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Canada

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

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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_2O)

- 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_2O
  - 3.0% from enteric fermentation
  - 1.1% from manure management
  - 4.4% from agricultural land

Sources of Trace Gases Emitted from Agriculture

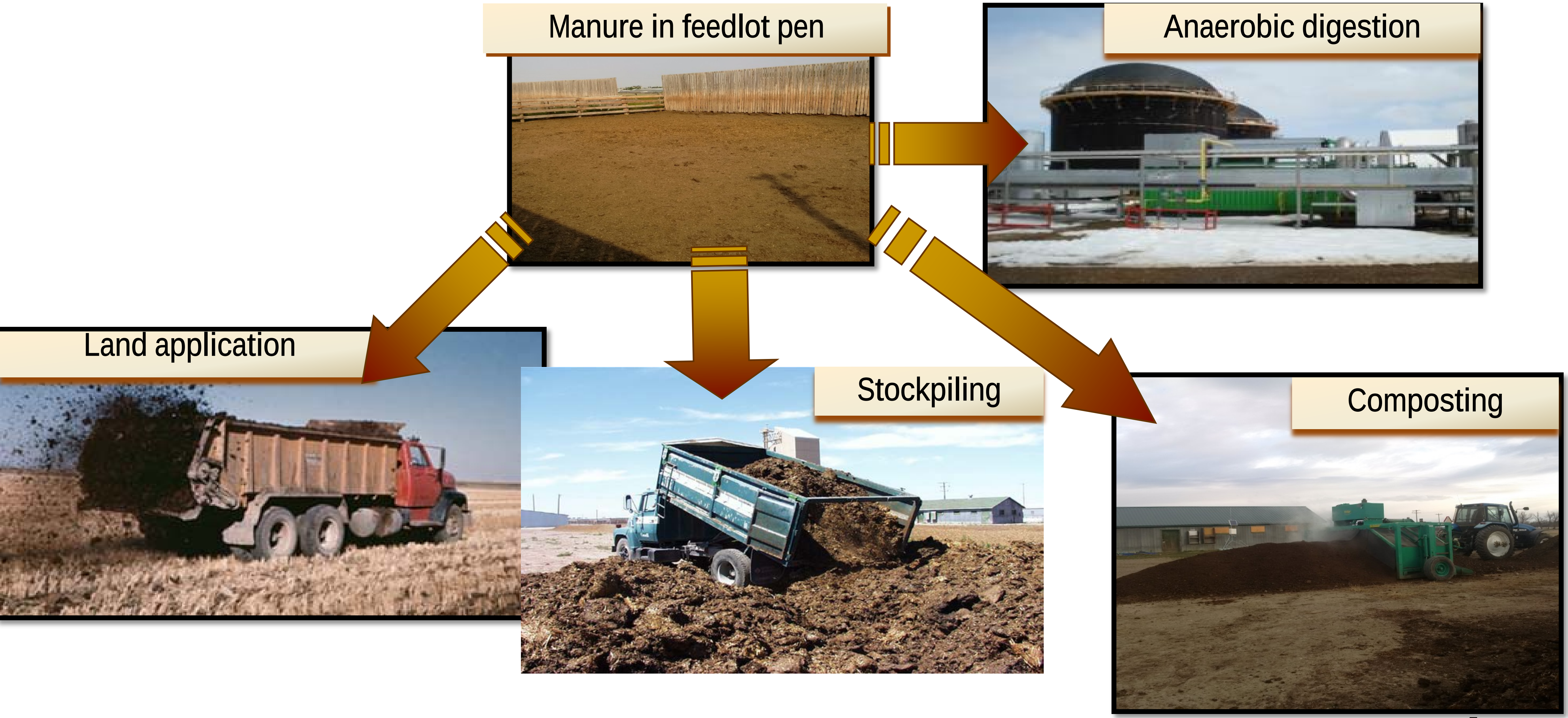
- Carbon dioxide (CO_2) – primary source is manure, urine and soil
- Methane (CH_4) – primary source is enteric fermentation and manure
- Nitrous oxide (N_2O) – primary source is manure, urine and fertilizers

- CH_4 and N_2O are the primary concerns because they have 28 and 265 times the radiative forcing potential of CO_2 (IPCC, 2013)
  - a greater global warming potential

Agricultural and Grazed Grassland Soils in Semiarid Regions

- Are typically sinks of CH_4 sources of N_2O
  - (Ellert and Janzen, 2008, *Can. J. Soil Sci.*; Gao et al., 2016, *Land Degrad. Dev.*)
- Management practices can be modified to limit N_2O 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 Application

Better

Good

Manure Management

- Ideally, manure needs to be land applied and incorporated as soon as possible to limit CH_4 and N_2O 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

