Non-legume cover crops can increase non-growing season nitrous oxide emissions

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Acknowledgements

• The technical assistance of Andrew Olson, Pam Caffyn, Bonnie Tovell, Brett Hill, Jessica Stoeckli, Kyle Shade and the staff at Lethbridge Research and Development Centre is gratefully appreciated

• Thanks to Sherry Fillmore for providing statistical advice
What are Greenhouse Gases?

- Atmospheric composition:
  - Dinitrogen (N$_2$): 78%
  - Oxygen (O$_2$): 21%
  - Agron (Ar): 0.9%

- Trace gases account for one-tenth of one percent of atmosphere (0.1%):
  - Ozone (O$_3$)
  - Carbon dioxide (CO$_2$)
  - Methane (CH$_4$)
  - Nitrous oxide (N$_2$O)

- Increase the radiative forcing potential (global warming potential)
Agricultures Contribution to Trace Gas Emissions

- Agriculture contributes approximately 8.5% of trace gas emissions in Canada, mainly in the form of CH$_4$ and N$_2$O
  - 3.0% from enteric fermentation
  - 1.1% from manure management
  - 4.4% from agricultural land
Sources of Trace Gases Emitted from Agriculture

- Carbon dioxide (CO₂) – primary source is manure, urine and soil
- Methane (CH₄) – primary source is enteric fermentation and manure
- Nitrous oxide (N₂O) – primary source is manure, urine and fertilizers

- CH₄ and N₂O are the primary concerns because they have 28 and 265 times the radiative forcing potential of CO₂ (IPCC, 2013)
  - a greater global warming potential
Agricultural and Grazed Grassland Soils in Semiarid Regions

• Are typically sinks of CH$_4$ sources of N$_2$O

• Management practices can be modified to limit N$_2$O emissions
  ○ (Gregorich et al., 2015, Adv. Agron.)

• Examples include:
  ○ Splitting fertilizer N applications (Matching N supply to crop N demand)
    ▪ Banding one starter N application prior to planting
    ▪ Using irrigation pivots to supply the remaining N through fertigation when crop demands N
  ○ Avoiding applying fertilizer and fertigation after heavy rains
  ○ Avoiding excessive irrigation water
  ○ Limiting post-harvest nitrate levels to < 5 ppm (Lemke et al., 1998; Gillam et al. 2008; Chantigny et al., 2010)
Some Manure Management Options

- Manure in feedlot pen
- Anaerobic digestion
- Land application
- Stockpiling
- Composting
Manure Application

Better

Good
Manure Management

• Ideally, manure needs to be land applied and incorporated as soon as possible to limit CH$_4$ and N$_2$O emissions, but mostly to avoid NH$_3$ loss

• The reality is that this is usually not feasible

• Managing beef cattle feedlot manure for reduced trace gas emissions has limitations due to the nature of the production system

• Remains a challenge for manure management in southern Alberta
Non-Legume Cover Crops Can Increase Non-Growing Season Nitrous Oxide Emissions

Cover crops retain post-harvest nutrients but how they impact non-growing season nitrous oxide (N₂O) emissions is unclear. Therefore, we quantified how cover crop type (full year (Secale cereale L.) or alfalfa (Medicago sativa L.) and fertilizer source (compost or inorganic fertilizer) affected N₂O emissions, soil water extractable N (SWE-N), and soil moisture content (SOMC) in a field experiment conducted over two non-growing seasons. A treatment with no fertilizer or cover crop was also included. Directly, N₂O fluxes were determined using vented static chambers; soil WECO and N₂O concentrations were measured monthly. Each non-growing season, mean N₂O fluxes were 7.4 to 456 mg N m⁻² h⁻¹ greater in the winter (December – February) than in spring (March – May). N₂O emissions were lower than those in the control (Secale cereale L. × C. Remington) or alfalfa [Medicago sativa L. ‘Tillage’ cultivar] and nutrient sources (compost or inorganic fertilizer) affected N₂O emissions. N₂O emissions were highest in Secale cereale L. × C. Remington and alfalfa; N₂O emissions were lowest in N₂O and no intercrops (Secale cereale L. × C. Remington and alfalfa) and the agronomic practices of the non-growing season (green wheat residue: 15% reduced N₂O flux than green wheat residue: 25% reduced N₂O flux). N₂O fluxes were reduced in non-growing season N₂O emissions, suggesting that cover crops concentrate denitrification substrates in root-associated soil to enhance N₂O fluxes. 

Core Ideas
- Nitrous oxide emissions are greater in winter than spring or fall.
- Tillage reduces increased over-winter N₂O fluxes.
- Non-legume cover crops increased N₂O emissions compared to N₂O limiting conditions.

