CASE STUDY ON EFFECT OF REWETTING GRASSLAND WITH ORGANIC SOILS ON GREENHOUSE GAS (GHG) EMISSIONS FROM SOIL

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Abstract. Rewetting grasslands with organic soils is an effective environmental strategy aimed at restoring natural water levels, crucial for mitigating GHG emissions. This process involves reintroducing water to previously drained or degraded peatlands, which helps in re-establishing wetland ecosystems. According to results of other studies rewetting slows down the decomposition of organic matter, significantly reducing carbon dioxide (CO_2) emissions; however, can increase methane (CH_4) emissions. Additionally, it supports biodiversity, enhances water quality, and can create new habitats for wetland species. This practice plays a vital role in climate change mitigation and ecosystem restoration. Our case study is implemented in former grassland near Smiltene, which was rewetted by closing culvert passing P27 road in late 80-ies during reconstruction of the road. Since that time the area is accumulating water from surrounding forests and farmlands. We measured GHG fluxes, groundwater, temperature, and other environmental parameters for two years once per month using the closed chamber method. Two-year measurements result that nearly 20-40 years after rewetting the grassland is still a significant source of GHG emissions – 6.04 tons CO_2-C·ha^{-1}·yr^{-1}, 0.62 kg CH_4·ha^{-1}·yr^{-1} and 0.67 kg N_2O·ha^{-1}·yr^{-1}. The net emissions from soil equal to 22.87 tons CO_2·ha^{-1}·yr^{-1}. This is about twice less than from cropland, but about the same level of emissions as in grassland according to other studies implemented in Latvia. Thus, our study does not provide evidence that rewetting can reduce GHG emissions from organic soil.

Keywords: nitrous oxide, methane, emissions, drained, wet, soil.

Introduction

Rewetting of grasslands with organic soil in Northern and Central Europe is an approach aimed at restoring ecosystems, enhancing biodiversity, improving soil quality, and contributing to climate change mitigation. This practice involves reintroduction of water to previously drained or dry areas to restore natural hydrological conditions.

The benefits of rewetting grasslands with organic soil include the enhancement of soil agrophysical properties, air quality improvement, erosion prevention, and biodiversity support through the growth of dense lawn coverings [1]. The ecological benefits of rewetting grasslands are multifaceted. Firstly, it significantly contributes to biodiversity conservation by restoring habitats for a wide range of plant and animal species. Wetlands and rewetted grasslands serve as crucial habitats for many endangered species, offering breeding grounds, food sources, and migration stopovers [1]. Rewetting can contribute to the carbon stock in meadow-pasture environments, as indicated by the higher organic carbon content in organic soils compared to mineral soils, offering a substantial opportunity for increasing carbon sequestration in the region [2]. Furthermore, the practice supports ecological intensification of arable systems by reducing the need for nitrogen fertiliser and controlling pests, leading to increased crop yield and decreased pest pressure [3].

However, there are challenges and drawbacks to consider. Rewetting may not significantly enhance carbon sequestration potential in some cases, as shown by a study focusing on the conversion of arable cropland to grassland, which showed no differences in soil organic carbon stocks between grassland and cropland up to 17 years old across various sites in the UK [4]. Moreover, soil respiration rates could vary significantly, influenced by factors like assimilate supply and climatic conditions, especially in intensively managed pastures [5]. Earlier studies in Latvia highlight lack of scientific evidences of the climate benefits of rewetting instead of afforestation of organic soils [6], while Bārdule et al. demonstrated that after rewetting of flooding of peatlands used for peat extraction greenhouse gas (GHG) emissions can actually increase due to high methane (CH_4) emissions and CO_2 emissions in summer [7]. This says that the outcomes of rewetting can be complex and influenced by local environmental conditions and management practices.

To maximize the benefits of rewetting grasslands with organic soil, future efforts should focus on integrated land management approaches that consider both ecological and socio-economic factors. This includes developing adaptive management strategies that are tailored to local conditions, engaging with local communities and stakeholders, and incorporating rewetting into broader climate change mitigation and biodiversity conservation policies. Research and monitoring are also crucial to better understand the long-term impacts of rewetting on ecosystem services, carbon dynamics, and biodiversity.

The aim of the study is to evaluate the effect of rewetting grasslands with organics-rich soils, where groundwater level regulation is stopped more than 10 years ago, in comparison to drained grasslands. Carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) emissions are compared in the study implemented in the period between 2021 and 2023.

