PRIVATE AND SOCIALLY OPTIMAL NITROGEN FERTILIZER RATES FOR CANOLA IN SASKATCHEWAN

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Introduction

- The Canadian agricultural industry accounts for 10% of national annual GHG emissions
  - Major contributor N_2O from N fertilizer application[1].
- Government of Canada national target to reduce absolute levels of GHG emissions from fert application by 30% from 2020 levels by the year 2030[1].

[1] Government of Canada, 2022

Introduction

- Over 2005-2019, Canadian fertilizer use increased by 71%,
- Resulted in N_2O emissions increasing by 54% over the years 2005-2019[2] (see Figure 1).
- Canola is a high N use crop
- Growing demand for edible oil, seed, meal and biodiesel products[3]

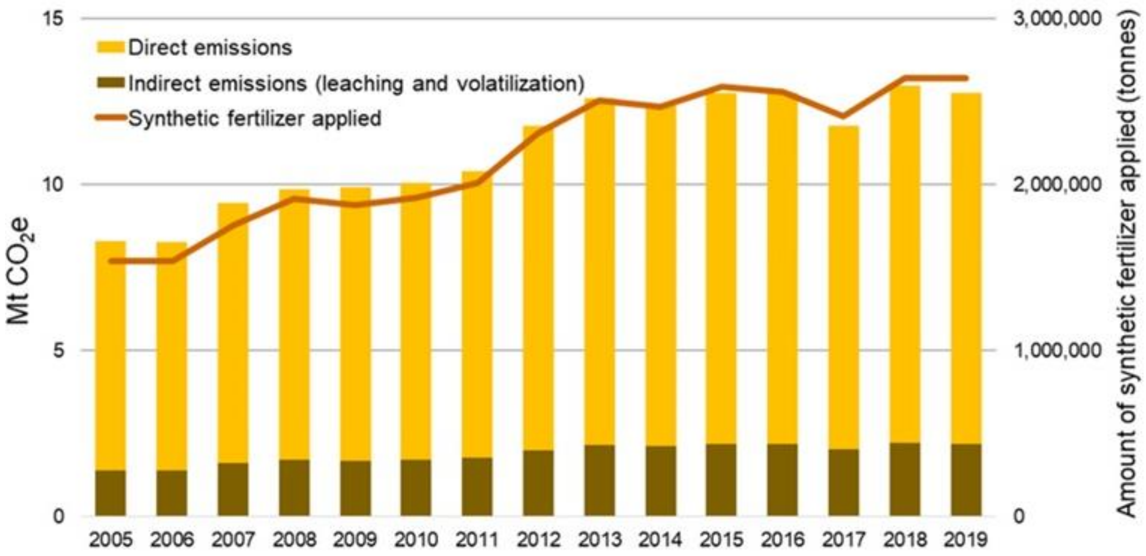


Figure 1 *Canada's Direct and indirect N_2O emissions from synthetic fertilizer application from 2005 to 2019*[1][2].

[1] Government of Canada, 2022

[2] ECCC, 2022

[3] Harker, et al., 2011

Background

- There is no mandatory reduction in N fertilizer use in Canadian
- AAFC has stated they want to support **voluntary** measures for producers to reduce their emissions

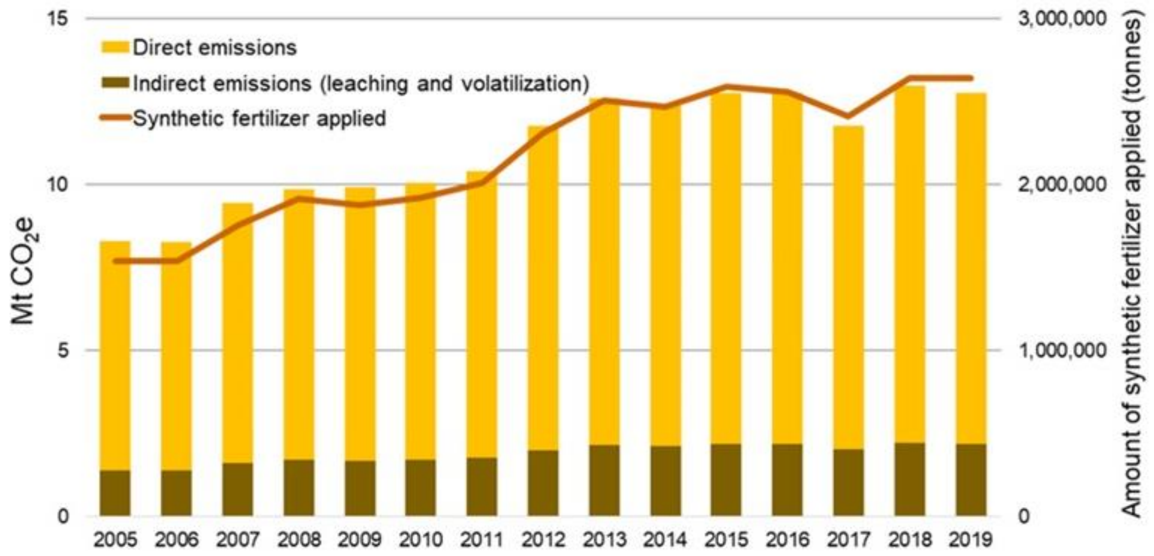


Figure 1 *Canada's Direct and indirect N_2O emissions from synthetic fertilizer application from 2005 to 2019*[1][2].

