NITROUS OXIDE (N_2O) AND METHANE (CH_4) FLUXES FROM TREE STEMS IN BIRCH AND BLACK ALDER STANDS – A CASE STUDY IN FORESTS WITH DEEP PEAT SOILS

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Abstract. The aim of the study is to evaluate greenhouse gas (GHG) fluxes from stems in black alder (*Alnus glutinosa* (L.) Gaertn.) and birch (*Betula pendula* Roth) stands with drained and naturally wet nutrient rich peat soils, as well as to evaluate correlation between the GHG fluxes, soil temperature and groundwater level. The study was implemented in 8 forest stands – three black alder stands with nutrient rich peat soil (stand types according to national classification – *Dryopterioso-caricosa* and *Filipendulosa*) and 5 birch stands with peat soil (stand type *Oxalidosa turf. mel.* and *Dryopterioso-caricosa*). Measurement of GHG fluxes was continued for 12 months using Gasmet DX4040 FTIR analyser and removable non-transparent chambers of fixed volume and area. GHG fluxes were measured at 0.5, 1.0 and 1.5 m height on 3 trees in every stand. According to the study results the average CH_4 emissions from stem surface in birch stands are 6.9 ± 6.2 g CO_2 eq $m^{-2}\cdot yr^{-1}$ and in black alder stands 1.0 ± 3.2 g CO_2 eq $m^{-2}\cdot yr^{-1}$. Groundwater level significantly effects CH_4 emissions – if it remains above 15 cm during summer, the CH_4 emissions from stem increases to 84.0 ± 25.2 g CO_2 eq. $m^{-2}\cdot yr^{-1}$. Tree stems in drained peat soils are not a source of CH_4 emissions. According to the study results tree stems in peat soils are not producing N_2O emissions.

Keywords: GHG, emissions, tree stems, alder, birch.

Introduction

Organic soils are the largest source of GHG emissions in Latvia contributing to more than 6,1 mill. tons $CO_2\cdot yr^{-1}$ according to the national GHG inventory [1]. However, only part of the sources of GHG emissions in organic soils can be reported using country specific emission factors [2]. To calculate emissions from organic soils in Latvia, so far country specific methods [3-5] and default methods provided by the IPCC guidelines [6ж 7] have been used. The review of the methods proposed by the IPCC guidelines points to large diversity of scientific approaches applied in the referred studies leading to large uncertainty of the elaborated emission factors [8]. This review also highlights importance of elaboration of the country specific methodological approaches for evaluation of GHG fluxes from organic soils.

The recent studies in neighbouring countries prove that trees can be a significant source of methane (CH_4) emissions, especially in areas with seasonally fluctuating or continuously high groundwater level. Increase of CH_4 emissions during seasonal floods and periodic increase of the groundwater level can contribute to more than 70% of the net CH_4 emissions in forests with water saturated soils [10]. This and earlier studies [10ж 11] studies have significantly clarified the processes affecting GHG fluxes in organic soils and pointed to underestimated sources of GHG emissions – pristine, naturally wet organic soils and tree stems. Comprehensive studies are necessary to prove the effect of certain climate change mitigation measures, e.g., seasonal adjustment of groundwater level in deciduous tree stands and use of selective harvesting (openings and bends of limited area) instead of regenerative clear-felling. Limited and controversial knowledge about GHG fluxes in organic soils in combination with high uncertainty hampers implementation of climate change mitigation measures aimed at reduction of the largest source of GHG emissions in Latvia.

The urgent need to improve knowledge base required to eliminate GHG emissions in organic soils is also determined by the Regulation (EC) No. 2018/841, recently published proposal for amendment of the regulation [12; 13] and the European Commission communication document No. COM(2018)773. According to the amendment to the regulation No. 2018/841 the neutrality target in LULUCF sector is set in 2030, requiring reduction of GHG emissions by at least 4 mill. tons CO_2 eq$\cdot yr^{-1}$ [14].

Accounting of GHG emissions and CO_2 removals in LULUCF sector in Latvia recently has been significantly improved, because of LIFE REstore project [15-17] and other studies. However, CH_4 fluxes from tree stems are not yet addressed resulting in potential underestimation of GHG emissions in forests with organic soils. This is limiting the ability to forecast the climate effect of different forest management scenarios.

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To address the most urgent needs of the climate policy in Latvia’s LULUCF sector this project is aimed at evaluation CH_4 and N_2O fluxes from the tree stems in birch and black alder stands and to evaluate the effect of the groundwater level and other factors on the CH_4 and N_2O emissions. The study results are unique at European level and are applicable in countries with similar climatic conditions.

