IMPACT OF LAND USE PRACTICES ON GREENHOUSE GAS EMISSIONS FROM AGRICULTURE LAND ONORGANIC SOILS

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Abstract. Greenhouse gas emissions (carbon dioxide, methane, nitrous oxide) from managed organic soils in cropland and grassland is significant part of greenhouse gas (GHG) emission profile of Latvia. Total area of organic soils in grassland and cropland in Latvia is around 8 %, but GHG emissions from this area constitute more than 30 % of the total agricultural GHG emissions (data vary by GHG inventory years and soil data set used). GHG emission measurement data characterizing different agricultural land use practices can support the most appropriate choice of organic soil management that contributes less to the total GHG emission amount. Within the scope of the LIFE REstore project "Sustainable and responsible management and re-use of degraded peatlands in Latvia" research was carried out to assess impact of the management practices to GHG emissions from agricultural land on organic soils. GHG gases from agricultural land were measured in two year cycle in permanent grassland and cropland sites. Ecosystem gas – CO_2, CH_4, and N_2O – exchange measurements were done, using the opaque chamber method and the transparent chamber method. Research results demonstrate the net ecosystem exchange of GHG emissions in relation to different management practices in cropland and grassland on organic soils. Average CO_2 emissions from cropland were 4.8t CO_2 –C ha^{-1}, but from grassland 4.4t CO_2 –C ha^{-1}. Study sites in cropland were sink of methane – 0.59 kg CH_4 C ha^{-1}, but source of methane in grassland 57.8 kg CH_4 C ha^{-1}. Average N_2O emissions from cropland were 7.1kg N_2O –N ha^{-1}, but from grassland 0.3kg N_2O –N ha^{-1}. Cumulative GHG emissions from organic soils on cropland and grassland show that cropland annually emits more - 20.8 t CO_2eq ha^{-1} than grassland – 18.1 t CO_2eq ha^{-1}thus looking from GHG emission budget perspective, perennial grassland is more advisable for management of organic soils in agriculture.

Keywords: land use, greenhouse gas emissions, organic soil, agriculture.

Introduction

Distribution of organic soils in Europe is imbalanced with considerably higher concentration in the Northern part of Europe [1] Distribution is mainly determined by the climate conditions during the last 10000 years, including rainfall and temperature regime, higher summer temperatures and lower rainfall rates determine lower peatland distribution [2]. In the European Union countries peatlands cover 7.7 % of total area and greenhouse gas emissions from managed peatlands in some countries reach more than one fifth of all emissions [3]. One of typical management practices of organic soils is agriculture.

Undisturbed peatland ecosystems may be effective carbon sequesters, globally peatlands contain approximately one third of global soil organic carbon [4]. Drainage and cultivation of peatlands may promote decomposition of previously stored organic material and consequently lead to increased carbon dioxide and nitrous oxide emissions while methane emissions decrease in aerobic circumstances [5] Historically peatlands were often drained for peat mining purposes and cutaway areas are under different after use scenarios including cropland and grassland management practices. In overall, agricultural usage of organic soils in Europe represents minor part of total area of organic soils, but greenhouse gas emissions from these soils contribute considerably to national greenhouse gas emission profiles [5].

In Latvia, the area of organic soils used for agricultural purposes is around 8 % of total agricultural land area (depending on the data source used for calculations), but greenhouse gas emissions from this area is more than 30 % of the total emissions from agricultural activities in the sectors of Agriculture and Land Use, Land Use Change and Forestry (LULUCF) according to the National Greenhouse Gas Inventory [6].

Considering the impact of greenhouse gas emissions, organic soil management in agriculture is potentially crucially important for policy makers to seek for the management practices that would be on low emission pattern, socially accepted and cost effective. One of the main obstacles for effective policy planning is lack of updated activity data and scarcity of knowledge about country specific GHG exchange data in cropland and grassland with organic soils.

Greenhouse gas emissions from organic soils managed for agriculture are calculated in the National Inventory Report of GHG Emissions (NIR) under the United Nations Framework Convention on Climate Change (UNFCCC), the Kioto Protocol and Regulation (EU) No 525/2013 of the European Parliament and of the Council. Reporting in the European Union countries is done in accordance with the Intergovernmental Panel on Climate Change IPCC (2006) Agriculture, Forestry and Other Land Use (AFOLU) guidelines, usage of the IPCC (2014) Wetlands Supplement is encouraged. IPCC definition of organic soil largely follows the definition of Histosols by FAO, but in order to allow country specific definitions has omitted the thickness of the peat layer [7].