Soybean. Vol. 5, No. 1; doi:10.1017/soy.2019.109 Published 15 March 2019

Fall Rye Reduced Residual Soil Nitrate and Dryland Spring Wheat Grain Yield

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ABSTRACT
Limited information about how cover crop management affects the performance of cover crop species in semiarid regions is common cover crop studies. Therefore, over 2 years we quantified how cover crop species (full year: Secale cereale L. × C. Remington or alfalfa [Medicago sativa L. ‘Tillage’ cultivar] and nutrient sources (compost or inorganic fertilizer) affected N₂O emissions, soil water extractable N (SWE-N), and soil moisture content (SOMC) in a field experiment conducted over two non-growing seasons. A treatment with no fertilizer or cover crop was also included. Directly, N₂O fluxes were determined using vented static chambers; soil WECO and N₂O concentrations were measured monthly. Each non-growing season, mean N₂O fluxes were 7.4 to 456 mg N m⁻² h⁻¹ greater in the winter (December – February) than in spring (March – May). N₂O emissions were lower than those in the control (Secale cereale L. × C. Remington) or alfalfa [Medicago sativa L. ‘Tillage’ cultivar] and nutrient sources (compost or inorganic fertilizer) affected N₂O emissions. N₂O emissions were highest in Secale cereale L. × C. Remington and alfalfa; N₂O emissions were lowest in N₂O and no intercrops (Secale cereale L. × C. Remington and alfalfa) and the agronomic practices of the non-growing season (green wheat residue: 15% reduced N₂O flux than green wheat residue: 25% reduced N₂O flux). N₂O fluxes were reduced in non-growing season N₂O emissions, suggesting that cover crops concentrate denitrification substrates in root-associated soil to enhance N₂O fluxes. 

Highly productive systems for winter cereal crops reduce the risk of soil erosion and nutrient loss through leaching and runoff during the non-growing season, while increasing the biodiversity of the ecosystem (Marten et al., 2015). Yet, few studies have directly investigated late summer to fall seeded cover crop management practices on selected regions (e.g., Minnesota and Missouri). Furlong et al. (2009), Blackshaw et al. (2010), Laraghi et al. (2014), Thomas et al. (2014), and Li et al. (2016) contrasted their adoption by farmers (Laraghi et al., 2015). A better understanding of how cover crop management practices impact subsequent annual crop performance could provide important information on how to expand cover crops in semiarid regions of North America. Thorp-Knowles (1997) coined the term “equivocal comparison” to describe the effect whereby cover crops assist yield, but then decrease yield and mineralize too slowly to supply the required N to the succeeding crop. Thus, the N supply to the subsequent crop depends on complex interactions among the cover crop characteristics, soil climate, and temperature, and the succeeding crop yield (Thorp-Knowles et al., 2003). For instance, cereal rye decomposed more quickly than barley (Hordeum vulgare L.) in northern Nebraska (Hilde and Ens, 2006), while glyphosate [N-(phosphonomethyl)glycine] killed fall cereal rye considerably reduced seasonal spring wheat yield relative to no cover crop in southern Alberta (Moore and Redhead, 2009). Whether residual rye N is a concern or not throughout the year is important to fall residue and subsequently decompose and mineralize to supply N in the succeeding crop has not been determined in southern Alberta.

Fall rye and oxidized rye are two contrasting cover crops. Fall rye is a perennial monocotyledon with excessive rhizomes that root deep, while oxidized rye is an annual dicotyledon with a large taproot. Fall rye must be killed prior to planting the succeeding crop, chemical fumigation (terbutylazine treatment) in spring being a common method, whereas oxidized rye can be killed, leaving a residue, for a no-tillage system. Soil samples were collected in early summer from the 0- to 10-cm surface layer from each plot and analyzed for N₂O fluxes using a soil chamber system. Therefore, we quantified how cover crop species (full year: Secale cereale L. × C. Remington or alfalfa [Medicago sativa L. ‘Tillage’ cultivar] and nutrient sources (compost or inorganic fertilizer) affected N₂O emissions, soil water extractable N (SWE-N), and soil moisture content (SOMC) in a field experiment conducted over two non-growing seasons. A treatment with no fertilizer or cover crop was also included. Directly, N₂O fluxes were determined using vented static chambers; soil WECO and N₂O concentrations were measured monthly. Each non-growing season, mean N₂O fluxes were 7.4 to 456 mg N m⁻² h⁻¹ greater in the winter (December – February) than in spring (March – May). N₂O emissions were lower than those in the control (Secale cereale L. × C. Remington) or alfalfa [Medicago sativa L. ‘Tillage’ cultivar] and nutrient sources (compost or inorganic fertilizer) affected N₂O emissions. N₂O emissions were highest in Secale cereale L. × C. Remington and alfalfa; N₂O emissions were lowest in N₂O and no intercrops (Secale cereale L. × C. Remington and alfalfa) and the agronomic practices of the non-growing season (green wheat residue: 15% reduced N₂O flux than green wheat residue: 25% reduced N₂O flux). N₂O fluxes were reduced in non-growing season N₂O emissions, suggesting that cover crops concentrate denitrification substrates in root-associated soil to enhance N₂O fluxes. 

