CFI 4R Nutrient Stewardship Research Report

Nitrogen stabilizers to enhance nitrogen use efficiency and reduce greenhouse gas emissions in Alberta cereal crops

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Summary

This report summarizes research findings of the Fertilizer Canada/IPNI-sponsored *Nitrogen stabilizers to enhance nitrogen use efficiency and reduce greenhouse gas emissions in Alberta cereal crops* Findings applicable to the 4R/NERP framework are presented in the following table:

4R/NERP Principle	Application of results from this research
Right Product/Source	1) Polymer-coated urea was associated with consistently higher cumulative soil N_2O emissions compared to conventional urea regardless of timing of application (fall or spring) when mid-row banded at shallow depths (5 cm). 2) Urea products treated with nitrification inhibitors (eNtrench) or both nitrification and urease inhibitors (SuperU) were associated with lower cumulative soil N_2O emissions compared to conventional urea, but the reduced emissions were small and not statistically significant. It is expected that these products would perform better when applied to soils with lower inherent N fertility and banded closer to the seed row.
Right Place/Right time	3) Fertilizers applied at the time of seeding should be placed as close to the seed row as possible and deeper that the seed row to ensure that the crop will be able to access applied N as early in the growing season as possible. 4) RIGHT PLACE: Regardless of spring or fall application, soil N_2O generated from applied fertilizer in shallow bands has a much greater probability of entering the atmosphere than fertilizer-generated N_2O in deep bands.

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1. Introduction and Objectives

Nitrogen use has contributed to a tripling of cereal grain production in five decades. Canadian annual use of N fertilizer is 1.8 million tonnes, however due to the inefficiency of plant uptake and utilization, crops seldom assimilate >50% of applied nitrogen. The average recovery of applied N in cereals worldwide is estimated at 33% (Raun and Johnson 1999). Nitrogen not recovered is lost from the cropping system and contributes to N loading into the environment. Nitrogen losses not only decrease NUE, causing economic loss, but also can influence water quality and contribute to greenhouse gas (GHG) emissions. Nitrogen use efficiency of a cropping system is the proportion of all N inputs that are removed in harvested biomass, contained in recycled crop residues and incorporated into soil organic matter or the inorganic N pool. Due to difficulties in accurately quantifying N in the soil pools, NUE can also be defined more simplistically as the amount of harvested biomass produced per unit of N applied. Loss of N to the environment usually occurs when high concentrations of soluble NO_3 are present in the soil solution in excess of amounts that plants can absorb. Management practices that enhance NUE include: i) use of soil testing to make the best use of soil nitrogen, ii) use of the right fertilizer type and form, at the rate rate, using the right application method at the right time, iii) incorporation of fertilizer into the soil, and iv) using split or delayed applications to ensure a continuing supply of N over the growing season.

NUE can be enhanced by providing N to the crop at the appropriate time, proportional to the crop's requirements. Cereal N requirements are generally low at the beginning of the growing season, increasing rapidly during vegetative growth and dropping sharply as the crop nears maturity. By keeping fertilizer N as urea or NH_4 until the plant is ready to use it, losses from denitrification or leaching are reduced or eliminated because only the NO_3 form of nitrogen is subject to denitrification (under anaerobic soil environments) and leaching; NH_4 is readily adsorbed onto negatively charged soil colloids and held against leaching, while NO_3 which is an anion (negatively charged) and is readily mobile in the soil. Split application of fertilizer (reserving some of the required nitrogen and applying it in the growing season) can also have a significant impact on GHG emissions, NUE, and can enhance uptake and yield.

The fertilizer industry is developing enhanced efficiency fertilizers that have the potential to substantially reduce GHG emissions and increase NUE (Akiyama et al. 2010). These include slow or controlled release fertilizers and stabilized fertilizers.

Controlled Release Fertilizers (CR)

Fertilizer solubility can be slowed through the use of hydrophobic polymer coated urea, such as ESN®. ESN can also reduce crop injury from seed placed urea fertilizer. ESN is currently available in western Canada. The effects of ESN on N_2O emissions varies with environmental conditions (Akiyama et al. 2010).

Urease Inhibitors (UI)

Urea, the most widely used nitrogen form, is hydrolyzed by urease to NH_3 and CO_2 with a rise in pH and accumulation of NH_4^+ (Giocchini et al 2002). Rapid formation of NH_3 can lead to gaseous losses, depending on environmental factors including temperature, soil texture and organic carbon and whether products are incorporated. UIs may slow the process, retaining fertilizer nitrogen in the soil and gradually providing nitrogen to the crop. The main use of UIs in production agriculture is to reduce NH_3 losses from surface applied urea by maintaining the N in the urea form for a longer period of time to allow for either rain incorporation or extend the window for incorporation. Agrotain®, a urease inhibitor that can be applied with either urea or UAN, is available in western Canada. Akiyama et al. (2010) reported that UI were generally not effective at reducing N_2O emissions using a meta-analysis of eight data sets.

Nitrification Inhibitors (NI)

NH_4+ is itself subject to nitrification to nitrite and nitrate which are susceptible to loss by leaching and/or denitrification. NIs slow this process, maintaining plant available NH_4^+ longer. NIs are sold separately under trade names like eNtrench™ (encapsulated nitrapyrin, nitrification inhibitor), or in combination with urease inhibitors under trade names like Agrotain Plus (DCD + Agrotain, nitrification and urease inhibitor for UAN) and SuperU® (DCD + Agrotain, nitrification and urease inhibitor pre-impregnated on a urea prill), and are alternatives to ESN.