Annual GHG emissions and removals from organic soils used for agriculture in Latvia are calculated using the so-called Tier 1 method of the IPCC guidelines. The Tier 1 method is the simplest approach and annual GHG emissions are calculated by multiplying activity data (organic soil area) by default area based emission factors (EFs). EFs describe the net annual soil GHG emissions and removals and reflect impacts of ecosystem type, land management and environmental conditions [8]. Area of organic soils in cropland and grassland is determined by the National Forest Inventory [9].

In NIR submission 2019 Latvia uses default IPCC (2014) Wetlands Supplement EFs for drained organic soils – 7.9 t CO_2–C ha^{-1} for cropland (cropland drained, Boreal and Temperate), 6.1 t CO_2–C ha^{-1} for grassland (grassland, deep-drained, nutrient rich, Temperate), 1165 kg CH_4 ha^{-1} (deep-drained Grassland, Cropland, drainage diches), proportion of area of drainage ditchesin cropland and grassland 5 %, 16 kg CH_4 ha^{-1} (grassland, deep-drained, nutrient rich) 13 kg N_20–N ha^{-1} for cropland (boreal and temperate drained organic soil) and 8.2 kg N_20–N ha^{-1} for grassland (temperate organic soil, deep drained, nutrient rich) [6]. Deep drained factors are chosen because of the absence of national information about mean annual water table and/or land-use intensity [7].

Default EFs are mean values of annualized net emission and removal estimates that are compiled from available studies data and categorized by climate zones. If national data are available, countries may opt for usage of the Tier 2 method that incorporates country specific EFs or a model based approach (Tier 3). Usage of higher Tier method with country specific EFs increases accuracy of national estimates. Organic soils in cropland and grassland are among the key sources of GHG emissions in Latvia. In 2017 the total amount of GHG emissions from cultivation of organic soil in croplands and grasslands in the Agriculture sector constituted 25.8 % of the total emissions from agriculture. The total amount of GHG emissions from organic soil in LULUCF sector corresponded to nearly 100 % of the total emissions from croplands and grasslands in this sector [6]. Country specific data on net annual soil GHG emissions and removals in cropland and grassland management of organic soils are *NEE*ded to allow more accurate GHG emission calculations, including possible stratification of more land use categories. More accurate GHG emission calculations promote better policy planning, considering possible management options.

The aim of the study is to acquire the net annual greenhouse gas exchange data from organic soils in cropland and grassland to verify country specific data against the default IPCC emission factors and to propose improved data for reporting of GHG emissions from organic soils in the National Greenhouse Gas Inventory.

Materials and methods

Site selection and description

Measurement sites in agricultural land were selected by using database of areas affected by peat extraction (LIFE REstore project data [10]) and the Land Parcel Information System data maintained by the State Support Service of Latvia.

Measurement sites representing the following agricultural land use and vegetation types were searched for selection:

1. perennial grassland (mown);
2. cropland (cultivated grass or crops).

Main sites selection criteria were lowered ground water table and highly decomposed fen or transitional mire peat. Potential sites were assessed from the physical accessibility point of view. Such sites were selected that could be reached by car throughout the whole year and whose centres were in no more than 300 m distance from the roadside. The random number selection method (random number generator in QGIS – function “Random selection within subsets”) was used for the final selection of the sites. Agreements with landowners ensured permanence of the sites during the measurement period.

The location of the measurement sites and their coordinates in the LKS-92 system are shown in Table 1.

Table 1

Location of measurement sites

Land use type	Crop rotation	Object	Coordinates (LKS-92)	
			X	Y
Perennial grassland on former peat extraction sites	Pasture	Kašķu Mire	474539	307542
	annually mowed grass	Stabulnieku I Mire	672977	254237
	annually mowed grass	Lielsala Mire	399127	358300
	hay production	Krista Mire	667644	275163
Cropland on former peat extraction sites – rotational crops	maize / maize	SIA “Mārupe”	496872	301104
	cereal / legumes	Diervanīne Mire I	684572	290033
	cereal / fallow	Gaveņpurs Mire	414206	332834
	legumes / legumes	Diervanīnes Mire II	667644	275163

Cropland sites were established in integrated farming systems with crop rotations – cereals/legumes, cereals/fallow, legume/legume and maize/maize. Agricultural management in the study sites was continued on business as usual base, including application of fertilizers.

