EVALUATION OF PEAT LAYER THICKNESS EFFECT ON SOIL GHG FLUXES

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Abstract. Organic soils are the largest source of GHG emissions in Latvia producing the amount of emissions comparable with the whole energy sector. Organic soils in cropland and grassland alone release about 4.5 mill. tonnes of CO_2 eq. annually, which is nearly twice as big as the total emissions from the agriculture sector in Latvia. The reduction of the emissions from the organic soils is the primary target to implement the climate neutrality target in the post-2050 period in LULUCF sector. One of the issues in reporting of GHG emissions from organic soils is different definitions of organic soils, e.g. Latvia is using the Intergovernmental Panel on Climate Change (IPCC) definition (at least 10 cm deep peat layer and at least 12% of carbon content in upper 20 cm of the topsoil), while other countries use different criteria, e.g., at least 30 cm or 40 cm deep peat layer. The scope of this study is evaluating the effect of the peat layer thickness on GHG fluxes in grasslands. The study results proved that increase of the peat layer depth is associated with a trend of increase of CO_2 and CH_4 emissions. There is also strong correlation between CH_4 emissions and the groundwater depth and soil temperature and CO_2 emissions. N_2O emissions are correlating with nitrogen content in soil. In the study sites soil turns into net source of CH_4 emissions if the depth of peat layer exceeds 40 cm. The study results point that the peat depth should be considered as one of the parameters in accounting of GHG emissions.

Keywords: greenhouse gas emissions, peat thickness, organic soils.

Introduction

Organic soils play an important role in cropland and grassland management in Latvia as they are a significant source of greenhouse gas emissions. In 2020 GHG emissions from organic soils in cropland and grassland was 2.7 mill. tons carbon dioxide (CO_2) eq, including nitrous oxide (N_2O), which is accounted under agriculture sector [1]. When water regime in organic soils is adopted for agricultural purposes, the soil organic matter decomposes more actively and releases CO_2 into the atmosphere. Simultaneously, N_2O is released, while methane (CH_4) emissions from soil significantly decrease, while persist in grasslands and from drainage ditches. This process can result in significant increase of the net greenhouse gas (GHG) emissions [2]. CH_4 is produced when the organic matter in the soil decomposes in anaerobic conditions, while N_2O is produced not only due to release of nitrogen (N) stored in organic matter, but also due to the use of mineral and organic fertilizers [3].

In croplands, organic soils are often drained to increase the amount of arable land available for farming, resulting in significant greenhouse gas emissions. In grasslands, overgrazing can also lead to the loss of organic soils and increased (GHG) emissions [4]. In Latvia, organic soils are accounted according to the definition proposed by the Intergovernmental Panel on Climate Changes (IPCC); respectively, areas, where content of organic carbon in upper 20 cm topsoil layer is at least 12% by mass [5]. Total area of organic soils is cropland and grassland in Latvia according to the national GHG inventory in 2020 was 159 kha and the area of drainage ditches is 5% of the total area of organic soils [1; 6]. The role of regulation of groundwater level is proved by significant reduction of area of organic soils in cropland and grassland since the previous soil inventory [6], while in forest lands the area and percentage of organic soil have not been changed during this period, approving the research results demonstrating that forests with organic soil are net sink of GHG fluxes [7; 8].

Latvia used country specific soil CO_2 emission factors (EFs) for cropland and grassland with organic soils in the 2022 inventory, 4.8 tons $C \cdot ha^{-1} \cdot yr^{-1}$ and 4.4 tons C $ha^{-1} \cdot yr^{-1}$, accordingly [1]; which is significantly less than the default EFs proposed by the IPCC guidelines, 7.9 tons C $ha^{-1} \cdot yr^{-1}$ and 6.4 tons C $ha^{-1} \cdot yr^{-1}$, accordingly [2]. While the default EFs were used in 2022 inventory for N_2O and CH_4 from drainage ditches; in cropland EF for N_2O was 13.00 kg N_2O-N $ha^{-1} \cdot yr^{-1}$ and EF for CH_4 emissions from drainage ditches (surface of the whole ditch area) are 1165.00 kg CH_4 $ha^{-1} \cdot yr^{-1}$ and in grassland EF for N_2O was 8.20 kg N_2O-$N \cdot ha^{-1} \cdot yr^{-1}$ and EF for CH_4 emissions from drainage ditches was

1165.00 kg $CH_4 \cdot ha^{-1} \cdot yr^{-1}$. Country specific EF was used for CH_4 from organic soils – 57.80 kg CH_4-$C \cdot ha^{-1} \cdot yr^{-1}$ [9].