NIs are the most widely tested mitigation option of N_2O emissions. In a meta-analysis of 85 data sets, NIs reduced N_2O by an average of 38% (Akiyama et al. 2010). A meta analysis of UI and NI (Abalos et al 2014) suggests that GHG emission reductions are variable, highest in irrigation, course textured soils, and crops receiving high rates of nitrogen. Overall they reported an average increase of NUE of 12.9%.

Yield Response

The yield response to controlled release and stabilized fertilizers has also been inconsistent. In US corn production, nitrification inhibitors have enhanced yield and decreased nitrogen losses (Wolt 2004) but in general those growing areas have significantly more leaching potential. A recent meta analysis including both Europen and North American studies found an average increase of yeild of 7.5%. In western Canada, fall applied polymer-coated urea has been shown to increase yield in winter wheat (Beres et al 2010) where nitrogen losses are high but it was not consistently superior to spring applied urea (McKenzie et al 2004). Malhi et al. (2010) reported that split applications of urea were superior to controlled release ESN in most instances. Grant et al (2012) reported that the use of controlled release urea provided no consistent advantages over split application of urea on barley, wheat or canola yield. They speculated that the time of release is too slow to provide initial N to crops in cooler soils. There have been no western Canadian studies that have directly compared polymer coated and stabilized nitrogen products to uncoated urea applied both in spring and fall.

When used in combination with other best management practices, the use of controlled release and stabilized fertilizer may reduce GHG emissions and increase the yield potential of cereal crops. In other studies, NIs have shown significant potential, but these relatively new products have not been examined in Western Canada. A lack of consistent crop yield response from CR fertilizers (Malhi et al 2010; Grant et al 2011), has dulled the interest of growers, who are motivated appropriately by increased profitably (Khakbazan et al. 2009). Given the lack of certainty and the potential additional cost to growers, further information is required before best management practices can be developed and compared with other methods of increasing yield.

Main Objectives:

This research project will assess stabilized and enhanced efficiency fertilizer products on N_2O emissions, NUE and crop yield response in cereal crops. We will compare:

1) Nitrogen stabilizers (nitrification inhibitors (NI) and urease inhibitors (UI)) compared to controlled-release fertilizers (ESN)
2) Effect of nitrogen rates ranging from deficient to superfluous (as determined by soil test recommendations for wheat)
3) Effect of time of application; spring compared to fall application

2. Materials and Methods

Field trials were carried out at the Ellerslie Research Farm (Edmonton, University of Alberta) and at the Farm Stewardship Center (Lethbridge) over the 2016 and 2017 growing seasons. A factorial experimental design with 4 replicates was implemented with the following three factors: 1) N fertilizer: urea, SuperU, eNtrench impregnated urea, and polymer-coated urea (ESN); 2) timing of fertilizer application, fall or spring – mid-row banded; and 3) N rate (0, 50, 100 and 150% of recommendation based on soil samples). Control (0N) treatments were established in fall and spring.

Research plots were established on canola stubble in the fall of 2015. Composite soil samples (0-15cm, 15-30cm and 30-60 cm) were collected from each of the four replicates and send to Exova Labs in Edmonton for analysis of plant-available nutrients. The Alberta Agriculture AFFIRM software was used to generate fertilizer recommendations. Based on the results from the lab, the recommended rates of N at each site were 60 and 80 kg N ha^{-1} for Lethbridge and Ellerslie, respectively.

Fall N banding treatments were applied at both sites on 4 Nov. 2015 and 27 Oct. 2016 (Ellerslie), and Nov. 23, 2015 and 14 Nov., 2016 (Lethbridge). Spring banding/seeding (spring wheat) dates were 9 May, 2016 and 12 May, 2017 (Ellerslie), and 19 May, 2016 and 4 May, 2017 (Lethbridge).

Field N_2O flux measurements using the non-steady state chamber method were limited to the 100% N rate level and control treatments. In fall banded treatments, gas flux measurements commenced 1 week after banding until the surface soil was frozen and commenced in the spring, once surface soil temperatures were above freezing. In the spring banding treatments, gas sampling commenced, 1 week following banding/seeding. For both fall- and spring-banded treatments, gas fluxes were measured until harvest.

For the 100% N rate level and control treatments, in both fall and spring banded treatments, pre-seeding and post-harvest soil samples (0-30, 30-60cm) were collected along with samples, 2, 4 and 6 weeks after seeding (0-15, 15-30cm). Soil samples were analyzed for plant available N.

At crop maturity, 4 rows over a 4-m length were hand harvested at Ellerslie for straw and grain yield determination. At Lethbridge, wheat yields were measured using a plot combine over a 1.5 X 7.6 m area.

3. Results and Discussion

Growing Conditions

Annual precipitation, growing season precipitation and growing degree days for the two growing seasons at the two locations are summarized in Table 1.

Year	Annual[a] Precipitation (mm)	Growing Season[b] Precipitation (mm)	Growing Degree Days[c]
		Lethbridge	
2016	359	260	1425
2017	247	154	1635
		Ellerslie	
2016	418	365	1183
2017	419	348	1226

[a] October 1 of previous calendar year to September 30 of stated calendar year
[b] April 1 – August 31 of stated calendar year
[c] base 5°C

Long-term normal annual precipitation for Lethbridge and Ellerslie are 395mm and 448mm, respectively, making these two years slightly drier than normal.

Crop Yield and Response to N fertilizer

Wheat grain yield for each site-year as a function of N rate and fertilizer product is summarized in Figs. 1 and 2. Overall, response to added N was low at both sites in both years. Despite low soil N test levels for both sites in both years, it appears there was significant in-season mineralization of soil organic N, resulting in high yields even in the control treatments with no added N. In Lethbridge, in 2017, lower yields were associated with high N rates. This is likely a result of the growing conditions where adequate early season soil moisture and precipitation resulted in higher leaf area in the 1.0X and 1.5X treatments that could have caused significantly more drought stress later in the growing season when there was little to no precipitation.

