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CLIMATE SMART MANAGEMENT ALTERNATIVES FOR MANAGEMENT OF ORGANIC SOILS UNDER AGRICULTURAL USE

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Organic soils in cropland and grassland are absolutely the largest source of greenhouse gas (GHG) emissions in Latvia contributing to output of 3.1 mill. tons CO_2 eq; therefore, it is important, to evaluate different management scenarios and their effect on the GHG emissions. In this study we compared 3 scenarios of management of organic soils used in agriculture: afforestation with birch and retaining of drainage system, afforestation with birch with following rewetting and management these areas as grasslands as a reference scenario. We estimated carbon stock changes in living biomass of trees and forest floor vegetation, litter, dead wood, harvested wood products and soil, substitution effect of forest biofuel, and N_2O and CH_4 emissions from soil. AGM model is used to create forest growth projections. The average annual GHG emissions from grassland is 7.3 tons CO_2 eq ha^{-1} yr^{-1}. In afforested and drained areas average GHG emissions are 2.6 tons CO_2 eq ha^{-1} yr^{-1}, and in afforested and rewetted areas – 3.8 tons CO_2 eq ha^{-1} yr^{-1}. Afforestation of grassland and maintenance of drainage system during 200 years period reduces GHG emissions by 916 tons CO_2 eq ha^{-1}, while the afforestation and rewetting reduces GHG emissions by 670 tons CO_2 eq. ha^{-1}. The substitution of fossil fuel has significant role in the climate change mitigation effect. The cost of the emissions' reduction in 2050 reaches 5.8 and 21.3 € ton^{-1} CO_2 eq in drained and rewetted areas, accordingly.

Keywords: *greenhouse gases; emissions; organic soil; grassland; afforestation*

INTRODUCTION

According to the European Environment Agency, the total area of organic soils reported by Member States in Europe is over 33 million hectares. Of this area, 74% is found in Finland and Sweden. Organic soils occur mainly in northern Europe, where the colder and wetter climate favours the build-up of carbon in soil. Six Member States report not having any organic soils, and in many other Member States, the area of organic soil is small. In grasslands, the largest areas of organic soils are found in Germany, Poland, Ireland, and the Netherlands. The area of organic soils decreased by 0.46 million hectares during the period 1990-2019 (European Environment Agency, 2022). The total area of organic soils in Europe may be subject to change due to various factors such as climate change, land use changes, and management practices (Mokma, 2005), as well as methodologies applied for elaboration of activity data (Jauhiainen et al., 2019a).

In 2019 European Union Member States reported net emissions of 108 Mt CO_2 from organic soil. The organic soils under cropland and grassland that are responsible for most of the emissions, while constituting 1.1% of the total area with cropland and 3.8% of the total area with grassland. Organic soils have significantly larger impact on overall emissions than mineral soils per hectare (European Environment Agency, 2022).

The long-term impact organic farming on soil-derived greenhouse gas emissions, including N_2O and CH_4 are discussed by Skinner et al. (2019). The article reports that lower area-scaled N_2O emissions and higher CH_4 uptake were determined in organic compared to non-organic farming systems. However, organically managed soils emitted more N_2O than soils in non-organic systems due to the yield gap between organic and non-organic farming.

Haas et al. (2022) discusses the long-term impact of residue management on soil organic carbon stocks and N_2O emissions from European croplands. The article reports that soil organic carbon sequestration in agricultural soils has been proposed as a strategy to mitigate GHG emissions from crop production.

In spite of the significant role of the organic soils in the GHG balance, knowledge and the applied quantification methods are at early development stages in most of the countries, and uncertainty level of the estimated uncertainty reach 200% or even more and some countries are not reporting GHG emissions from organic soils at all due to application of country specific criteria for identification of organic soils (Jauhiainen et al., 2019a). Tubiello et al. (2016) attempted to assess the greenhouse gas emissions from drained organic soils worldwide. The article discusses the uncertainties associated with estimating emissions from organic soils, including emission factor and activity data uncertainties. Tiemeyer et al. (2020) proposed a new methodology for estimating greenhouse gas emissions from organic soils in national inventories. The article discusses the challenges associated with estimating emissions from organic soils, including the lack of data and the need for standardized methods. Overall, recently published synthesis articles suggest that the lack of data and standardized methods for estimating greenhouse gas emissions from organic soils is a major challenge in reporting emissions. The articles also highlight the need for standardized methods and protocols for measuring and reporting soil carbon change and soil organic carbon sequestration (Jauhiainen et al., 2019b; Rumpel et al., 2020; Smith et al., 2020; Tiemeyer et al., 2020).