[1] Government of Canada, 2022

Previous Literature

- Producers are applying N at rates above those that are privately optimal (Rajsic et al., 2009; De Laporte, et al., 2021)
- Reducing N application through a cap or tax could result in both environmental and farm profit advantages (De Laporte, et al., 2021; De Laporte, et al., 2021)

Research Objectives:

Optimizing N fertilizer application is crucial for farm profitability, and GHG mitigation therefore this study will:

1. Estimate the economic private optimum rate of applied N for Saskatchewan Canola using a large, producer reported field-scale data set
2. Estimate the marginal abatement cost for direct N_2O emissions from N fertilizer application in Saskatchewan.
3. Assess impact of hypothetical policies of a 1) Pigouvian tax on N fertilizer use and 2) regulated 30% reduction in N fertilizer emissions

Data

- Producer reported field level data (2011-2019) from Saskatchewan Crop Insurance Corporation (SCIC)
- Over 47,059 canola field observations across 20 of the 23 grain cropping risk zones of Saskatchewan

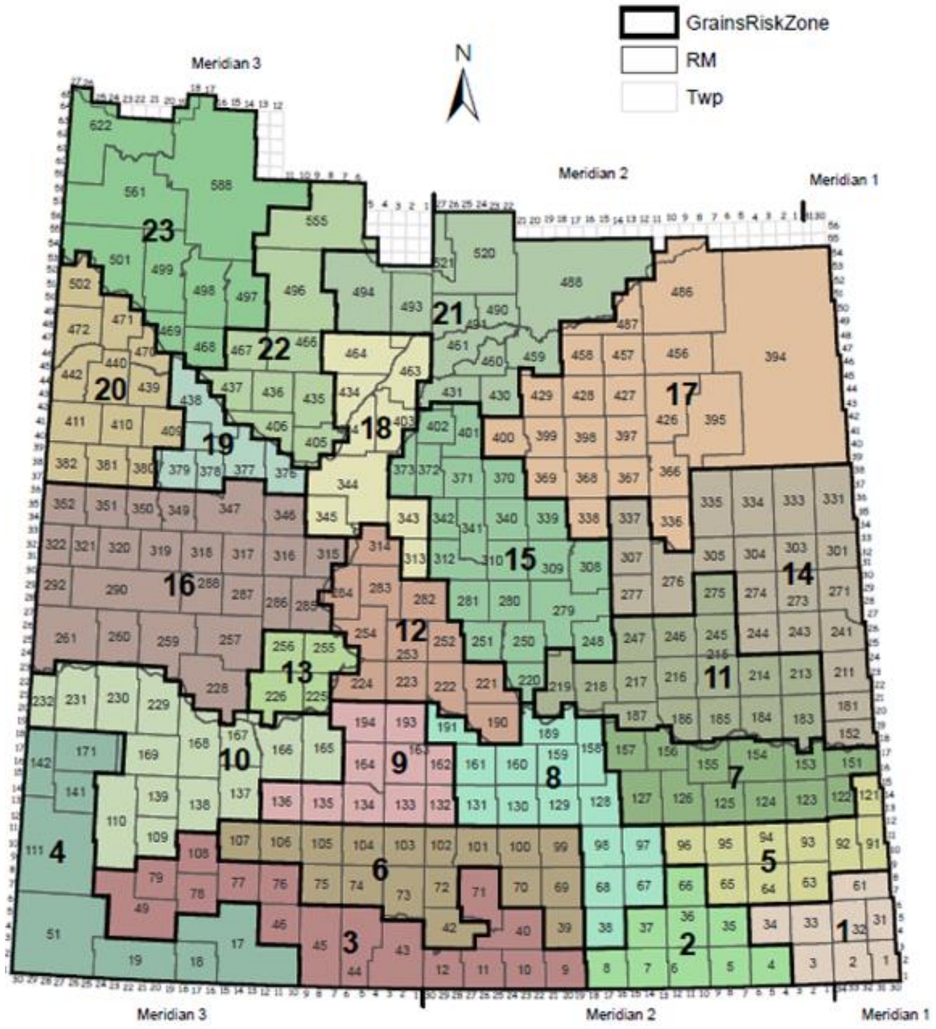


Figure 3 *Grain risk zone regions of Saskatchewan as classified by SCIC*[14].

Table 2: *Descriptive statistics of variables in canola production model.*

Variable	Mean	St.dev
Yield[a] ($kg\ ha^{-1}$)	2370	559
Nitrogen[a] ($kg\ ha^{-1}$)	109	25.6
Phosphorous[a] ($kg\ ha^{-1}$)	32.3	10.7
Potassium[a] ($kg\ ha^{-1}$)	4.30	8.50
Sulphur[a] ($kg\ ha^{-1}$)	20.8	10.2
Seeding date[a] (days after May 14)	9.68	7.66
Growing Season Precipitation[b] (mm)	243	75.1
Avg Precipitation[b] (mm)	274	51.3
Variety index[a] (% of L252)	93.3	9.1

Categorical Variable	Mean
Fungicide[a]	
Fungicide	30.9%
No Fungicide	69.1%
Previous crop[a]	
Pulse	9.70%
Cereal	57.8%
Oilseed	32.5%
Herbicide system[c]	
Roundup Ready	32.4%
Liberty Link	63.2%
Clearfield	4.40%

[a]Source: SCIC, 2019
[b]Source: Environment and Climate Change Canada, 2019
[c]Source: Government of Canada, 2021

Methods – Canola Production Function

- Estimated canola production function where canola yield in an individual field is a function of variable inputs, management and agro-ecological factors
- Fixed effects: **Producer x Year, Soil class, and Risk zone**.