Soil N_2O Emissions

Average (N=4), daily soil N_2O emissions and meteorological conditions for both sites in 2016 and 2017 are summarized in Figures 3 through 6. A summary of average cumulative emissions for both sites and both years is presented in Figure 7. Daily N2O fluxes responded to soil warming and precipitation events. As expected, cumulative emissions were greater at Ellerslie because of higher levels of soil organic matter and higher soil moisture levels.

Pre-seeding N_2O emissions were not measured in the spring-banded treatments. However, it was assumed that the spring emissions measured in the fall-banded control treatment were representative of spring fluxes in the spring-banded treatments in order to compare total annual N2O emissions for both fall- and spring-banded treatments. When this adjustment was made, there were no apparent differences in cumulative N_2O emissions between fall- and spring-banded treatments.

For both daily and cumulative fluxes, the slow release, ESN product showed consistently higher emissions compared to conventional urea for both spring- and fall-banded treatments at both sites in 2016 and in 2017 for Lethbridge. The enhanced efficiency fertilizers (SuperU, eNtrench treated urea) had mean cumulative emissions lower than conventional urea (***not statistically significant***) for the following scenarios:

For Lethbridge:

1) fall-banded eNtrench and SuperU at Lethbridge in 2016 – 23% reduction;

2) spring-banded SuperU at Lethbridge in 2016 – 20% reduction;

3) fall-banded eNtrench in 2017 – 25% reduction;

4) Spring-banded SuperU and eNtrench in 2017 – 10 to 20% reduction;

For Ellerslie

1) Fall-banded eNtrench in 2017 – 12% reduction;
2) Spring-banded SuperU in 2017 - 14% reduction;

Comparison to results in the literature

The performance of the enhanced efficiency fertilizer products in this study was not as impressive as those reported in the literature. Akiyama et al. (2010) report significant soil N_2O emission reductions on the order of 35% when using polymer-coated and nitrification inhibitor treated fertilizer products. They reported that products with urease inhibitors were not associated with reduced soil N_2O emissions.

With respect to the inhibitor-treated urea produced (SuperU and eNtrench) it appears that inhibitor efficacy was reduced under the conditions experienced during these growing seasons. Peak daily N_2O fluxes were associated with soil thawing for fall-banded treatments, and following significant precipitation events after seeding for both fall- and spring-banded treatments (Figs. 3 through 6). These peak flux events make significant contributions to annual cumulative emissions. However, with the exception of fall-banded SuperU at Ellerslie in 2016 and spring-banded eNtrench at Ellerslie in 2017, inhibitor-treated urea did not show significantly lower peak fluxes compared to conventional urea. These peak fluxes occurred under relative high soil moisture conditions which are ideal for denitrification, however, if the nitrification inhibitors in SuperU and eNtrench were inhibiting nitrification, one would expect lower fluxes than conventional urea. Another potential pathway involved in N_2O production during these times is the hydroxyl-amine pathway during the conversion of ammonia to nitrite which is the first step in nitrificaiton. This pathway may be significant especially for spring-banded urea products. Again, if the nitrification inhibitors in SuperU and eNtrench were active, one would expect reduced peak emissions from these products compared to conventional urea.

If the efficacy of the inhibitors in the SuperU and eNtrech products were reduced, the reasons are not clear at this point. There is some evidence in the literature than soil organic matter levels may influence the efficacy of nitrification inhibitors (McGeough et al., 2016). Another possibility is that soil freeze-thaw cycles may affect the efficacy of inhibitors, but this is only a hypothesis.

Peak fluxes in the ESN treatments tended to be higher or at the same level as conventional urea (Fig. 3 through 6). There were also significant late-season fluxes (July, August) in the ESN treatments at the Ellerslie site in both growing seasons (Fig. 3, 4). The significant late season fluxes are likely because there was still significant amounts of urea being released from the fertilizer prills into the soil late in the growing season, resulting excess available N when crop uptake was low (at the end of the growing season).

4. Conclusions

With respect to the 4R/NERP framework, the following conclusions from this research can be made:

1) RIGHT SOURCE: Polymer-coated urea was associated with consistently higher cumulative soil N_2O emissions compared to conventional urea regardless of timing of application (fall or spring) when mid-row banded at shallow depths (5 cm). These higher cumulative fluxes associated with ESN were a result of higher emissions during peak emission events in the spring and following seeding and also late in the growing season when crop demand for N was low, especially at the Ellerslie site in the Black Soil Zone.
2) RIGHT SOURCE: Urea products treated with nitrification inhibitors (eNtrench) or both nitrification and urease inhibitors (SuperU) were associated with lower cumulative soil N_2O emissions compared to conventional urea, but the reduced emissions were small and not statistically significant. It is not clear at this point why these inhibitor-treated products were not associated with lower emissions. Further investigation into the influence of soil properties such as organic matter levels and pH on inhibitor efficacy is likely required.
3) RIGHT PLACE: Observed nitrogen use efficiency was low for all fertilizer products in this study. Fertilizers applied at the time of seeding should be placed as close to the seed row as possible and deeper than the seed row to ensure that the crop will be able to access applied N as early in the growing season as possible.
4) RIGHT PLACE: Regardless of spring or fall application, soil N_2O generated from applied fertilizer in shallow bands has a much greater probability of entering the atmosphere than fertilizer-generated N_2O in deep bands.