Several scientific articles report the positive effects of afforestation of organic soils in cropland and grassland. These effects include soil organic carbon sequestration, increased carbon sequestration in the biomass and soil, and the recovery of soil conditions in ecosystems in semi-arid regions; whereas there is limited information available about organic soils (Bjarnadottir et al., 2021; Hou et al., 2020; Nave et al., 2013). Afforestation can also facilitate the absorption of carbon through the accumulation of above ground and underground biomass, reduce carbon loss through retarding the decomposition of soil organic matter and soil erosion, and increase the amount and quality of soil organic matter content, whose bonding properties promote soil aggregation. The positive effects of afforestation on soil organic carbon stocks and N_2O emissions from European croplands have also been reported (Bjarnadottir et al., 2021; Hou et al., 2020). Similarly, afforestation of organic soils in cropland and grassland is identified as the most important climate change mitigation measure in Latvia (Licite & Lupikis, 2020).

Total area of organic soils (histosols and semi-hydromorphic soils) in Latvia is 1.2 mill. ha (19% of the country area). Area of drained organic soils is 0.63 mill. ha (52% of the area of organic soils). Area of forests with organic soils is 0.69 mill. ha and area of farmlands with organic soils is 0.15 mill. ha (Latvia University of Life Sciences and Technologies et al., 2018; Līcīte et al., 2022; Petaja et al., 2018). Organic soils are absolutely the largest source of greenhouse gas (GHG) emissions in Latvia contributing to output of 5.3 mill. tons CO_2 eq., including 3.1 mill. tons CO_2 eq. of emissions from cropland and grassland (Ministry of Environmental Protection and Regional Development, 2022).

National emission factors for organic soils in cropland, grassland and forest land are recently elaborated and implemented in national GHG inventory providing possibility of more accurate prediction of carbon turnover and GHG emissions under different management regimes (Butlers et al., 2022, 2023; Licite & Lupikis, 2020; Vanags-Duka et al., 2022).

Significant climate change mitigation potential of afforestation of organic soils in cropland and grassland in Latvia, as well as improved knowledge about the relationship between the emissions and land management practices provides opportunity to evaluate different management options of organic soils. In this study we compared two management options – afforestation with birch considering retaining drainage systems or following rewetting. In both cases managed grasslands with drained organic soil is considered as the alternative management scenario.

RESEARCH METHODS

The evaluation of the effect of afforestation of organic soils includes carbon stock changes in living biomass of trees and forest floor vegetation, litter, dead wood (DW), harvested wood products (HWP) and soil, as well as substitution effect of forest biofuel assuming that it is substituting natural gas. It is also assumed that harvesting residues are extracted in the afforestation scenario considering retaining of drainage systems. Additionally, N_2O and CH_4 emissions from soil including ditches is estimated. The average values of GHG fluxes (tier 2 method according to Eggleston et al., 2006) in forests with nutrient rich drained and rewetted or wet organic soils and GHG emissions from nutrient rich drained grassland are used to calculate GHG emissions from soil. The default IPCC 2006 emission factors are used to estimate the substitution effect of forest biofuel. Long term effect on the emissions and cost of the emission reduction is calculated according to average forest management service costs in 2021. AGM model is used to create forest growth, natural mortality and production projections (Lazdiņš et al., 2019; Šņepsts et al., 2018). The total calculation period is 200 years, rotation period of birch – until it reach target diameter or target age for regenerative felling.

Calculation of undergrowth biomass and carbon in soil with residues of these plants in afforested areas is based on the publication by Bārdule et al. (2021). The carbon input and the stock data are transferred into polynomial equations, where the first values equals to the ones in grasslands. Calculation of HWP is based on assumption that output of sawn materials is 25% of sawlogs, 25% of plate wood and 50% are residues used as biofuel production. The output of paper and cardboard is 50% of pulpwood. These calculations are done for wood without bark. Losses of harvesting residues during biofuel production are 50% in thinning and 30% in regenerative felling. The output of roundwood assortments is calculated using species specific polynomial equations elaborated by JSC Latvia's state forests (2010).