Materials and methods

GHG measurements were implemented in eight forest stands – tree black alder stands with nutrient rich peat soil (stand types according to national classification – *Dryopterioso-caricosa* and *Filipendulosa*) and five birch stands with peat soil (stand type *Oxalidosa turf. mel* and *Dryopterioso-caricosa*). Additionally, stem fluxes from birch were measured in one of the black alder stands. Information on stands including location is provided in Table 1. The study was implemented from November 2020 till October 2021, 12 months. Frequency of sampling – once per two weeks between April and October and once per month during winter months (in total 20 measurement campaigns).

Table 1

Stand characteristics in measurement plots

Dominant species	Stand ID	Age	Height, m	Diameter, cm	Basal area, $m^2 \cdot ha^{-1}$	Density, $trees \cdot ha^{-1}$	Location, WGS84	
							X	Y
Birch	031-99-9	20	15	14	21	1180	57.3218	26.0641
Birch	502-457-2	30	17	12	20	498	56.6873	25.0482
Birch	504-408-3	59	21	27	16	462	56.6942	24.5836
Black alder	508-45-11	23	11	9	17	1890	56.6596	24.1421
Birch	012-186-1	60	16	18	25	1243	57.2906	25.9987
Birch	501-20-15	70	22	22	11	289	56.9289	24.9666
Black alder	501-20-17	53	24	22	12	265	56.9280	56.9280
Black alder	505-84-3	72	26	29	31	584	56.5737	56.5737

GHG fluxes were measured at 0.5, 1.0 and 1.5 m height on three trees in every stand, excluding the stand where two plots – for measurement of the fluxes from birch and black alder were installed. Height and diameter of the measured trees are provided in Table 2.

Measurement of GHG fluxes was done using Gasmet DX4040 FTIR analyser and removable non-transparent chambers of fixed volume and area. Different chambers (Table 3) were used depending on the diameter of trees. Before the measurement the area of the bark surface, where the chamber is attached to the stem surface, was treated with silicone to avoid air exchange, when the chamber is installed.

Measurement continued for 30 minutes per tree, simultaneously at all heights. Manual multiplexers were used to switch between different chambers. Content of gases was determined after installation of the chamber and after 8, 10, 18, 20, 28 and 30 minutes. If different intervals are used, it is noted out during the measurement and later considered in the calculation. In parallel to the flux measurements, the groundwater level, soil and air temperature were recorded.

Table 2

Dimensions of the measured trees

Dominant species	Stand ID	Diameter of trees at 1.3 m height, cm			Height of trees, cm		
		tree 1	tree 2	tree 3	tree 1	tree 2	tree 3
Birch	031-99-9	20.5	16.4	11.5	18.5	17.8	16.0
Birch	502-457-2	20.3	14.7	12.7	21.4	18.2	19.4
Birch	504-408-3	28.6	25.9	19.5	22.7	22.4	18.2
Birch	508-45-11	14.5	10.6	9.2	12.6	12.2	12.0
Birch	012-186-1	20.5	18.0	12.9	22.4	21.3	20.2
Birch	501-20-15	29.9	21.0	14.0	25.4	23.6	20.8
Black alder	508-45-11	11.3	11.1	8.7	11.4	11.4	9.7
Black alder	501-20-17	24.3	19.3	14.2	23.7	21.3	19.8
Black alder	505-84-3	36.9	23.9	21.2	30.2	27.1	26.7

Table 3

Dimensions of the measurement chambers

Chamber ID	Height, cm	Width, cm	Thickness, cm	Volume, m^3	Area, m^2
1	20.1	25.0	2.2	0.00111	0.05025
2	20.5	42.0	2.3	0.00198	0.08610
3	20.0	56.5	2.5	0.00283	0.11300
4	19.0	73.0	2.8	0.00388	0.13870