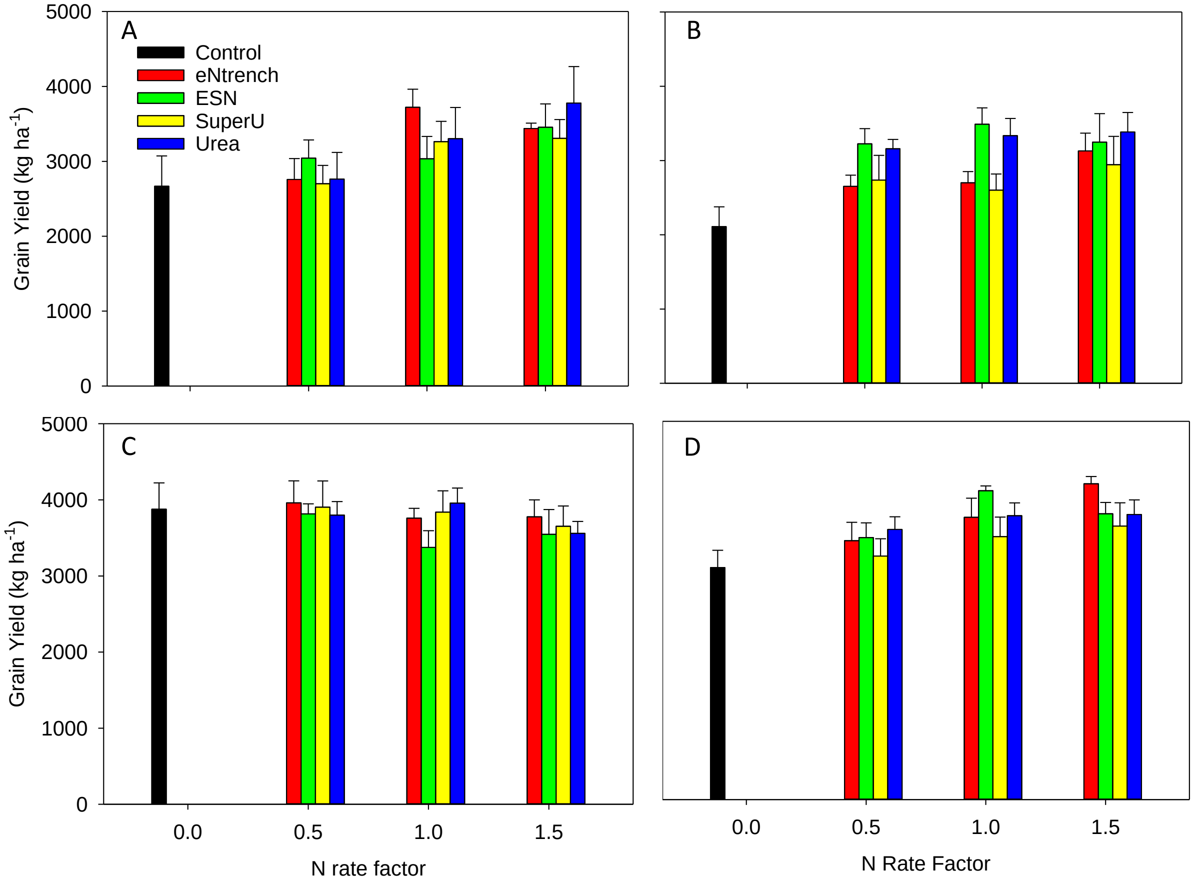

Figure 1: Summary of grain yields for the Ellerslie site: A) 2016 Fall-banded Treatments; B) 2016 Spring-banded Treatments; C) 2017 Fall-banded treatments; and D) 2017 Spring-banded Treatments. N Rate factors of 0, 0.5, 1.0 and 1.5 correspond to rates of 0, 40, 80 and 120 kg N ha^{-1}, respectively.

