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Effects of regional variation in climate and SOC decay on global warming potential and eutrophication attributable to cereal production in Norway

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ABSTRACT

Life Cycle Assessment (LCA) is a common tool for analyzing the environmental footprint of a production chain, such as that of cereal production. In an earlier study, we found that net mineralization of soil organic carbon (SOC) may contribute significantly to the CO_2-emissions from a cereal producing farm at high latitudes, where huge amounts of C are stored in not only organic but also mineral soils. Changes in SOC are, however, rarely included in LCA studies. In this study, we have used LCA to analyze the production chains of grain, from cradle to farm gate, under the contrasting climatic conditions of three typical farms representing the major grain producing areas in Norway; southeast, central southeast, and central. The assessment comprised global warming potential (GWP), marine (ME) and freshwater eutrophication (FE), where the effects of SOC changes were highlighted by means of the ICBM-model. Data for the production of various inputs were taken from the LCA-database Ecoinvent and management details were based on interviews with the local advisory services and Norwegian recommendations. The relatively wide system boundaries used resulted in a GWP of 0.5–0.9 kg CO_2-eq. per kg grain, depending on the cereal crop (barley, oats, spring or winter wheat) and site. On average, the contribution to total GWP was 20% for the manufacturing of machinery and buildings, 19% for the manufacturing of inputs, 8% for driving related emissions, and 53% for field emissions. Reduction in SOC accounted for up to 38% of the field emissions and on average 12% for the total GWP. The magnitude of the estimated SOC decay rates was more affected by the distance to the coast than by latitude. When halving the initial SOC level from 2% to 1%, the model simulations indicated C-sequestration at all sites, whereas an initial SOC level above 3.6–4.7% released CO_2 from SOC in amounts exceeding the combined emissions from all other sources. The range of ME was 9–18 g N-eq. per kg grain, of which 98% was caused by drainage and runoff from the cropped fields. FE was in the range of 0.2–0.7 g P-eq. per kg grain. Leaching losses were the most important category, followed by manufacturing of inputs, with the production of P fertilizer as the major contributor. Our results show that field emissions may be important both for a global indicator such as GWP and for indicators of more local concern, such as ME and FE. Hence, further environmental improvements should be sought at the farm level.

1. Introduction

Food production is essential for our existence. Agricultural practices have, however, great impact on our environment, particularly through emissions causing eutrophication and increased global warming. In Norway, agriculture is estimated to be responsible for 4.2% of the total greenhouse gas emissions (Statistics Norway, 2011). Looking ahead, food production must be performed with as little environmental impact as possible. In the short term we need to find methods to reduce emissions related to our current farming practice, and in the longer term we need to find methods to increase food production without increasing the environmental burden significantly. In order to gain appropriately detailed knowledge on the environmental cost of a specific food production, one must include the whole production chain and quantify the impacts per unit produced. So far the best product-oriented assessment method is Life Cycle Assessment (LCA) (Halberg et al., 2005). In an earlier case study using LCA to assess Norwegian grain production (Roer et al., 2012), we concluded that factors which are commonly excluded from published LCA studies, such as the manufacturing of machinery and buildings, pesticide production and use, mineralization of SOC and NO_x losses from the use of mineral fertilizer, actually have pronounced impacts on the results. They should therefore be included in order to obtain more realistic conclusions.

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Grain production is fundamental to most forms of food production for human consumption. In a recent work, we assessed the environmental burden of producing bread baked from Norwegian grain (Korsaeth et al., 2012), including all of the factors mentioned above. One main finding of this study was that on-farm processes accounted for a large share of the impact (e.g. 50% of the greenhouse gas (GHG) emissions). We also found that net mineralization of soil organic carbon (SOC) accounted for almost half of the field emissions of GHG in grain production. Huge amounts of C are stored in soil in cool weather regions, such as Scandinavia and Canada. The rising temperatures which are observed not only globally, but for these regions in particular, imply that the risk of enhanced CO_2-emissions from SOC increases. Arable systems, with mainly cereals in the crop rotation, have been shown to result in a reduction of SOC over time, but with diverging decay rates between regions as a result of the initial SOC levels (Riley and Bakkegard, 2006). Net SOC reduction occurs when CO_2–C emissions are higher than the input of assimilated C in roots and residues and C added in organic amendments. Increasing crop yields, e.g. through higher fertilization, thus reduces the net C losses from soil. Increased fertilization levels also result, however, in an enhanced risk of GHG emissions and eutrophication of fresh- and saltwater recipients. Addressing these issues with sufficient spatial resolution, is thus important in order to achieve robust conclusions on both global and local environmental effects of grain production in northern areas.