Materials and methods

The study was implemented in seven measurement sites of grasslands in central and western part of Latvia, including three rewetted sites and four drained measurement sites (Table **Error! Reference source not found.**). The depth of ditches in drained sites is from 50 to 200 cm; in rewetted sites LV102 and LV302 rewetting was done naturally, due to deterioration of drainage ditches and building of beaver dams, in site LV303 rewetting was done artificially during reconstruction of the road by closure of culvert ensuring output of water from this area. A transect consisting of three measurement plots in different distances from the drainage ditch or bordering environment were set up in each sampling site. Coordinates of the central measurement point are provided in the table.

Table 1

Peat depth and location of sampling plots

Object	Drainage status	Management	Peat layer depth, cm	LKS92 coordinates
LV103	Drained	Perennial grassland for fodder production, conventional management methods	35	56.55928, 22.84283
LV301	Drained	Perennial grassland for fodder production, before 2017 managed for crop production	23	56.46735, 22.92954
LV306	Drained	Perennial grassland, before 2016 managed for crop production	21	56.21155, 21.18903
LV310	Drained	Perennial grassland, before 2016 managed for crop production	21	56.21228, 21.18977
LV102	Rewetted	Perennial grassland for fodder production, extensive use without fertilization	32	56.22810, 21.11740
LV302	Rewetted	Perennial grassland for fodder production, extensive use without fertilization	27	56.22949, 21.12201
LV303	Rewetted	Abandoned grassland, partially overgrown by bushes	30	57.32282, 26.07054

Several measurement programs were implemented in all plots, including: (1) manual measurement of groundwater level in piezometers; (2) greenhouse gas (CH_4 and N_2O) sampling for gas chromatography (GC) analyses (2 permanent collars in every location, analyses using Shimadzu Nexis GC2030, software LabSolutions 5.93) and heterotrophic respiration measurements using EGM5 analyser (3 measurement points in every location); (3) soil temperature measurements at 10 cm depth during site visits; (4) soil heterotrophic respiration (3 permanent measurement locations).

Measurement plots were visited once per month during 24 months period, from 15.01.2021 to 31.01.2023. Heterotrophic respiration was measurement with an EGM5 portable CO_2 gas analyser (PP Systems) spectrometer using a non-transparent chamber with the 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, the chambers were flushed before every measurement. The heterotrophic respiration continued during the vegetation period; during the rest of time CO_2 data from GHG flux analyses were applied. CH_4 and N_2O measurements were continued during the whole measurement period (at least 24 sample sets per sites were acquired). After arrival to the plot, the chambers were flushed and located over permanently installed collars (2 collars per measurement point). 100 cm^3 air samples were collected in grass bottles every 10 min during 30 min period (4 samples in a series), representing change of the gas content in the chamber. Volume of the 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 [8] was used to calculate heterotrophic respiration, beginning of 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 following formula were used to calculate GHG fluxes in GC data. Measurements with $R^2 < 0.95$ for linear regression of CO_2 concentration changes were excluded from evaluation of GHG fluxes. No other outliers, e.g. in case of very high CH_4 outputs, were excluded following to recommendation in the IPCC guidelines [9]. The applied CO_2 equivalent of CH_4 is 28 and of N_2O – 265 [10].

$$CO_2 - C(N_2O - N, CH_4 - C)\left[\mu gC(N) \cdot m^{-2} \cdot h^{-1}\right] = \frac{M\left[g \cdot mol^{-1}\right] \cdot P[Pa] \cdot V\left[m^3\right] \cdot \delta\upsilon[ppm(\upsilon)]}{R\left[m^3 \cdot Pa \cdot K^{-1} \cdot mol^{-1}\right] \cdot T[K] \cdot A\left[m^2\right] \cdot ppm}$$

where P – 101300 Pa;
R – 8.3143 $m^3 \cdot Pa \cdot K^{-1} \cdot mol^{-1}$;
V – 0.0655 m^3 and 0.023 m^3;
A – 0.19625 m^2 and 0.076 m^2;
M CO_2 – 44.01 $g \cdot mol^{-1}$; M CH_4 – 16.04 $g \cdot mol^{-1}$; M N_2O – 44.01 $g \cdot mol^{-1}$.

