Greenhouse gas fluxes in boreal agricultural soils under conventional tillage and no-till practice

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Abstract

Emissions of nitrous oxide (N_2O), carbon dioxide (CO_2) (total ecosystem respiration), and methane (CH_4) were measured on conventionally ploughed agricultural soils and from respective soils under no-till practice. Six pairs of tilled and no-till soils were studied during a one year period. The results suggest that there is a risk of increased N_2O emissions in no-till agriculture in northern European climate. It seems that it is not possible to achieve reliable estimates on the climatic effects of no-till agriculture with the current scientific knowledge. We need more data for improving the GHG emission inventories and for future land use policies.

Introduction

There has been increasing interest on agricultural practices that reduce carbon losses from soils recently. In no-till farming the new crop is sown on the stubble of the previous crop without the need to till the soil at any stage. The advantages of this technique are reduced costs of labor and fuel and reduced leaching of nitrogen to watercourses. The crop residues are not mixed with soil (Fig. 1) and the aggregation of the topsoil becomes more stable; thus the decomposition of the plant material may slow down and potentially soil carbon is conserved in the surface layer of the soil (Lal 1997). There are, however, many reports stating that the carbon content of the whole soil profile does not change in no-tillage (Angers et al. 1997, VandenBygaart et al. 2002, Dolan et al. 2006).

Direct drilled soil with a higher moisture content and more dense structure compared to ploughed soil is a suitable environment for denitrifying bacteria. Thus there is a risk of enhanced N_2O emissions in these soils. Since N_2O is a 300 times more efficient greenhouse gas than CO_2 it has been estimated that increased N_2O emissions in no-till agriculture could offset even 75-310 percent of the advantage gained from the carbon sequestration (Li et al. 2005). There are reports of both decreased and increased emissions of N_2O in no-till (Table 1). It is

Table 1:
The effect of no-till practice on N_2O emissions from soil

Location	N_2O-N (kg ha^{-1} month^{-1})		Reference
	Tilled	No-till	
Saskatchewan	0.7	1.2	Aulakh et al. 1984
Canada	0.8	2.0	
Quebec, Canada	0.8	1.0	MacKenzie et al. 1998
Scotland	1.1	1.9	Ball et al. 1999
Ontario,	0.32	0.24	Kaharabata et al. 2003
Canada	0.27	0.26	
Brazil	0.37	0.27	Passianoto et al. 2003
S.E. England	0.1-0.5*	0.7-2.5*	Baggs et al. 2003

*kg ha^{-1} in 21 days (time after fertilization)

Figure 1:
Tilled (a) and no-till (b) soil after harvest

probable that in arid climates the N_2O emissions do not increase as in humid climates. In a meta-analysis of 62 sites across Canada it was observed that in western Canada no-tillage increased the soil carbon storage without enhanced N_2O emissions, while in eastern Canada with a wetter climate there was no net increase in soil carbon but the N_2O emissions were expected to enhance (VandenBygaart et al. 2003; Grant et al. 2002). Since the soil structure changes in no-till soil the effects on N_2O emissions may also depend on soil type.
The objectives of this pilot study were to find out

1) if there is a risk of increased N_2O emissions in no-till farming in northern European climate and
2) whether the effects on N_2O fluxes are dependent on soil type or other soil properties.

Materials and methods

Sites for the study were either fields of neighboring farmers (sites 4 and 6) or field experiments (sites 1-3 and 5) and represented the typical soil types of

Table 2:
Climate and soil properties of the experimental sites

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
	Till/no-till	Till/no-till	Till/no-till	Till/no-till	Till/no-till	Till/no-till
Soil type	Silty clay	Clay	Silty clay	Sand	Silty loam	Organic
Annual precipitation (mm)[a]	607	607	626	618	527	527
Mean temperature (°C)[a]	4,3	4,3	4,5	4,2	3,6	3,6
Crop in 2005	Barley	Barley	Barley	Barley	Barley	Oat/Barley
Total N (g kg^{-1})[b]	2.0/2.1	2.3/2.3	2.7/2.2	1.5/-	1.2/1.6	5.5/5.3
Organic C, 0-20cm (g kg^{-1})	27/28	27/28	26/37	28/23	15/20	80/78
Organic C, 20-40cm (g kg^{-1})	14/7,2	9,7/-	12/22	19/-	6,1/7,9	56/55
C/N, 0-20 cm	13.5/13.3	11.7/12.2	9.6/16.8	18.7	12.5/12.5	14.5/14.7
Mineral N summer (mg kg^{-1})[b]						
NH_4	2.2/3.3	1.8/2.3	1.4/1.0	2.0/2.6	-	-
NO_3	1.4/1.6	2.1/2.7	1.4/0.6	0.6/2.8	-	-
Mineral N autumn (mg kg-1)b						
NH_4	4.7/1.9	3.9/1.1	0.8/2.0	3.0/1.5	1.4/3.5	3.7/5.8
NO_3	1.3/2.8	1.5/2.8	3.5/1.4	6.2/2.6	6.8/11.2	24/40