Changes in the SOC pool have very rarely been included in LCA studies, with some exceptions. Meisterling et al. (2009) accounted for the transfer of carbon from the atmosphere to the soil (soil as a sink) during the production of organic and conventional wheat in the US. They emphasized, however, that the uncertainty ranges for the (negative) influence on GWP of soil carbon were very large, but they did not describe any details about the methodology used to obtain their SOC related estimates. Röös et al. (2011) calculated changes in the SOC pool by means of the ICBM-model, when assessing wheat production for pasta on mineral soils in southern Sweden (Skåne).

The objective of this study was to quantify the effects of current (i.e. last decade) cereal production performed under the contrasting climatic conditions of the three major grain production areas in Norway, on global warming potential and local eutrophication. We have paid particularly attention to the role of SOC decay in the life cycle context, using the state of the art ICBM-model.

2. Materials and methods

2.1. Studied objects

Grain production in Norway is mainly performed in southern Norway, and is concentrated in three distinct regions. These include areas around the Oslofjord in the southeast (SE) and Lake Mjøsa in central southeast Norway (CSE), and the Trondheimsfjord region in central Norway (C). Climatic differences between these regions are shown in Table 1.

Grain production in all regions is mainly performed on soils developed either on morainic till overlying Cambro-Silurian limestone and shale, or on marine clays deposited at the end of the Weichsel ice age. The former are mostly loams, and the latter silty clay loams.

In this study we focus on purely arable farms, while farms with husbandry or mixed production are omitted from our data sets. The grain farm sizes typically decrease with increasing latitude, from approximately 30 ha farmland around the Oslofjord to 20 ha around the Trondheimsfjord. However, most of the production apparatus used is similar.

We wished to study farms which were typical in terms of size, production and management for each of the three regions. As a starting point, we used data from Statistics Norway (A. Snellingen Bye, pers. comm.) and the Norwegian Agricultural Authority (Ø. Breen, pers. comm.) to select three actual farms, which each appeared to be close to the respective region average for crop rotation, total area and crop distribution. An additional constraint was that the farms should be located on the most prevalent soil

Table 1
Key parameters of the three farms located in Central (C), Central Southeast (CSE) and Southeast Norway (SE).

Region	C	CSE	SE
Midpoint location	63.9°N, 11.3°E	60.7°N, 11.2°E	59.4°N, 11.4°E
Annual mean temperature (°C)[a]	4.8	3.8	5.4
Temperature growth season (°C)[b]	11.5	12.4	13.4
Annual mean prec. (mm)[a]	800	550	780
Soil organic matter (%)[c]	3.42	3.42	3.42
Climatic correction (r_e)[d]	1.28	1.21	1.56
Total farm size (ha)	28.3	30.5	32.4
Crop rotation (relative area)	Barley (88%)	Barley (62%)	Barley (27%)
		Oats (10%)	Oats (29%)
		S. wheat (28%)	S. wheat (16%)
	W. wheat (12%)		W. wheat (28%)
Yields (kg ha^{-1})	Barley: 3420	Barley: 4690	Barley: 4090
		Oats: 4760	Oats: 4470
		S. wheat: 5460	S. wheat: 3880
	W. wheat: 4390		W. wheat: 5210
Fertilization (kg N ha^{-1}/kg P ha^{-1})	Barley:	Barley: 111/13	Barley: 117/14
	95/11	Oats: 97/12	Oats: 113/14
		S. wheat: 124/11	S. wheat: 117/11
	W. wheat: 118/10		W. wheat: 137/12
Straw treatment	Ploughed under	Ploughed under	Ploughed under
Time of ploughing	90% in autumn	70% in autumn	50% in autumn
Harrowing	Yes	No[e]	Yes

[a] Mean period: 1961–1990.
[b] May–September.
[c] Initial value, corresponding to approx. 2% organic C, and 64 t C ha^{-1}.
[d] Correction factor used in the C-model ICBM, calculated on the basis of daily values of soil temperature and moisture for the period 2000–2009 for six farms within each region (see Section 2.4 for details).
[e] Harrowing is omitted in CSE due to the use of a large combined seed and fertilizer drill designed for use directly after ploughing or cultivation (common for this region).