Monthly average and yearly fluxes were calculated for every plot, site and moisture conditions and according to the depth of the peat layer. Correlation and regression analysis was done to identify factors affecting GHG fluxes, particularly, the air temperature and groundwater level, demonstrating the largest correction with GHG fluxes. Random forest algorithm (python method *Predict*) was used to combine different parameters to predict GHG fluxes. Uncertainty is expressed as standard error of mean. A non-parametric Wilcoxon Signed-Rank Test was used to determine the significance of difference.

Results and discussion

Average results of the measurements of the soil heterotrophic respiration, N_2O and CH_4 emissions are provided in Fig. 1. No statistically significant difference is found between the drained and rewetted sites; however, CO_2 losses due to heterotrophic respiration and N_2O emissions tend to be higher in drained sites and CH_4 emissions tends to be higher in rewetted sites. N_2O and CH_4 emissions are negligible both, in drained and rewetted sites.

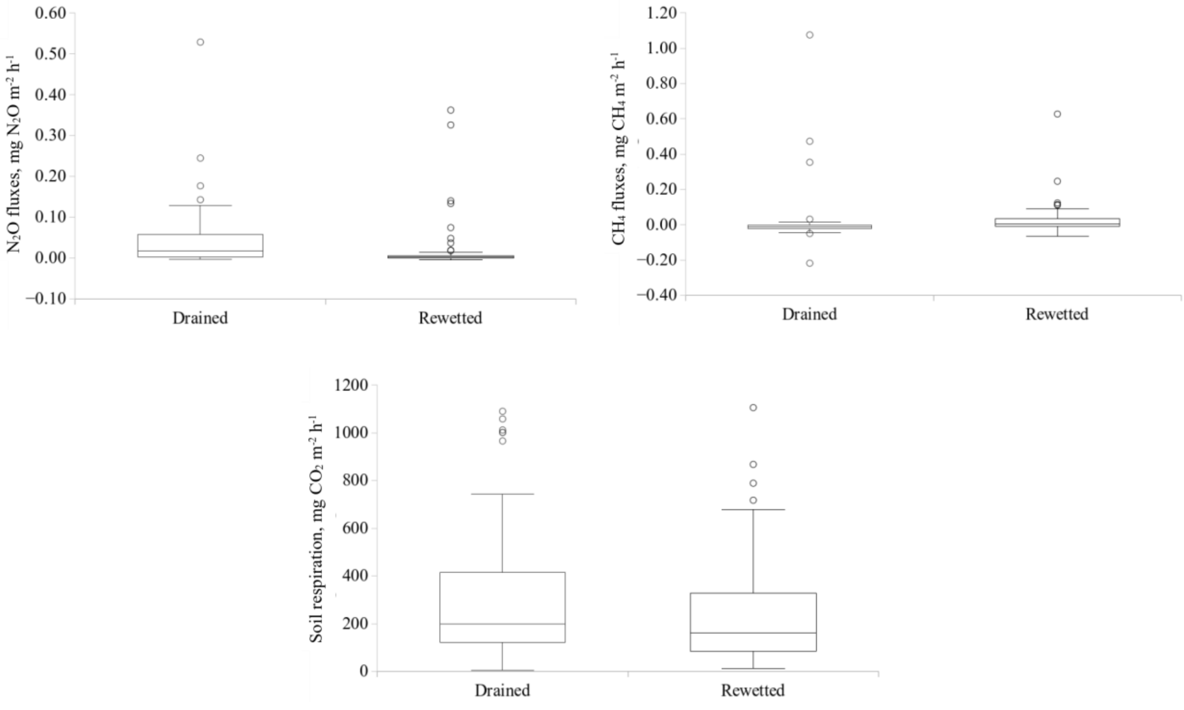

Fig. 1. **Average GHG emissions and soil heterotrophic respiration in measurement sites**

Monthly average soil heterotrophic respiration, CH_4 and N_2O emissions calculated to tons of CO_2 equivalents per ha are summarized in Fig. 2. The distribution of emissions does not differ significantly depending on the moisture regime; however, in drained sites GHG emissions are bigger in August. In drained sites total annual carbon losses due to heterotrophic soil respiration equal to 25.059 ± 2.455 tons $CO_2 \cdot ha^{-1}$, CH_4 emissions – to 0.073 ± 0.065 tons CO_2 eq.$\cdot ha^{-1}$, N_2O emissions – 0.879 ± 0.280 tons CO_2. Total GHG emissions from soil in drained sites equal to 26.010 ± 2.471 tons CO_2 eq. ha^{-1}. In rewetted sites total annual carbon losses due to heterotrophic soil respiration equal to 22.152 ± 2.465 tons $CO_2 \cdot ha^{-1}$, CH_4 emissions – to 0.063 ± 0.031 tons CO_2 eq.$\cdot ha^{-1}$, N_2O emissions – 0.652 ± 0.283 tons CO_2. Total GHG emissions from soil in drained sites equal to 22.868 ± 2.482 tons CO_2 eq.$\cdot ha^{-1}$. No significant difference was found between the drained and rewetted sites. Soil heterotrophic respiration is a dominant source of emissions in drained and rewetted sites.