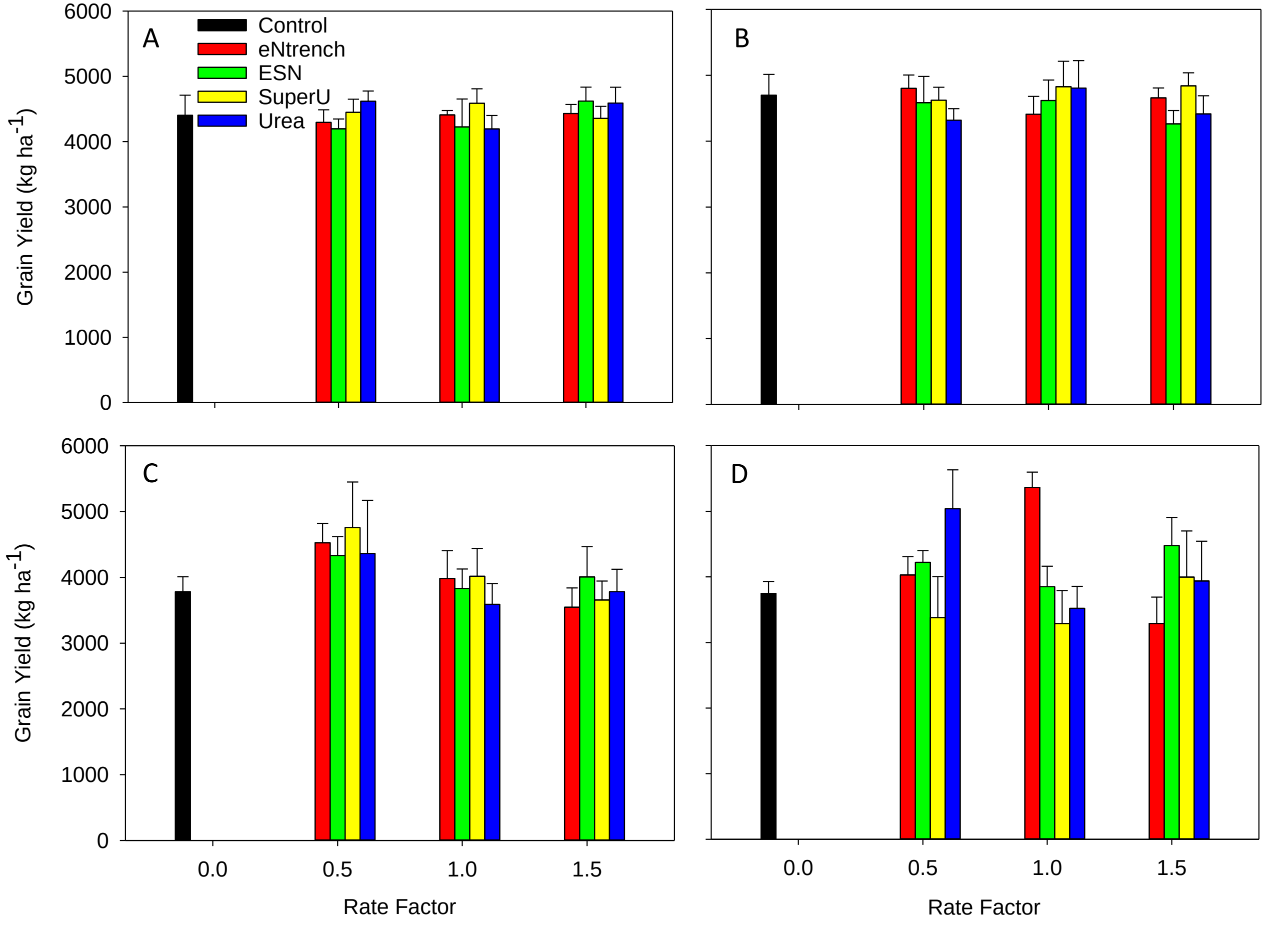

Figure 2: Summary of grain yields for the Lethbridge site: A) 2016 Fall-banded Treatments; B) 2016 Spring-banded Treatments; C) 2017 Fall-banded treatments; and D) 2017 Spring-banded Treatments. N Rate factors of 0, 0.5, 1.0 and 1.5 correspond to rates of 0, 30, 40 and 80 kg N ha^{-1}, respectively.

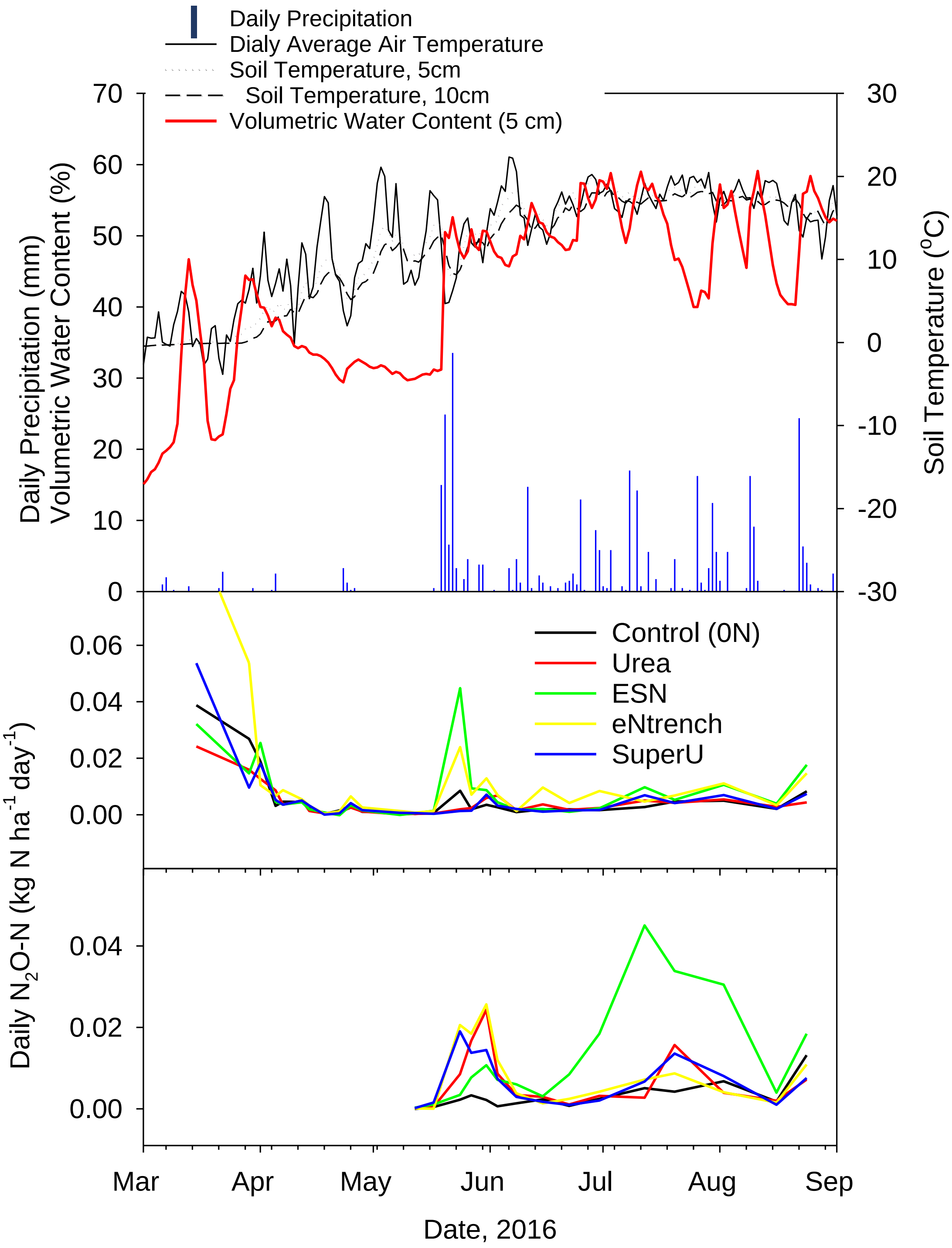

Figure 3: Summary of average (N=4), daily soil N_2O-N emissions (kg N ha^{-1} day^{-1}) measured in the 100% N rate treatments (80 kg N ha^{-1}), precipitation, air temperature soil temperature and soil water content at Ellerslie in 2016.

