Government of Saskatchewan
Ministry of Agriculture

ADF Project Progress Report Format

1. **Collecting the Carbon Data Needed for Climate-Smart Agriculture in Saskatchewan, 20200291, Progress Report for Jan 2021 - Apr2024 period**
   Funded by:
   - The Saskatchewan Ministry of Agriculture — Agriculture Development Fund
   - Saskatchewan Wheat Development Commission
   - Saskatchewan Canola Development Commission
   - Saskatchewan Oat Development Commission

2. **Principal Investigator:**
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3. **Collaborators:**
   Dr. Rich Farrell, Department of Soil Science, University of Saskatchewan
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   Dr. Tristan Skolrud, Agricultural Economics, University of Saskatchewan

   Technician:
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4. **Abstract (Not more than 250 words).** *Describe in lay language the progress towards the project objectives over the last reporting period. Include any key findings and any interim conclusions. Include any deviations from the original methodology.*

By establishing a new greenhouse gas (GHG) monitoring research station using micrometeorological techniques in Saskatoon, our goal is to provide direct, year-round field-scale GHG emission measurements for a representative prairie cropping system. These measurements will provide a better understanding of the periods of high risk for GHG emission, and to understand the crop management practices that lead to reduced emissions. From 2019 to 2022, significant thaw related N_2O emissions only occurred in 2 of the 4 years and were associated with higher fall nitrate levels and a more gradual soil thawing period. Measured cumulative N_2O emissions for the non-growing season were 123 to 938 g N ha^{-1}. Although these values were much smaller than those obtained at other cold climate sites, the average contribution of non-growing season N_2O emissions amounted to 52% of annual total emissions. The Mar to Apr period, specifically, contributed 30% of the annual total N_2O emissions in years without major thaw events, but 70% in years with significant thaws. Since 2021 and continuing into 2024, we are comparing divergent N management practices where half the field is under conventional N management and the other half is under "improved" N management, for a canola-wheat rotation. Preliminary results show that the improved N management scenario reduced N_2O emissions by 59% compared to the conventional scenario, with no effect on crop yield.

5. **Introduction:** *Brief project background and rationale (**Maximum of 1500 words or 1.5-3 pages).***

Carbon footprinting is a now an important component of provincial, national, and international sustainability initiatives, and crops produced with a low carbon footprint have a competitive advantage in the global marketplace (Amiro et al., 2014). However, there is a significant gap when it comes to carbon footprinting data for Saskatchewan cropping systems. Surprisingly, though a number of researchers have estimated C footprints using various carbon models (Gan et al., 2014, 2012, 2011; Shrestha et al., 2014), there is no **direct annual data** on net carbon footprints for Saskatchewan cropping systems. One reason for this is that direct measurement of the parameters needed to determine the carbon footprint generally relies on the use of micrometeorological methods and, to date, there have been no other efforts to establish a micrometeorological station devoted to direct measurement of the C footprint of cropping systems in Saskatchewan. Traditional chamber-based methods of measuring GHG fluxes are not designed to measure CO_2 uptake by the crop during photosynthetically active periods and thus are missing a significant portion of the data needed to determine net ecosystem exchange (NEE; i.e., the balance between CO_2 uptake during photosynthetically active periods and CO_2 loss via plant [and soil] respiration). At the same time, carbon models often have a high degree of uncertainty, with a trade-off between accuracy and model completeness (Goglio et al., 2015), yet the direct annual data needed to calibrate the models for Saskatchewan conditions is currently unavailable. The proposed research will address these gaps by providing spatially and temporally integrated data on greenhouse gas (GHG; N_2O and CO_2) emissions at the field scale that can be used to determine NEE and the net carbon footprint. Using a micrometeorological approach, the proposed research will provide the first direct measure of the carbon footprint of a typical Saskatchewan cropping system. The ultimate goal of this research is to support policy development for local producers as they enter the carbon economy and ensure the competitiveness of Saskatchewan agriculture.

