Greenhouse gas emissions from oats, barley, wheat and rye production

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Abstract. The aim of this study was to analyze greenhouse gas (GHG) emissions from oats, barley, spring wheat and rye production in Finland. The GHG emissions were analyzed in a conventional production chain, direct drilling chain and reduced tillage chain. The greenhouse gases were analyzed per kilogram grain (kg CO_2-eq. kg^{-1}) and hectare (kg CO_2-eq. ha^{-1}). The main part of the GHG emissions of the grain production chain originated from fertilizer manufacturing and soil. Soil emissions were a result of using N-fertilizer which induced N_2O-emission and liming which induced CO_2-emission. GHG emissions from soil were about half of all emissions of grain production. Therefore, the N-fertilizer application rate had a strong direct and indirect effect on the GHG emissions. Wheat (2,330kg CO2-eq. ha^{-1}) and rye (2,270kg CO_2-eq. ha^{-1}) had higher GHG emissions per hectare than oats and barley. The main reason for this was the higher application rate of N-fertilizer. The emissions of oats and barley were 1,800 and 1,930kg CO_2-eq. ha^{-1}. The yield had a strong impact on the emissions per kilogram of grain. Oats (570g CO_2-eq. kg^{-1}), barley (570g CO_2-eq. kg^{-1}) and wheat (590g CO_2-eq. kg^{-1}) had lower greenhouse emissions than rye. A low grain yield together with high N-fertilizer application rate caused higher greenhouse gas emission for rye (870 g CO_2-eq. kg^{-1}). Direct drilling and reduced tillage resulted in some lower GHG emissions than conventional tillage. However, differences between production chains were minor.

Key words: Greenhouse gas emission, grain production, oats, barley, rye, winter wheat.

INTRODUCTION

According to the FAO (2002), agriculture is a major source of greenhouse gas emissions. GHG emissions of agriculture are estimated to increase worldwide in the future (IPCC, 2007a). Finland`s GHG-emissions from agriculture have decreased since the 1990ies (STV, 2008). Agriculture releases approximately 10–15% of all GHG-emissions in Finland (MMM 2001, 4). Cold weather decreases GHG emissions, but the large proportion of organic soils (peat soils) increases GHG emissions in Finland compared with many other countries (Pipatti et al., 2000). The most significant GHG gases from agriculture are CO_2, CH_4 and N_2O (IPCC, 2007a). CO_2 gas emissions are essentially in balance in agriculture because the plant binds the same amount of CO_2 in photosynthesis as it induces in decomposition. However, the intensive cultivation of soil, the use of fertilizers and liming increase CO_2 emissions. Animal husbandry and rice production are responsible for the CH_2 emissions. Fertilizers induce N_2O emissions from soils indirectly (Pipatti et al., 2000; IPCC, 2007a).

GHG emissions from agriculture are not well known compared to other sectors. Especially CO_2 and N_2O emissions from soil are badly known (MMM 2001). There are still many uncertainties in the estimations of greenhouse gas emissions. According to the IPCC (2007b), agricultural land is globally the most significant source of N_2O related to human activity. Emissions are not unambiguous, because for example liming induces CO_2 emission, but it also intensifies the N intake of plants and decreases demand for N-fertilizer. Besides the emission from the soil, agriculture also uses energy, such as fuel for machines and for manufacturing, in addition to using production inputs, such as fertilizers, which induces emissions (MMM, 2001).

The aim of this study was to analyze greenhouse gas emissions for oats, barley, spring wheat, and rye production in Finland. This study is based on the literature and the statistics of Finnish agriculture. Bernesson et al. (2006) have estimated GHG emissions from wheat production as a part of bioethanol production chain. In their studies the GHG emissions from wheat production were 2,210kg CO_2 eq. ha^{-1} (Bernesson et al., 2006). The results are almost the same as in this study. Wanhalinna (2010) has estimated GHG emissions of grain production as a part of carbon print of bread. GHG emissions for wheat were 720g kg^{-1} and for rye 900g kg^{-1}. Grain yields were almost the same as in this study. A reason for a little higher emission was a higher GHG coefficient for N-fertilizer.