Table 1: *Independent variables in canola production model.*

Variable Inputs	Management Factors	Agro-Ecological Factors
Nitrogen	Previous Crop	Growing Season Precipitation[9]
Phosphorous	Variety[10]	3yr Avg Precipitation [9]
Potassium	**Producer**	**Risk Zone**
Sulphur		**Soil Class**
Fungicide		**Year**

[9] ECCC, 2019

[10] Government of Canada, 2021

Methods – Economic Private Optimal N Rate Calculation

- Using the estimated coefficients of the canola production function, we find the estimated marginal product of nitrogen (MP_N) using the first order condition

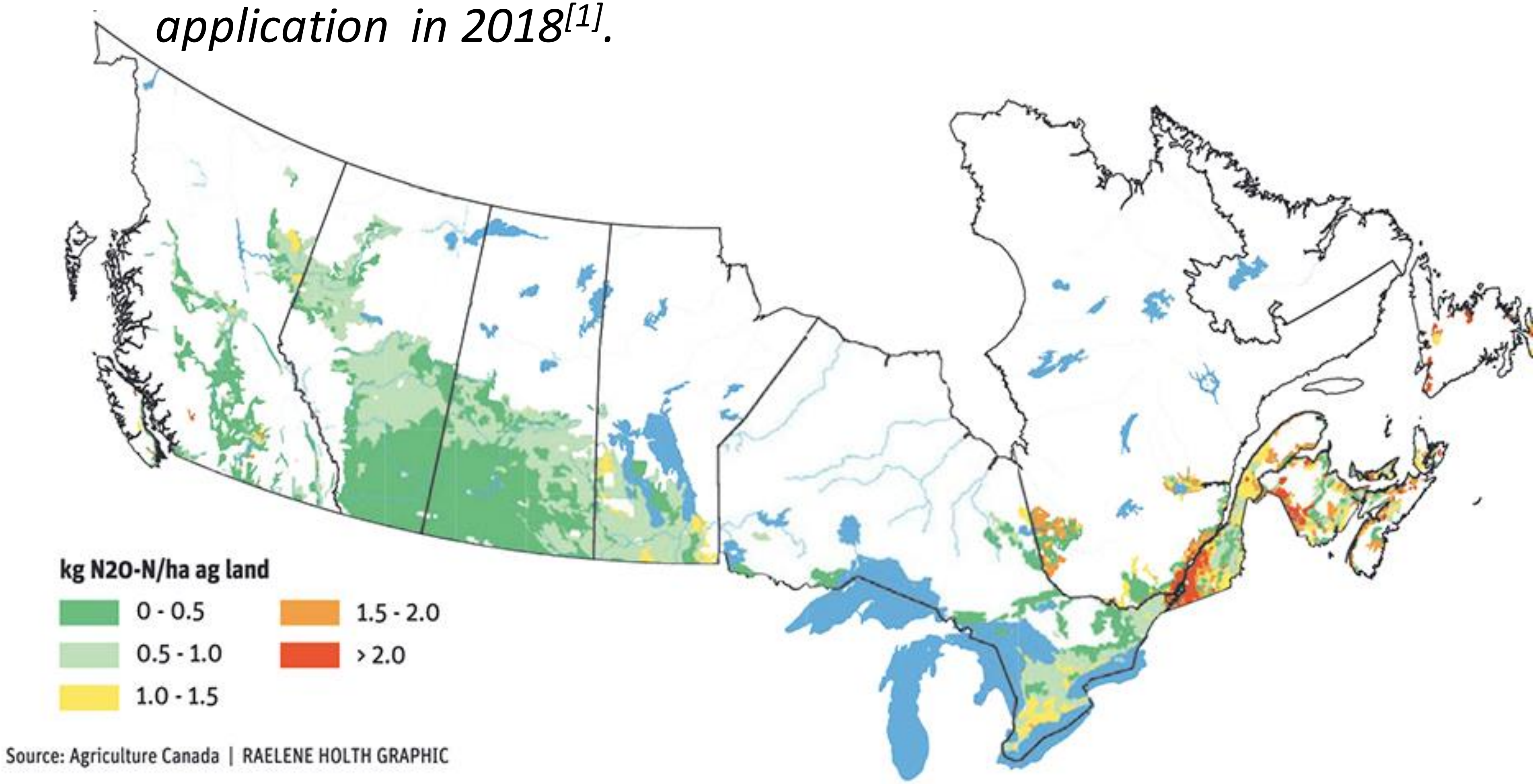
- The economic optimal rate of N applied is calculated where the expected input cost (w_{tN}[12]) to output price (p_{tC}[11])ratio is equal to the estimated MP_N

$$\mathbf{MP_N = \frac{w_{tN}}{E[p_{tC}]}}$$

[11] Saskatchewan Ministry of Agriculture, 2022
[12] Alberta Agriculture and Forestry, 2019

Methods- Emissions Factor Estimates

Figure 4 *Indirect and direct N_2O emissions from synthetic fertilizer application in 2018*[1]*.*



