Soil N_2O Emissions: Contribution of Legumes and No-till

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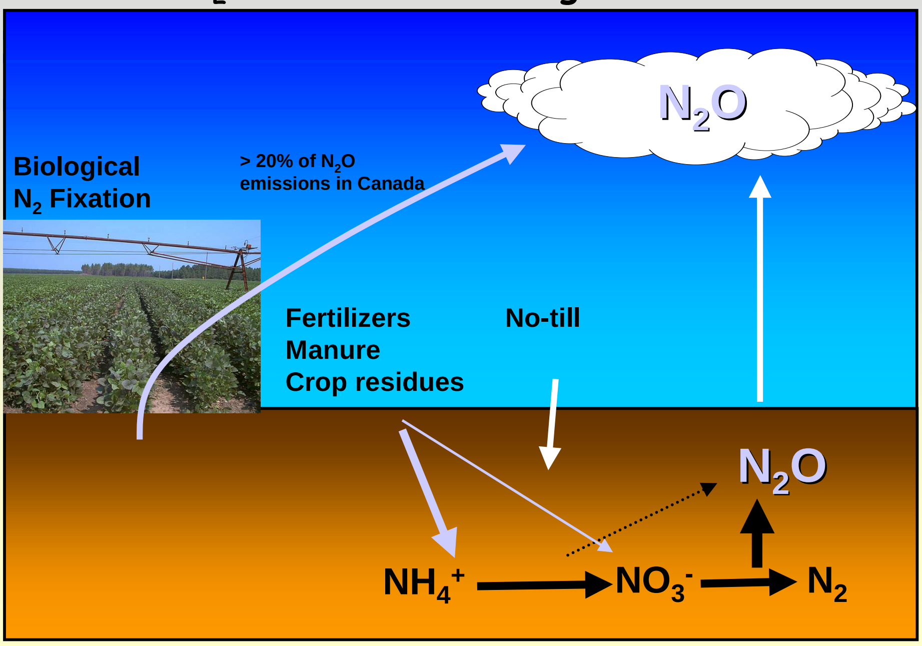
"IPCC" N_2O Sources from Agricultural Soils



N_2O from Legumes

- According to IPCC (1997), legumes can produce N_2O in two ways:
  - During the N_2 fixation itself
  - When N-rich crop residues are returned to the soil
- Legume crop residues increase N_2O emissions (Aoyama and Nozawa, 1993; Larsson et al., 1998; Baggs et al., 2000; Huang et al., 2004; Rochette et al, 2004)
- Emissions during biological N fixation (BNF) seem less certain

N fixation can produce N_2O

- *Rhizobium* can denitrify nitrate and release N_2O (O'Hara and Daniel, 1985; van Berkum and Keyser, 1985; Bryan et al., 1985; Smith and Smith, 1985; Bonish et al, 1991; Garcia-Plazaola et al., 1993; Rosen et al., 1996)
- Several benefits for *Rhizobium*:
  - Eliminates NO_3^- and NO_2
  - Supplies energy

Significance of N_2O emissions during N Fixation remains uncertain and unproven

- O'Hara and Daniel, 1985:
  - "Denitrification can occur in normally-aerated soils" and "on an area basis, the nitrogen losses are similar in magnitude to the N gained by symbiotic rhizobial N fixation, even when soil numbers of *Rhizobia* are quite moderate"
- Garcia-Plazaola et al., 1993:
  - "…even with optimal conditions for denitrification and the highest rhizobial populations found in agricultural soils, the contribution of *Rhizobium* to the total denitrification was virtually negligible as compared to other soil microorganisms"

IPCC "Tier I" BNF N_2O Factor

- Very few field data quantifying N_2O emissions from BNF prior to 1995:
  - Duxbury et al. (1982) = 2.3 and 4.2 kg N_2O-N ha^{-1} yr^{-1} from alfalfa
  - Bremner et al. (1980) = 0.3 to 2.0 kg N_2O-N ha^{-1} yr^{-1} from soybean
- 1997 IPCC "Tier I" factor for BNF was estimated at <u>1.25% of fixed N</u>

Objective

- Summarize recent N_2O data from agricultural legume crops to assess the emission factor associated with rhizobial N fixation (BNF)

Material and Methods

- Sources:
  - Bouwman et al. (2002); an extensive list of flux and ancillary data from field studies published prior to 2000;
  - Additional references published before 2000 but not included in Bouwman et al. (2002).
  - Studies published after 1999.
  - Unpublished data from Canadian studies summarized by Helgason et al. (2005).