Soil & Water Management & Conservation

Non-Legume Cover Crops Can Increase Non-Growing Season Nitrous Oxide Emissions

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Cover crops retain post-harvest nutrients but how they impact non-growing season nitrous oxide (N_2O) emissions is unclear. Therefore, we quantified how cover crop type (fall rye [*Secale cereale* L.] or oilseed radish [*Raphanus sativus* L.]) and fertilizer source (compost or inorganic fertilizer) affected N_2O emissions, soil water-extractable organic C (WEOC) and nitrate (NO_3) dynamics over two non-growing seasons. A treatment with no fertilizer or cover crop was also included. Weekly, N_2O fluxes were determined using vented static chambers; soil WEOC and NO_3–N concentrations were measured monthly. Each non-growing season, mean N_2O fluxes were 74 to 450% greater in the winter (21 December–20 March) than spring (21 March–20 June) or fall (22 September–20 December). In winter 2014–2015, oilseed radish increased the mean N_2O flux by 39 and 323% compared with fall rye and no cover crop, respectively, while the mean N_2O fluxes were strongly correlated to the pre-winter (16 Dec. 2014) NO_3 concentrations (r = 0.96; P < 0.001), indicating NO_3 levels < 6 mg NO_3–N kg^{-1} limited N_2O fluxes. In 2014–2015, fall rye and oilseed radish had 76 and 154% greater cumulative N_2O emissions than amended soils with no cover crop, respectively. Across both winters, an exponential model explained 67% of variability between the pre-winter WEOC to NO_3 ratio and N_2O fluxes, indicating that organic C and NO_3 controlled over-winter N_2O fluxes. Non-legume cover crops increased non-growing season N_2O emissions, suggesting that cover crops concentrate denitrification substrates in root-associated soil to enhance N_2O fluxes.

Abbreviations: FRC, fall rye with compost; FRF, fall rye with inorganic fertilizer; MDL, minimum detection limit; ORC, oilseed radish with compost; ORF, oilseed radish with inorganic fertilizer; NCC, no cover crop with compost; NCF, no cover crop with inorganic fertilizer; CON, non-amended soil with no cover crop; WEOC, water-extractable organic carbon.

Core Ideas

- **Nitrous oxide emissions were greater in winter than spring or fall.**
- **Tillage radish increased over-winter N_2O fluxes.**
- **Non-legume cover crops increased N_2O fluxes under apparent NO_3 limiting conditions.**

Post-harvest seeding of cover crops reduces the risk of wind erosion and nutrient loss through leaching and runoff during the non-growing season, but how cover crops affect C and N transformations during this time is poorly understood. Although soil microbial activity slows during the non-growing season, this period is particularly prone to N_2O emissions in temperate regions (Wagner-Riddle and Thurtell, 1998; Dörsch et al., 2004; Ellert and Janzen, 2008; Hao, 2015). Whether cover crops reduce N_2O emissions during the non-growing season by assimilating ammonium (NH_4) and NO_3 is uncertain. In part, this is because cover crops release labile C and N through root exudates and rhizodeposition during their growth phase and freeze–thaw cycles, which can stimulate microbial activity and increase N_2O emissions (Petersen et al., 2011; Gul and Whalen, 2013; Mitchell et al., 2013). This may counter the crop N uptake and explain why there is no clear consensus on how non-legume cover crops effect N_2O emissions (Basche et al., 2014). A better understanding of N_2O emissions and the substrates that drive N_2O production during the non-growing season could improve cover

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

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ABSTRACT

Limited information about how cover crop management impacts the agronomic performance of succeeding annual crops in semiarid regions constrains cover crop utilization. Therefore, over 2 yr we quantified how cover crop species (fall rye [*Secale cereale* L. 'AC Remington'] or oilseed radish [*Raphanus sativus* L. 'Tillage radish']) and nutrient source (compost or inorganic fertilizer) affected cover crop biomass and N uptake, soil nitrate N (NO_3–N) and ammonium N (NH_4–N), and the agronomic performance of the succeeding spring wheat (*Triticum aestivum* L.) test crop. Fall rye reduced pre-plant NO_3–N by 2 to 18 times compared with oilseed radish, and reduced spring wheat grain yields by 38 to 58% compared with amended soils with no cover crop and oilseed radish. Inorganically fertilized soils led to 21% greater pre-plant soil NO_3–N concentrations than the compost-amended soil in 2013–2014 but nutrient source did not significantly affect NO_3–N concentrations in 2014–2015. A quadratic function explained 93% of the variability between pre-plant soil NH_4–N plus NO_3–N (0–7.5-cm depth) and spring wheat grain yield in 2014, indicating that the N supply limited spring wheat grain yield. We conclude that fall rye scavenged residual NO_3–N better than oilseed radish during the non-growing season, particularly during the spring period when this perennial species assimilates N, but under semiarid conditions it may decompose and mineralize too slowly to supply N at the right time for the subsequent crop, while oilseed radish tended to boost spring wheat grain yield.

Core Ideas

- Fall rye reduced pre-plant nitrate by 2 to 18 times compared with tillage radish.
- Fall rye reduced dryland spring wheat grain yield by 38 to 58% compared with tillage radish.
- Pre-plant soil NH_4–N plus NO_3–N explained 93% of spring wheat grain yield variability.