[1] Government of Canada, 2022

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Methods – Emissions Factor Estimates

- The social cost of N_2O emission from N application was calculated using direct emission estimates for the black and brown soil zones in Saskatchewan

Table 3: *Canada's direct GHG emission factors per tonne of applied N fertilizer (ECCC, 2022; Rochette et al., 2018)*

Ecoregion	N_2O-N (kg)	CO_2 eq. (t)	Ext. Cost $/t of N @ $170/t CO_2
Brown soil zone	1.60	0.749	$127 (8.5%)
Black soil zone	3.3	1.545	$261 (17%)
Eastern Canada	21.1	9.88	$1680 (112%)

Results of Canola Production Function
Dep variable: Canola yield kg ha^{-1}

Variable	Units	Estimates (s.e)
P	kg ha^{-1}	2.34 (1.02)*
K	kg ha^{-1}	3.36 (1.18)**
S	kg ha^{-1}	2.77 (0.973)**
Variety Index	% of 252 yield	4.66 (2.31)*
LL (=1)	[0,1]	529 (155)***
RR (=1)	[0,1]	419(153)**
Variety Index x LL		−4.91 (1.63)**
Variety Index x RR		−4.26 (1.61)**
Avg. Precip	mm	1.86 (0.771)*
Avg. $Precip^2$	mm	−0.00272 (0.00142)+
GS Precip	mm	0.469 (0.352)
GS $Precip^2$	mm	-0.00128 (0.0000651)*
Seeding Date	Days after May 14	4.79 (1.30)***
Seeding $Date^2$	Days after May 14	−0.376 (0.0691)***
Fungicide (=1)	[0,1]	152 (9.01)***
Prev. Cereal (=1)	[0,1]	21.5 (19.7)
Prev. Pulse (=1)	[0,1]	63.9 (29.5)*

Variable	Units	Estimates (s.e)
N	kg ha^{-1}	1.86 (1.81)
N^2	kg ha^{-1}	−0.0140 (0.00535)**
N x Prev. Cereal		−0.155 (0.176)
N x Prev. Pulse		−0.482 (0.268)+
N x Variety Index		0.0444 (0.0155)**
Num. Obs.		47059
R^2		0.853
R^2 Adj.		0.803
R^2 Within		0.038
Std.Errors		Hetero-robust
FE: Producer*Year		X
FE: Risk zone		X
FE: Soil class		X

+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Results of Canola Production Function

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- The estimated privately optimal N application rate increased with increasing canola variety yield index.

- The estimated privately optimal N rates were significantly higher on cereal or oilseed stubble versus pulse stubble.

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Estimated Private Economically Optimal N Rates for 2019

Table 5: *Estimated Optimal N Rates for 2019.*

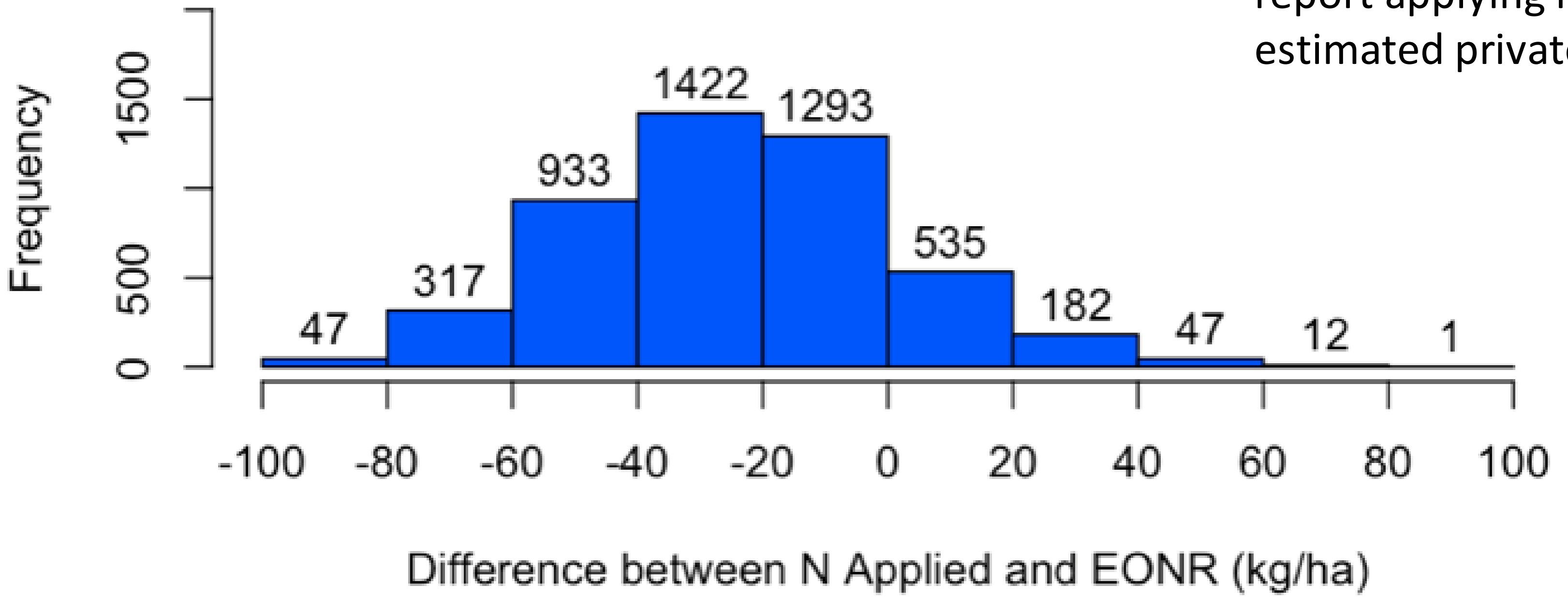
Previous Crop	Mean Variety Index	Prices ($ t^{-1})		N application rate (kg ha^{-1})	
		Canola[a]	Nitrogen[b]	Optimal (s.e.)	Observed annual mean[c]
Oilseed	104%	511	1,208	147 (19.1)	121
Cereal	104%	511	1,208	142 (17.5)	119
Pulse	104%	511	1,208	130 (17.5)	118