MATERIALS AND METHODS

Greenhouse gas emissions

Three main GHG gases were included in our study. These GHG gases were carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4). The following sources of GHG emissions were included in the analysis: emissions from the fuels of the machinery (from ploughing to transport to mill), emissions from soil and emissions from production and use of the fertilizers and the seeds. The GHG emissions caused by manufacturing and maintenance of machines were ignored in the calculations. Changes of carbon balance in soil were also ignored.

Production inputs

GHG emissions were calculated for a conventional production chain, direct drilling chain and reduced tillage chain. Fuel consumption used in the analysis is the average of the figures given by different sources (Danfors, 1988; Kalk & Hulsbergen, 1999; Suomi et al., 2003; Rinaldi et al., 2005; McLaughin et al., 2008; ÖKL, 2009). For diesel fuel, the energy content of 36.3MJ l^{-1} and GHG emission 98.48g CO^2 MJ_{fuel}^{-1} was used in the calculations (Mäkinen et al., 2006).

Seed rate per hectare was 210kg for oats, 235kg for barley, 258kg for wheat and 155kg for rye. The seeding rate was 10% higher in direct drilling than in conventional production or reduced tillage. In this study, it is assumed that the seeds were produced at the same farm with the grain and the seed production process is similar to the grain production. The seeding rate used in the calculations was 30% higher than the actual seeding rate to compensate the losses occurred in the sorting of the seed.

Application rates of N-fertilizer were averages from ProAgria's (2010) data (Table 1). Fertilizers were chosen from the fertilizer selection Yara (2010), which is the market leader in Finland. In this study Yara Pellon Y3 (23-3-8) has been used for oats and barley, Yara Pellon Y2 (24-4-4) for wheat, and Yara Pellon Y1 (27-2-2.5) for rye. The GHG emissions used in the calculations were: 2.9kg CO_2 eq kg^{-1}, 0.71kg CO_2 eq. kg^{-1} P and 0.46kg CO_2 eq. kg^{-1} K (Ahlgren et al., 2009). N-fertilizer manufacturing has decreased due to the new production technique of N-fertilizer. N_2O-emission from soil was calculated using an IPCC (2007b) coefficient. It is estimated that 2.55% from N-fertilizer is converted to N_2O (Mäkinen et al., 2006).

Fields were limed in intervals in five years. The application rate of lime was 4,000kg ha^{-1}. In calculations the lime dose was distributed evenly for each year (800kg $year^{-1}$). GHG emission released from the soil as a result of liming is estimated to be 431kg CO^2-eq. t^{-1} (Mäkinen et al., 2006).

The use of plant protection chemicals was 2.5l ha^{-1}. The GHG emission that is used in the calculations was 17.3kg CO_2-eq. kg^{-1} (Edwards et al., 2006). Couch grass is usually a problem in direct drilling. This is why Glyphosate was used in direct drilling more often than in conventional farming.

Straw was left in the field. The average moisture content of the harvested grains was: oats 18.5%, barley 18.8%, spring wheat 20.5%, and rye 23.1%. Moisture contents were average values from Evira's quality grain research from the years 1999 to 2007. In this study, it was assumed that grain was dried in a hot air dryer to the moisture content of 14%. This is the minimal quality requirement for food grain.

Average distance from fields to the farm was 2.1km (Myyrä, 2001). In this study it was assumed that the average distance from the farm to the mill was 100km.

Grain yield

In this study grain yields were 3,157kg ha^{-1} for oats, 3,380kg ha^{-1} for barley, 3,940kg ha^{-1} for wheat, and 2,619kg ha^{-1} for rye. The yield is assumed to be the same in all production chains. The yield of rye was calculated using N response function by Astover (2010). The yields of oats, barley and wheat were calculated using scaled N response function by Hilden et al. The yields used in the function were too high compared to the average yields in Finland. For that reason the function was scaled to equate the average Finnish yields. The grain yield has a strong impact on GHG emissions per kilogram of grain.