R^2 of the linear regression of the CO_2 concentration changes is used to ensure that outliers are excluded from the flux calculation. Only data series with $R^2 > 0.95$ are used in the calculation. GHG fluxes were calculated using the following equation [15]:

$$CO_2 - C\left[\mu gC \cdot m^{-2} \cdot h^{-1}\right] = \frac{M\left[g \cdot mol^{-1}\right] * P[Pa] * V\left[m^3\right] * \delta v\left[ppm \cdot h^{-1}\right] * f_1 * f_2 * f_3}{R\left[m^3 \cdot Pa \cdot K^{-1} \cdot mol^{-1}\right] * T[K] * t[h] * A\left[m^2\right]},$$

where P – air pressure in the chamber, assumed constant 101300 Pa);
V – chamber volume, m^3 (Table 3);
δv – slope of regression representing gas concentration changes per hour;
R – universal gas constant (8.3143 $m^3 \cdot Pa \cdot K^{-1} \cdot mol^{-1}$);
T – soil temperature, K;
t – measurement time, hours;
M – molar mass of measured gases, 16.04 CH_4, $g \cdot mol^{-1}$;44.01 N_2O, $g \cdot mol^{-1}$;
A – chamber surface area, m^2 (Table 3);
f_1, f_2 and f_3 – recalculation coefficients (Table 4).

Table 4

Coefficients for calculation of GHG fluxes

Gas	f_1	f_2	f_3
CH_4	0.75	1.00	1.00
N_2O	0.64	1.00	1.00

Emissions were extrapolated to an area by calculation of the stem surface of an average tree, assuming that it is cone and by multiplication the average surface area with the number of trees per ha. Branches are not considered in the estimation due to lack of published information on the surface area of crown and a ratio between the GHG fluxes from stem and from branches.

Results and discussion

CH_4 emissions were observed in birch stands during summer months. In autumn, spring and winter months no CH_4 emissions were observed (Fig. 1). In black alder stands only one occurrence of significant CH_4 emissions was found in spring. The main reason for the difference was higher groundwater level in several birch stands. No N_2O emissions were observed during most of the time, birch stem surface is acting as net sink of N_2O removals; however, the effect is negligible.

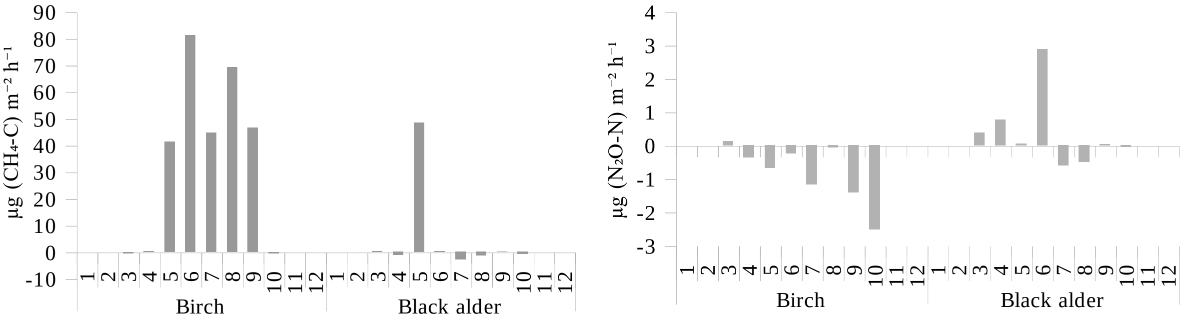

Fig. 1. **Results of measurements – average monthly fluxes**

Comparison of GHG fluxes and the groundwater level demonstrates significant correlation with CH_4 emissions in birch stands and no correlation in black alder stands (Fig. 2). It was also found that only in two birch stands the groundwater level increased above 15 cm during the vegetation season. As soon as the groundwater level drops below 15 cm, no CH_4 emissions from the stem surface appear; however, when the groundwater level increases, particularly in spring and summer, CH_4 emissions increase. No correlation was found with N_2O emissions and the groundwater level.

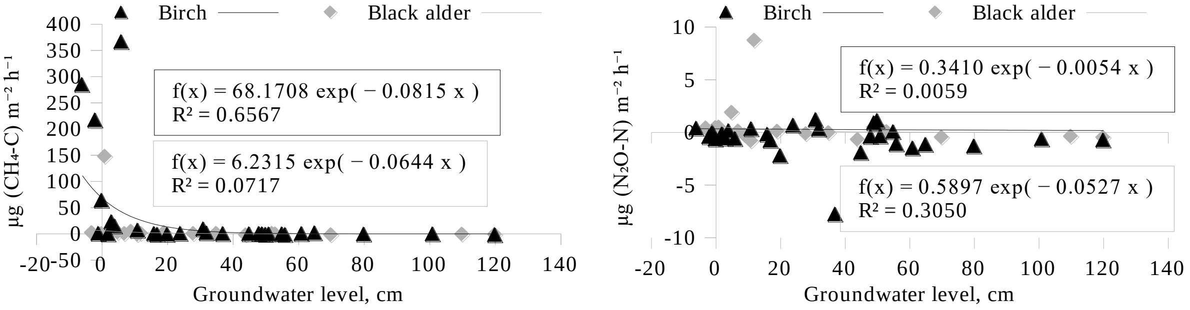

Fig. 2. **Correlation between groundwater level and GHG fluxes**

Increase of soil temperature is also increasing CH_4 emissions; however, only in case of high groundwater level (Fig. 3). No correlation was found between temperature and N_2O emissions from stems.