[a] Source: Saskatchewan Ministry of Agriculture, 2022

[b] Source: Alberta and Agriculture Forestry, 2021

[c] Source: Saskatchewan Crop Insurance Corporation 2019 dataset.

2019 Frequency of Reported N Application Rates Relative to Estimated Optimal N Rate



- On average, the majority of producers report applying N near or below the estimated privately optimal N rate.

Observed vs Estimated Optimal N Rate

- 31.2% of the reported field N rates in the dataset were below the estimated optimal N rate at the 95% confidence level over the years 2011-2019.
- Only 2.64% of reported field N applications were above the estimated optimal N rates at the 95% confidence level while the vast majority reported applying N within the 95% interval of the EONR.

Observed vs. Estimated Optimal N Rate

- Observed producer applied N may deviate from the estimated privately optimal N rate due to:
  - Differing individual N response curves
  - Risk Perceptions
  - Logistical Constraints
  - Credit constraints

Policy Scenarios

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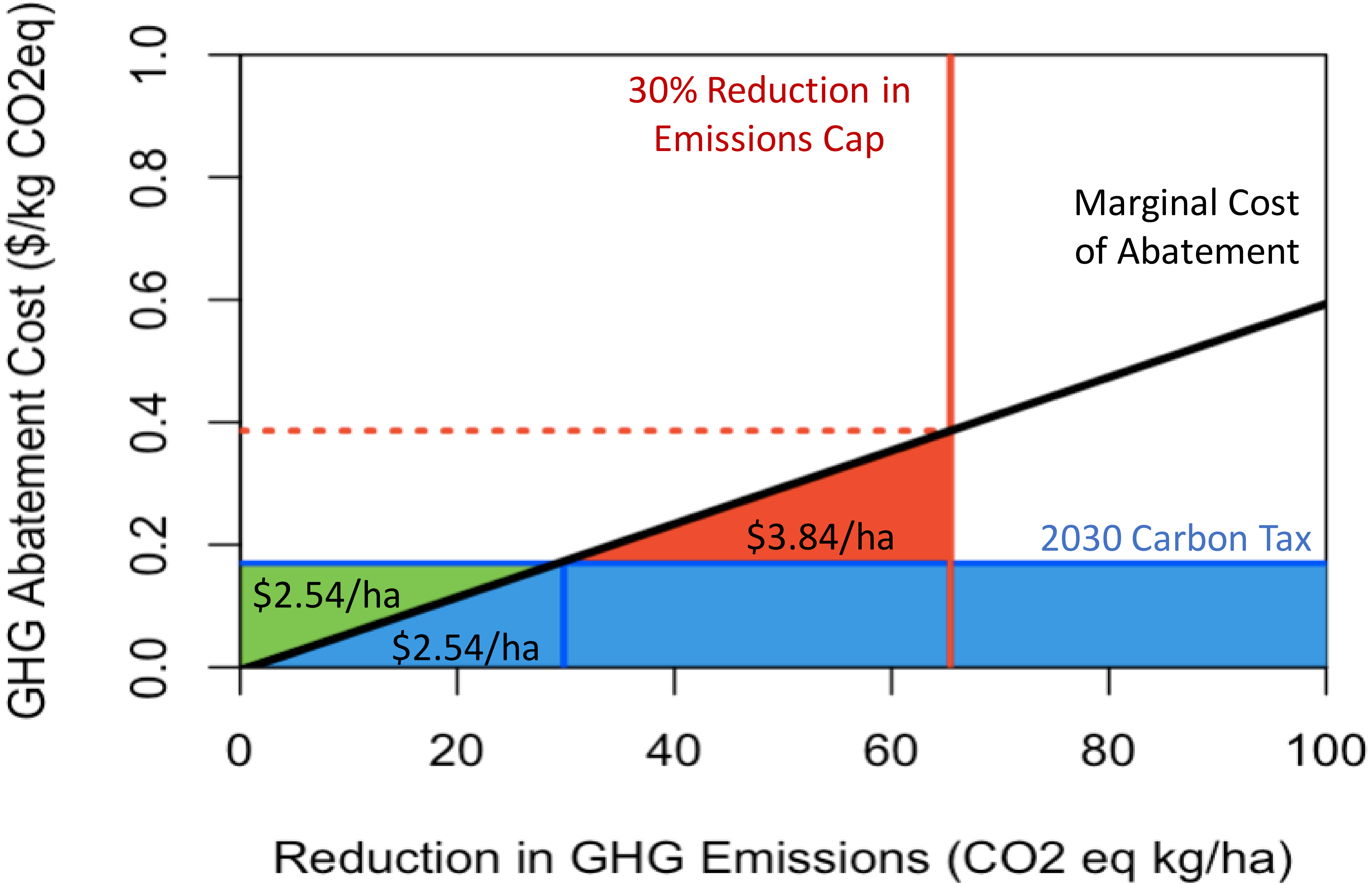
Assess the effect of two policy scenarios on social welfare and producer return:

