg N kg^{-1} dry soil basis) was estimated as the difference between NO_2^-+NO_3^- (mg N kg^{-1} dry soil basis) from determination with the Cu–Cd reduction step and NO_2^- (mg N kg^{-1} dry soil basis) with the reduction step. Nitrate exposure (g N kg^{-1} days) was calculated in a similar way as ΣN_2O by summing daily estimates of soil NO_3^--N concentrations obtained by linear interpolation between sample dates from post-planting to freeze up. During gas sampling occasions, soil temperature at 2.5-cm depth and volumetric moisture content (VMC) at 5-cm depth were measured using a Traceable Long-stem Thermometer (Fisher Scientific Canada, Ottawa, ON) and a Delta-T WET Sensor (Delta-T Devices Ltd., Cambridge, England), respectively. A tipping bucket rain gauge monitored total daily precipitation and a shielded thermometer air temperature during the growing season.

Canola Yield and Biomass

A Wintersteiger Classic plot combine with yield and moisture monitor was used to straight cut canola in each plot for separation of grain and residue (aboveground nongrain material) biomass. Samples were dried at 48°C before dry-weight determination, ground using a Thomas Wiley Laboratory Mill Model 4 grinder (Thomas Scientific, Swedesboro, NJ). Total N concentrations (g kg^{-1} dry material) in plant samples were determined using an Elementar CN combustion analyzer. Dry-weight grain yield (Mg ha^{-1}) and N concentrations (g kg^{-1}) in grain and residues were determined. Grain (NUgrain) and total aboveground plant material (NUabove) N uptake were determined as NUgrain = grain N concentration × grain yield; NUabove = (grain N concentration × grain yield) + (residue N concentration × residue yield). Yield-scaled EI, was calculated as the ratio of cumulative emissions to yield for each plot and expressed as kg N Mg^{-1} grain yield.

Following harvest, soils were sampled to 0-4’ using a tractor-mounted hydraulic probe to determine residual NO_3^- in soil for all treatment plots.

For expedience of reporting, only N_2O emission results are provided in this report.

Results

Weather

Weather conditions over the study were obtained from the Carman Research Station of the University of Manitoba. All three years of the study were drier than normal, especially 2020 (Table 3). 2019 had a drier early growing season and August, and a wetter July. 2020 had a drier early growing season and August and normal July. 2021 had a normal early growing season, much drier July and slightly wetter August than normal.

Nitrous Oxide Fluxes

In 2019 there were two episodes of fluxes, post seeding and fertilization and also in July (Fig. 1 and 2) as it was wetter than normal. Urea Shallow stands out as a high emission treatment whereas SuperU Surface, SuperU Shallow, ESN Shallow and DMPSA Deep had low emissions.

In 2020 moisture conditions were normal in July and an emission episode in that month was not observed (Fig. 3 and 4) unlike in 2019. Urea Shallow and Urea Deep had the highest emissions with enhanced efficiency nitrogen products containing a nitrification inhibitor or being controlled released (ESN Shallow) having lower emissions.

2021 had a drier-than-normal July and an episode of emissions was not observed in that month (Fig. 5 and 6). The 2021 South site had observably higher emissions for Urea Shallow and less for Urea Deep than other treatments. Again, enhanced efficiency nitrogen products containing a nitrification inhibitor or being controlled released (ESN Shallow) had lower emissions.

Table 3. Monthly mean air temperature and total precipitation for the Carman Research Station and climate normal (1980-2010).

	2019		2020		2021		Climate Normal	
	Air T	Precip	Air T	Precip	Air T	Precip	Air T	Precip
May	10.1	46	10.8	42	11.0	76	11.6	70
June	17.4	31	18.7	40	20.1	93	17.2	96
July	20.4	103	21	71	22.1	5	19.4	79
August	18.1	32	19.3	20	18.6	94	18.5	75
	Total Precip	212 mm		173 mm		268 mm		320 mm