Study design

GHG were measured monthly for two consecutive years from December of 2016 until December of 2018 in 5 measurement points (permanent plastic collar in the ground in each of the points) with a distance between points 10 to15m in each of the sample plot. Two methods were used for GHG measurements – manual autotrophic measurements with opaque closed chambers and air sampling (CO_2, CH_4 and N_2O); manual ecosystem flux measurements with closed transparent chambers (only CO_2). Transparent chambers were used only during April – October, when the air temperature is over 0 ºC to measure photosynthetic CO_2 uptake and ecosystem CO_2 emissions under different lighting intensity (25 %, 50 % and 100 % shading). Opaque chambers were used throughout the year, also in winter.If the vegetation in the chambers was higher than the height of the chambers, then we used extensions – extension height is 50cm.

Measurements with opaque chambers

The volume of the opaque chambers is 65 L and the diameter – 40 cm, and the chamber is made of white plastic material. Duration of every measurement campaign with opaque chambers was 60 minutes. Air samples were collected in vacuumed 100 ml glass bottles 0, 20, 40 and 60 minutes after the headspace is placed on the collar. The collected air samples were transported to laboratory and analysed by Shimadzu GC-2014 gas chromatograph.

Measurements with transparent chambers

We used an EGM-5 portable CO_2 gas analyser to measure monthly CO_2 fluxes in transparent chamber from the beginning of April until the end of October. Transparent chamber is made of organic glass and is 35 cm in height and 50 cm in diameter. The chamber is equipped with a cooling system, temperature sensors and photosynthetically active radiation (PAR) sensors. There are two tubes connected to the chamber for air outflow and inflow from the gas analyser. The same collars as for measurements with opaque chambers were used. The duration of measurement in each sample point was 150 seconds.

Additionally to GHG flux measurements, soil and water data were acquired in the measurement sites to detect parameters that can influence soil GHG emissions. Sampling was done with probes for undisturbed samples. Soil sample preparation and analyses were done according to the ICP Forests guidelines [11]. Soil analyses were done by the Latvian State Forest Research Institute “Silava” Forest Environment Laboratory.

Calculation of CO_2 net ecosystem exchange

Net Ecosystem Exchange (*NEE*) (from April to October) was modelled, using the CO_2 flux data from the measurements with transparent chambers and EGM-5 and air temperature, ground water level and PAR as linear regression model parameters (1). Those variables were measured directly during field measurements. We used air temperature values and radiation measurements from closest-to-site meteorological towers (which had radiation measurements), and manual ground water measurements from ground water wells installed in the sites as variables for linear regression models. Linear regression models were created for each of the sites. In rest of the year (from November and December) CO_2 *NEE* were calculated as mean ecosystem respiration, which was measured by opaque chambers and manual air sampling.

$$NEE = a + a1 \cdot \mathrm{T} + a2 \cdot GW + a3 \cdot PAR, \quad (1)$$

where T – air temperature during the measurements, ℃;
GW – water table level below the ground surface, cm;
PAR – photosynthetically active radiation, umol $m^{-2} \cdot s^{-1}$.

Flux measurements include carbon captured by photosynthesis in crops which is later harvested, but not captured by flux measurements. When the biomass was harvested, carbon removed in biomass was included in calculations by adding it to the total *NEE* as source of emissions. We used harvested crop yield to biomass ratio [12] model total carbon removed by harvesting.

Calculation of CH_4 and N_2O net ecosystem fluxes

Closed opaque chamber methods were used to collect data to estimate CH_4 and N_2O ecosystem fluxes. The yearly emissions are calculated as a sum of mean monthly values for each of the sites. If there were no data for some of the months due to errors, the gaps we filled by modelling CH_4 emissions for the missing month. Soil temperature and ground water level were used as a model parameter to fill the missing values. In case of missing values for N_2O, monthly values were interpolated (average from previous and next month).

Results and discussion

The air temperature, PAR and the ground water level were significant factors influencing the CO2 flux rate and could explain 0.29 % to 0.72 % of total *NEE* shown in Table 2.The low accuracy of the linear regression model in SIA "Mārupe" (crop rotation – maize/maize) could be explained due to too low chamber height and it was not possible to cover the maize with the chamber without damaging the crops.