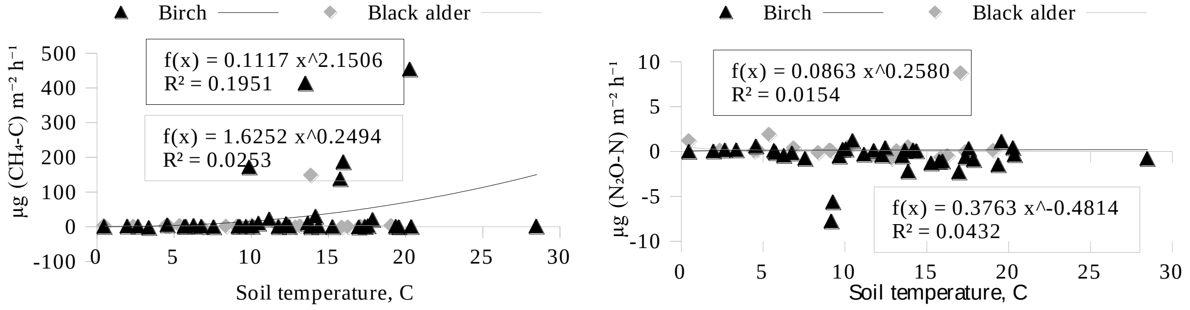

Fig. 3. **Correlation between soil temperature and GHG fluxes**

According to the study results the emissions seem to be more relevant to the groundwater level than the species, since the emissions are determined only if the groundwater level remains above 15 cm. If the groundwater level is high during most of the vegetation season or the area is flooded, the CH_4 emissions from stem increase to 325 ± 81 kg CO_2 eq. $ha^{-1}\cdot yr^{-1}$ (84.0 ± 25.2 g CO_2 eq. $m^{-2}\cdot yr^{-1}$). These results point out the importance of regulation of the water regime to eliminate hotspots of CH_4 emissions in forest lands with organic soils. According to earlier studies [15], CH_4 emissions in flooded areas equal to 100.6 CH_4, kg CH_4-C $ha^{-1}\cdot yr^{-1}$ (3.3 tons CO_2 eq $ha^{-1}\cdot yr^{-1}$). According to this study results stem fluxes in average conditions are negligible; however, high groundwater level or increase of the groundwater level during the vegetation period significantly increases CH_4 emissions. In one of the birch stands stem fluxes of CH_4 reached 10% of the total CH_4 emissions from soil and stem surface, if the soil CH_4 emission factor applied in the national GHG inventory is used to estimate CH_4 emissions from soil. The study does not approve findings by other authors, e.g. [15] that increase of the groundwater level in alder stands increases N_2O emissions. This may be associated with different periods of the increase of the groundwater level, in our study it was high in alder stands in spring, till June. Significant increase of CH4 emissions from the stem surface due to increase of the groundwater level is reported by several authors, e.g. [10; 18]. According to these authors changes are correlating with soil fluxes – reduction of CO_2 emissions and increase of CH_4 emissions from soil.

Conclusions

1. The research proves the results of earlier studies that the deciduous tree in organic soils can be a significant source of CH_4 emissions, while no significant N_2O emissions are detected.
2. Tree stem surface becomes a source of CH_4 emissions only in areas, where the groundwater level is above 15 cm, and the emissions rapidly grow if the groundwater level is higher.
3. CH_4 emissions are correlating also with temperature; however, the correlation is weak and CH_4 emissions only increase in case of high groundwater level, therefore both factors – groundwater level and temperature – should be used in projections of CH_4 emissions from the tree stem surface.
4. Significant improvements of activity data (dynamic maps of groundwater level) are necessary to estimate CH_4 emissions from tree stems at a national or regional scale.

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Author contributions

Methodology, A. L. and A.B..; data analysis, R.A.; writing – review and editing, A. L., A. B., R. A. All authors have read and agreed to the published version of the manuscript.

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