- Only growing-season emissions when possible
- Divided into fertilized and unfertilized

N_2O Emissions from Legume Crops

Crop grouping	# studies	N_2O emissions (kg N ha^{-1} yr^{-1})	
	(site-years)	mean	std. dev.
Perennial (pure)	16	1.8	1.3
Perennial (+grass)	5	0.4	0.3
Annual w/o N	31	1.0	0.9
Annual with N (162 kg N ha^{-1} yr^{-1})	16	1.5	1.3
IPCC background		1.0	
IPCC legumes		3 to 6	

Rochette and Janzen (2005)

IPCC-1997 vs Measured Data

- We conclude that BNF N_2O emissions are:
  - Approximately equal to background N_2O emissions (0.4 to 1.8 kg N ha^{-1} yr^{-1})
  - Largely overestimated using IPCC Tier I 1997 methodology (3 to 6 kg N ha^{-1} yr^{-1})

N_2O during BNF

- Little N_2O emission during BNF under field conditions agree with recent findings from process-level laboratory studies
- Zong et al., 2004:
  - N_2O emissions in inoculated legumes = emissions from non-inoculated legumes
- Thyme and Ambus, 2005:
  - Only 0-2% of N_2O-N originated from recently-fixed N

Conclusions - Legumes

- Legumes stimulate N_2O emissions
- These emissions are attributable to N release from roots during growing season and from decomposition of crop residues rather than to BNF
- Under field conditions, *Rhizobia* denitrification does not reduce significant amounts of nitrate and / or N_2O represents only a small fraction of the gaseous N products
- 2006 IPCC methodology for national GHG inventory does not include BNF *per se* as a source of soil N_2O

Influence of No-till on N_2O Emissions

- No-till has increased in several regions
- No-till modifies several soil properties that influence N_2O emission:
  - Density
  - Temperature
  - Water content
  - Distribution and availability of crop residues C and N

Influence of No-till on N_2O Emissions

- Impacts of no-till on soil N_2O emissions has been variable
- Increases (Ball et al., 1999; Rochette et al., 2008) and decreases (Chatskikh and Olesen, 2007; Gregorich et al., 2008) have been reported

Hypothesis

- We hypothesized that the response of soil N_2O fluxes to the adoption of no-till is influenced by soil aeration

Methodology

- Results from 22 field studies were grouped according to soil aeration status
- 3 soil aeration classes were defined:
  - Good : good or medium drainage + precipitations < 400mm
  - Medium : good or medium drainage + precipitations > 400mm
  - Poor : poor drainage