Table 2

Linear *NEE* regression model and model parameters

Object	**Parameters**				R^2
	intercept	$a1$	$a2$	$a3$	
Kašķu Mire	-0.27	0.0729	$0.856.10^{-3}$	$-1.63.10^{-3}$	0.59
Stabulnieku I Mire	-1.16	0.113	0.0135	$-1.50.10^{-3}$	0.52
Lielsala Mire	-0.42	0.0398	0.0122	$-1.47.10^{-3}$	0.69
Krista Mire	-3.07	0.243	0.0281	$-2.96.10^{-3}$	0.72
SIA "Mārupe"	0.27	0.0493	$4.44.10^{-3}$	$-0.838.10^{-3}$	0.29
Diervanīne Mire I	-0.87	0.105	$2.49.10^{-3}$	$-1.53.10^{-3}$	0.67
Gaveņpurs Mire	-0.65	0.0950	$2.43.10^{-3}$	$-1.02.10^{-3}$	0.40
Diervanīnes Mire II	0.022	0.111	$-6.00.10^{-3}$	$-1.95.10^{-3}$	0.62

Average annual net carbon dioxide emissions from cropland were 4.8 t CO_2–C ha^{-1}, but from perennial grassland 4.4t CO_2–C ha^{-1}. This result in Table 3 coincides with the previous studies, indicating that organic soils used in agriculture for growing cereals and grasses in boreal and temperate climate zones (studies from Finland, Sweden and Netherland) are net emitters of CO_2 and the fluxes range from 2.2 to 31 t C $ha^{-1} \cdot yr^{-1}$ [5; 13; 14]. After drainage, peat decomposition and mineralisation increase rapidly, causing CO_2 emissions, CO_2 uptake by photosynthesis cannot compensate ecosystem CO_2 losses and net ecosystem exchange is positive. Study results compared with IPCC (2014) Wetlands Supplement CO_2 EFs for drained organic soils, show lower net ecosystem exchange in the study sites. In one study site (Gaveņpurs Mire) in cropland cereal production was followed by fallow that possibly impacted the particular result (decrease of emissions) because of biomass left in soil. Quite high variations among CO_2 emissions reported in different studies may partly be explained with differences of grassland and cropland systems. Under grassland definition there can be intensively managed (fertilized) areas, as well as low-intensity grasslands [13].

Table 3

CO_2-C net emissions

Land use	Site name	Cultivation	t CO_2-C ha^{-1} annually		
			1st year	2nd year	Average
grassland	Kašķu Mire	pasture	5.19	4.63	4.91
grassland	Krista Mire	hay production	3.81	8.42	6.12
grassland	Lielsala Mire	annually mowed grass	2.30	1.65	1.98
grassland	Stabulnieku I Mire	annually mowed grass	3.17	5.95	4.56
cropland	Diervanīnes Mire I	cereal/legumes	6.05	4.19	5.12
cropland	Gaveņpurs Mire	cereal/fallow	5.44	2.66	4.05
cropland	SIA "Mārupe"	maize/maize	4.06	4.78	4.42
cropland	Diervanīnes Mire II	legumes/legumes	6.42	4.44	5.43

Methane emissions tend to decrease after drainage. Soils can be sources as well as sinks of CH_4 emissions. Well drained soils are quite often sinks of CH_4 because of activity of methanotrophic bacteria that use CH_4 for growth [15]. As shown in Table 4, the study sites in cropland were sink of methane (Table 4) – 0.59 kg CH_4 C ha^{-1} annually (from -0.07 to -1.26 kg CH_4 C ha^{-1}), but source of methane in perennial grassland sites 57.8 kg CH_4 C ha^{-1} annually (from -0.76 to -188.73 kg CH_4 C per hectare). The reason of high methane emissions in Krista and Lielsalas mire was extremely high precipitation amount in 2017 (1st year), when the annual rainfall was one of the highest since the beginning of meteorological observations followed by high ground water level. Findings from other researches in boreal and temperate zone reports annual fluxes of CH_4 emissions from cropland and grassland management on organic soils in a range of – 3.7 kg CH_4–C ha^{-1}uptake to emission of 40 kg CH_4–C ha^{-1} [15-18]. The study results compared with IPCC (2014) Wetlands Supplement CH_4 EFs for drained organic soils, on average show higher net emissions in the study sites.