Afforestation and forest management expenses are estimated using information published by Central statistical bureau and characterizing situation in 2021 (Table 1). Assumptions for income are based on the summary of the assortment prices (Table 2) summarized from timber procurement announcements available on internet.

Table 1. Forest establishment and management cost

No.	Type of cost	Measurement unit	Value
1.	Soil scarification	€ ha^{-1}	168.0
2.	Seedlings	€ ha^{-1}	426.0
3.	Planting	€ ha^{-1}	151.1
4.	Tending (during 4 years after planting)	€ ha^{-1}	144.7
5.	Pre-commercial thinning (3 times)	€ ha^{-1}	157.2
6.	Harvest in commercial thinning	€ m^{-3}	9.9
7.	Harvest in regenerative felling	€ m^{-3}	7.1
8.	Forwarding in thinning	€ m^{-3}	6.4
9.	Forwarding in regenerative felling	€ m^{-3}	4.9
10.	Production of harvesting residues	€ $tonna^{-1}$	4.9
11.	Road transport	€ m^{-3}	6.5
12.	Maintenance of drainage systems	€ $ha^{-1}yr^{-1}$	25.0
13.	Administration	% of total cost	7%

Table 2. Forest establishment and management cost

No.	Type of cost	Measurement unit	Value
1.	Logs; 12-17.9	€ m^{-3}	61.0
2.	Veneer logs; FIA, 18<	€ m^{-3}	73.0
3.	Veneer logs; FIB, 18<	€ m^{-3}	74.0
4.	Firewood	€ m^{-3}	34.0
5.	Pulpwood; 7-49.9	€ m^{-3}	63.0
6.	Wood chip price	€ loose volume (LV) m^{-3}	20.0

Growing rate projections are calculated according to average growth rate in Oxalidosa turf. mel. (drained) and Dryopterioso-caricosa (wet) stand types. Duration of rotation 61 and 71 years in drained and wet sites, accordingly (Figure **1**). Increment, mortality, harvested wood and growing stock is transferred into biomass using Formula 1 (Liepiņš et al., 2017, 2021).

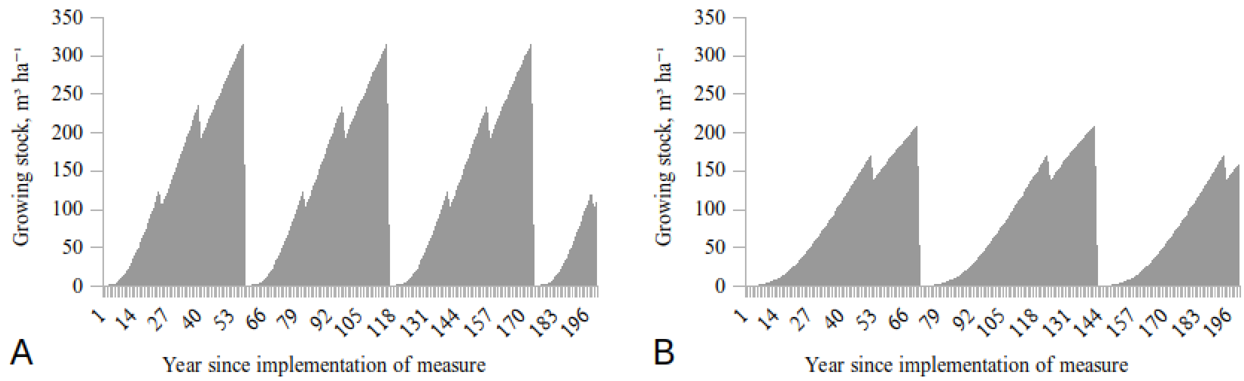

Figure 1. Summary of changes of growing stock after afforestation; **(a)** afforested drained organic soils; **(b)** afforested and rewetted organic soils.

$$Biomass, kg = k * exp\left(a + b * \frac{D}{(D+m)} + c * H + d * ln(H) + e * ln(D)\right) \quad (1)$$

where *D* – diameter at breast height, cm;
H – tree height, m;
a, b, c, d, e, m, k – coefficients from Table **3**.