The proposed research—which builds on a unique collaboration between Drs. Congreves and Farrell at the University of Saskatchewan and Dr. Claudia Wagner-Riddle at the University of Guelph—will provide direct measurements of NEE and develop a net carbon footprint for the predominant crops grown in Saskatchewan (i.e., wheat and canola) by using one of Dr. Wagner-Riddle's flux gradient micrometeorological systems (hereafter referred to as "Micromet") at a research site maintained by the U of S. The Micromet approach enables near-continuous measurement of GHG fluxes (every half-hour), year-round, and over a large area (12 ha field-scale assessments)—yielding emission data that is both spatially and temporally integrated (Wagner-Riddle et al., 2005). As a result, the Micromet approach is the "gold standard" for quantifying GHG emissions at the farm-scale, feeding into carbon footprint calculations.

We have spent the past several years getting the system operational and developing modifications needed to adapt the system for the much harsher winters experienced in Saskatchewan compared to Ontario. As a result, we can now measure overwinter soil N_2O emissions (a task that was previously challenging due to harsh winter conditions that preclude chamber-based measurements) and NEE (year-round CO_2 balance between photosynthetic sequestration and soil respiration). These data—together with other life cycle metrics—are needed to develop an accurate carbon footprint for any cropping system. Moreover, the proposed field-scale assessments are needed to bring Saskatchewan into line with other provinces that already have GHG Micromet research stations that feed data into developing climate-smart cropping practices i.e., Manitoba and Ontario (Amiro et al., 2017; Congreves et al., 2017; Glenn et al., 2012; Tenuta et al., 2016; Wagner-Riddle et al., 2007).

Soils are by far the main anthropogenic source of N_2O, contributing 65% of Canada's national N_2O emissions, and as much as 70% of annual N_2O emissions from croplands occur when the soil thaws. While previous research suggested that cold winter conditions of the prairies drive higher N_2O fluxes at thaw (Wagner-Riddle et al., 2017), our preliminary research with the Micromet system in Saskatoon points towards fairly low overwinter N_2O emissions relative to those measured at similar GHG research stations in Manitoba and Ontario. This implies that Saskatchewan might have a lower carbon footprint than other cropping regions in Canada; at present, however, the data needed to support this assertion is lacking—underscoring the need for research to determine the annual carbon footprint of representative Saskatchewan cropping systems. We hypothesize that prairie cropping systems are a net carbon sink. Furthermore, our proposed research will encompass field-scale assessments of 4R+ practices where 4R fertilizer strategies are combined with other agronomic 'best management bundles' aimed at minimizing carbon footprints. Providing farm-ready methods of reducing carbon footprints is a promising way to bolster the competitiveness of Saskatchewan agriculture in the era of environmental stewardship.

6. Objectives and the *progress towards meeting each objective*

Objectives (*Please list the original objectives and/or revised objectives if Ministry-approved revisions have*	**Progress (e.g. completed/in progress)**

been made to original objective. A justification is needed for any deviation from original objectives)	
a) Provide direct, year-round field-scale measurements of greenhouse gas emissions from a representative cropping system	Measurements collected in 2021, 2022, and 2023; data filtering and analysis in progress. The N_2O data has been filtered and analysed from 2018-2023; write-up in progress.
b) Test the hypothesis that Saskatchewan cropping systems are a net carbon sink by determining net ecosystem exchange and the net carbon footprint of the cropping system	Measurements collected in 202, 2022, and 2023; data filtering and analysis in progress. The N_2O data has been filtered and analysed from 2018-2023; write-up in progress.
c) Provide field-scale assessments that encompass 4R+ practices aimed at minimizing carbon footprints	Measurements collected in 2021, 2022, and 2023; data filtering and analysis in progress. The N_2O data has been filtered and analysed from 2018-2023; write-up in progress.

7. **Changes in the work plan, or budget:** *Briefly explain new challenges found during the work completed in this reporting period and the impact on the work plan or the budget **(Maximum of 1 page)***

Challenges: 2021 was extremely dry, largely hampering canola crop production. Like most farmers that year, we also found germination patchy, heat and drought-stressed crops, and very low yields. This informed the fertilizer management scenarios in 2022, because there was a fair amount of residual fertilizer N left in the soil after harvest in 2021. As such, in 2022, we continued the conventional vs "improved" N management comparison with 50 kg N ha^{-1} of urea *vs* no fertilizer representing the "improved" scenario. The 2022 and 2023 growing season were better than in 2021. In 2023, we continued with the conventional vs "improved" N management comparison with 100 kg N ha^{-1} of urea *vs* the "improved" scenario of 50 kg N ha^{-1} as SuperU.