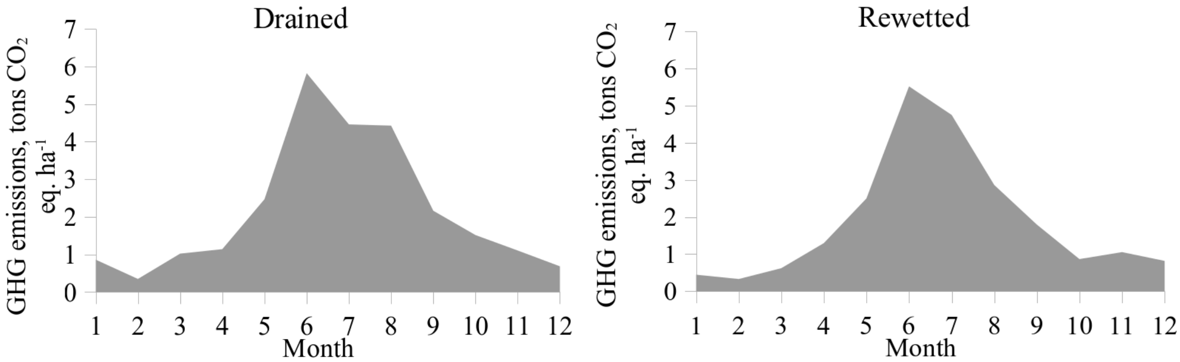

Fig. 2. **Net GHG emissions from soil including soil heterotrophic respiration**

Correlation between the air temperature and the emissions was found for soil heterotrophic respiration (Fig. 3). The reaction to the changes of the air temperature is similar in drained and rewetted sites. Similarly, soil heterotrophic respiration is correlating with the groundwater level in rewetted sites (R^2 = 0.44), while in drained sites such correlation is not observed. The most probable reason for lack of such correlation is the depth of drained lands, which during the vegetation season are at a depth, where it is not affecting GHG emissions. Monthly fluctuations of the groundwater level in drained and rewetted sites are provided in Fig. 4. Notably that in spite of high groundwater level in rewetted sites in spring and autumn in summer months it drops to 40-60 cm, which means that evapotranspiration in the rewetted sites significantly exceeds the input of water and without significant inflow of water these sites will be relatively dry during most of the season; however, the groundwater level in drained sites is significantly deeper during the whole year.

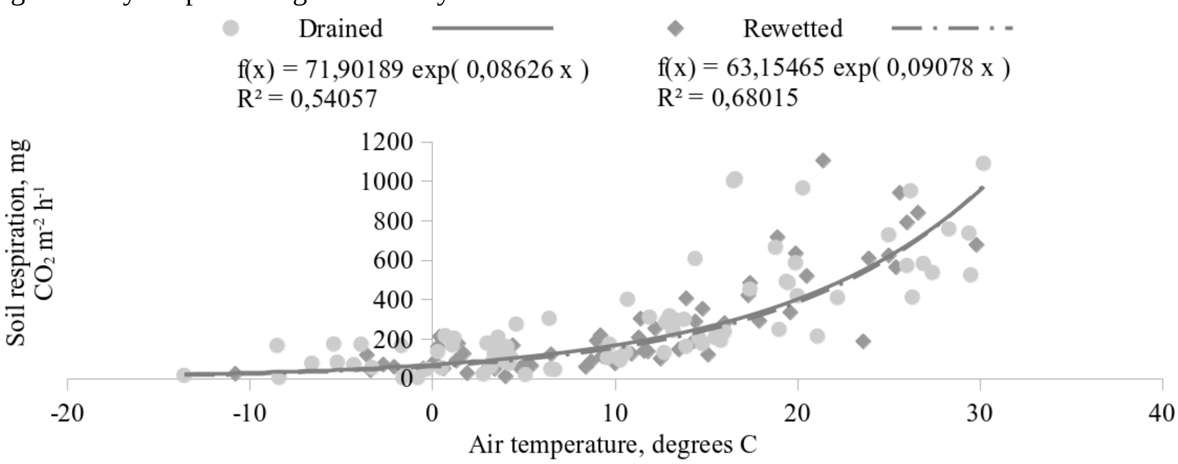

Fig. 3. **Correlation between air temperature and soil heterotrophic respiration**