- 1) A tax on direct N_2O emissions from N fertilizer

Ecoregion	CO_2 eq. (t)	Ext. Cost $/t @ $170/t CO_2 = T*
Black soil zone	1.545	$261 (20%)

- 2) A 30% reduction in N fertilizer emissions via a 30% reduction in N application

Figure 5: Marginal GHG Abatement ($/ha): N_2O Pigouvian Tax vs. 30% N Reduction, starting from estimated privately optimal N rates of 142 kg/ha in 2019.



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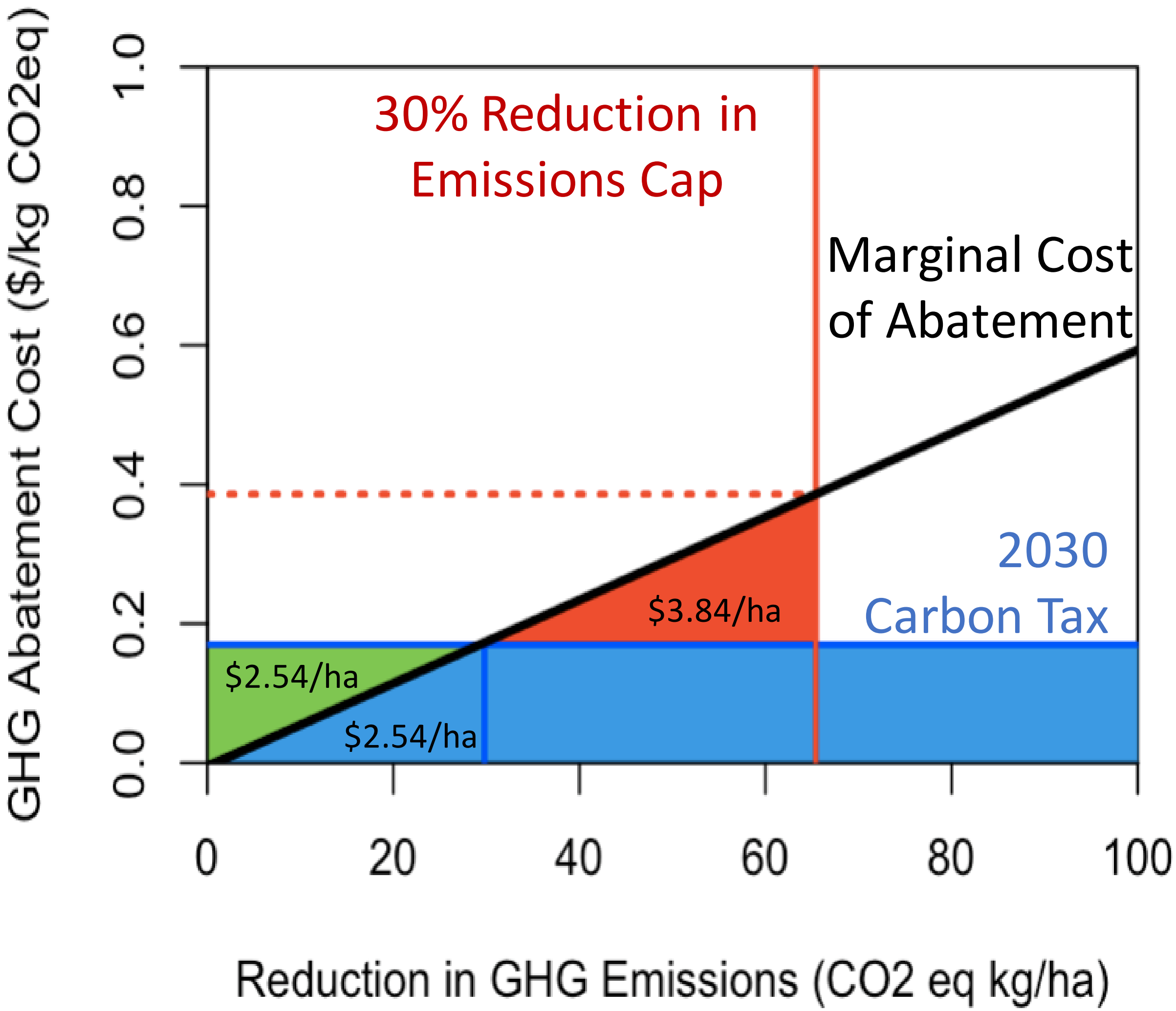

A **direct N_2O tax** using the 2030 social cost of carbon of \$0.17/kg CO_2eq (\$170/tonne)

- Additional cost of **\$261/tonne (20%)** of N
- Estimated to reduce N rate applied by **19 kg/ha (13%)** from the estimated private optimal N rate
- Reduce producer return by **\$34.8/ha**[a]
- Reduce emissions by **29.8 CO_2eq kg/ha** (equivalent to **\$5.08/ha**)