Biomass is recalculated to carbon stock changes using variables listed in Table **4**. Carbon stock and other variables in grassland are assumed according to the most recent national GHG inventory report (Ministry of Environmental Protection and Regional Development, 2022); carbon stock in above ground biomass – 3.2 tons C ha^{-1}; in below ground biomass – 1.2 tons C ha^{-1}; soil carbon input with above ground biomass – 0.9 tons C ha^{-1}, with below ground biomass – 0.5 tons C ha^{-1} and with fine roots – 0.7 tons C ha^{-1}. Soil GHG emissions are calculated using factors provided in Table **5**. They are based on researches implemented in Latvia (Butlers et al., 2022, 2023; Licite & Lupikis, 2020).

Table 3. Coefficients to be used in Formula 1.

Biomass fraction	a	b	c	d	e	m	k
Above ground biomass	-2.1284	9.3375	0.0221	0.2838	0.0000	11.0000	1.0041
Stem biomass	-2.9281	8.2943	0.0184	0.7374	0.0000	11.0000	1.0020
Branch biomass	-1.0091	16.9249	0.0000	-2.0462	0.0000	12.0000	1.0745
Below ground biomass	-3.6432	0.0000	0.0000	0.0000	2.5127	0.0000	1.0060

Emission factors for the forest lands are applied directly after afforestation, which might lead to overestimation of the emissions during the early development years. It should be noted that emission factor for grasslands is elaborated for nutrient poor soils; therefore, it might underestimate GHG emissions from soil and the total mitigation effect of the afforestation measure.

Table 4. Biomass parameters in the reference and afforestation scenarios.

Water regime	Average wood density, tons m^{-3}	Carbon content in wood, tons ton^{-1}	Dead wood turnover period, years	Average carbon stock in litter, tons C ha^{-1}	Period to reach steady litter stock, years
Drained forest soil	0.5	0.5	20	12.1	150
Wet forest soil	0.5	0.5	20	12.1	150

Table 5. Emissions factors in the reference and afforestation scenarios.

Water regime	CH_4 emissions from ditches, kg CH_4 ha^{-1} yr^{-1}	Proportion of ditch area	CH_4 emissions from soil, kg CH_4 ha^{-1} yr^{-1}	N_2O emission from soil, kg N_2O ha^{-1} yr^{-1}	Heterotrophic soil respiration, tons CO_2 ha^{-1} yr^{-1}
Drained forest soil	217	3%	-2.92	1.59	15.92
Wet forest soil	-	-	-1.16	3.11	13.22
Drained soil in grassland	1165	5%	26.56	0.50	11.73

In the financial analysis we applied different discount rates for the cash flow. Cost of the emission reduction is calculated for 25 years period, separately, for the net emission reduction due to implementation of the measure and emissions reduction excluding substitution effect, which is accounted in energy sector.

RESEARCH RESULTS AND DISCUSSION

According to the assumptions applied in the study the average annual GHG emissions from grassland with organic soils in the reference scenario (area managed as grassland with drained organic soil) is 7.3 tons CO_2 eq. ha^{-1} yr^{-1}, reaching 1453 tons CO_2 eq. ha^{-1} during 200 years period. The main source of emissions is soil heterotrophic respiration, which is only partly compensated by carbon input with plant residues.

In the scenario considering afforestation with birch and retaining drainage system the area remains the source of emissions after the afforestation; however the emissions are considerably smaller than in the reference scenario – 2.6 tons CO_2 eq. ha^{-1} yr^{-1}, reaching 537 tons CO_2 eq. ha^{-1} during 200 years period. The substitution of fossil fuel more then double positive effect of this scenario; the average annual emissions without substitution effect reduces to 6.4 tons CO_2 eq. ha^{-1} yr^{-1}, reaching 1275 tons CO_2 eq. ha^{-1} during 200 years period. In the scenario considering afforestation with following rewetting the still area remains the source of emissions after the implementation of the measure; however the emissions are considerably smaller than in the reference scenario – 3.8 tons CO_2 eq. ha^{-1} yr^{-1}, reaching 769 tons CO_2 eq. ha^{-1} during 200 years period. The substitution of fossil fuel is significantly less important than in the alternative afforestation scenario; the average annual emissions without substitution effect in the afforestation and rewetting scenario reduces to 5.5 tons CO_2 eq. ha^{-1} yr^{-1}, reaching 1108 tons CO_2 eq. ha^{-1} during 200 years period. The acquired results demonstrates that use of forest biofuel is one of the key elements to ensure the mitigation effect in afforested lands; while in areas left for implementation the nature restoration targets proper strategy might be afforestation with following rewetting.