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Post-harvest seeding of cover crops reduces the risk of wind erosion and nutrient loss through leaching and runoff during the non-growing season, while increasing the biodiversity and resilience of prairie cropping systems (Martens et al., 2015). Yet, few studies have directly investigated late-summer to-fall seeded cover crop management practices in semiarid regions (e.g., Moyer and Blackshaw, 2009; Blackshaw et al., 2010; Liebig et al., 2015; Thomas et al., 2016a), which constrains their adoption by farmers (Liebig et al., 2015). A better understanding of how cover crop management practices impact subsequent annual crop performance could provide important knowledge to advance the use of cover crops in semiarid regions of North America.

Thorup-Kristensen (1993) coined the term "pre-emptive competition" to describe the effect whereby cover crops assimilate N, but then decompose and mineralize too slowly to supply the retained N to the succeeding crop. Thus, the N supply to the subsequent crop depends on complex interactions among the cover crop characteristics, soil and climatic properties, and the succeeding crop itself (Thorup-Kristensen et al., 2003). For instance, oilseed radish decomposed more quickly than barley (*Hordeum vulgare* L.) in southern Manitoba (Halde and Entz, 2016), while glyphosate [*N*-(phosphonomethyl)glycine]-killed fall rye consistently reduced unfertilized spring wheat yield relative to no cover crop in southern Alberta (Moyer and Blackshaw, 2009). Whether oilseed radish may scavenge N as efficiently as fall rye and subsequently decompose and mineralize to supply N to the succeeding crop has not been determined in southern Alberta.

Fall rye and oilseed radish are two contrasting cover crops. Fall rye is a perennial monocotyledon with an extensive fibrous root system, while oilseed radish is an annual dicotyledon with a large taproot. Fall rye must be killed prior to planting the succeeding cash crop, chemical burndown (herbicide treatment) in spring being a common method, whereas oilseed

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Abbreviations: FRC, fall rye with composted beef cattle manure, FRF, fall rye with inorganic fertilizer, ORC, oilseed radish with composted beef cattle manure, ORF, oilseed radish with inorganic fertilizer, NCC, no cover crop with composted beef cattle manure, NCF, no cover crop with inorganic fertilizer; CON, non-amended control soil with no cover crop.

Introduction

- Post-harvest seeding of cover crops:
  - Reduces the risk of wind erosion (Larney et al. 2016, *Can. J. Plant Sci.*)
  - 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 (NO_3)

- Typically, ammonium (NH_4) is rapidly nitrified to NO_3
  - Presents problems because 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

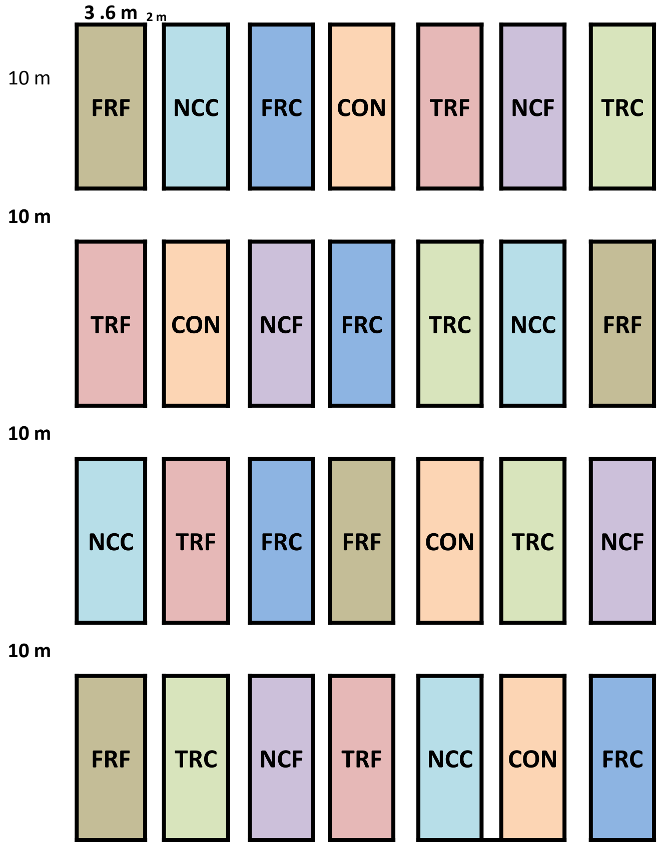
  - o Oilseed Radish (Tillage Radish®)
    - Winter kills
    - Large taproot

Materials and Methods

- Two contrasting nutrient sources were selected:
  - 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})
  - 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_3-N concentrations were measured in the soil samples

Cover Crop Establishment

Oilseed Radish

2013

2014
40 kg N uptake ha^{-1} by Nov. 6

Fall Rye

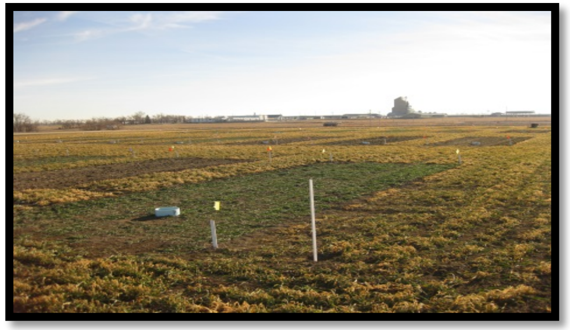
2013

2014
42 kg N uptake ha^{-1} by Nov. 6

- Oilseed radish and fall rye on Oct.15, 2013 and Oct. 20, 2014
- Poor oilseed radish establishment in 2013 caused by flea beetle