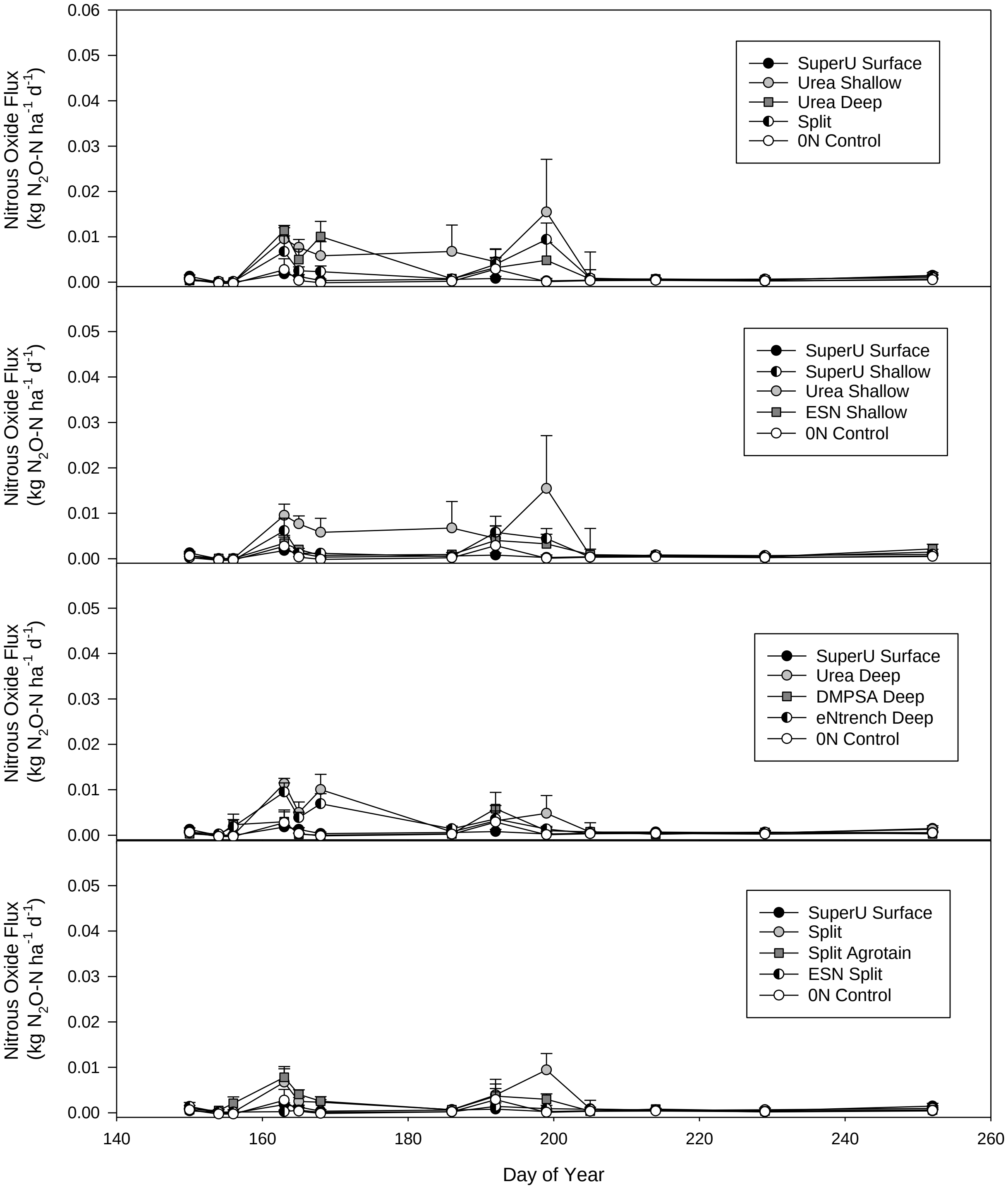

Figure 1. Nitrous oxide fluxes during the growing season of the four treatment groupings at the 2019 North site. Shown are treatment means (n=4) and ±1 of the standard error of the mean.

