**ADF Project Progress Report Format**

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


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3. **Collaborators: Drs. Rich Farrell, Claudia Wagner-Riddle, Warren Helgason, Tristan Skolrud**


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.*


Better understanding the carbon balance of agricultural systems offers a pathway towards more sustainable agriculture. With this research project, our goal is to provide direct, year-round field-scale greenhouse gas (GHG) emission measurements for a representative cropping system in Sask. We laid the foundation for this project back in fall 2018 (i.e., started getting the equipment to the site, and people trained); and with the funding in winter 2021, we officially started. We use flux-gradient micrometeorology to measure GHG emissions near-continuously, year round, over about 11 hectares for a canola-wheat rotation—with different N rates and N products. We collect $N_2O$ and $CO_2$ data every half-hour, year round over this large spatial scale. With this data, we can measure net totals (C balance), in other words: how much get emitted *vs.* how much gets sequestered.


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 has been no effort 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 (i.e., NEE – cumulative $N_2O$ [expressed in $CO_2$-equivalents]). 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 (16 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 few 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 been made to original objective. A justification is needed for any deviation from original objectives)*** | **Progress (e.g. completed/in progress)** |
|---|---|
| **a)** Provide direct, year-round field-scale measurements of greenhouse gas emissions from a representative cropping system | Measurements colleted in 2021; data filtering and analysis in progress. The $N_2O$ data has been filtered and analysed from 2018-2021; 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 colleted in 2021; data filtering and analysis in progress. The $N_2O$ data has been filtered and analysed from 2018-2021; write-up in progress. |
| **c)** Provide field-scale assessments that encompass 4R+ practices aimed at minimizing carbon footprints | Measurements colleted in 2021; data filtering and analysis in progress. The $N_2O$ data has been filtered and analysed from 2018-2021; 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, we also found germination patchy, heat and drought-stressed crops, and low yields. This will have an impact on the fertilizer management scenarios in 2022 (see last paragraph of the methods section where we outline the adaptations).

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*. 16 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*. 4-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 be 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), and are gearing up to track emissions in 2022 for wheat production (in progress).


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

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.

Specifically, 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 will be planting wheat and continue comparing fertilizer management scenarios. For 2022, we have to adapt to the legacy of the 2021 growing season—which was really dry, leading to poor crop yields and therefore low N removals. As such, the site had fairly high N contents after the 2021 harvest. This means that, for the 2022 season, the fertilizer management comparison will be adapted to best reflect a "business as usual scenario" compared to a "better N management" scenario. The "business as usual" scenario will be a 50 kg N $ha^{-1}$ application of urea, banded at wheat planting. The "better N management scenario" will be applying N according to the soil-test recommendation (which ends up being close to 0 kg N $ha^{-1}$). As such, it doesn't make sense to apply an enhanced efficiency product in 2022 for the "better N management scenario" because little to no fertilizer is even necessary. Nonetheless, we are 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 carbon footprinting.

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).***

Data from 2021 is being used in conjunction with data from 2018 to 2020 for a fuller dataset and longer-term picture. Carbon footprinting is in progress; the data is being assembled. For the $N_2O$ data (which is the key component of the carbon footprint), preliminary results and key observations are reported here:

- Annual cumulative $N_2O$ emissions have been relatively low over the past few years (Fig 2), most likely due to the persistently dry conditions. Nonetheless, overwinter emissions (Nov to Mar each year) plus spring what (Apr) represent a sizable portion annual cumulative $N_2O$ emissions i.e., 29 to 71% of annual emissions, depending on the year (Fig 2)
- Neglecting the overwinter period (Nov to Mar) would underestimate the annual $N_2O$ emissions by a considerable amount, even here on the prairies where it is cold for a long period of time. Despite the small daily fluctuations in $N_2O$ during the cold winter (Fig 3), they to add up to constitute a net source of emissions (Fig 2).

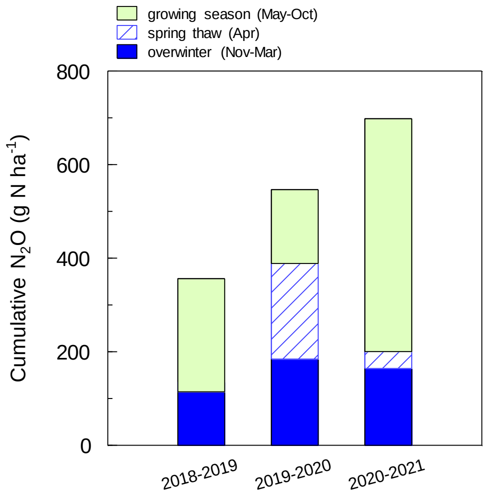


*Figure 2 The proportion of annual cumulative nitrous oxide ($N_2O$) emissions attributed to the growing season, overwinter period, and spring thaw—as per the micrometerological data from 2018 to 2021 at our Saskatoon greenhouse monitoring site.*