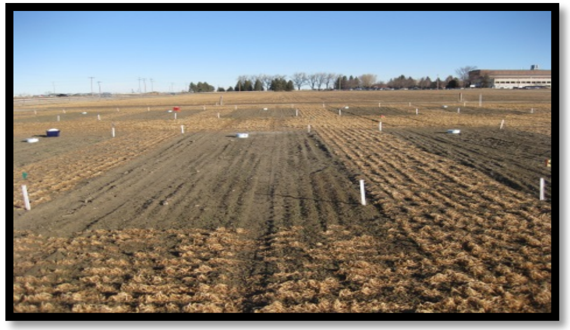
2013-2014 Non-growing Season


Oct. 29, 2013


Nov. 27, 2013

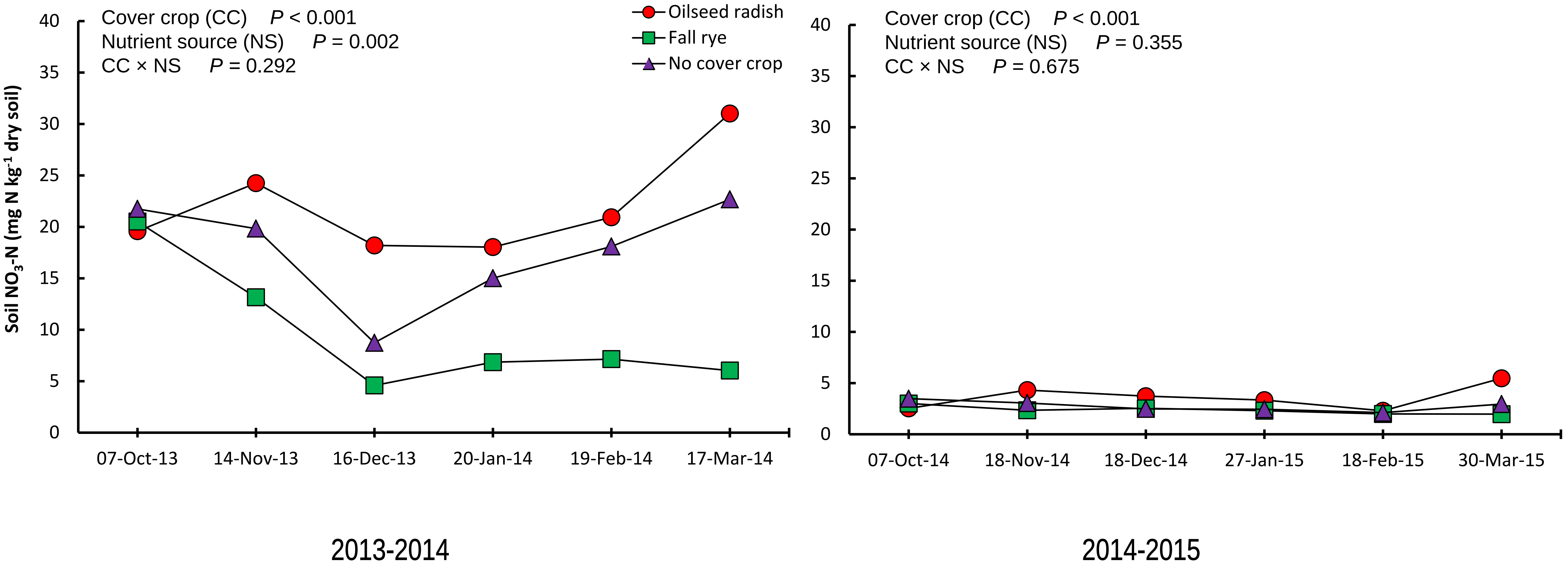

Dec. 12, 2013


Jan. 9, 2014


Feb. 18, 2014

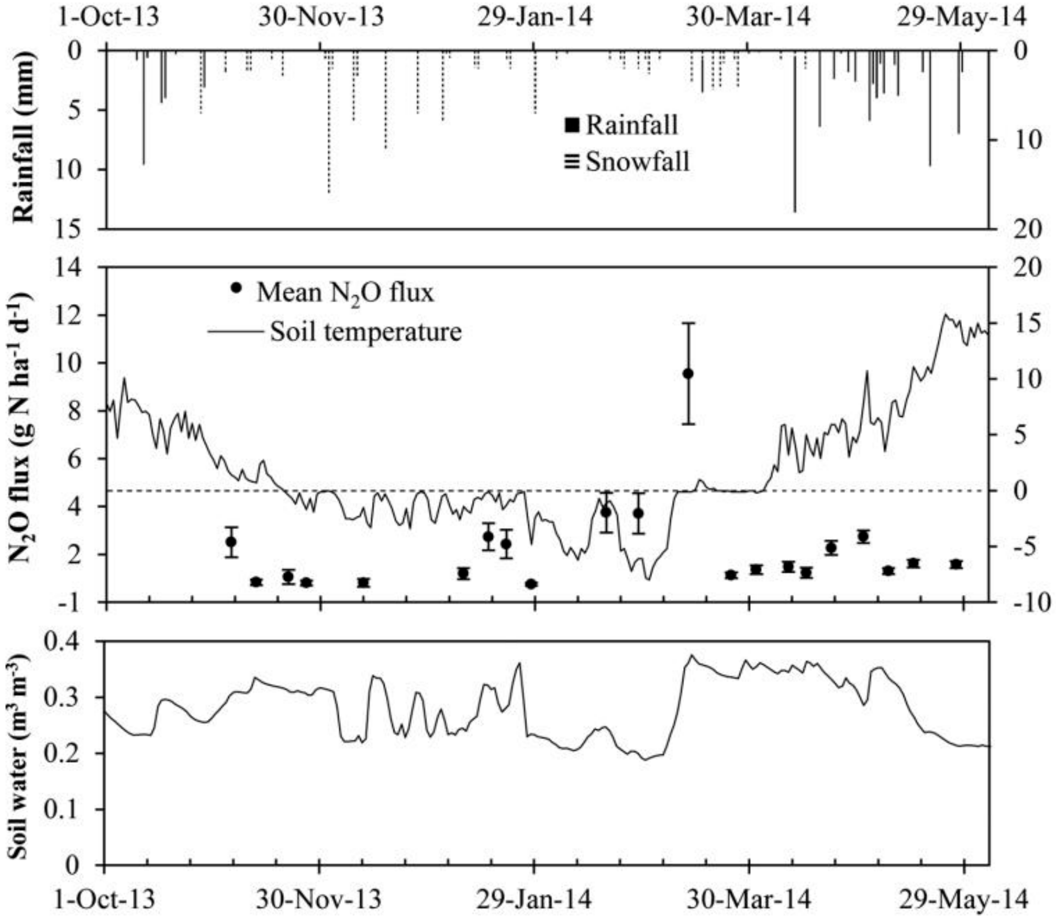