Table 4

CH_4-C net emissions

Land use	Site name	Cultivation	kg CH_4-C ha^{-1} annually		
			1st year	2nd year	Average
grassland	Kašķu Mire	pasture	-0.61	-0.90	-0.76
grassland	Krista Mire	hay production	343.48	33.97	188.73
grassland	Lielsala Mire	annually mowed grass	58.51	12.25	35.38
grassland	Stabulnieku I Mire	annually mowed grass	15.52	0.42	7.97
cropland	Diervanīn Mire I	cereal/legumes	0.13	-0.27	-0.07
cropland	Gaveņpurs Mire	cereal/fallow	-0.61	-0.40	-0.51
cropland	SIA "Mārupe"	maize/maize	-0.35	-0.71	-0.53
cropland	Diervanīnes Mire II	legumes/legumes	-1.19	-1.33	-1.26

There are constrains to obtain precise nitrous oxide emissions because of great sessional and annual variations [19], as well as the formation process of N_2O emissions is complicated and still not entirely investigated. Scientific evidences show that non-growing season N_2O emissions should not be ignored in EFs calculations, because inclusion of these emissions significantly impacts (increases) EFs [20]. Agricultural management in the study sites was continued on business as usual base, including regular application of fertilizers that is one of explanations of relatively high N_2O emissions in cropland management practice sites – 7.1 kg N_2O–N ha^{-1}(from 1.95 to 16.80 kg N_2O–N ha^{-1} annually)and 0.3 kg N_2O–N ha^{-1}(from -0.08 to 1.01kg N_2O–N ha^{-1} annually) for permanent grassland. The study results of N_2O emissions are shown in Table 5. Annual numbers were impacted by significant rise in N_2O emissions during the spring months. We observed seasonal impact on GHG emissions for N2O emissions that during spring months well exceeded annual average. Similar impact is reported by several other studies [17; 19; 21]. Increased N2O data collection frequency during spring and summer months could contribute to emission data precision.

On average, N_2O emissions from the study sites fall into the flux range demonstrated in the previous studies of cropland and grassland on organic soils in temperate and boreal zone 2.0 to 11.0 kg N_2O–N $ha^{-1}\cdot yr^{-1}$ [19; 21; 22]. The study results compared with IPCC (2014) Wetlands Supplement N_2O EFs for drained organic soils, in the study sites show lower net ecosystem exchange.

Table 5

N_2O-N net emissions

Land use	Site name	Cultivation	kg N_2O–N ha^{-1} annually		
			1st year	2nd year	Average
grassland	Kašķu Mire	pasture	-0.13	-0.02	-0.08
grassland	Krista Mire	hay production	1.10	0.91	1.01
grassland	Lielsala Mire	annually mowed grass	0.01	-0.02	-0.01
grassland	Stabulnieku I Mire	annually mowed grass	0.07	0.17	0.12
cropland	Diervanīn Mire I	cereal/legumes	5.60	5.13	5.37
cropland	Gaveņpurs Mire	cereal/fallow	0.22	3.68	1.95
cropland	SIA "Mārupe"	maize/maize	17.97	15.63	16.80
cropland	Diervanīnes Mire II	legumes/legumes	5.48	3.58	4.53

Cumulative GHG emissions (expressed in CO_2 equivalents) from organic soils on cropland and grassland show that cropland annually emits more -20.8 t CO_2 eq ha^{-1} than grassland – 18.1 t CO_2 eq ha^{-1}.

Conclusions

This study for the first time in Latvia provides country specific information on the net ecosystem exchange for different land use practices on organic soils in agriculture – permanent grassland and cropland. The net ecosystem CO_2 exchange was 4.8 t CO_2–C ha^{-1} and 4.4 t CO_2–C ha^{-1} for cropland and grassland respectively and these values are below IPCC default emission factor values currently used in the National GHG Inventory for LULUCF sector for drained organic soils. Similarly, the study results of fluxes of N_2O (7.1 kg N_2O–N ha^{-1} from cropland and 0.3 kg N_2O–N $ha^{-1}$from grassland) are smaller to compare to IPCC default values, but the results of CH_4 fluxes (-0.59 kg CH_4–C ha^{-1} from cropland and 57.8 kg CH_4 C ha^{-1} from grassland) exceed the IPCC default values as regards grassland. IPCC encourages countries to use country specific EFs, if available. We suggest introduction of EFs obtained by this study into the National GHG Emission Inventory.

Cumulative GHG net emissions from cropland (20.8 t CO_2 eq ha^{-1}) on organic soils exceed grassland emissions (18.1 t CO_2 eq ha^{-1}). Looking from GHG emission budget perspective, perennial grassland is more advisable for management of organic soils in agriculture than cropland.

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