To mitigate GHG emissions, several strategies can be employed, such as rewetting of organic soils, restoring degraded peatlands and implementing sustainable land management practices targeted at reduction of GHG emissions. By managing organic soils sustainably, cropland and grassland managers can help reduce GHG emissions and contribute to efforts to mitigate climate change [10].

Different countries can use different definitions of organic soils – from 6% of carbon content in topsoil in Denmark to at least 40 cm deep in Lithuania pointing out potential overestimation or underestimation of GHG emissions from organic soils depending on the soil definition. There is a correlation between carbon content in soil and GHG emissions from the soil, as soil carbon plays an important role in regulating GHG emissions from the soil. Overall, the correlation between carbon content in soil and GHG emissions from the soil is complex and context-dependent, as it is influenced by a range of factors such as land use, management practices, soil type, and climate conditions [11; 12]. The discussion on the definition of organic soils is continuing also in Latvia, therefore it is important to evaluate GHG fluxes depending on carbon stock and depth of peat layer to avoid underestimation of the emissions in case of changes of the definition of organic soils, e.g. to 40 cm deep peat layer. The scope of this study is to compare GHG emissions from grasslands with different depth of the peat layer. Grasslands are selected for the study, because in croplands topsoil is mixed and there are other factors, e.g. fertilizing significantly affecting GHG fluxes.

Materials and methods

The study was implemented in three fields of grasslands in central and western part of Latvia, entitled as E2SOILAGRI1, 2 and 3. A transect consisting of three measurement plots with different peat depth was established in each field (Table 1). Each plot is established in the centre of circle with about 500 m^2 area and similar peat depth in the whole circle.

Table 1

Location of measurement plots

Plot	Average peat depth, cm	Establishment date	Coordinates (EPSG:4326 – WGS 84)	
			X	Y
E2SOILAGRI_1_A	15	2021-06-30	21.18826	56.21136
E2SOILAGRI_1_B	20	2021-06-30	21.18817	56.21148
E2SOILAGRI_1_C	30	2021-06-30	21.18812	56.21168
E2SOILAGRI_2_A	20	2021-06-30	22.84421	56.55879
E2SOILAGRI_2_B	40	2021-06-30	22.84415	56.55887
E2SOILAGRI_2_C	70	2021-06-30	22.84395	56.55900
E2SOILAGRI_3_A	10	2021-06-30	24.75648	56.77243
E2SOILAGRI_3_B	15	2021-06-30	24.75663	56.77254
E2SOILAGRI_3_C	25	2021-06-30	24.75687	56.77279

Seven measurement programs were implemented in all plots, including: (1) manual measurement of groundwater level in piezometers and sampling of water for chemical analyses (pH, conductivity – EVS, potassium – K, calcium – Ca, magnesium – Mg, total nitrogen – TN, dissolved organic carbon – DOC); (2) continuous measurement of groundwater level using automatic divers; (3) greenhouse gas (CH_4 and N_2O) sampling for gas chromatography (GC) analyses (3 permanent collars in every location); (4) continuous soil temperature measurement at 10 and 40 cm depth duplicated by manual measurement of soil temperature at 10 cm depth during site visits; (5) soil heterotrophic respiration (3 permanent measurement locations); (6) ground vegetation sampling places (four 25 x 25 cm above- and below-ground biomass sampling places in every location); (7) soil sampling places nearby biomass plots (100 cm^3 soil samples were collected at 0-10, 10-20, 20-30, 30-40, 40-50 cm depth and 100 cm^3 mixed samples from 50-75 and 75-100 cm depth, Figure 1).