Use of random forest regression to estimate soil heterotrophic respiration and using the Python method ‘*predict*’ soil heterotrophic respiration, air temperature and groundwater level measurement data results in accurate prediction models – R^2 for drained soils is 0.94 and for rewetted sites – 0.95. For other gases prediction accuracy is significantly smaller.

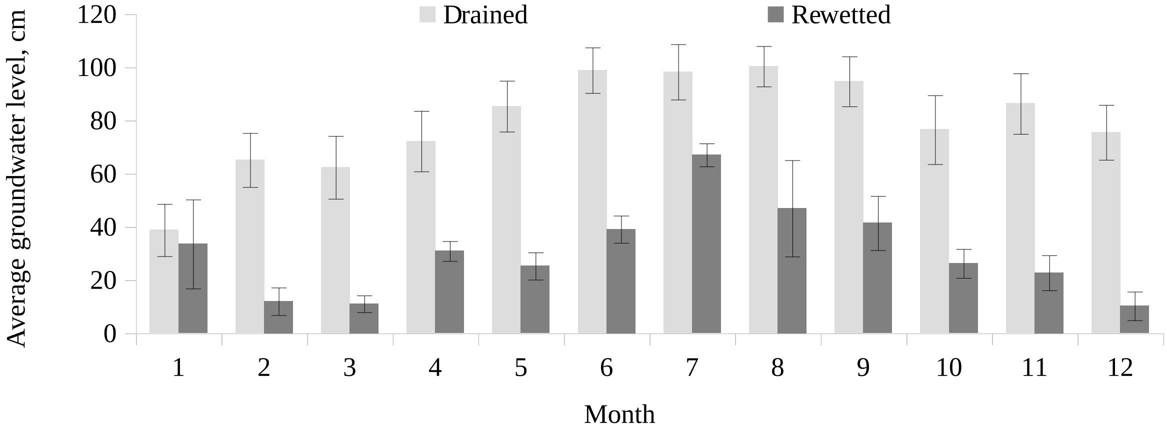

Fig. 4. **Average groundwater level**

The study results are in line with the earlier findings in forest lands demonstrating that naturally wet and rewetted soils can be a significant source of CO_2 emissions [7; 11], most probably due to evapotranspiration causing significant reduction of the groundwater level during summer months. Since the GHG emissions from soil in drained and rewetted sites are similar, the net GHG balance is determined by biomass production and soil carbon input with plant residues. Several studies report increase of biomass production after rewetting of grassland, e.g. [12; 13]; while other studies prove increase of biomass production after drainage, e.g. [14]. Smaller biomass production in drained sites usually is explained with draught, which usually is not an issue in Latvia, while bigger production is associated with accessibility of nutrients and reduced risk of natural disturbances.

Conclusions

1. The study demonstrates that drained and rewetted areas with organic soils are significant sources of GHG emissions dominated by CO2, and there is no significant difference between drained and rewetted sites, in spite of the trend to increase CO2 emissions in drained sites and CH4 emissions in rewetted sites.
2. In spite the rewetted study sites do not have water outflow, the groundwater level significantly decreases during the vegetation season resulting in the increase of CO2 emissions and negligible CH4 fluxes.
3. The biomass production and soil carbon input are the most important factors determining net GHG emissions from organic soils in grasslands; however, reliable data on biomass production depending on the moisture regime are missing and the applied assumptions may lead to overestimation or underestimation of the effect.
4. The most important parameters for prediction of the soil heterotrophic respiration are the air temperature and groundwater level. For other gases average annual values can be applied.

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Author contributions:

Conceptualization, A.L.; methodology, A.L. and I.S.; software, A.B.; investigation, I.S., G.S. and E.M.; data curation, A.L.; writing – original draft preparation, A.L. and I.S.; writing – review and editing, A.B. and I.S.; project administration, A.L. All authors have read and agreed to the published version of the manuscript.

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