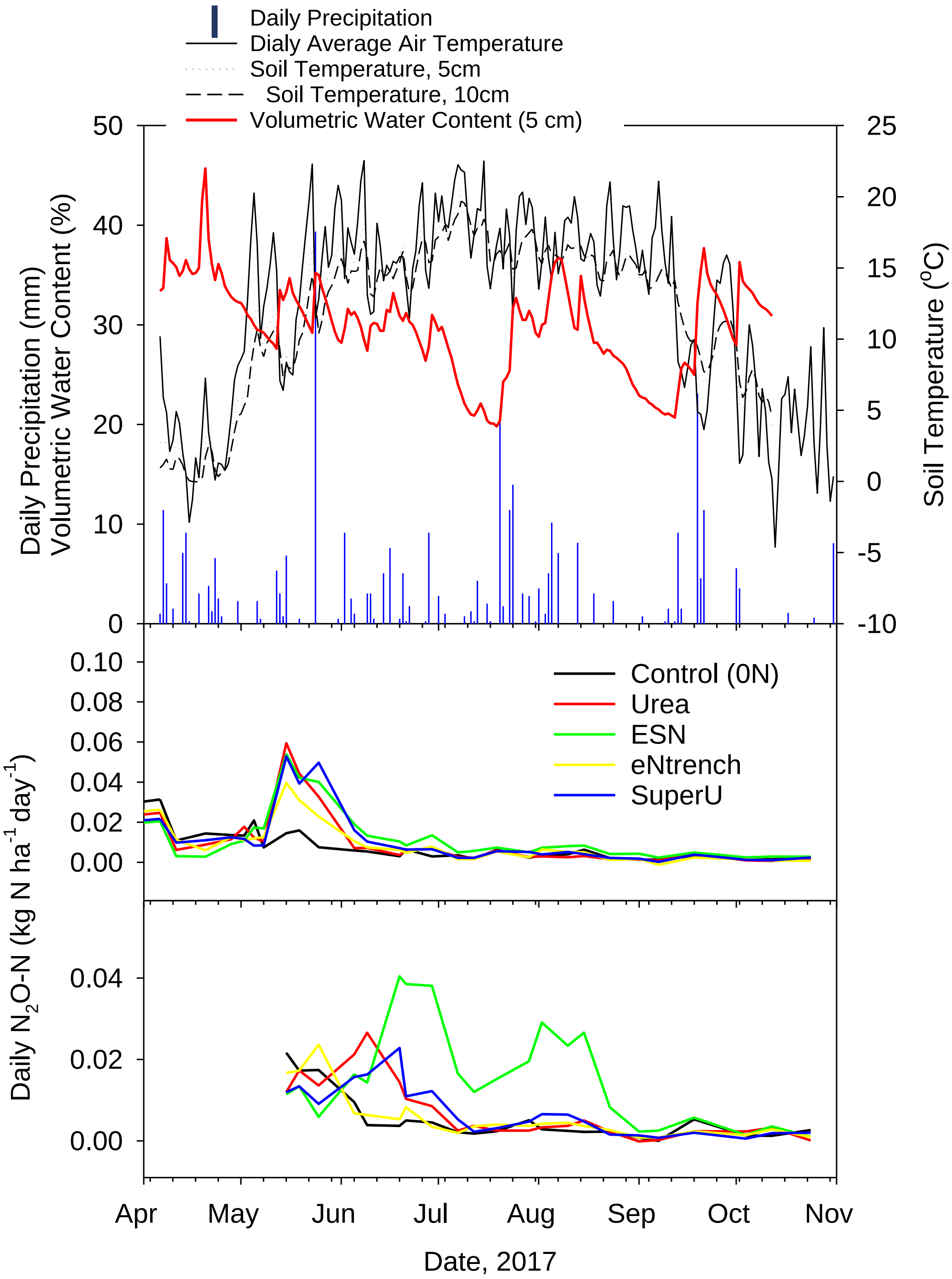

Figure 4: Summary of average (N=4), daily soil N_2O-N emissions (kg N ha^{-1} day^{-1}) measured in the 100% N rate treatments (80 kg N ha^{-1}), precipitation, air temperature soil temperature and soil water content at Ellerslie in 2017.