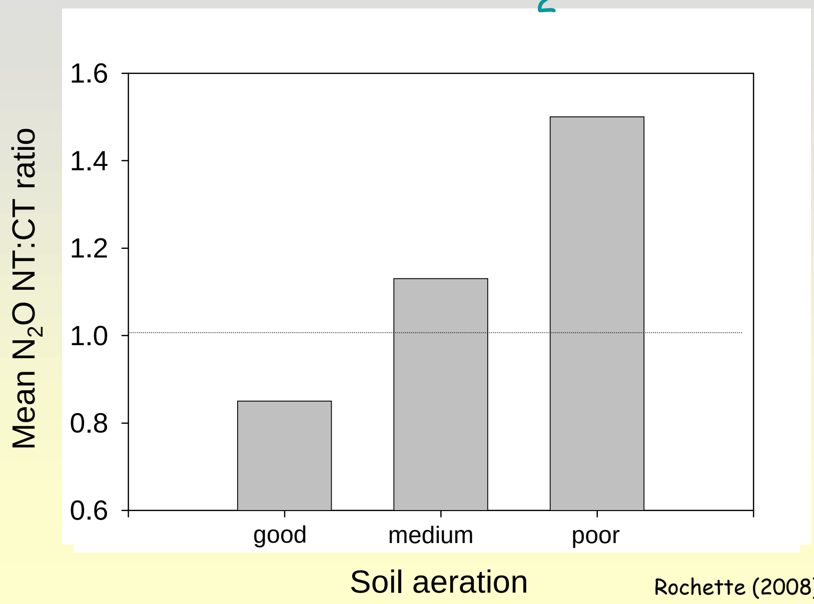
Aeration status	Drainage	Precip.	Soil texture	Climate	Tillage	period	Cumulated N_2O emissions NT	T	NT-T	Reference
		mm				d yr^{-1}	kg N_2O-N ha^{-1}			
Good	high	384	loam	cool	MP (30)	365	1.32	0.80	0.52	Oorst et al. (2007)
	high	305	loam	semi-arid	MP (15)	365	0.25	0.31	-0.06	Kessavalou et al. (1998)
	medium	271	sandy cl. loam	semi-arid	R (10)	110	0.12	0.25	-0.12	Malhi et al. (2006)
	medium	270	sandy cl. loam	semi-arid	R (10)	130	0.34	0.40	-0.06	Malhi and Lemke (2007)
	medium	320	loam	semi-arid	R (10)	170	0.30	0.29	0.01	Lemke et al. (1999)
	medium	242	clay loam	semi-arid	R (10)	170	0.97	1.46	-0.49	Lemke et al. (1999)
							0.38	0.38	0.0	Dusenbury et al. (2008)
mean		299				218	0.39	0.45	-0.06	NT/T = 0.87
Medium	ns	694	volcanic ash	cool humid	MP (25)	365	0.83	0.27	0.56	Koga et al. (2004)
	high	640	sandy loam	cool humid	MP (20)	215	1.11	0.99	0.12	Rochette et al. (2008)
	high	622	loam	cool humid	MP (ns)	365	132	1.20	0.12	Grandy et al. (2006)
	high	429	loamy sand	cool	MP (20)	113	0.43	0.89	-0.46	Chatskikh and Olesen (2007)
	medium	410	loam	cool humid	ns (25)	65-79	1.97	0.46	1.51	Baggs et al. (2003)
	high	620	loam	cool humid	C+RT	150	1.84	1.88	-0.04	Jacynthe and Dick (1997)
	high	560	loam	cool humid	MP (20)	180	1.00	1.34	-0.34	Gregorich et al. (2008)
	medium	552	clay loam	semi-arid + Ir.	MP (ns)	365	1.19	1.51	-0.32	Liu et al. (2005)
	medium	552	clay loam	semi-arid + Ir.	MP (ns)	365	0.99	1.29	-0.30	Mosier et al. (2006)
	high	574	loam	cool humid	MP (20)	225	2.10	1.80	0.30	Larouche (2006)
mean		565				242	1.16 [c]	101 [c]	0.15	NT/T = 1.15
Poor	poor	430	clay loam	cool humid	MP (15)	215	3.35	3.82	-0.47	Drury et al. (2006)
	poor	430	clay loam	cool humid	MP (15)	215	1.00	1.15	-0.15	Kaharabata et al. (2003)
	poor	590	loam	cool humid	C (18)	365	7.74	7.58	0.16	Parkin and Kaspar (2006)
	poor	400	heavy clay	cool humid	MP (ns)	200	4.40	2.00	2.40	Burford et al. (1981)
	poor [e]	377	clay loam	cool humid	MP (20)	77	13.0 [f]	3.80 [f]	9.20	Ball et al. (1999)
	poor	680	silty loam	cool humid	MP (25)	260	12.0	9.20	2.80	Choudhary et al. (2002)
	poor	574	heavy clay	cool humid	MP (20)	240	2.79	1.99	0.80	MacKenzie et al. (1997)
	poor	640	heavy clay	cool humid	MP (20)	215	32.7	13.3	19.34	Rochette et al. (2008)
mean		515				223	5.97 [c]	3.97 [c]	2.00	NT/T = 1.50

Soil N_2O emissions from CT and NT soils

Aeration	Drainage	Precip.	N_2O emissions			
		mm	kg N ha^{-1} yr^{-1}			
			NT	CT	NT-CT	NT/CT
good	med-high	300	0.39	0.45	**-0.06**	**0.87**
medium	med-high	565	1.16	1.01	**0.15**	**1.15**
poor	poor	515	5.97	3.97	**2.00**	**1.50**

Rochette (2008)

NT:CT Soil N_2O ratio



Rochette (2008)

Conclusions - No-till

- Response of N_2O emissions to no-till varies according to soil aeration
- Soil organic matter often increases after adoption of no-till
- Sink for atmospheric CO_2
- Increases are usually < 200 kg C ha^{-1} yr^{-1}
- Emission of 1 kg N_2O ≈ loss of 125 kg C
- **No-till may increase net GHG emission from many poorly-drained agricultural soils.**

Background

- N_2O is a potent greenhouse gas
- Agriculture is a major source of N_2O
- National inventory of N_2O emissions is required by international initiatives (UNFCCC and Kyoto Protocol)
- IPCC methodology (Intergovernmental Panel on Climate Change)

Conclusions

- Consequently, we propose that:
  - N_2O emissions induced by the growth of legume crops be estimated solely as a function of crop residue decomposition

IPCC vs Measured Data

- Total N_2O emissions from legume crops vary from 0.4 to 1.8 kg N ha^{-1} yr^{-1}
- These emissions include all sources
- Background N_2O emissions from agricultural soils are approximately = 1 kg N ha^{-1} yr^{-1}
- Estimates using the IPCC "Tier I" factor = 3 to 6 kg N ha^{-1} yr^{-1}