8. **Methodology:** *Specify project activities undertaken during this reporting period. Include approaches, experimental design, tests, materials, sites, etc. Please note that any significant changes from the original work plan will require written approval from the Ministry.* ***(Maximum of 5 pages)***

Obj. 1) Provide direct measurement of net ecosystem exchange and determine the net carbon footprint of a representative cropping system in Saskatchewan; Obj. 2) Test the hypothesis that Saskatchewan cropping systems are a carbon sink

A new Micrometeorology research station was established within the lands at the University of Saskatchewan's North Management Area (near the former U of S feed lot). The soil at this site was sampled for initial physico-chemical characterization. This site is equipped with flux-gradient micrometeorology techniques to collect half-hourly measurements of N_2O and CO_2 fluxes over a large area of land (i.e., *ca*. 12 ha, divided into 4 equally sized quadrants), which provides a very powerful tool for better understanding large-scale GHG emissions.

The experimental site consists of four *ca*. 3-ha plots with a trailer that houses the gas detection and control systems located at the center of the site. Our research encompasses a 2-yr canola-cereal rotation for two cycles (4 years). Gas collection towers (with tubing and cable running from the towers back to the trailer) are located in the centre of each of the four plots. In addition, equipment to measure wind speed and direction, soil temperature, soil moisture, and air temperature and humidity are placed in the center of one of the four plots. The plots were first established in the fall of 2018, with gas measurements commencing immediately upon installation. As such, we have obtained preliminary data for greenhouse gas emissions overwinter and at spring thaw in 2019 and 2020 (barley production). In 2021, we tracked emissions for canola production (Figure 1), continued to do so in 2022 for wheat production (Figure 2), in 2023 for canola production, and we are continuing to do so in 2024 for wheat production.

Figure 1 Photos of the micromet equipment (loggers, anemometer, and sampling towers) during canola production in 2021 (Photo credit: Kate Congreves).

Figure 2: Photos of the micromet site during wheat production in 2022 (Photo credit: Olivia Otchere).

Soil sampling was conducted at pre-plant and at harvest for 0–15, 15–30, and 30–60 cm depths as a composite of 10-12 cores per quadrant. Soil samples were frozen prior to analysis; where, upon thawing, sub-samples will be extracted with KCl and analyzed for ammonium and nitrate concentrations. At harvest, above-ground biomass, seed yield, and test weights were determined; seed N content was also determined. A C footprint for each crop and for the rotation, will be calculated using the NEE and N_2O emissions data combined with other life cycle metrics. Cumulative GHG emission estimates and NEE will be calculated; GHG-intensities (i.e., cumulative emissions expressed on a yield basis) also will be determined and related to crop nitrogen use efficiency (NUE).

Obj. 3) Provide field-scale assessments that encompass 4R+ practices aimed at minimizing the carbon footprint of a canola–cereal cropping system

Specifically targeting reduced emissions during the thaw period could play a key role in reducing annual emissions from cropping systems. This objective will determine how fertilizer management influences N_2O emissions – as well as CO_2 emissions and net ecosystem exchange – which will allow us to develop a more accurate carbon footprint for the cropping system.