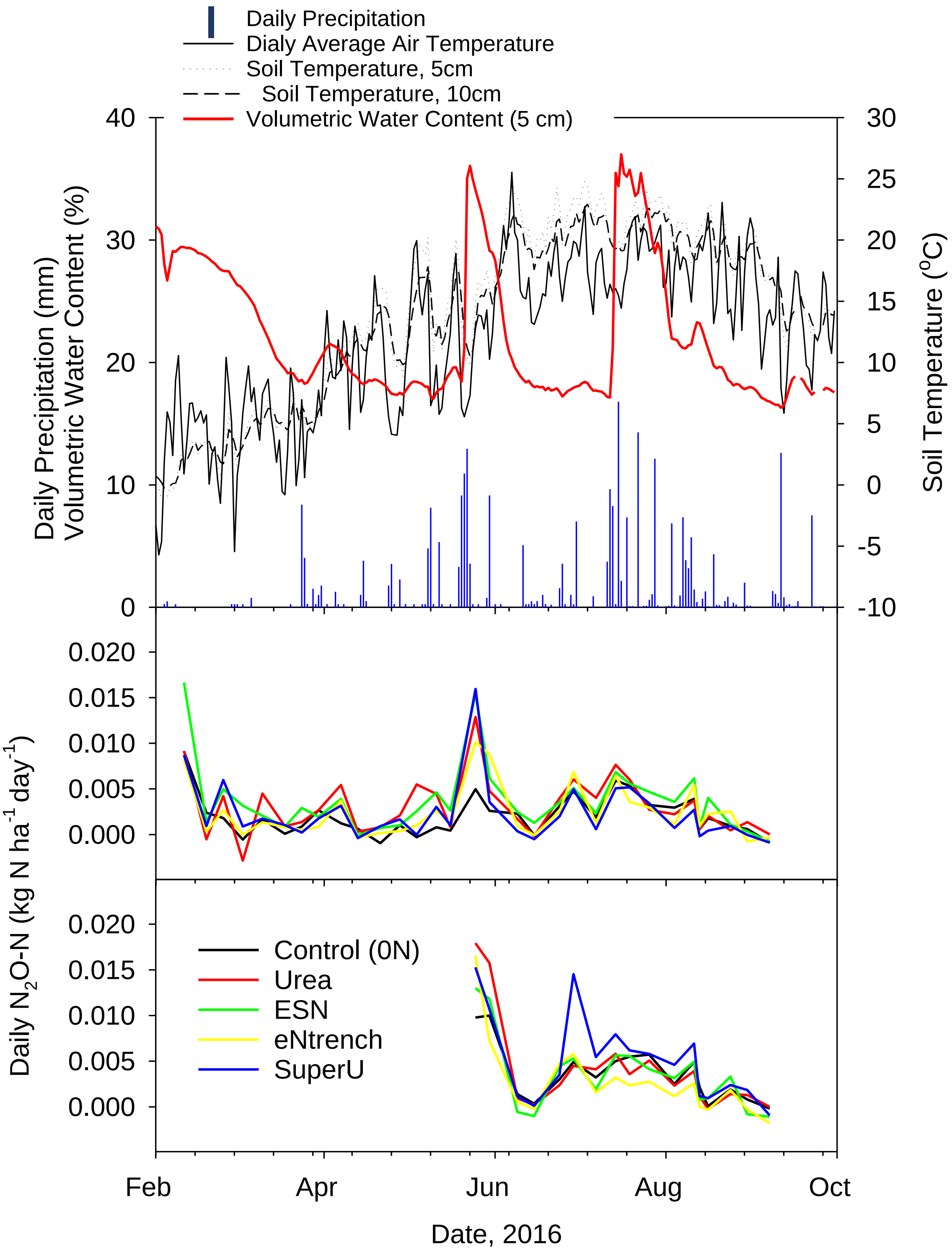

Figure 5: Summary of average (N=4), daily soil N_2O-N emissions (kg N ha^{-1} day^{-1}) measured in the 100% N rate treatments (60 kg N ha^{-1}), precipitation, air temperature soil temperature and soil water content at Lethbridge in 2016.