[a]Reference period 1971-2000 (Drebs et al. 2002)
[b]at 0-20 cm layer

Table 3:
Mean fluxes of greenhouse gases (±SD) from tilled and no-till sites, the gas balance as CO_2-equivalents, and the resulting change in the gas balance relative to the change from conventional tillage to no-tillage

Site		N_2O-N (mg m^{-2} h^{-1})	CO_2 (mg m^{-2} h^{-1})	CH_4 (mg m^{-2} h^{-1})	Gas balance (mg CO_2-eq. m^{-2} h^{-1})	Change* (%)
Site 1	Tilled	0.014±0.024[a]	590±820[a]	-0.004±0.014[a]	594	
	No-till	0.046±0.069[b]	590±890[a]	-0.004±0.019[a]	614	3,4
Site 2	Tilled	0.003±0.005[a]	440±700[a]	0.008±0.022[a]	441	
	No-till	0.016±0.017[b]	560±750[a]	-0.003±0.016[a]	567	28,7
Site 3	Tilled	0.027±0.064[a]	430±460[a]	-0.001±0.017[a]	446	
	No-till	0.006±0.006[a]	330±460[a]	0.012±0.015[a]	337	-24.3
Site 4	Tilled	0.013±0.017[a]	350±350[a]	-0.0002±0.028[a]	353	
	No-till	0.092±0.171[b]	530±400[b]	-0.003±0.017[a]	577	63.5
Site 5	Tilled	0.086±0.101[a]	590±910[a]	-0.002±0.013[a]	628	
	No-till	0.195±0.286[b]	860±1350[b]	-0.004±0.018[a]	951	51.3
Site 6	Tilled	0.183±0.202[a]	990±1300[a]	-0.006±0.016[a]	1076	
	No-till	0.233±0.146[a]	800±1160[b]	-0.005±0.016[a]	905	-15.9

Different letters denote statistically significant differences between the respective tilled and no-till sites.
*Positive value indicates increase in total gas emissions when changing from tillage to no-till farming.

Finland. All sites comprised of pairs of tilled and no-till soil, and the no-till soils had been under no-till practice for 5-20 years. Soil properties are shown in Table 2. Sites 1 and 2 were located in Jokioinen, southern Finland, site 3 in Vihti, southern Finland, site 4 in Säkylä, south-west Finland and sites 5 and 6 in Ylistaro, western Finland.

Greenhouse gas measurements with closed chambers were conducted 10 times on each site during a one-year period in 2005-2006. The gas samples were analyzed within 48 hours with a gas chromatograph equipped with flame ionization (FID) and electron capture detectors (ECD) and a nickel catalyst for converting CO_2 to CH_4. The linear response resulting from the analysis of four gas samples taken during the 30 min enclosure period was used for calculating the emission rate. The volume of each analyzed gas in the chamber was corrected according to the chamber temperature. The gas balance of different sites was calculated using the global warming potential (GWP) of each gas (IPCC 2001). The GWP was 23 for CH_4 and 296 for N_2O.

Results and discussion

In most field pairs we observed higher N_2O emissions from no-till soil (Table 3). Furthermore, also the total ecosystem respiration was usually higher from no-till plots indicating higher decomposition activity. Fluxes of methane did not differ significantly between tilled and no-tilled plots. The total greenhouse gas emissions were reduced in no-till practice in two of the site pairs studied, and even 50-60% increases were observed.

On the average, the soil moisture was higher in no-till soils compared to their ploughed counterparts. We also observed that the frost was deeper in some of the ploughed soils, and that the frost melted earlier in the ploughed plots. In most cases the content of nitrate was higher in no-till soils indicating the possibility of overfertilization in no-till farming. However, it is possible that the mineralization activity has different timing in tilled and no-till soils. The density of earthworms has not been determined on all plots yet but the first results suggest that the N_2O emissions were the highest on sites with high densities of earthworms.

The results suggest that there is a risk of increased N_2O emissions in no-till agriculture in the climate of northern Europe. Reasons for increased denitrification activity and N_2O emissions from no-till fields can be e.g. 1) higher soil moisture, 2) increased density of earthworms, 3) soil compaction or 4) over-fertilization. Our further studies will explore the significances of these factors. The effect of soil type was not clear since all three clay soils (sites 1-3), for example, reacted differently to the change from conventional tillage to no-till. Further analysis of the soil properties will hopefully clarify this question.

In many countries there has been discussion lately on whether to elect for Article 3.4 of the Kyoto protocol and whether to choose to report cropland management or not. In this context the parties needed to evaluate among other things the effects of no-tillage agriculture on carbon stocks of soils. The default method of the IPCC guidelines for LULUCF only takes into account carbon sequestration and not the possibility of increased emissions of N_2O from these soils (IPCC 2003). It seems that it is not possible to achieve reliable estimates on the climatic effects of no-till agriculture with the current scientific knowledge. We need more data for improving the GHG emission inventories and for future land use policies.

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