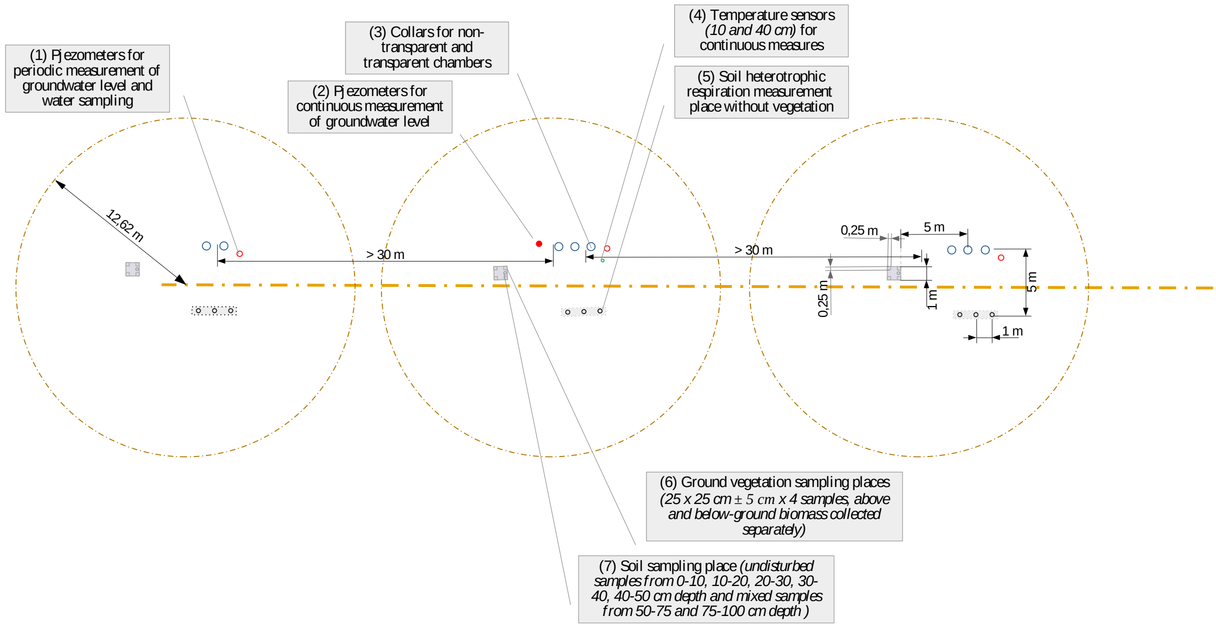

Fig. 1. **Basic design of measurement plot**

Measurement plots were visited once per month for 18 months period. Heterotrophic respiration was measurement with an EGM5 spectrometer using a non-transparent chamber with above-ground volume of 0.023 m^3 (diameter 31.5 cm, height 30.0 cm). Measurement of heterotrophic respiration continued for 180 seconds, 3 repetitions in every location, chambers were flushed before every measurement. The heterotrophic respiration continued during the vegetation period (positive air temperatures); during the rest of time CO_2 data from GHG flux analyses were applied. GHG flux measurements were continued during the whole measurement period. Vegetation was removed and ingrowth of roots avoided in the heterotrophic respiration measurement plots. After arrival to the plot, chambers were flushed and located over permanently installed collars. 100 cm^3 air samples were collected in grass bottles every 10 min. during the 30 min. period (4 samples in a series), representing change of the gas content in the chamber. Volume of chamber is 0.0655 m^3 (bottom diameter 50 cm, top diameter 42.5 cm, height 39,5 cm). CH_4, N_2O and CO_2 were determined in the collected samples in the laboratory using GC technology. Piezometers were emptied before collection of water samples to acquire fresh samples for analyses. Gasfluxes module from CRAN package of R software suite [13] was used to calculate heterotrophic respiration, beginning of the measurement period was automatically trimmed to reach the highest coefficient of correlation (usually 30 sec. at the beginning of the measurement period). Spreadsheet application and the following formula were used to calculated GHG fluxes in GC data. Measurements with $R^2 < 0.95$ for linear regression of CO_2 concentration changes were excluded. No other outliers, e.g. in case of very high CH_4 outputs were excluded following the recommendation in the IPCC guidelines [5].