In 2021 we evaluated the impact of fertilizer source (conventional urea *vs.* enhanced efficiency formulation of urea with Anvol™). The application of fertilizer source was bundled with other best agronomic management practises (amount of fertilizer) to represent "4R" management 1) Urea fertilized banded at the typical recommended rate (based on removals) of 100 kg N ha^{-1}, compared to 2) Urea + Anvol applied at the 30% less the soil-test recommended rate (50 kg N ha^{-1}). Note: 2021 was extremely dry — and the canola production was largely hampered by the climatic conditions. In 2022, we planted wheat and continued comparing fertilizer management scenarios. For 2022, the soil residual N levels informed the N fertilizer management comparison of 50 kg N ha^{-1} of urea fertilizer vs 0 fertilizer application, representing the "better N management" scenario and comparison. In 2023, the N fertilizer management comparison was also informed by soil-tests, the comparison continued as 100 kg N ha^{-1} of urea fertilizer vs 50 kg N ha^{-1} applied as SuperU (which has urease and nitrification inhibitors), representing the "better N management" scenario. Overall, we have been able to continue with comparing the two divergent scenarios and will continue to evaluate the accumulated impact from year to year (canola to wheat) for greenhouse gas emissions and carbon footprinting. In 2024 for wheat production, the treatments will be similar, comparing 100 kg N ha^{-1} of urea to 50 Kg N ha^{-1} of SuperU (an enhanced efficiency product, with urease and nitrification inhibitors).

9. **Results and discussion:** *Describe research accomplishments during the reporting period under relevant objectives listed under section 6. The results need to be accompanied with tables, graphs and/or other illustrations. Provide discussion necessary to the full understanding of the results. Where applicable, results should be discussed in the context of existing knowledge and relevant literature. Detail any major concerns or project setbacks.* ***(Maximum of 20 pages of text not including figures or tables).***

Understanding Overwinter Emissions

Distinct emission events occurred in Apr 2020 and Mar to Apr 2022 associated with the thaw period and also with fertilizer application in June of the canola year (2021) starting on day 150 (Fig. 1). Prolonged emission events did not occur in the other years during growing season or non-growing season, but emissions did increase for shorter periods such as in Jan and Feb 2019 in non-growing season, Jun and Jul 2019 and Jun 2022 in the growing season.

Differences in cumulative soil freezing degree days were not significantly related to non-growing season N_2O emissions ($P=0.7$) (data not shown). Soil water content at time of thaw was close to saturation in all years and did not vary significantly between fields. However, fall soil nitrogen levels were higher for the conventional N management fields in 2019 and 2021. The fall soil nitrate level was a strong explanatory variable for the difference in observed total emission during the Nov-Apr period with an r^2 of 0.485 ($P = 0.037$) (Fig. 4).

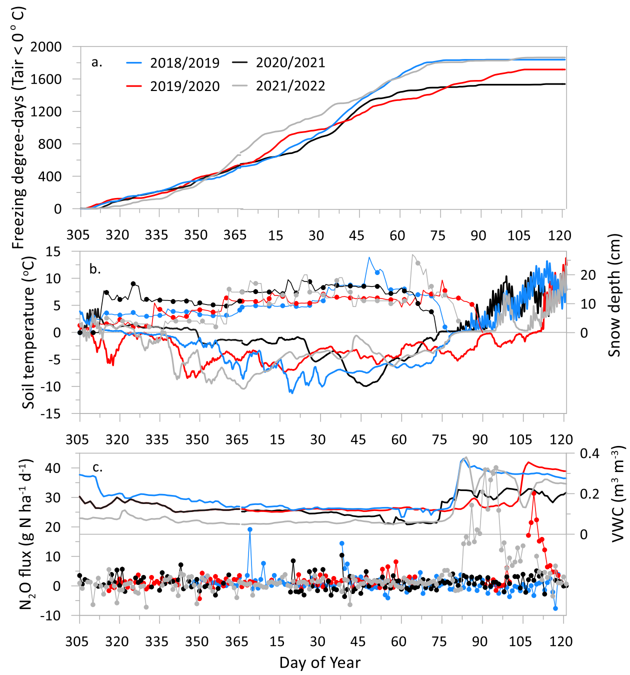


Figure 1. a. Daily air temperature b. half-hourly soil temperature at 10 cm depth (solid line) and daily snow depth (line with symbols), and c. daily volumetric soil water content (VWC) at 10 cm depth (solid line) and daily N_2O flux (line with symbols) at the experimental site from Nov 1 (day 305) to Apr 30 (day 121) for the four study years (fall 2018/spring 2019, fall 2019/spring 2020, fall 2020/spring 2021, and fall 2021/spring 2022).