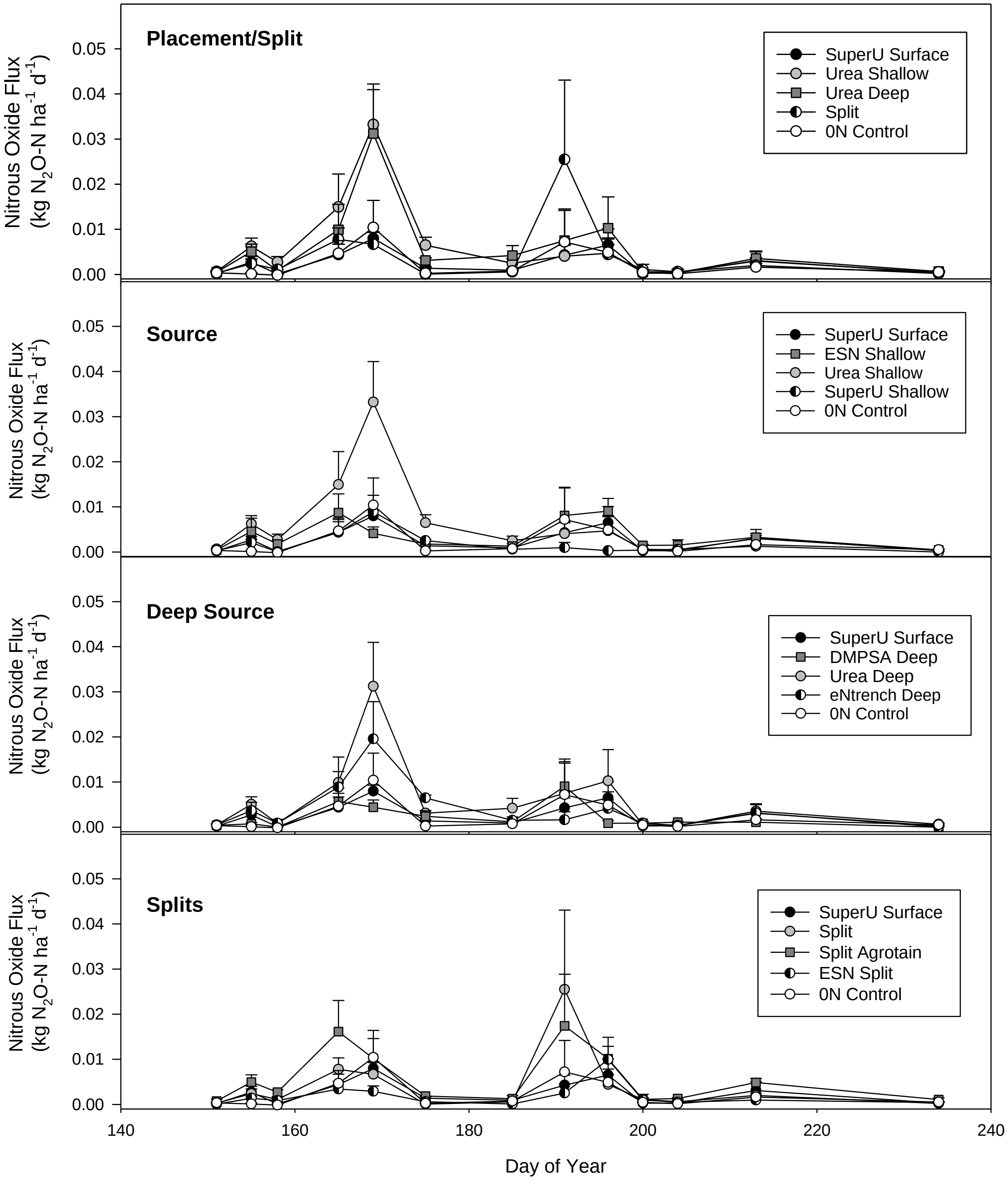

Figure 2. Nitrous oxide fluxes during the growing season of the four treatment groupings at the 2019 South site. Shown are treatment means (n=4) and ±1 of the standard error of the mean.

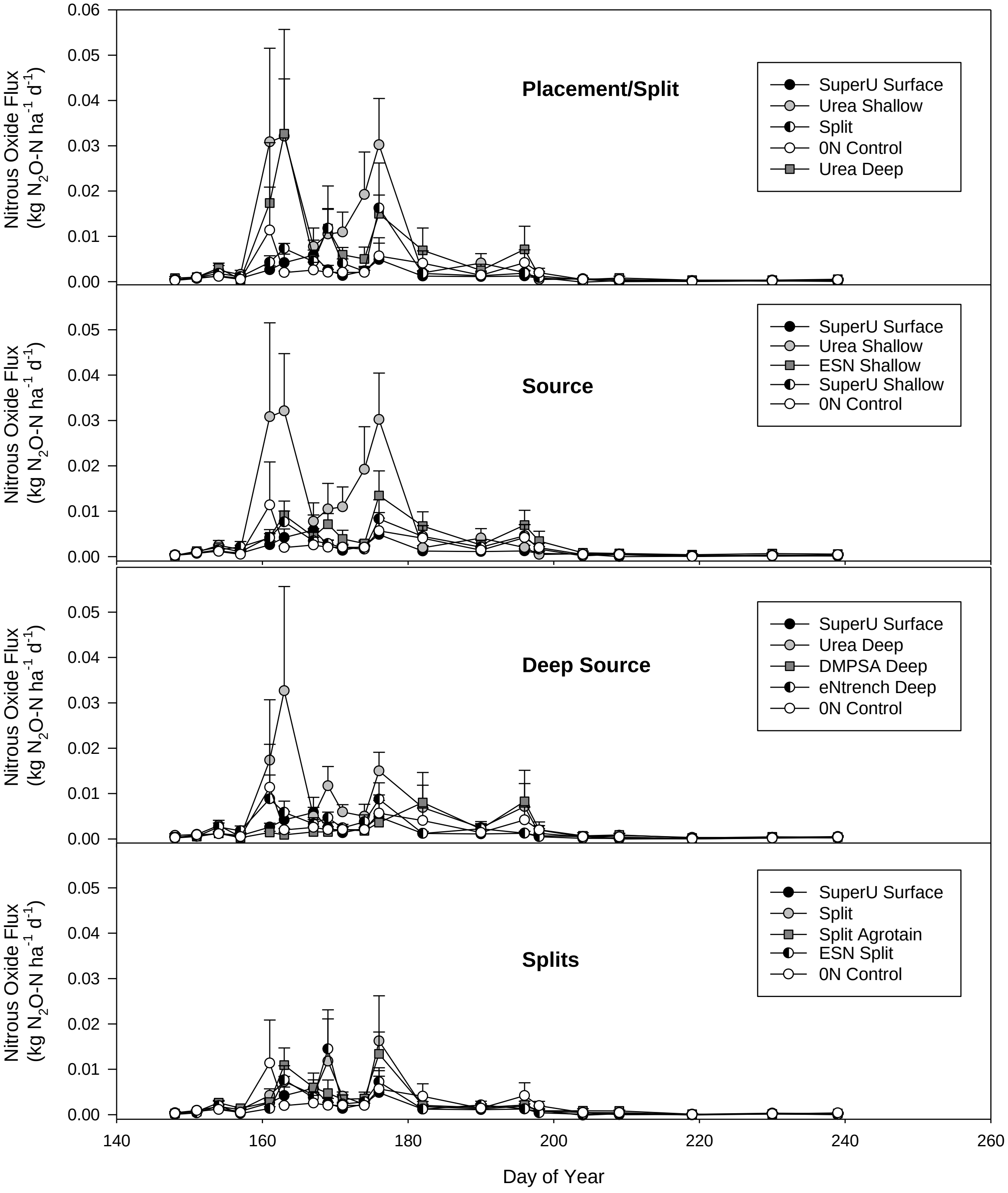

Figure 3. Nitrous oxide fluxes during the growing season of the four treatment groupings at the 2020 Haywood site. Shown are treatment means (n=4) and ±1 of the standard error of the mean.

