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Distribution and cultivation intensity of agricultural peat and gyttja soils in Sweden and estimation of greenhouse gas emissions from cultivated peat soils

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ABSTRACT

Digitised maps of Quaternary deposits, ^{40}K radiation data and Integrated Agricultural Control System databases (IACS) were used in a GIS analysis to estimate the distribution and land use of agricultural peat and gyttja soils in Sweden. The total area of agricultural land (cropland and pastures) in Sweden was estimated at 3,496,665 ha and 8.6% of this area (301,489 ha) was classified as agricultural peat and gyttja soils, with 202,383 ha of deep peat, 50,191 ha of shallow peat and 48,915 ha of gyttja soils. Using detailed information on crop distribution from agricultural databases, it was possible to estimate the cultivation intensity (land use) of the agricultural land. One-quarter of the agricultural area of peat soils was intensively cultivated with annual crops and the remaining area was extensively used, dominated by managed grasslands and pastures. There was great variation in cultivation intensity between areas, from 50% annual crops down to 10%. The gyttja soils were in general more intensively cultivated than the peat soils. The improved estimates of acreage and cultivation intensity of agricultural peat soils were used to calculate annual greenhouse gas emissions from subsidence data. The total carbon dioxide (CO_2) emissions from Swedish agricultural peat soils in 2003 were estimated to be between 3100 Gg CO_2 and 4600 Gg CO_2, which is similar to or lower than previously reported values. Emissions of nitrous oxide (N_2O) were estimated at 3.2 Gg N_2O in 2003. Estimated combined total emissions of CO_2 and N_2O from agricultural peat soils in Sweden in 2003 amounted to 4000–5600 Gg CO_2-equivalents, which corresponds to approximately 6–8% of the total emissions of all greenhouse gases reported by Sweden (excluding the sink for land use, land use change and forestry — LULUCF). Agricultural peat soils represent a minor fraction of the agricultural land in Sweden but still have a significant effect on total national greenhouse gas emissions.

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1. Introduction

Under natural conditions most peatlands are accumulators of organic plant material and, at least in their early life, carbon sinks. Peat represents approximately one-third of the total global soil carbon pool (Joosten and Clark, 2002). Drainage and cultivation of peat soils increase soil aeration and reverse the carbon flux into net carbon dioxide (CO_2) emissions. Peatlands dominate the emissions of CO_2 from agricultural land in Sweden and are also major contributors of nitrous oxide (N_2O) (EEA, 2004; SNIR, 2006). However, estimates of emissions are generally based on uncertain assumptions about the oxidation rate of the organic material, land use and the extent of the peatland area used for agriculture (Eriksson, 1991; Kasimir-Klemedtsson et al., 1997).

Over one-quarter of the European (not including Russia, Belarus and Ukraine) peatland resource is located in Sweden (Montanarella et al., 2006), with more than 25% of the land area of Sweden covered with peat of varying thickness (Fredriksson, 1996). In 1946, the area of cultivated organic soils (peat and gyttja) was estimated to be 705,000 ha (Hjertstedt, 1946) which corresponded to 12.3% of the total area of organic soils in Sweden and 20% of the total area of agricultural soils. By 1961, the area of cultivated peat and gyttja soils had decreased to an estimated 400,000 ha (Hallgren and Berglund, 1962), which represented 12% of all arable soil at that time. The acreage of cultivated peat and gyttja soils in 1996 was roughly estimated to be 10% of all arable land, and amounted to 250,000 ha or 300,000 ha with grazing land included (Berglund, 1996). All these historical estimates were made in the absence of a national soil survey and detailed knowledge of land use.

Greenhouse gas (GHG) emissions from agricultural organic soils must be included in the National Inventory Report under the United Nations Framework Convention on Climate Change. To enable better estimates to be made of the release of greenhouse gases from these soils, a soil survey to determine the area of peat and gyttja soils under agriculture was needed. A traditional soil survey of the agricultural land in Sweden was considered too expensive. We therefore opted to use digitised maps of Quaternary deposits (soil type at 0.5 m depth) and potassium content maps produced from ^{40}K radiation, together with information on cultivation intensity and acreage in existing

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agricultural databases (IACS), in order to estimate the distribution and land use of agricultural peat and gyttja soils in Sweden. The results of the analyses were used to estimate total carbon dioxide and nitrous oxide emissions per year from agricultural peat soils in Sweden.

2. Materials and methods

2.1. Climate 2.1

Most of Sweden has a cool temperate moist climate according to the IPCC classification scheme of default climate regions (Eggleston et al., 2006), with a daily average temperature between 14 and 17 °C in July and 0 and −17 °C in January (SMHI, 2008). Most precipitation occurs during summer and autumn, and amounts to 500–1000 mm yr^{-1} (SMHI, 2008).

2.2. Soil types

In our analysis, we used the soil type classes 'gyttja', 'marl and marl-containing gyttja', 'clay gyttja–gyttja clay', 'moss peat', 'fen peat' and 'shallow peat (depth less than 0.5 m)' (Table 1). Gyttja clay, clay gyttja and marl are soils with organic matter content less than 20% and in most classification systems they are not classified as organic soils. However, they still represent a considerable carbon pool and have properties more similar to organic soils than mineral soils (Berglund, 1996) and were therefore included in the area and cultivation intensity analysis. The maps generally show the type of deposit at a depth of 0.5 m below the surface, with the exception of shallow peat, which is less than 50 cm deep. If peat is found at a depth of 50 cm, it is very likely that the topsoil is also a peat soil. In the case of gyttja soils, however, the area can be overestimated, since they are very often overlain by peat soils. Not all soil types were distinguished in all areas. The results are therefore presented in only three groups, deep peat, shallow peat and gyttja soils.