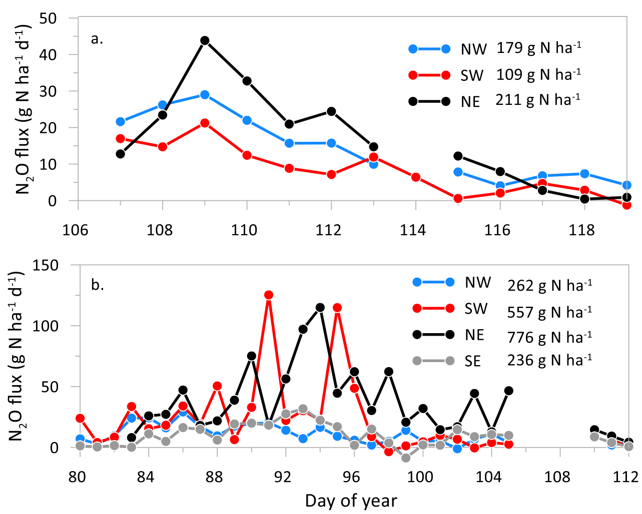


Figure 2. Daily N_2O fluxes during the main thaw for a. spring 2020 and b. spring 2022 by field (note the difference in scales between a and b). In fall 2019, the NW and SW quadrant received irrigation and NW quadrant received a fertilizer application. Data was unavailable for the SE quadrant in 2020. No specific treatments were applied in fall 2021 but spring fertilizer applications differed starting in spring 2021 (the northern quadrants are under conventional N management, whereas the southern quadrants are under better N management). Values in legend are cumulative N_2O emissions for day 107 to 119 in 2020 and day 80 to 105 in 2022.

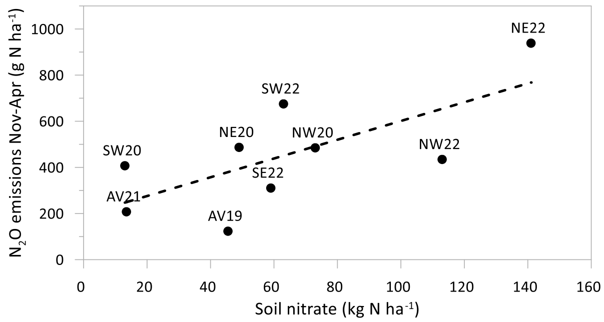


Figure 3. Relationship of fall soil nitrate levels (0-15 cm depth) and cumulative N_2O emissions for Nov to Apr over the 2018 to 2022 study period. Labels on each data point indicate the field (e.g., SW denotes the southwest field ["improved" N], SE denotes the southeast field [also "improved" N], NW denotes the northwest field [conventional N], and NE denotes the northeast field [also conventional N]) and spring year (e.g., '19' shows the spring of the 2018/2019 year) with 'AV' indicating when the average of all fields is displayed. The dashed line shows a linear regression between the soil nitrate levels and the N_2O emissions where Y = 4.07 X + 194.4 with n = 9 and r^2 = 0.489 (P = 0.036).

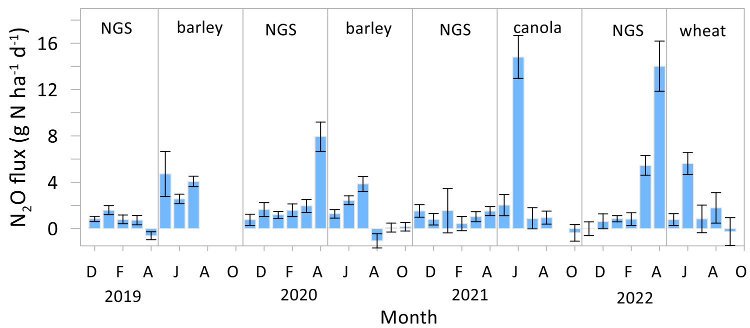


Figure 4. Mean daily N_2O fluxes for each measurement month across all four fields from Dec 2018 to Sept 2022. Vertical lines delineate non-growing season (NGS, from Nov to Apr) and growing season (May to Oct) with crops grown each year. Error bars indicate standard error of the mean.