Mar. 25, 2014

Soil Nitrate Response to Cover Crop Species

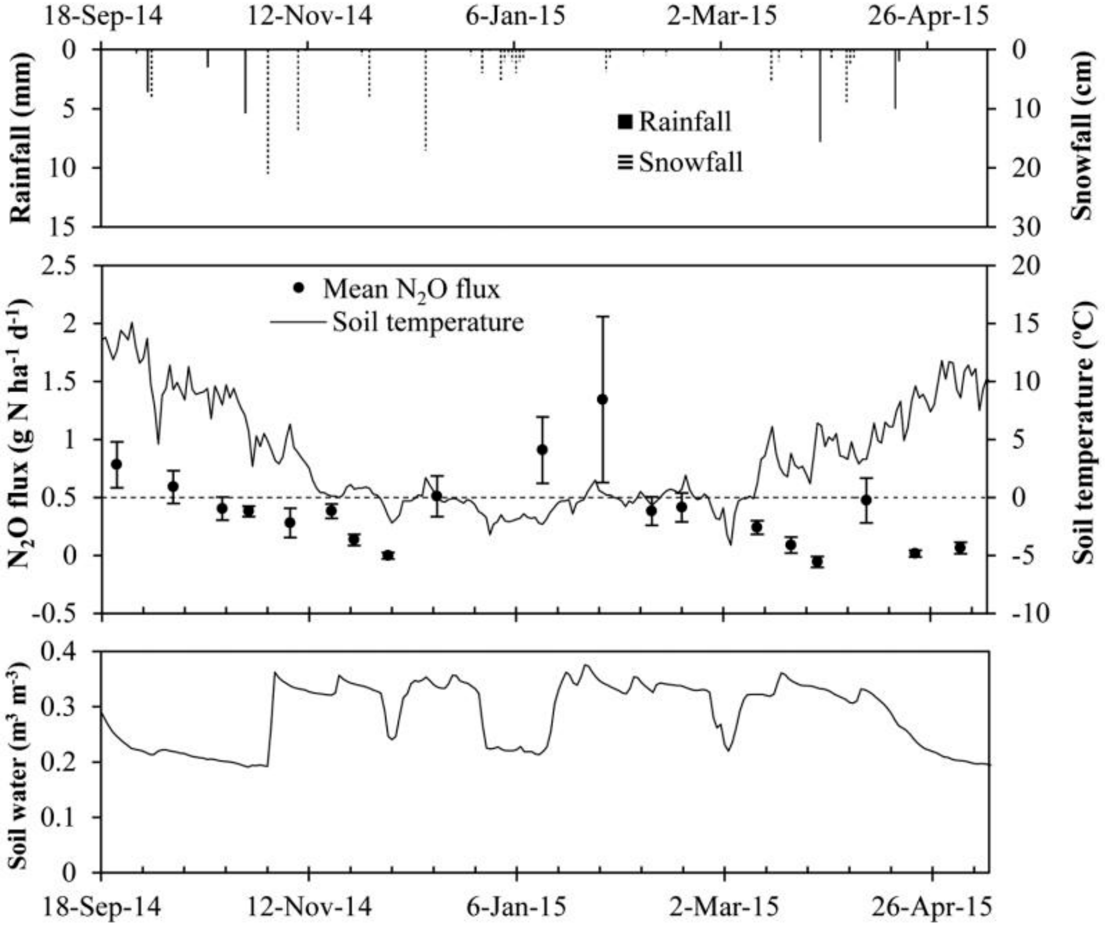


N_2O emissions were only effected by cover cropping in 2014-2015, when NO_3 levels were low