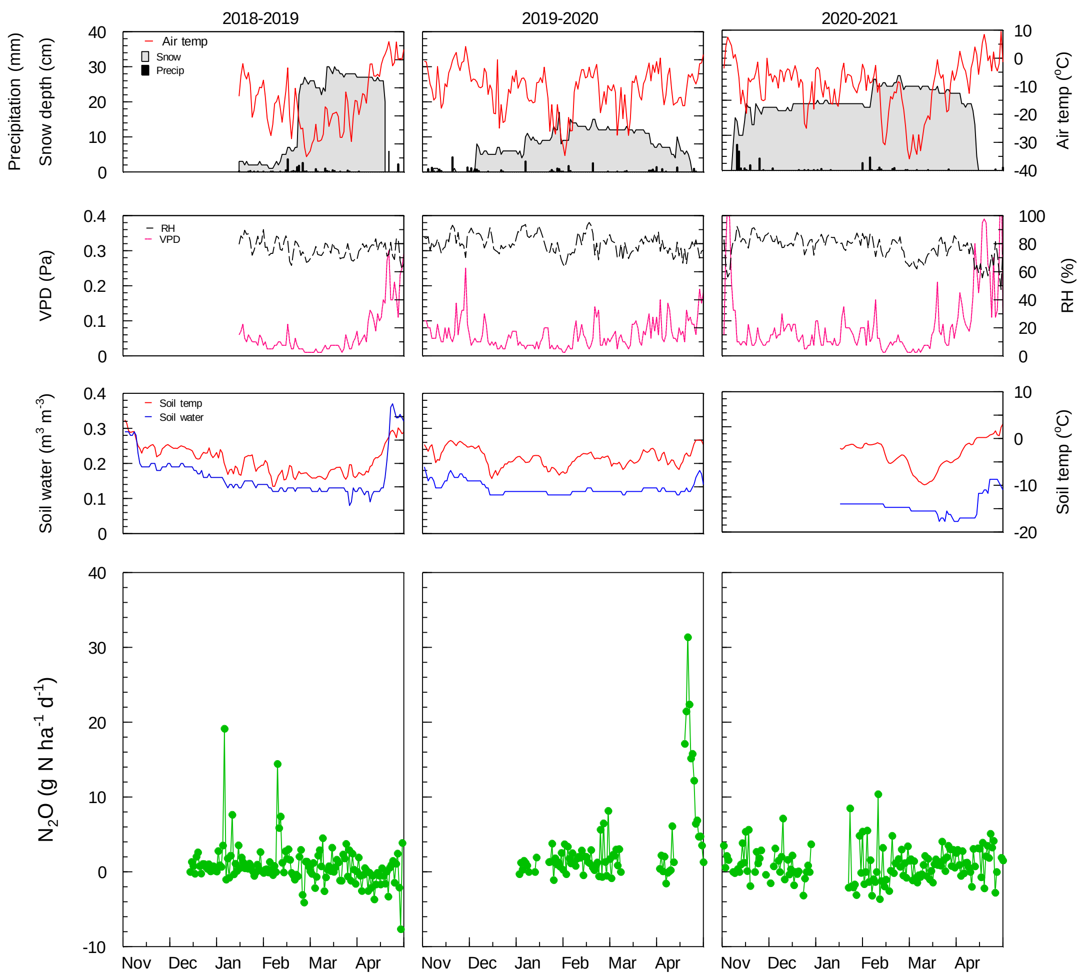


*Figure 3 Nitrous oxide ($N_2O$) emissions from Nov to Apr for each of the past three years; in context of key factors known to regulate emissions (i.e., snowpack depth, precipitation, air temp; vapour pressure deficit (VPD) and relative humidity; soil water and temperature in the top 10 cm depth).*

- Interestingly, the vapour pressure deficit appears inversely related to $N_2O$ emissions at spring thaw (Apr). When the vapour pressure deficit was high during the spring thaw (i.e., a “dry melt”), emissions tended to be lower (Fig 4). This might be a new way of looking at $N_2O$ production during spring thaw…and may explain why prairie cropping systems have been experiencing lower than expected $N_2O$ emissions during spring thaw. We will explore this concept further by calculating soil potential evaporation dynamics.

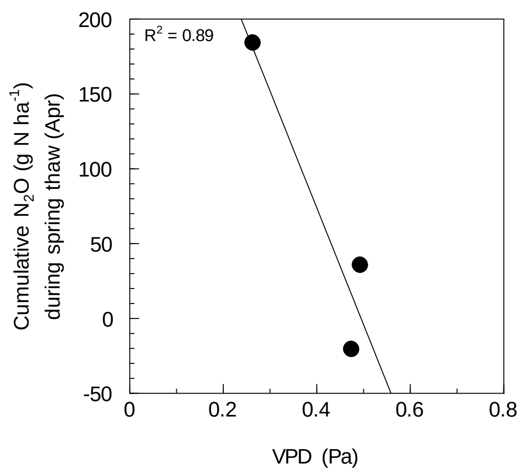


*Figure 4 Nitrous oxide emissions might be negatively correlated to the vapour pressure deficit (VPD) — a metric that indicates the “dryness” of melting conditions. More data is needed (and is being collected) for a robust analysis.*

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

It is too early to draw definitive conclusions

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

*Interviews*

- Interview with Carolyn King for Top Crop Manager article, Feb 2022.

*Presentations*

- 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*.

*Publications*

- Cultivating Diversity. Canadian Council of Academies Report on the Risks to Plant Health in Canada. Jan 24, 2022. (Congreves was a co-author).

*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