[a] Source: Saskatchewan Ministry of Agriculture, 2022

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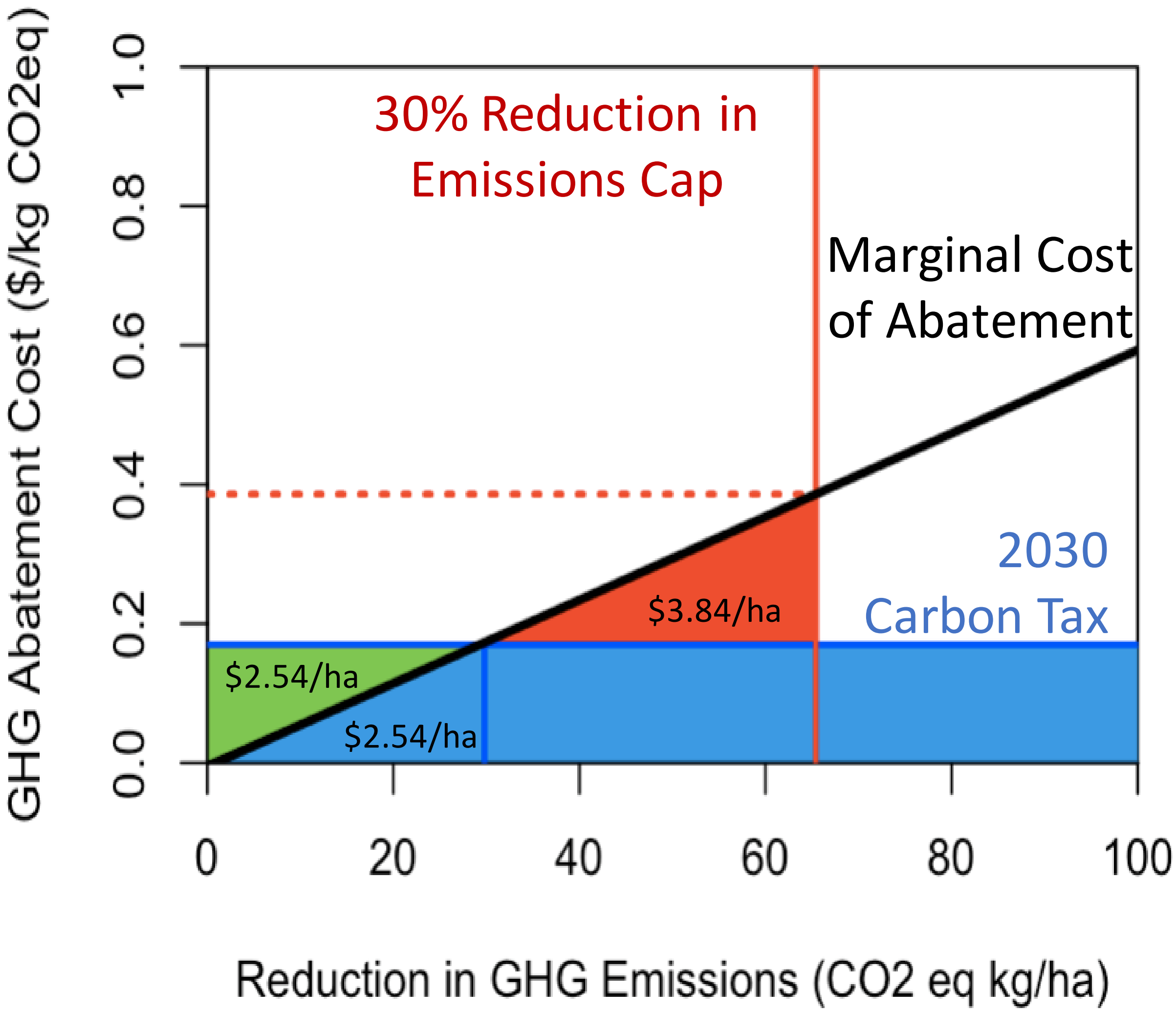
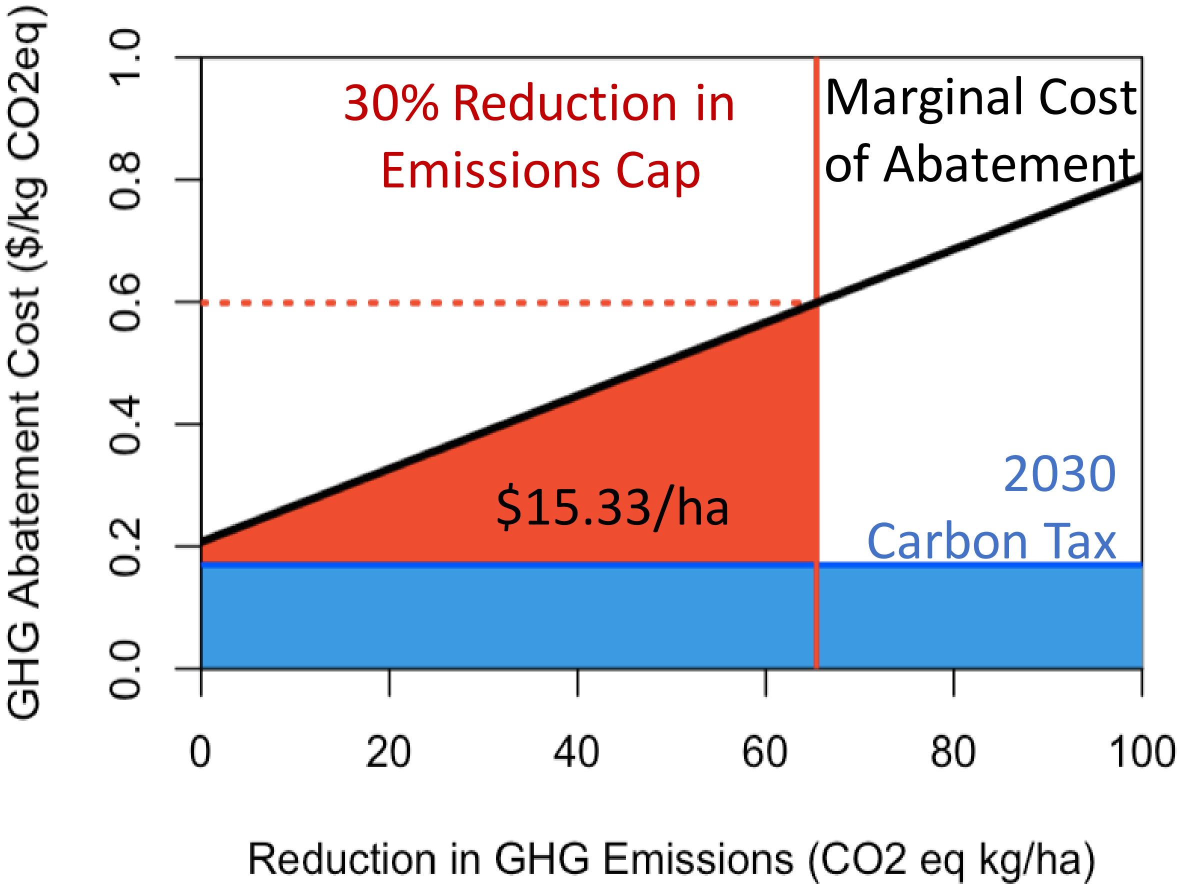