Understanding how N Management Influences Production and Emissions

Yield

The N fertilizer management had no effect on crop yields (Figure 5). Canola yields averaged 83 kg ha^{-1} in 2021, but 1,249 kg ha^{-1} in 2023. Average wheat yields were 2,857 kg ha^{-1} in 2022 and TBD in 2024. According to the data from the Ministry of Saskatchewan Crop Report and Saskatchewan Crop Insurance Corporation (Government of Saskatchewan, 2023b), the average canola yields for the Saskatoon region were 599 kg ha^{-1} for 2021 and 1,591 kg ha^{-1} in 2023. As for spring wheat, the average regional yield was 1,915 kg ha^{-1} in 2022 and TBD in 2024.

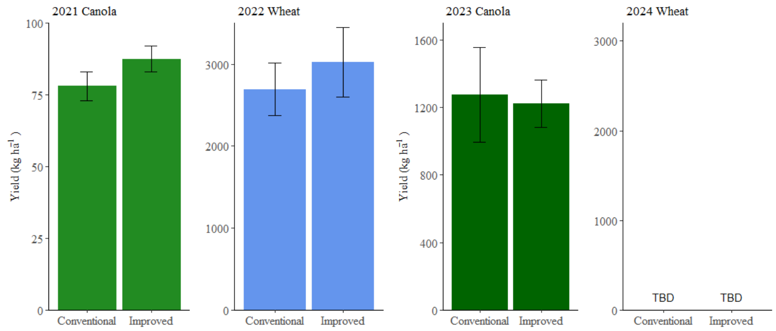
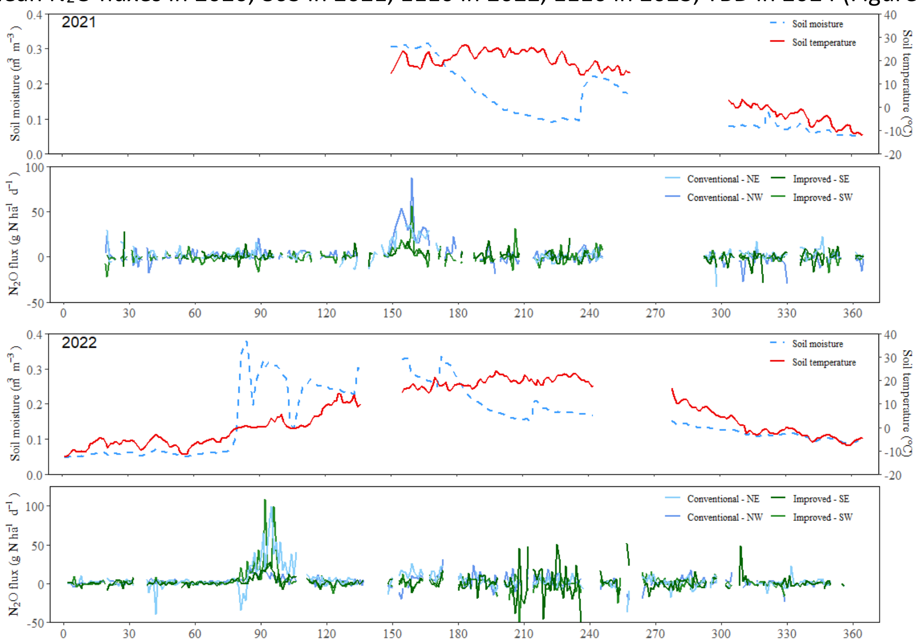


Figure 5. Wheat and canola yield (kg ha^{-1}) for each N fertilizer management treatment (conventional and improved). Error bars represent the standard error of the mean. *Note the different y-axis scales for each year.

Nitrous oxide emissions

High frequency individual daily N_2O fluxes from the four fields were collected from November 2020 to present day, with 91 daily mean N_2O fluxes in 2020, 863 in 2021, 1110 in 2022, 1110 in 2023, TBD in 2024 (Figure 6).