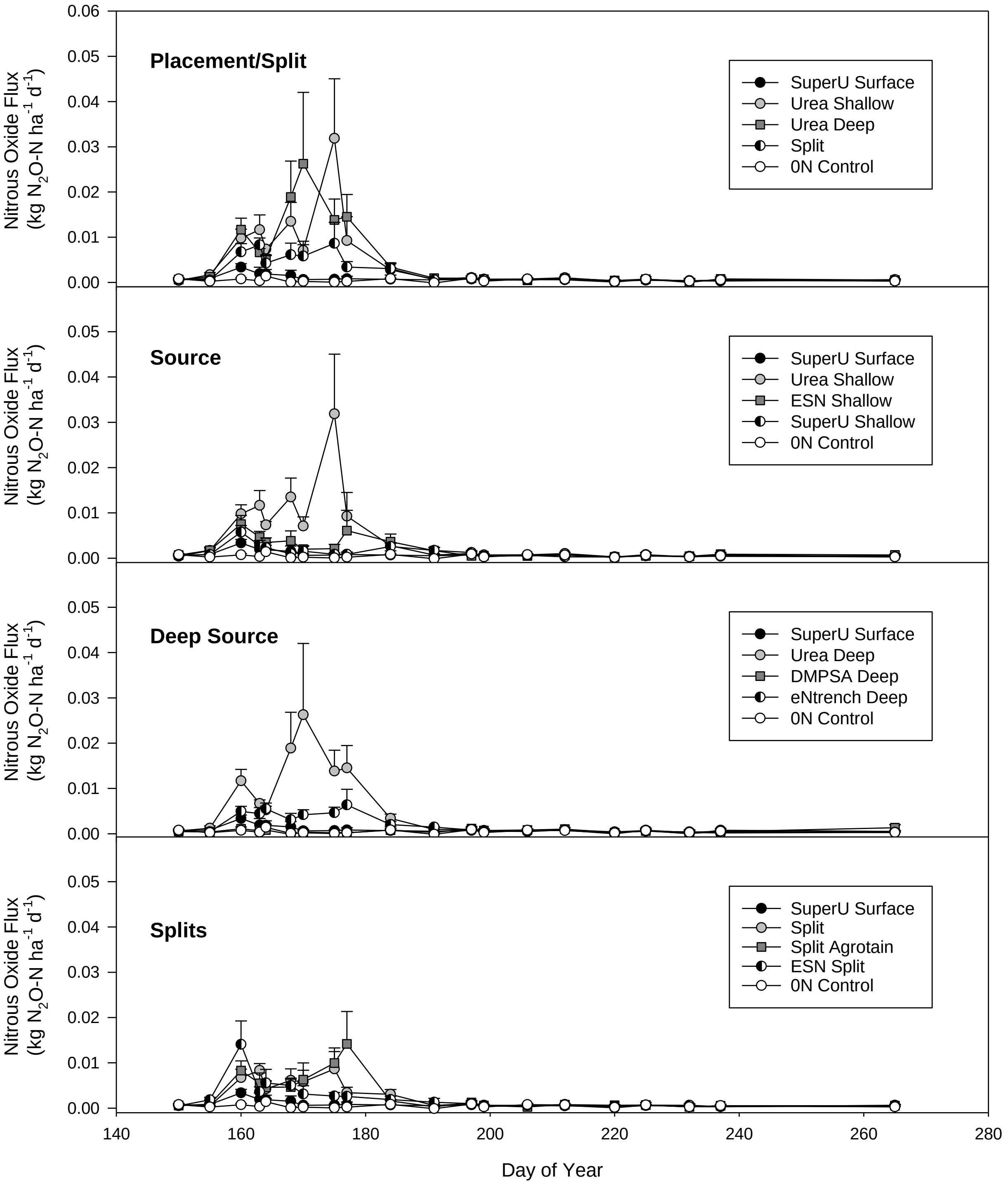

Figure 4. Nitrous oxide fluxes during the growing season of the four treatment groupings at the 2020 St. Claude site. Shown are treatment means (n=4) and ±1 of the standard error of the mean.