$$\mathrm{GHG} = \frac{MVP\delta v f_1}{RTA}, \tag{1}$$

where GHG – fluxes per hour, $\mu g \cdot m^{-2} \cdot h^{-1}$;
P – pressure, 101300 Pa;
T – temperature during measurement, K;
R – gas constant, 8.3143 m^3 $Pa \cdot K^{-1} \cdot mol^{-1}$;
δv – slope of linear regression;
f_1 – factor for recalculation to atomic mass (0.273 for CO_2-C, 0.636 for N_2O-N, 0.750 for CH_4-C);
V – volume of chamber, 0.0655 m^3 and 0.023 m^3;
A – surface area covered by chamber, 0.19625 m^2 and 0,076 m^2;
M – molecular mass, $g \cdot mol^{-1}$ (44.01 for CO_2, 16.04 for CH_4 and 44.01 for N_2O.

Monthly average and yearly fluxes were calculated for every plot and according to the depth of the peat layer. Correlation and regression analysis was done to identify the factors affecting GHG fluxes. Uncertainty is expressed as standard error of mean.

Biomass samples were collected at the beginning of July to ensure that it corresponds to maximum carbon stock in the biomass. Above-ground biomass and 47.5% of below-ground biomass, according to assumptions for the forest land [14], were accounted as annual soil carbon input.

Results and discussion

The field measurement continued from July 2021 to November 2022. In average one series of measurements were acquired per month – more series during the vegetation season and less – during winter. Data analysis is based on 24 measurement series per plot, which are combined into monthly average series to calculate hourly average (Tables 2 and 3). No statistical difference was found between the heterotrophic respiration and N_2O fluxes in the measurement plots using two-tailed test ($p > 0.05$), while the CH_4 fluxes differed significantly ($p < 0.05$) between E2SOILAGRI1 and E2SOILAGRI3 and between E2SOILAGRI2 and E2SOILAGRI3 plots. In E2SOILAGRI3 plots the average peat depth and CH_4 emissions are smaller. No statistically significant difference ($p > 0.05$) was found during comparison of the monthly CO_2 fluxes in subplots of the same plot, while statistically significant difference was found by comparison of N_2O fluxes in E2SOILAGRI3 subplots A and C and B and C. N_2O emissions are smaller in subplot C of this plot. This plot has also the thinnest peat layer. CH_4 fluxes are significantly bigger in subplot C in comparison to subplot A in the E2SOILAGRI2 plot and in subplot C in comparison to subplots A and B in the E2SOILAGRI3 plot.

Table 2

Average CO_2 emissions due to heterotrophic respiration in different subplots

Plot	CO_2-C, mg $C \cdot m^{-2} \cdot h^{-1}$			
	Mean	Error	Max.	Min.
E2SOILAGRI_1A	194.5	± 117.8	637.7	12.1
E2SOILAGRI_1B	135.9	± 71.3	443.0	14.8
E2SOILAGRI_1C	156.4	± 106.6	681.1	-
E2SOILAGRI_2A	170.7	± 86.1	440.6	13.6
E2SOILAGRI_2B	199.8	± 124.5	677.6	-
E2SOILAGRI_2C	210.8	± 146.7	860.4	0.5
E2SOILAGRI_3A	82.3	± 33.2	192.5	-
E2SOILAGRI_3B	79.5	± 32.9	202.0	-
E2SOILAGRI_3C	106.9	± 47.2	250.7	5.0

Table 3

Average N_2O and CH_4 emissions in different subplots

Plot	N_2O-N mg $N \cdot m^{-2} \cdot h^{-1}$				CH_4-C, mg $C \cdot m^{-2} \cdot h^{-1}$			
	Mean	St. error of mean	Max.	Min.	Mean	St. error of mean	Max.	Min.
E2SOILAGRI_1A	0.010	± 0.005	0.031	-0.004	-0.008	± 0.004	0.001	-0.029
E2SOILAGRI_1B	0.009	± 0.006	0.030	-0.014	-0.015	± 0.006	0.002	-0.040
E2SOILAGRI_1C	0.011	± 0.009	0.041	-0.031	0.003	± 0.020	0.105	-0.089
E2SOILAGRI_2A	0.128	± 0.116	0.755	0.005	-0.013	± 0.010	0.008	-0.045
E2SOILAGRI_2B	0.042	± 0.056	0.421	-0.006	0.000	± 0.029	0.188	-0.036
E2SOILAGRI_2C	0.019	± 0.014	0.088	-0.012	0.016	± 0.027	0.162	-0.057
E2SOILAGRI_3A	0.018	± 0.014	0.071	-0.019	-0.057	± 0.026	0.062	-0.117
E2SOILAGRI_3B	0.014	± 0.006	0.034	0.002	-0.062	± 0.020	-0.001	-0.149
E2SOILAGRI_3C	0.002	± 0.007	0.023	-0.026	-0.030	± 0.021	0.050	-0.103