RESULTS AND DISCUSSION

The main part of the greenhouse gases of grain production chain originated from fertilizer manufacturing and from the soil. Soil emissions resulted from N-fertilizer which induced N_2O-emissions and liming which induced CO_2-emissions. GHG emissions from the soil were about half of all the emissions of grain production chain. Therefore the application rate of fertilizer has an outstanding influence on the magnitude of GHG emissions per hectare.

GHG emissions were calculated per hectare and per produced grain kilograms. Wheat production chain and rye production chain had higher GHG emissions per hectare than oats and barley production chains (Table 1). Higher GHG emissions originated mainly from the higher application rate of the N-fertilizer (116kg ha^{-1}). This higher use of N-fertilizer also induced N_2O-emission from soil indirectly. Oats had the lowest emissions due to low application rate of N-fertilizer. Differences of GHG emission between production chains were minor. GHG emissions were lower in direct drilling and reduced tillage than in conventional production chain. Ploughing was the main reason for higher emission in conventional production chain.

Table 1. GHG emissions from conventional production chain, direct drilling chain and reduced tillage chain per hectare.

			GHG-emissions per hectare (kg CO_2-eq. ha^{-1})		
	Yield (kg $hectare^{-1}$)	N-fertilizer (kg $hectare^{-1}$)	Conventional production	Reduced tillage	Direct drilling
Oats	3,157	77	1,800	1,720	1,720
Barley	3,380	86	1,930	1,850	1,850
Wheat	3,940	116	2,330	2,250	2,250
Rye	2,619	116	2,270	2,190	2,190

GHG emissions per kilogram grain were calculated by dividing the emissions per hectare by the grain yield per hectare. Rye production had higher GHG emissions per the produced kilograms of grain than oats, barley and wheat production chains (Table 2). The low yield of rye was the main reason for higher GHG emissions per kilogram. Oats, barley and wheat didn't have large differences between GHG emissions per kilos. Although wheat had the highest greenhouse gas emission per hectare, GHG emissions per kilograms were quite low due to the higher yield.

Table 2. GHG emissions from conventional production chain, direct drilling chain and reduced tillage chain per produced kilograms.

			GHG-emissions per hectare (kg CO_2-eq. ha^{-1})		
	Yield (kg $hectare^{-1}$)	N-fertilizer (kg $hectare^{-1}$)	Conventional production	Reduced tillage	Direct drilling
Oats	3,157	77	0.57	0.54	0.54
Barley	3,380	86	0.57	0.55	0.55
Wheat	3,940	116	0.59	0.57	0.57
Rye	2,619	116	0.87	0.84	0.84

The application rate of the fertilizer and the grain yield had the biggest impact on GHG emissions. The grain yield had a strong impact on emissions per kilogram. If the grain yield increased by 20%, the amount of GHG emissions per produced grain kilos decreased by 23%. If the grain yield decreased by 20%, the GHG emissions per produced grain kilos increased by 16%. The yield has also an effect on the mass of the grain that had to be dried and transported. All other factors were held constant.

Changes in the application rate of fertilizer had a lower impact on emissions than on changes in the grain yield. If the application rate of fertilizer increased by 20%, GHG emissions per hectare increased by circa 10%. If the application rate of fertilizer decreased by 20%, GHG emissions per hectare decreased by circa 10%. Changes in the application rate of the fertilizer had an indirect effect on the emission from soil. All other factors were held constant.

CONCLUSIONS

In this study, GHG emissions from oats, barley, spring wheat, and rye production in Finland were estimated. This study is based on the literature and the statistics of Finnish agriculture. GHG emissions from oats and barley production per hectare were lower than those from rye and wheat production. However, GHG emissions from oats, barley and wheat production per kilogram were lower than in rye production. Low grain yield and high application rate of fertilizers were the main reasons for higher GHG emissions for rye. The application rate of N fertilizer and the grain yields had the biggest effect on GHG emission per hectare or kilogram. However, greenhouse gas emissions from N-fertilizer manufacturing have decreased due to the new production technique of N-fertilizer. The result of GHG emission from grain production shows that there are no big differences between production chains.

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