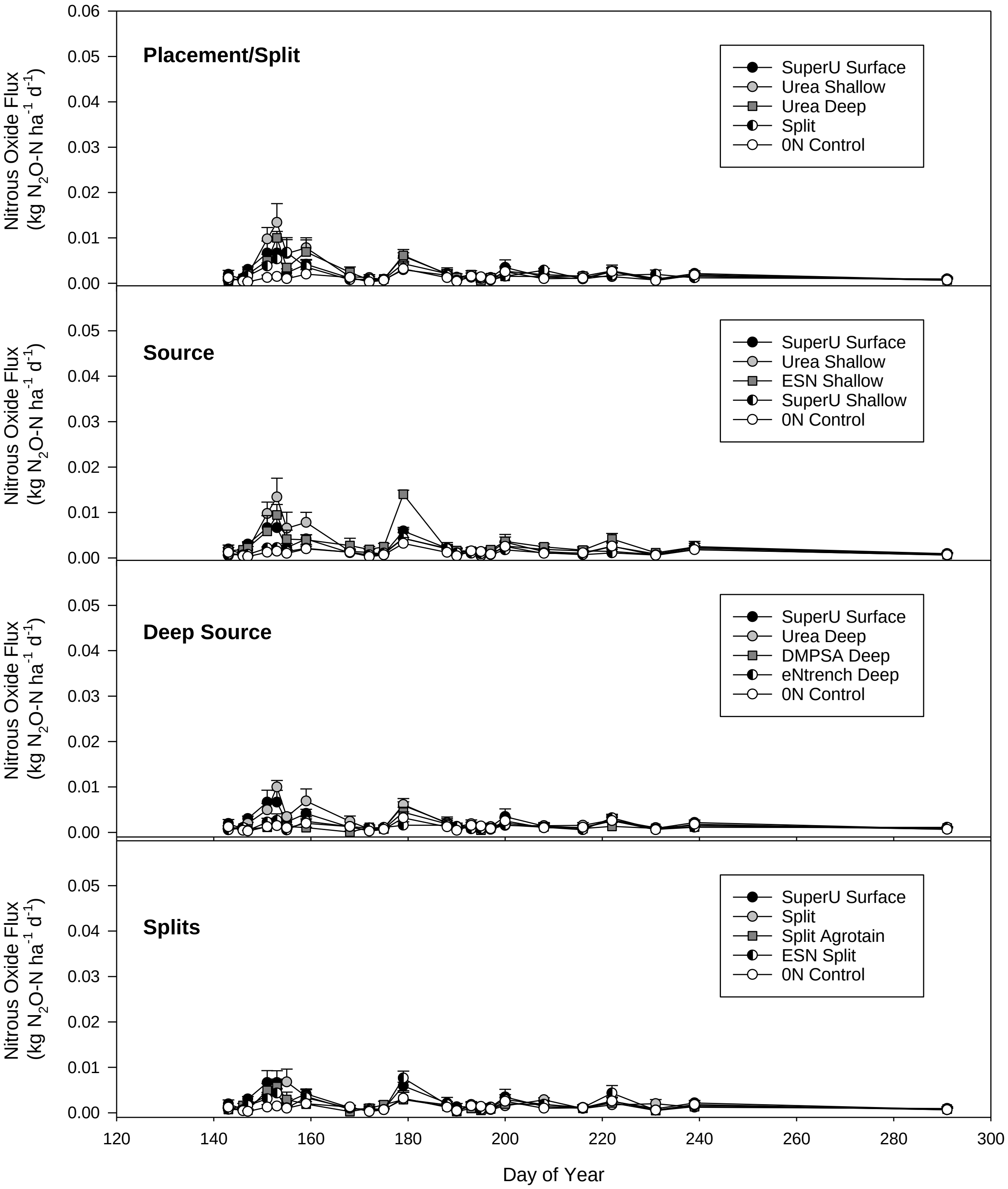

Figure 5. Nitrous oxide fluxes during the growing season of the four treatment groupings at the 2021 North site. Shown are treatment means (n=4) and ±1 of the standard error of the mean.