Core Ideas
- Fall rye reduced residual soil nitrate and increased dryland spring wheat grain yield.
Introduction

- **Post-harvest seeding of cover crops:**
  - Limits nutrient loss via leaching and runoff
  - Increases biodiversity and resiliency of prairie cropping systems (Martens et al. 2015, *Can. J. Plant. Sci.*)

- **Uncertain whether cover crops increase or decrease nitrous oxide emissions** (Basche et al. 2014, *J. Soil Water Conserv.*)

- **Limited information about how cover crops directly impact the subsequent crop constrains adoption by farmers in semiarid regions** (Liebig et al. 2015, *Agron. J.*)
Soil Nitrate ($\text{NO}_3$)

- Typically, ammonium ($\text{NH}_4$) is rapidly nitrified to $\text{NO}_3$
  - Presents problems because $\text{NO}_3$ is prone to loss pathways
- The principal substrate for denitrification
- The principal source of leaching losses during heavy rainfall events
Study Objective

- Directly quantify how cover crop species (fall rye or oilseed radish) and nutrient source (compost or inorganic fertilizer) affects:
  - Cover crop N uptake
  - Soil NO$_3$–N dynamics over the non-growing season
  - Soil nitrous oxide fluxes over the non-growing season
  - Agronomic performance of unfertilized dryland spring wheat over two consecutive years
Materials and Methods

• Study site: Lethbridge, AB

• Two contrasting cover crops were selected:
  o Fall Rye
    ▪ Survives the winter
    ▪ Extensive fibrous root system
  o Oilseed Radish (Tillage Radish®)
    ▪ Winter kills
    ▪ Large taproot
Materials and Methods

• Two contrasting nutrient sources were selected:
  
  o Inorganic fertilizer applied at 45 kg N ha$^{-1}$
    - Ammonium nitrate and super triple phosphate
    - Readily plant-available
    - Assumed about 55% was plant-available (~ 25 kg N ha$^{-1}$)
  
  o Composted beef cattle manure applied at 100 kg N ha$^{-1}$
    - < 12% of total N is in plant-available form
    - Assumed about 25% was plant available (~ 25 kg N ha$^{-1}$)
Materials and Methods: Experimental Design

• 3 x 2 Factorial arranged as RCBD with four blocks:
  1. Fall rye with compost (FRC)
  2. Fall rye with inorganic fertilizer (FRF)
  3. Oilseed radish with compost (ORC)
  4. Oilseed radish with inorganic fertilizer (ORF)
  5. No cover with compost (NCC)
  6. No cover with inorganic fertilizer (NCF)
  7. No cover without compost or inorganic fertilizer (CON)
Gas and Soil Sampling and Analysis

- Gas samples were collected from vented static chambers about weekly
- Soil samples (0 to 7.5 cm) were collected about monthly
- Soil NO\textsubscript{3}-N concentrations were measured in the soil samples
Cover Crop Establishment

- Poor oilseed radish establishment in 2013 caused by flea beetle

2013
- 40 kg N uptake ha\(^{-1}\) by Nov. 6

2014
- 42 kg N uptake ha\(^{-1}\) by Nov. 6
2013-2014 Non-growing Season
Soil Nitrate Response to Cover Crop Species

***N₂O emissions were only effected by cover cropping in 2014-2015, when NO₃ levels were low***
Mean Daily Nitrous Oxide Fluxes and Environmental Conditions
Seasonal N₂O fluxes

2013-2014

P < 0.001

Error bars represent ± SEM

2014-2015

P < 0.001

Error bars represent ± SEM
Winter and Cumulative N$_2$O Fluxes in Response to Cover Crop Species in 2014-2015

2014-2015 Over-winter flux

- No cover crop
- Fall rye
- Oilseed radish

Mean daily N$_2$O flux (g N ha$^{-1}$ d$^{-1}$)

Cumulative emission

- No cover crop
- Fall rye
- Oilseed radish

$r = 0.97; P < 0.001$

$n = 7$
Grain Yield Response to Cover Crop Species

Spring wheat grain yield (kg DM ha⁻¹)

- **Fall Rye**
  - 2014: b
  - 2015: b

- **Oilseed Radish**
  - 2014: a
  - 2015: a

- **No cover crop**
  - 2014: a
  - 2015: a
Study Summary

• Nitrous oxide emissions were greater in winter than spring or fall
• Oilseed radish increased over-winter N$_2$O fluxes
• Oilseed radish and fall rye increased N$_2$O emissions under apparent NO$_3$ limiting conditions
• Fall rye more effectively scavenged and retained N than oilseed radish during the two non-growing seasons
• Overall, the N$_2$O emissions represented a relatively small source of N loss over the non-growing season in southern Alberta
Proper Accounting Tools Required

• Yield-scaled N₂O emission can provide a fairer comparison of management practices (Gregorich et al., 2015, Adv. Agron.)

• Captures the environmental and agronomic aspects

• Example:
  - If we scale the N₂O emissions based on grain yield (mean of two years):
    - Oilseed radish: 0.10 g N₂O-N kg⁻¹ grain yield
    - Fall rye: 0.21 g N₂O-N kg⁻¹ grain yield
    - Amended soil with no cover crop: 0.09 g N₂O-N kg⁻¹ grain yield