To evaluate the effect of the peat depth on the GHG fluxes all subplots are grouped according to average peat depth (10, 20, 30 and 40 cm). Subplot with 70 cm deep peat is added to the last group

(40 cm deep peat). Table 4 and 5 show a trend to increase CO_2 and CH_4 emissions with increase of the peat depth. However, two-tailed t-test shows no statistically significant difference ($p > 0\ .05$) of CO_2 emissions due to heterotrophic respiration and N_2O emissions between the subplots depending on the peat depth. Statistically significant difference ($p < 0.05$) of CH_4 emissions was found between subplots, where the peat depth is 10 cm and subplots with deeper peat layer, and between the subplot with 20 cm and at least 40 cm deep peat layer. CH_4 emissions increase with increase of the depth of the peat layer.

Table 4

Average CO_2 emissions due to heterotrophic respiration averaged according to peat depth

Rounded peat depth, cm	CO_2-C, mg $C \cdot m^{-2} \cdot h^{-1}$			
	Mean	St. error of mean	Max.	Min.
10	120.3	± 43.6	637.7	-9.4
20	136.4	± 37.9	443.0	5.0
30	156.4	± 106.6	681.1	-1.8
40	204.9	± 90.0	860.4	-3.6

Table 5

Average N_2O and C_4 emissions averaged according to peat depth

Rounded peat depth, cm	N_2O-N mg $N \cdot m^{-2} \cdot h^{-1}$				CH_4-C, mg $C \cdot m^{-2} \cdot h^{-1}$			
	Mean	St. error of mean	Max.	Min.	Mean	St. error of mean	Max.	Min.
10	0.014	± 0.005	0.071	-0.019	-0.042	± 0.012	0.062	-0.149
20	0.045	± 0.039	0.755	-0.026	-0.019	± 0.008	0.050	-0.103
30	0.011	± 0.009	0.041	-0.031	0.003	± 0.020	0.105	-0.089
40	0.031	± 0.028	0.421	-0.012	0.007	± 0.019	0.188	-0.057

Logarithmic regressions in Figure 2 demonstrate strong correlation between the soil heterotrophic respiration and CH_4 emissions from soil with the depth of the peat layer. Increase of the depth of the peat layer from 20 cm to 40 cm doubles CO_2 emissions from soil and turns the soil from net sink of CH_4 into a net source. No such correlation is found for N_2O emissions from soil.

The correlation analysis, however, demonstrates that the primary factor determining CO_2 emissions from soil due to heterotrophic respiration is the soil temperature (r = 0.70), while this factor has no strong correlation with CH_4 and N_2O emissions. N_2O emissions have strong positive correlation with nitrogen (N) content in water (r = 0.50); respectively, the emissions increase in nutrient rich soils. CH_4 emissions from soil correlate with the peat depth (r = 0.40) and N content in water (r = 0.41) and have negative correlation with the groundwater level (r = -0.36) and belowground biomass (r = -0.46); respectively, increase of the groundwater level raises CH_4 emissions, especially in nutrient rich soils with a deep peat layer, while areas with small CH_4 emissions are associated with a well-developed root system and increased carbon stock in living biomass.