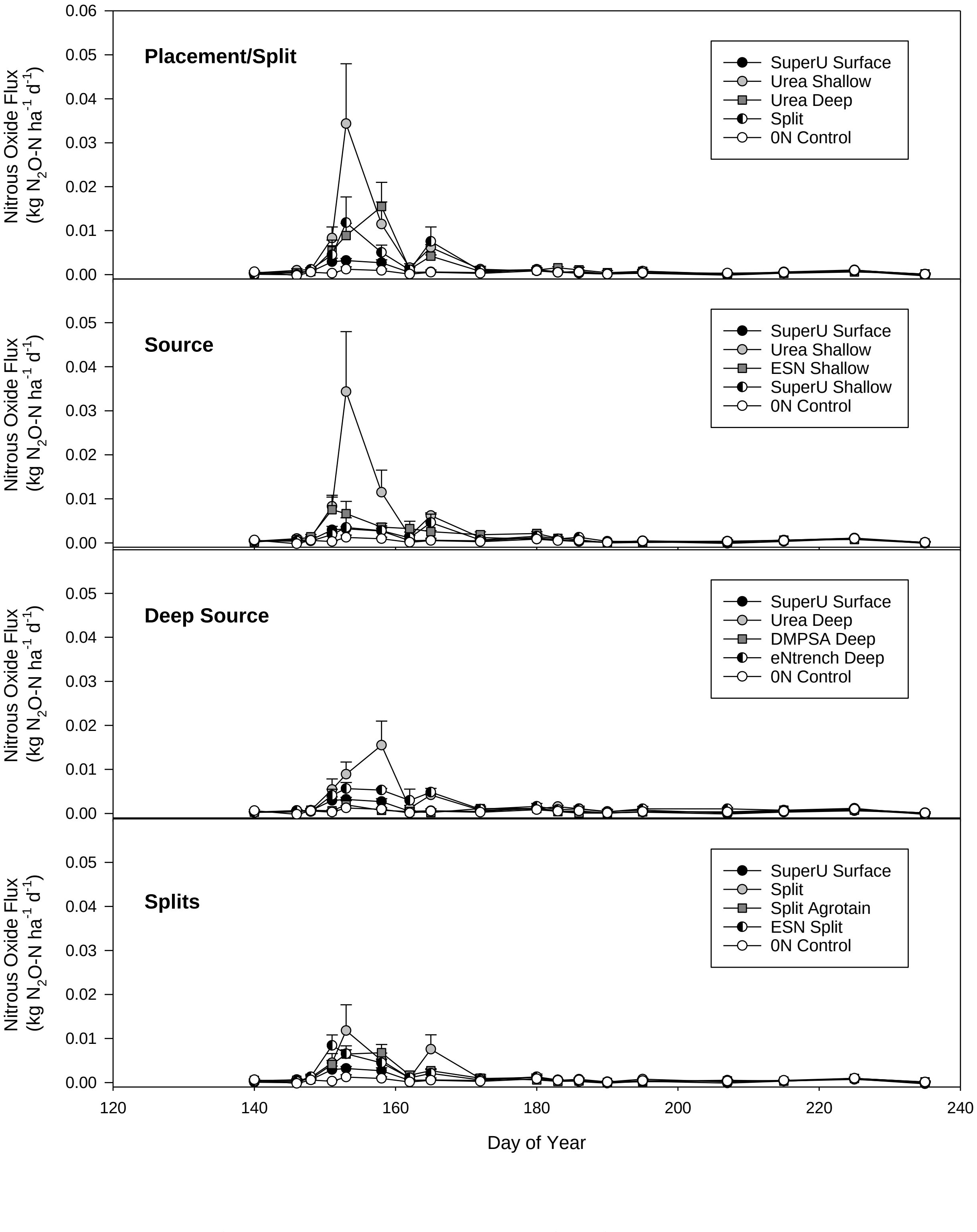

Figure 6. Nitrous oxide fluxes during the growing season of the four treatment groupings at the 2021 South site. Shown are treatment means (n=4) and ±1 of the standard error of the mean.

Cumulative Nitrous Oxide Emissions

For the Depth and Split treatment grouping, Urea Shallow and Urea Deep had significantly higher emissions than Deep Split, SuperU Surface and the 0 N Control (Table 4). The later three treatments were not different from each other.

Amongst treatments of the Shallow grouping, Urea Shallow was significantly higher than other treatments (Table 4). The SuperU treatments either shallow or surface applied were not different from the 0 N Control. The ESN Shallow was lower in emissions than Urea Shallow but higher than SuperU Surface.

For the Deep treatment grouping, Urea Deep was significantly higher in cumulative emissions than other treatments (Table 4). eNtrench Deep had lower emissions than Urea Deep but higher than the 0 N Control. The other nitrification alone inhibitor treatment, DMPSA Deep was much lower than Urea Deep and no different than the 0 N Control. The dual inhibitor treatment, SuperU Surface also containing a nitrification inhibitor but of a different mode of action than the single inhibitors was lower in emissions to Urea Deep but not different than eNtrench Deep and DMPSA Deep.

Interaction between treatment and site was significant for the Split treatment grouping (Table 4). The interaction was observed because, for four of the six sites, there were no differences between treatments within this grouping. However, for 2019 South and 2020 St. Claude, the Split Agrotain had higher emissions than SuperU Surface and 0 N control (Fig. 7).

Across all sites, the order of treatment was significantly greater in cumulative emissions than the 0 N control was Urea Shallow > Urea Deep > ESN Shallow > Deep Split (Fig. 8). The nitrification alone treatment, DMPSA Deep had nearly the same emissions as the 0 N Control.

Table 4. Two-way ANOVA results for the four treatment groupings. Within Treatment (Trt) and Site factors, means of growing season emissions (ΣF_{N2O}) followed by the same letters are not statistically different by the Tukey Test (P>0.05). SE is ±1 standard error of the mean.