2.3. Geological databases and ^{40}K radiation data

The Geological Survey of Sweden (SGU) has map data on Quaternary deposits at local, regional and national level (1:50,000–1:1,000,000) covering the majority of Sweden (SGU, 2006). The level of accuracy varies, since the databases are based on maps that vary in scale, quality and age. Thirty-eight per cent of the area has been updated since the year 2000 but 29%, 24%, 7% and 2% was updated during the 1990s, 1980s, 1970s and 1960s respectively. Most maps are based on aerial photo interpretation and extensive fieldwork. The majority of the maps are already digitised and available in databases with different degrees of resolution. In some areas in the northern part of Sweden, only map data on a scale of 1:1 million are available in digital form.

The local database (JOGI in Fig. 1) contains data on the distribution, structure and properties of Quaternary deposits, ground-level boulders and landforms. The JOGI database corresponds to the data on Quaternary deposits in the printed Ae map series published by SGU (Maps of Quaternary deposits, 1:50,000) and Ak (Maps of Quaternary deposits, 1:50,000–1:100,000). The data used for series Ae are based on aerial photo interpretation and extensive fieldwork. The areas covered are mainly in southern Sweden. Peat, shallow peat and different types of gyttja soils are distinguished, but in our study all gyttja soils are presented as one class. The data used for series Ak are less detailed and cover areas in central and northern Sweden. The data are based mainly on aerial photo interpretation combined with roadside field observations. Only peat and shallow peat are distinguished in this database and the gyttja soils are mainly included in the peat classes. These areas are therefore less reliable when it comes to surface determination and classification than the Ae maps.

The regional databases (1:100,000–1:250,000) are less detailed and for southern Sweden they are based on aerial photo interpretation, complemented by roadside field observations (JOLC in Fig. 1). Only peat and shallow peat are distinguished in this database and the gyttja soils are mainly included in the peat classes. Regional map data for central and northern Sweden are based primarily on compilations of existing data sources (such as county maps), complemented to some extent by aerial photo interpretation and field observations (JOLD and JOLN in Fig. 1).

The national databases (JOMI database in Fig. 1) contain data on the most important features of Sweden's Quaternary deposits. The database is designed for presentation on a scale of 1:500,000–1:1,000,000, which means that data are much generalised. Of the soil types in Table 1, only peat is distinguished in the JOLD, JOLN and JOMI databases and the gyttja soils are mainly included in the peat class.

When no digitised information on the area of peat soils was available, a digitised map of potassium content (%) in the upper soil/bedrock layers was used. This potassium map is based on gamma radiation measurements (^{40}K) made by SGU (white areas in Fig. 1). Airborne measurements of natural terrestrial gamma radiation (including ^{40}K radiation) have been used in soil moisture assessments (Carroll, 1981), uranium prospecting and bedrock surveys (Ek et al., 1992). ^{40}K radiation is blocked by water and since peat soils consist of a very large proportion of water, the radiation data can be used to detect peat soils (Ek, 1987). A peat layer exceeding 0.5 m depth screens off all radiation. Peat soils are thus identifiable as land areas with low potassium content. Airborne measurements of gamma radiation started in 1968 in Sweden and currently have a better coverage than the geological database. Measurements are made every 20 m at 60 m height and with 200 m between the flight lines. The height and coordinates of every measuring point are recorded.

Potassium content data were delivered as raster maps with 200 m cell size. A calibration was performed in a 106,495 ha square area with known peat distribution (JOGI database) located in Norrbotten (18°42′E, 65°38′N). In areas with peat, the potassium content recorded was on average 1% ± 0.4 (s.d) and over non-peat the potassium content recorded was 2% ± 0.4 (s.d). We decided to use a value of 1.4% as the upper limit to classify the raster cell as peat. A validation of this value as the limit was performed in a different area in Uppland (18°6′E, 60°3′N) with a total size of 141,000 ha. The validation process involved creating maps with different values of potassium content (0.9–1.5%) as the limit. An error matrix was developed (Congalton and Green, 1999; Jensen, 1996) for each map to compare it with the JOGI map. In order to compare the accuracy between the maps a Kappa analysis was performed and the KHAT coefficient (an estimate of Kappa) was computed (Congalton et al., 1983). A KHAT value of 1 indicates that all pixels were classified correctly and KHAT values close to 0 mean that the agreement was no better than for randomly classified pixels. A potassium value of 0.9% had the best agreement (KHAT = 0.44, overall accuracy = 87%) for the total area, but when only the agricultural area (IACS block area) was considered, which is the main interest in this investigation, both the overall accuracy (98%) and KHAT coefficient (0.65) were highest with a potassium value of 1.4%.

Table 1
Soil types (Karlsson and Hansbo, 1984) included in the GIS analysis.

Soil type	Organic matter content (wt.%)	Organic matter type
Sediment		
Gyttja clay	2–6	Gyttja
Clay gyttja	6–20	Gyttja
Chemical sediment		
Marl	<20	Gyttja
Organic sediment		
Gyttja	>20	Gyttja
Marl-containing gyttja	>20	Gyttja
Peat		
Fen peat	>20	Peat
Moss peat	>20	Peat

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