A **30% reduction** in N fertilizer emissions via a 30% reduction in N application

- Results in a DWL of **$3.84/ha**
- Marginal cost of abatement of **$0.386/kg CO_2eq** ($386/tonne CO_2eq kg), 200% the 2030 scheduled price of carbon
- Reduce producer net return by **$75.3/ha**[a]

[a] Source: Saskatchewan Ministry of Agriculture, 2022

Figure 6 Marginal GHG Abatement ($/ha): N_2O Pigouvian Tax versus 30% N Reduction, starting from the average observed rate in 2019 of under application of N by 23kg/ha.



When applying N at the observed rate in 2019 (underapplying by 23 kg ha^{-1} relative to the private optimal N rate):

- DWL of a regulated 30% reduction in emissions is **$15.33/ha**
- Marginal cost of abatement of **$0.612/kg CO_2eq** ($612/tonne CO_2eq) 3.5 times the 2030 scheduled price of carbon

Conclusions

- The majority of Sask canola producers report applying N near or below what we estimate to be the private economically optimal N rate.
- These results contrast previous findings in Canadian economic literature, where it was found the majority of producers were overapplying N relative to the economic optimal rate (De Laporte, et al., 2021).

Policy Implications

- Across-the-board, overly restrictive policies to reduce N fertilizer application rates would lead to reduced:
  - Yields
  - Social welfare
  - Producer profitability

Policy Implications

- Given the wide range of emissions factors across ecoregions and individual farming practices, focusing on optimizing fertilizer use
    - 4R's of Nutrient Stewardship
    - Investing in agronomic research & innovation
    - Extension

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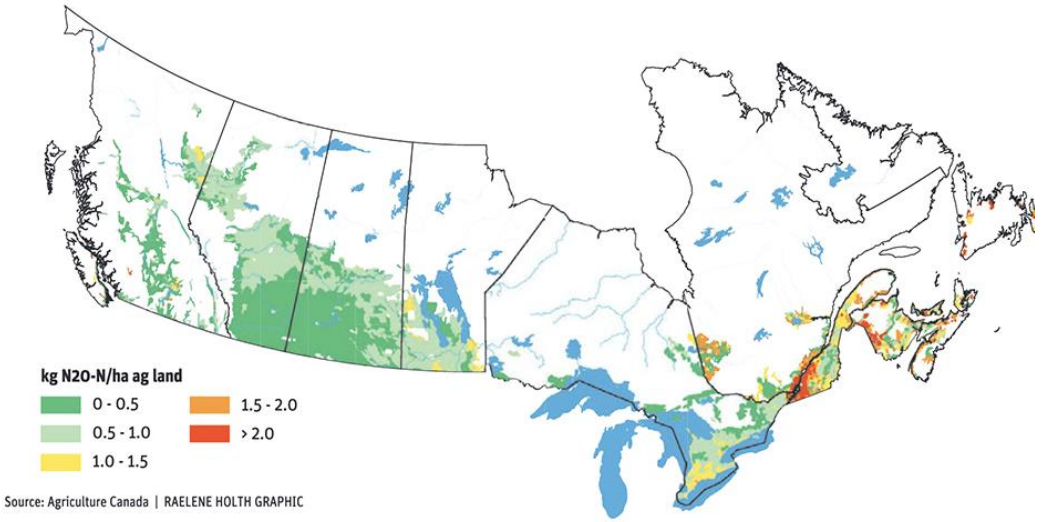

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