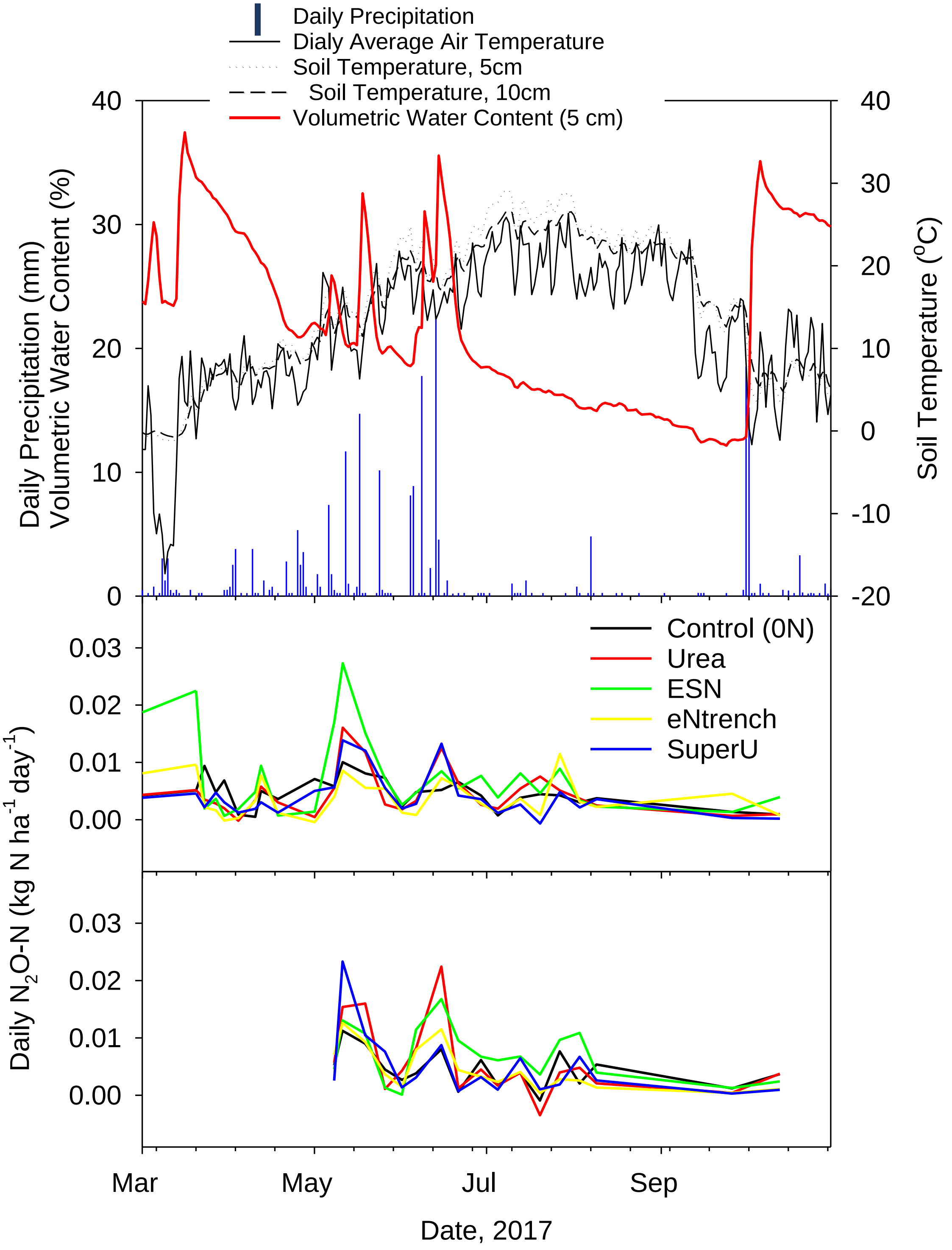

Figure 6: Summary of average (N=4), daily soil N_2O-N emissions (kg N ha^{-1} day^{-1}) measured in the 100% N rate treatments (60 kg N ha^{-1}), precipitation, air temperature soil temperature and soil water content at Lethbridge in 2017.

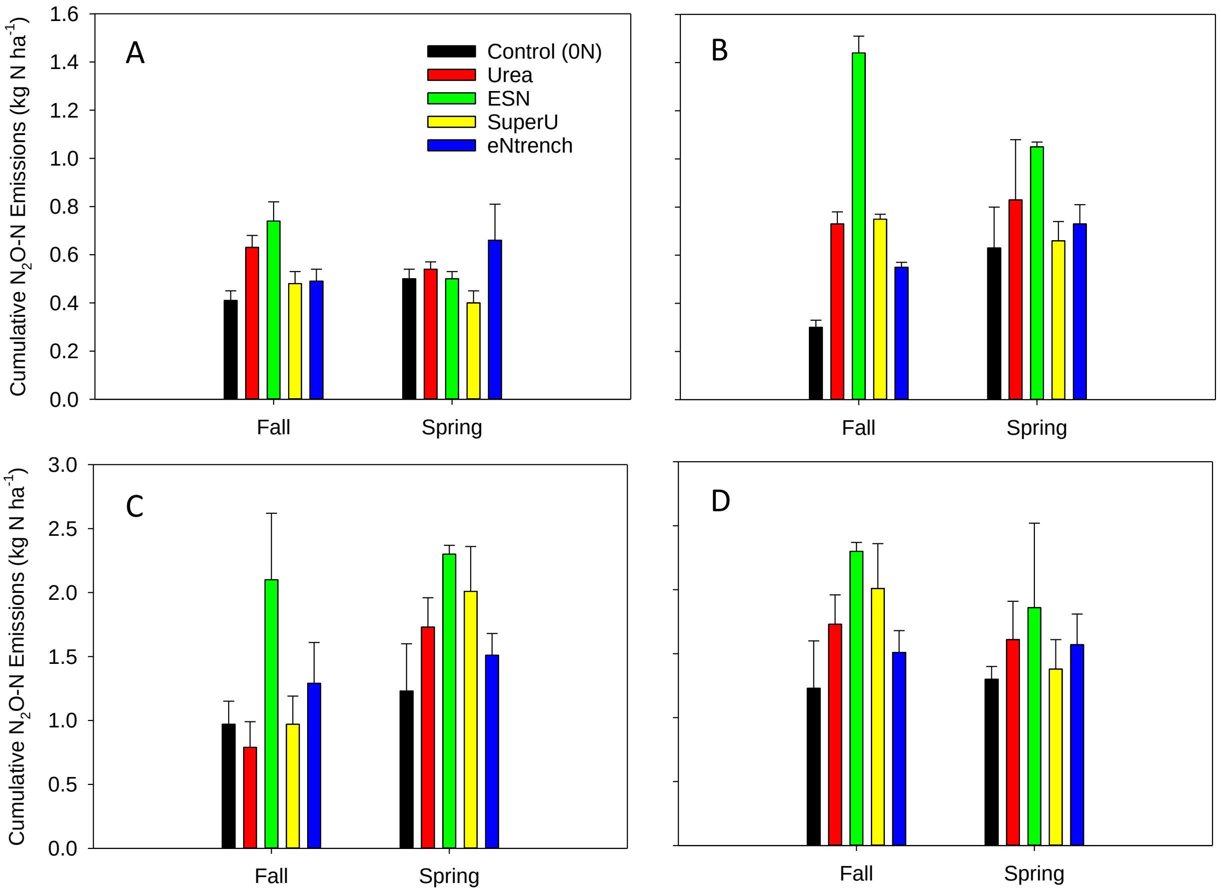

Figure 7: Summary of average (N=4), cumulative soil N_2O-N emissions (kg N ha^{-1} day^{-1}): A) Lethbridge, 2016; B) Lethbridge, 2017; C) Ellerslie, 2016, and D) Ellerslie, 2017. For spring-banded treatments, 0.139 (Lethbridge, 2016) , 0.044 (Lethbridge, 2017), 0.64 (Ellerslie, 2016), and 0.58 kg N_2O-N/ha (Ellerslie, 2017) were added to measured cumulative fluxes for the spring-banded treatments to account for pre-seeding emissions and allow comparison to fall-banded treatments.

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