According to the GHG inventory of Latvia and IPCC 2013 Wetlands supplement the peat depth is not considered as a factor affecting GHG emissions from soil and any area with at least 20 cm deep peat layer is considered as organic soil [1; 2]. The study results demonstrate that there is significant difference between the GHG emissions from soil depending on the peat depth and in grasslands a 40 cm deep peat layer is the threshold turning the soil into net sink of emissions. Other studies evaluating GHG fluxes from organic soils are more concentrating on the groundwater level and soil temperature, e.g. [15; 16], while this study proves that the peat depth is a significant factor to consider, especially in development of GHG reporting systems and planning of GHG mitigation measures. Correlation between the thickness of the peat layer and GHG emissions was studied by Yli-Halla et al. [17], and the researchers found correlation between leaching of nutrients and peat thickness, they did not find correlation with GHG emissions. Notably that this study was implemented in a freshly established field. Indirectly correlation between the thickness of the peat layer and GHG emissions is mentioned in the review report [18] concluding that GHG emissions are correlating with exposure of peat layer to oxygen, respectively, if deeper the peat layer is aerated, the emissions are bigger.

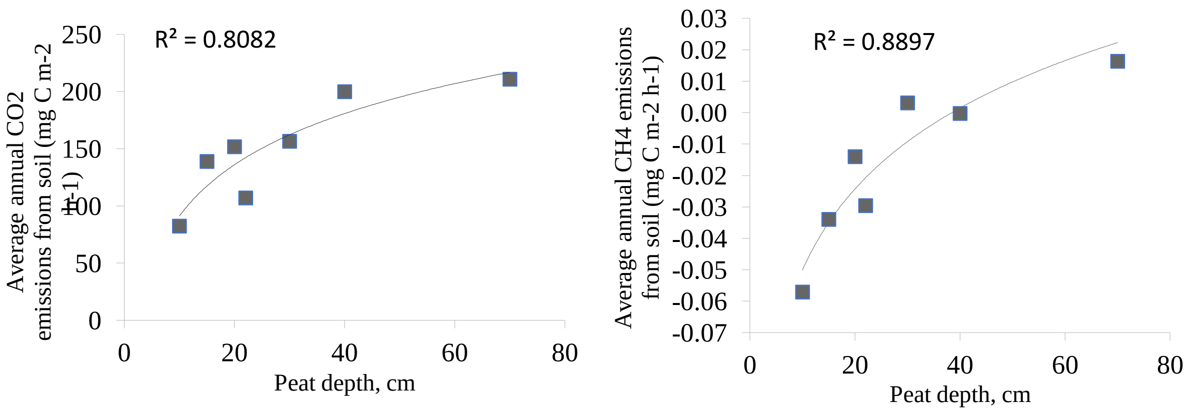

Fig. 2. **Average annual emissions from soil depending on peat layer depth**

Other studies, e.g. [19], prove that decomposition of peat in agricultural systems continues until equilibrium point, when carbon content in soil reaches values characteristic for mineral soils; however, no difference between the emission rate and residual carbon stock in soil is pointed out. Application of Yasso model in mineral soils [20] points out that the structure of organic matter changes in time and share slowly decomposing fractions are increasing with time in systems with reducing carbon input, pointing out that there could be difference in GHG emissions if the thickness of the peat layer is affected by the structure of organic matter.

Conclusions

1. Increase of the depth of the peat layer is associated with a trend of bigger emissions of CO_2 and CH_4 from soil in grasslands in the study sites; however, exposure of the peat layer and meteorological conditions have dominating effect.
2. The currently applied 20 cm threshold of peat depth in the National GHG inventory may lead to overestimation or underestimation of CO_2 and CH_4 emissions in grasslands, depending on the depth of the peat layer.
3. No correlation is found between N_2O emissions and the thickness of the peat layer; however, there is correlation between N_2O emissions and N content in soil, pointing that estimation of N_2O emissions from organic soils in grasslands should be associated with soil fertility.
4. It is important to improve activity data on organic soils in grasslands including information on the depth of the peat layer and, consequently, update GHG projection models applied in the GHG inventories and projection systems.

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Author contributions

Conceptualization, A.B.; methodology, D.P. and A.B.; validation, L.P.; formal analysis, A.L. and D.P.; data acquiring, G.S., A.T.; writing – original draft preparation, D.P.; writing – review and editing, I.L. and A.B.; visualization, D.P.; funding acquisition, A.L. All authors have read and agreed to the published version of the manuscript.

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