Mean Daily Nitrous Oxide Fluxes and Environmental Conditions



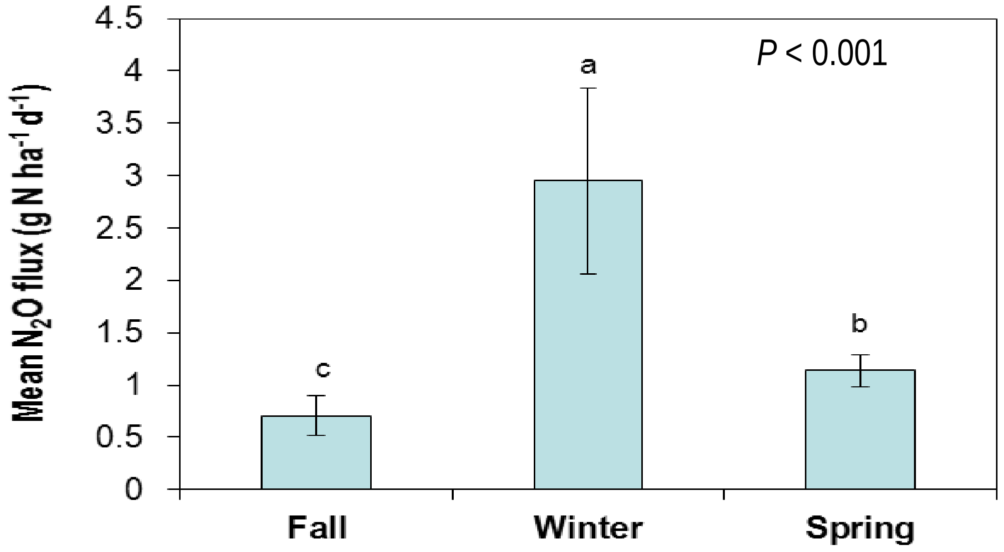
2013-2014



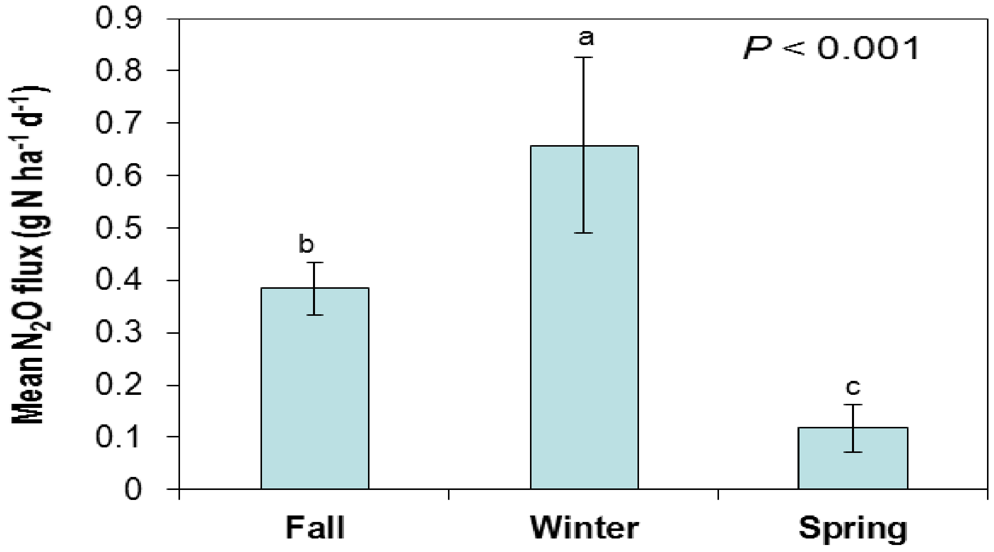
2014-2015

Seasonal N_2O fluxes

2013-2014

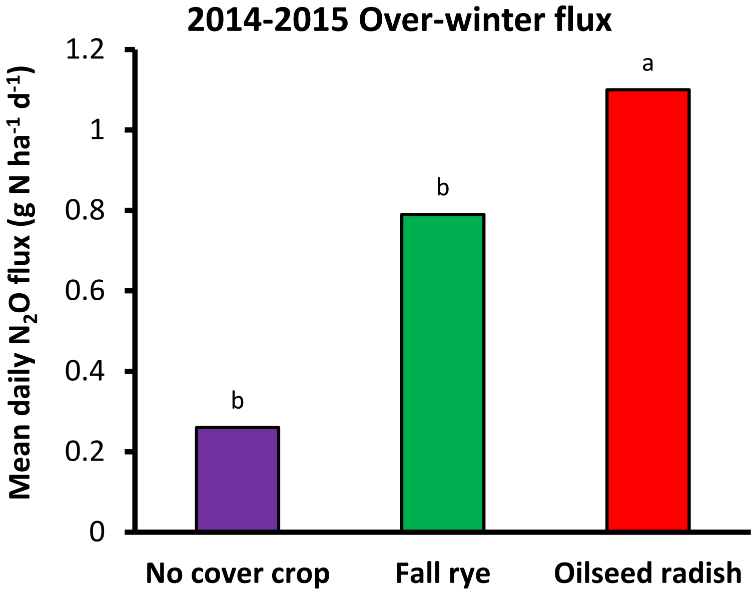


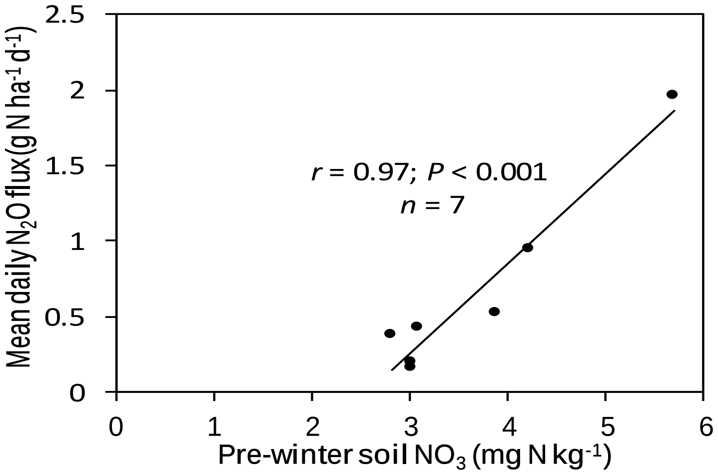
2014-2015

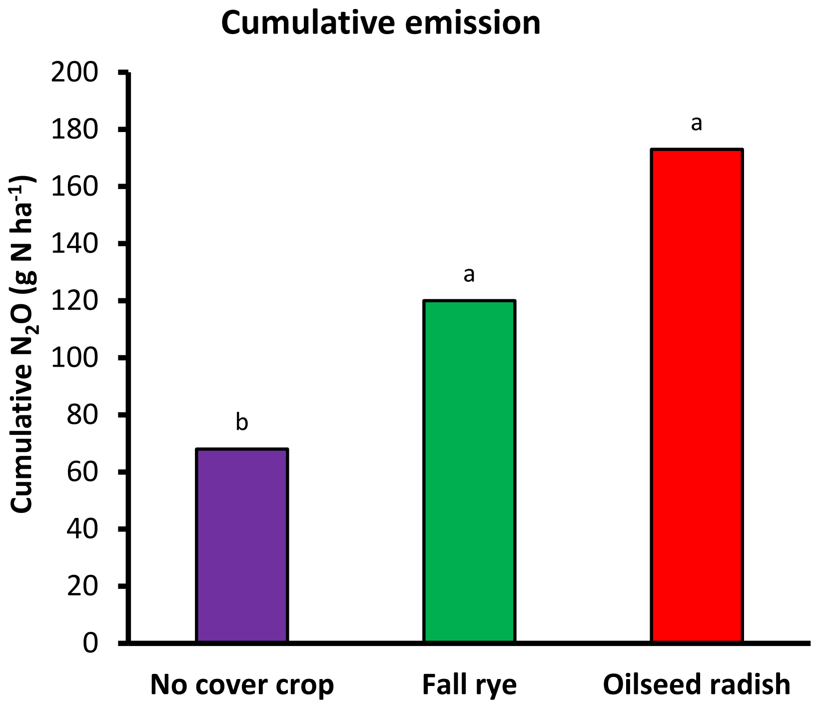


Error bars represent ± SEM

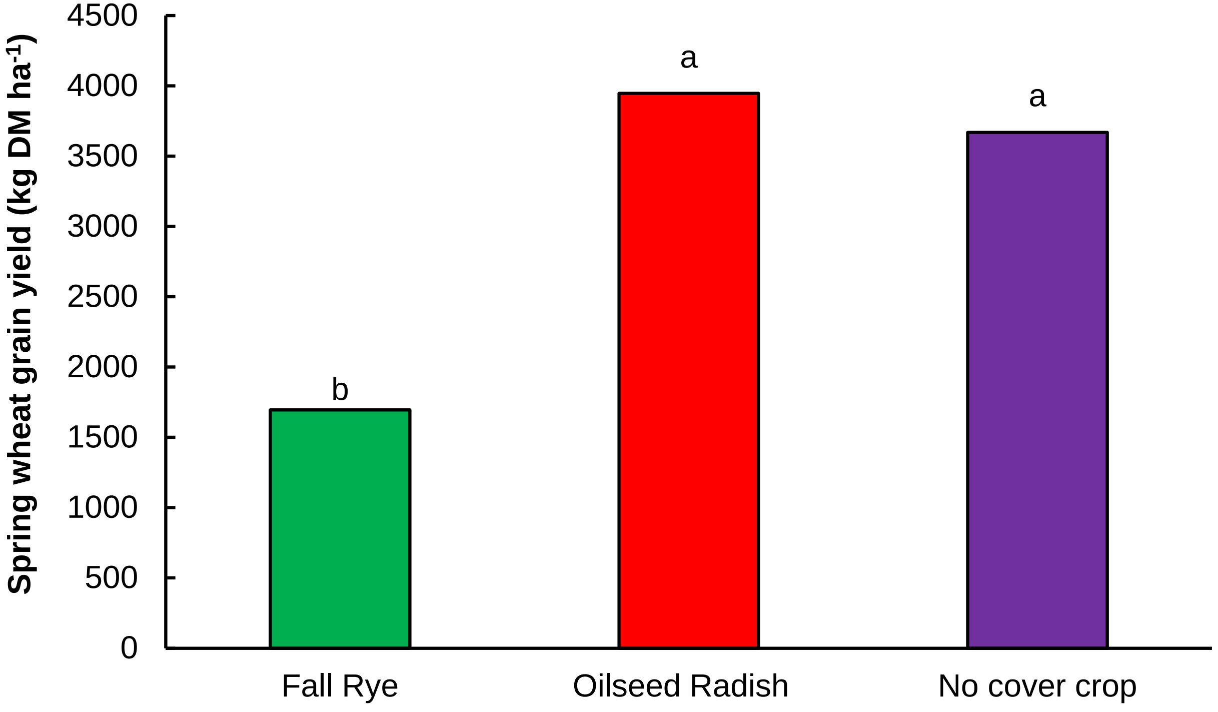