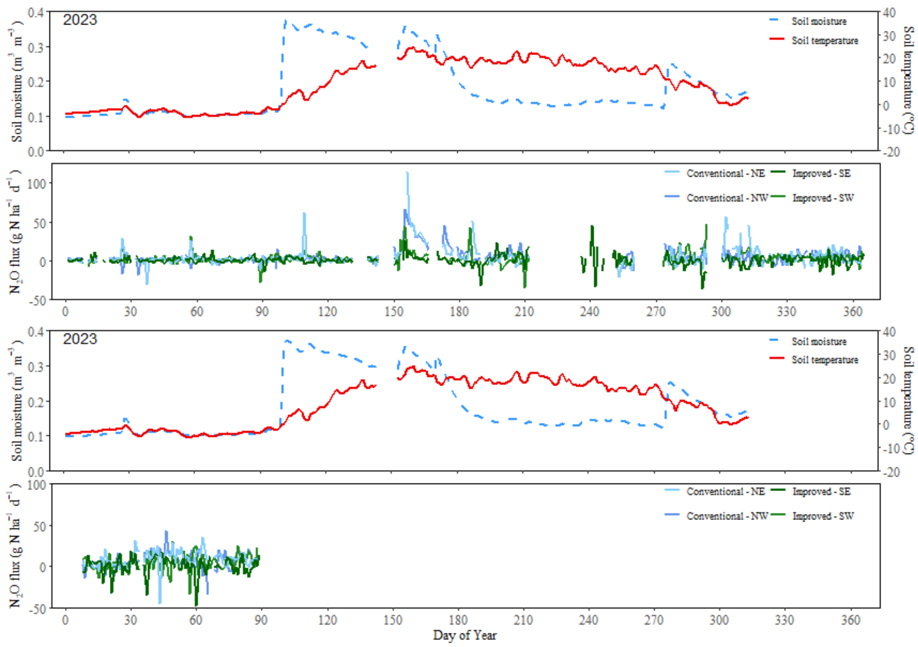


Figure 6. Daily measured N_2O fluxes (g N ha^{-1} d^{-1}) from each field (NW, NE, SW, SE) from 2021 to 2024, with associated average soil moisture (m^3 m^{-3}) and soil temperature (°C). NW: North-West; NE: North-East; SW: South-West; SE: South-East.

The average cumulative N_2O emissions for the conventional and improved N treatments are 1380 ± 403 g N ha^{-1} yr^{-1} and 547 ± 188 g N ha^{-1} yr^{-1} (Figure 7). The improved N treatment had a compounding effect, reducing the total cumulative N_2O emissions of the 4-year crop rotation by 59 ± 8%.

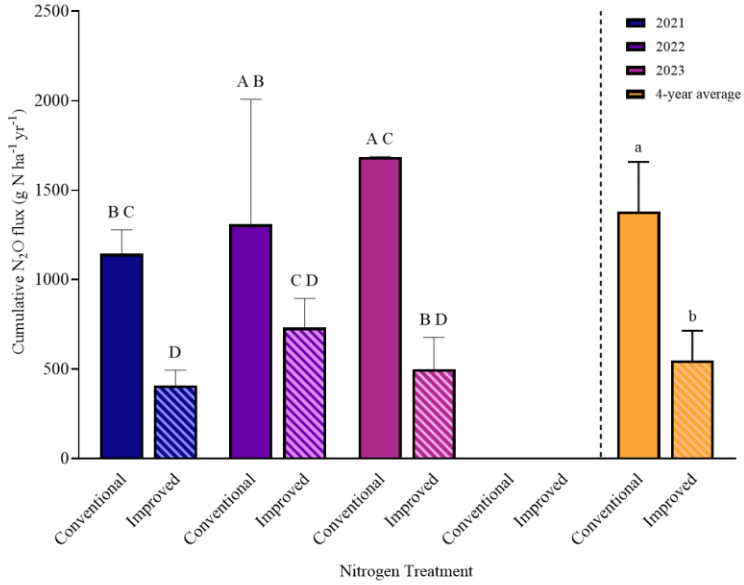


Figure 7. Annual and 4-year average cumulative N_2O emissions (g N ha^{-1} yr^{-1}) of conventional and improved N treatments from 2021 to 2024. The dotted line separates the statistical analysis into (left) a two-way ANOVA conducted for individual years and N treatments, and (right) a Mann-Whitney U test for 4-year average and N treatments.