Depth & Splits			Shallow			Deep			Splits		
Trt	**ΣF_{N2O}**	**SE**	**Trt**	**ΣF_{N2O}**	**SE**	**Trt**	**ΣF_{N2O}**	**SE**	**Trt**	**ΣF_{N2O}**	**SE**
0 N	0.114a	0.018	**0 N**	0.114a	0.018	**0 N**	0.114a	0.018	**0 N**	0.114	0.018
SU Surf	0.135a	0.021	**SU Surf**	0.135a	0.021	**DMPSA Deep**	0.123ab	0.020	**SU Surf**	0.135	0.021
Deep Split	0.213a	0.022	**SU Shall**	0.163ab	0.019	**SU Surf**	0.137ab	0.021	**ESN Shall Split**	0.148	0.019
Deep	0.330b	0.036	**ESN Shall**	0.265b	0.034	**eNtrench Deep**	0.197b	0.018	**Deep Split**	0.213	0.022
Shallow	0.383b	0.042	**Shallow**	0.383c	0.042	**Deep**	0.330c	0.036	**Deep Split AT**	0.226	0.056
Site	**ΣF_{N2O}**	**SE**	**Site**	**ΣF_{N2O}**	**SE**	**Site**	**ΣF_{N2O}**	**SE**	**Site**	**ΣF_{N2O}**	**SE**
6	0.146a	0.024	**6**	0.129a	0.021	**6**	0.103a	0.016	**6**	0.103	0.013
1	0.205ab	0.054	**1**	0.169a	0.054	**1**	0.142a	0.027	**1**	0.105	0.019
4	0.221ab	0.040	**4**	0.206a	0.043	**4**	0.153ab	0.035	**3**	0.151	0.018
3	0.247ab	0.043	**3**	0.227ab	0.034	**3**	0.186abc	0.038	**4**	0.152	0.023
5	0.277b	0.019	**2**	0.248ab	0.032	**5**	0.237bc	0.017	**5**	0.247	0.015
2	0.315b	0.040	**5**	0.296b	0.028	**2**	0.260c	0.035	**2**	0.249	0.035

ANOVAs

Source	DF	Prob	Source	DF	Prob	Source	DF	Prob	Source	DF	Prob
Treatment	5	0.006	**Treatment**	5	0.002	**Treatment**	5	<0.001	**Treatment**	5	<0.001
Site Year	4	<0.001	**Site Year**	4	<0.001	**Site Year**	4	<0.001	**Site Year**	4	<0.001
Interaction	20	0.819	**Interaction**	20	0.558	**Interaction**	20	0.269	**Interaction**	20	0.010
Residual	90		**Residual**	90		**Residual**	90		**Residual**	90	
Total	119		**Total**	119		**Total**	119		**Total**	119	