Winter and Cumulative N_2O Fluxes in Response to Cover Crop Species in 2014-2015



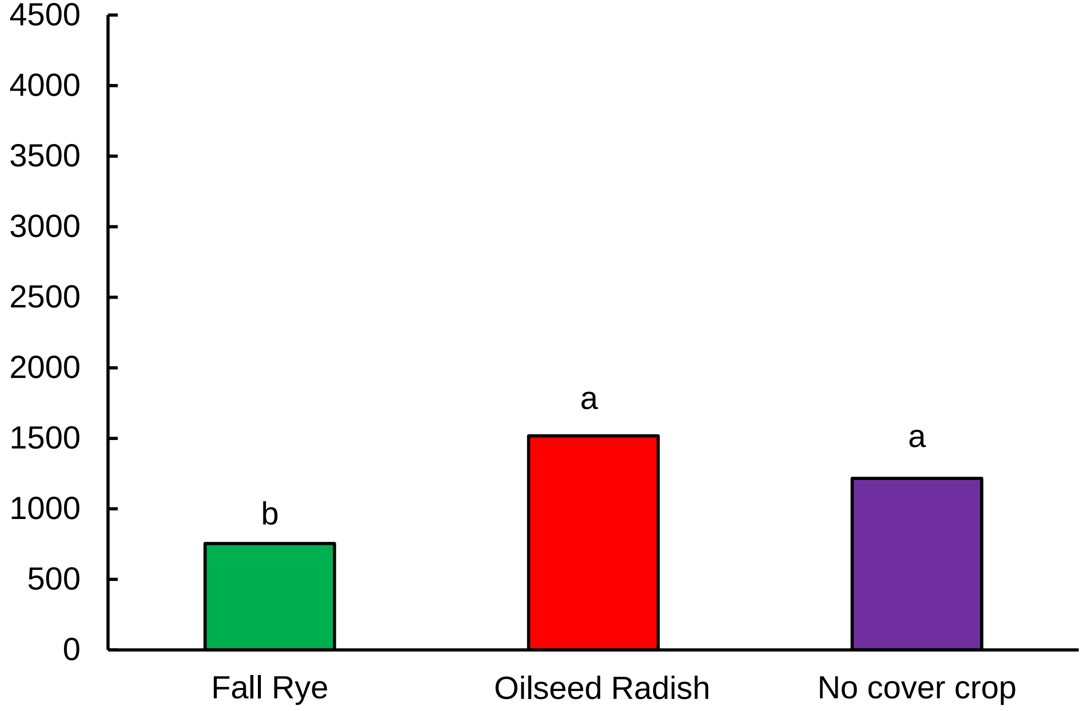




Grain Yield Response to Cover Crop Species



2014



2015

Study Summary

- Nitrous oxide emissions were greater in winter than spring or fall
- Oilseed radish increased over-winter N_2O fluxes
- Oilseed radish and fall rye increased N_2O 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_2O emissions represented a relatively small source of N loss over the non-growing season in southern Alberta

Proper Accounting Tools Required

- Yield-scaled N_2O 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 N_2O emissions based on grain yield (mean of two years):
    - Oilseed radish: 0.10 g N_2O-N kg^{-1} grain yield
    - Fall rye: 0.21 g N_2O-N kg^{-1} grain yield
    - Amended soil with no cover crop: 0.09 g N_2O-N kg^{-1} grain yield