10. Interim conclusions (*Maximum of 500 words*).

It is crucial that we continue this research because it demonstrates that low-carbon cropping systems are possible here, and it provides the carbon data needed to support the field crop production industry in Saskatchewan. So far, we have identified key take-home messages like:

A. At our site, non-growing N_2O emissions were not explained by cumulative freezing degree days unlike most other cold climate sites. We propose that non-growing season N_2O emissions are more strongly influenced by soil moisture dynamics during soil freezing-thawing conditions in dry regions whereas soil freezing intensity is the more dominant factor for wetter regions.
B. Even in a cold semi-arid region the non-growing season is an important source of N_2O emissions and must be considered for more accurate reporting and developing mitigation strategies.
C. Preliminary results show that the improved N management scenario reduced N2O emissions by 59% compared to the conventional scenario, with no effect on crop yield.

11. List any technology transfer activities undertaken in relation to this project: *Include conference presentations, talks, papers published etc.*

Publications

- Wagner-Riddle, C., Congreves, K.A., Brown, S.E., Helgason, W.D., Farrell, R.E., 2024. Overwinter and spring thaw nitrous oxide fluxes in a northern Prairie cropland are limited but a significant proportion of annual emissions. Global Biogeochemical Cycles, doi.org/10.1029/2023GB008051

Presentations

- Ferland, Daphnée, Brown, S. E., Wagner-Riddle, C., Farrel, R.E., Congreves, K.A. (March 5-6th, 2024). Nitrous oxide emissions from a canola-wheat cropping system in Saskatchewan. Soils and Crops, Saskatoon, SK.
- Ferland, Daphnée, Brown, S. E., Wagner-Riddle, C., Farrel, R.E., Congreves, K.A. (June 26-29th, 2023). Greenhouse gas emission measurements from a canola-wheat cropping system in Saskatchewan. Annual Meeting, Canadian Society of Soil Science, Truro, NS.
- Ferland, Daphnée, Brown, S. E., Wagner-Riddle, C., Farrel, R.E., Congreves, K.A. (March 15-16th, 2024). N2O emissions from a canola-wheat cropping system in Saskatchewan. 39th Plant Science Graduate Student Symposium, University of Saskatchewan, Saskatoon, SK.
- Congreves, K.A. (2021). Balancing acts for a sustainable food future. Café Science. Sept 28, 2021.
- Congreves, K.A. (2021). Moving towards sustainable agriculture by nurturing soil ecosystem services. 36th Plant Sciences Graduate Student Symposium, Saskatoon (Virtual), Mar 4, 2021. *Invited Keynote*.

Micromet training

- Sent Olivia (Technician) and Daphnée (new MSc student) to Guelph for a week-long training session to build the equipment operation and maintenance skills, as well as data processing and management.

Highly qualified personnel recruitment

- Recruited new MSc student, Daphnée Ferland, to work on this project (2023)
- MSc student, Shiva, recruited to work on economics under Dr. Skolrud
- Trained Olivia Otchere, Research Tech, to take over field management of the micromet site (2022)

Interviews

- Congreves interviewed by Carolyn King for Top Crop Manager article, Feb 2022.
- Ferland interviewed by Radio-Canada. Récit numérique – ICI Saskatchewan. 855 entreprises agricoles créées par des femmes en 5 ans en Saskatchewan. (8 mars, 2023). Radio-Canada, Saskatoon, SK,
- Ferland interviewed by Radio-Canada. Balado – Pour faire un monde. Des bancs d'école aux champs : le parcours d'une jeune agricultrice. (7 février, 2024; 6 mars, 2024). Radio-Canada, Saskatoon, SK.

Courses

- Taught PLSC 440/840 Climate Smart Agriculture, winter term 2022.

Panel

- Panelist for the "Career workshop" for Climate Smart Soils Annual Conference, Apr 2022.

12. Identify any changes expected to industry contributions, in-kind support, collaborations, or other resources.

No changes

13. Appendices: *Include any additional materials supporting the previous sections, e.g., detailed data tables, maps, graphs, specifications, literature cited (using a consistent reference style), acknowledgments*

Not applicable