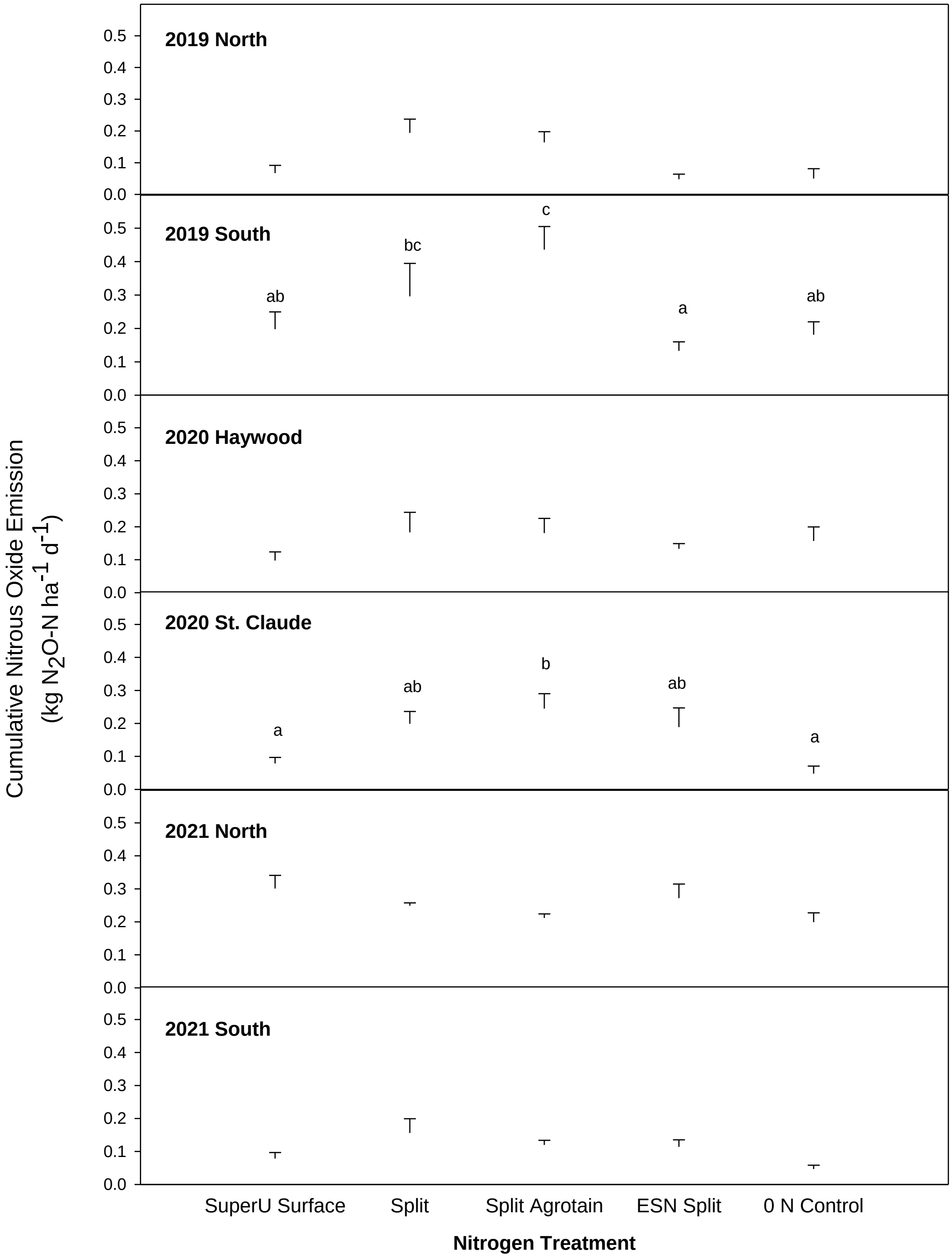

Figure 7. Cumulative nitrous oxide emissions during the growing season for treatments in the split application grouping by site. Within a site, treatment with different letters are significantly different ($P<0.05$) by the Tukey test. Shown are treatment means ($n=4$) and +1 of the standard error of the mean.

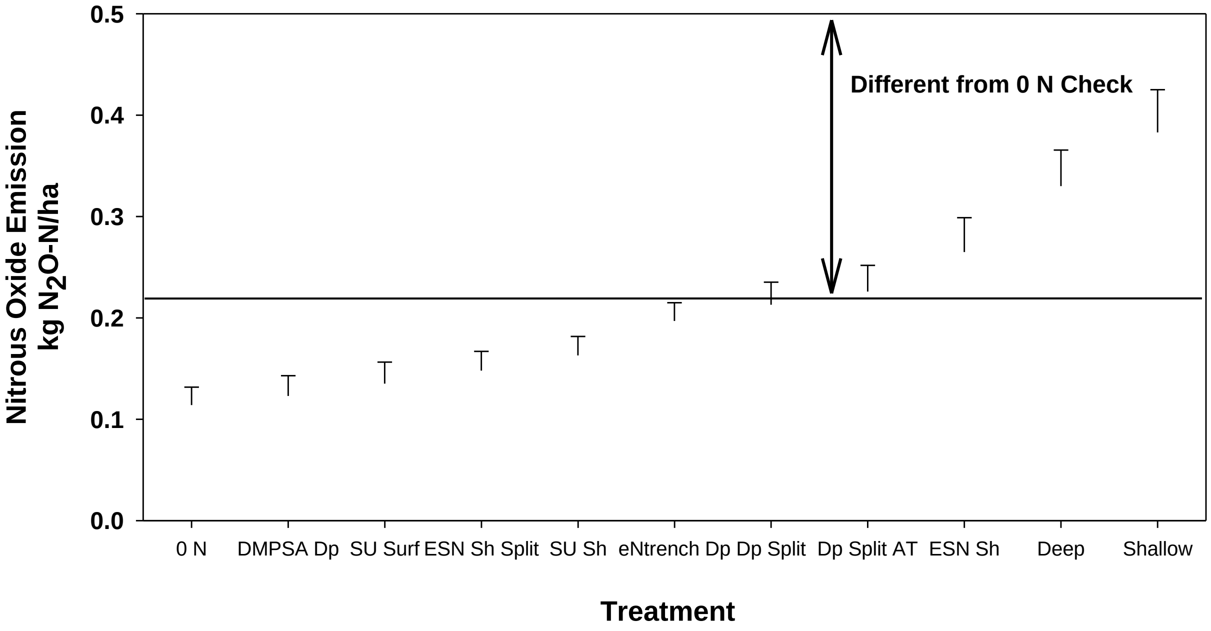

Figure 8. Cumulative nitrous oxide emissions during the growing season by treatment across all sites. Treatment means above the horizontal line are significantly different ($P<0.05$) from the 0 N Control by the Tukey test. Shown are treatment means (n=4) and +1 of the standard error of the mean.

Project Highlights

- A total of six replicated trials were performed from 2019-2021 on commercial fields of sand soil in south-central Manitoba
- Eleven nitrogen fertilizer treatments were compared for emissions of nitrous oxide for canola production
- Shallow Urea (banded 0.75-1”) had the highest cumulative emissions of nitrous oxide followed by Deep Urea banded (3-4”) at planting
- The lowest emissions and near that of the 0 N Control were the nitrification alone inhibitor, DMPSA Urea, applied deep banded and the dual inhibited urea containing a nitrification inhibitor, SuperU, applied shallow banded
- The nitrification alone inhibitor, eNtrench Urea, was intermediate between the highest emission treatment, Shallow Urea, and the lowest, 0 N Control
- Split application where UAN was streamed in-season at rosette stage reduced emissions compared to Shallow Urea and Deep Urea at planting.
- Combining the controlled release urea product, ESN with split application of UAN reduced emissions compared to ESN all at planting
- The results confirm our previous finding that Shallow Urea increases nitrous oxide emissions (Tenuta et al. 2023) and that nitrification-inhibited urea (either single or dual) be used when shallow banding
- The results also confirm that nitrification-inhibited alone urea products can reduce emissions as effectively as dual-inhibited (urease and nitrification) urea (Wood et al. 2023)

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