The afforestation of grassland with organic soil with birch and retaining of drainage system reduces GHG emissions by 916 tons CO_2 eq. ha^{-1} during 200 years period (4.6 tons CO_2 eq ha^{-1} yr^{-1}). Most of the effect (752 tons CO_2 eq. ha^{-1}) is ensured by substitution of fossil fuel. Afforestation of grassland with organic soil with following rewetting reduces GHG emissions by 670 tons CO_2 eq. ha^{-1} during 200 years period (3.3 tons CO_2 eq ha^{-1} yr^{-1}). About half of the effect (339 tons CO2 eq. ha^{-1}) is secured by substitution of fossil fuel (Figure **2**).

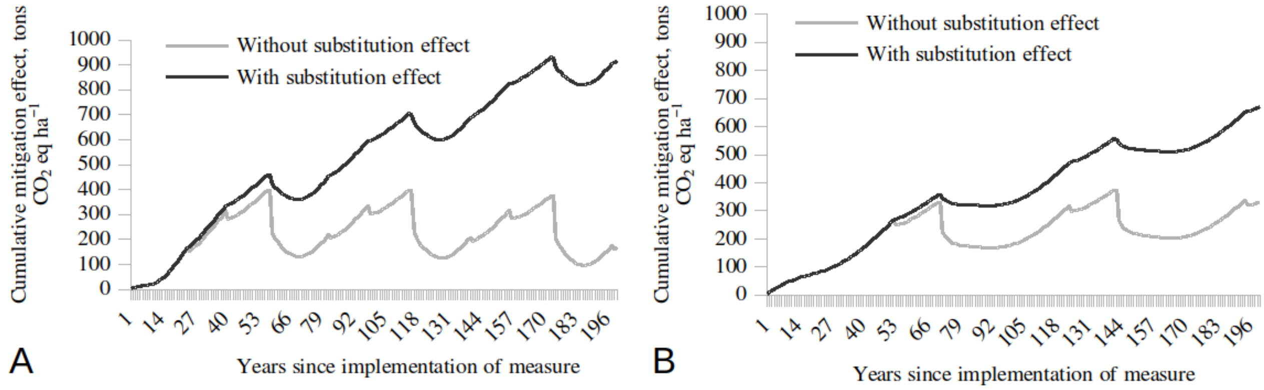

Figure 2. Cumulative reduction of GHG emissions due to implementation of the measures; **(a)** afforestation of grassland and maintenance of drainage systems; **(b)** afforestation with following rewetting.

Climate neutrality targets are set for 2050; therefore, the effect of both afforestation scenarios is calculated also for 25 years period assuming that the measure is implemented before 2025. The afforestation of grassland with organic soil and retaining of drainage system reduces GHG emissions by 173 tons CO_2 eq. ha^{-1} during 25 years period. Most of the effect (155 tons CO_2 eq. ha^{-1}) is ensured by reduction of GHG emissions of soil and accumulation of carbon in living biomass. The afforestation with following rewetting reduces GHG emissions by 90 tons CO_2 eq. ha^{-1} during 25 years period. There is no substitution effect considered because the first thinning in rewetted areas will take place later than in drained areas.

The initial investments, including soil scarification, planting material, planting and early tending during the first years after planting in the scenario considering afforestation and retaining the drainage system according to the applied assumptions are 1551 € ha^{-1} and in case of the afforestation with following rewetting – 1416 € ha^{-1}.

The cost of the emissions' reduction, assuming that the measures are implemented before 2025, in 2050 would reach 5.8 € ton^{-1} CO_2 eq in current prices in case of the afforestation and retaining of drainage systems and 21.3 € ton^{-1} CO_2 eq in current prices in case of the afforestation with following rewetting (Figure **3**). Faster growth of trees in drained area ensures smaller cost of the climate mitigation and significantly bigger effect.

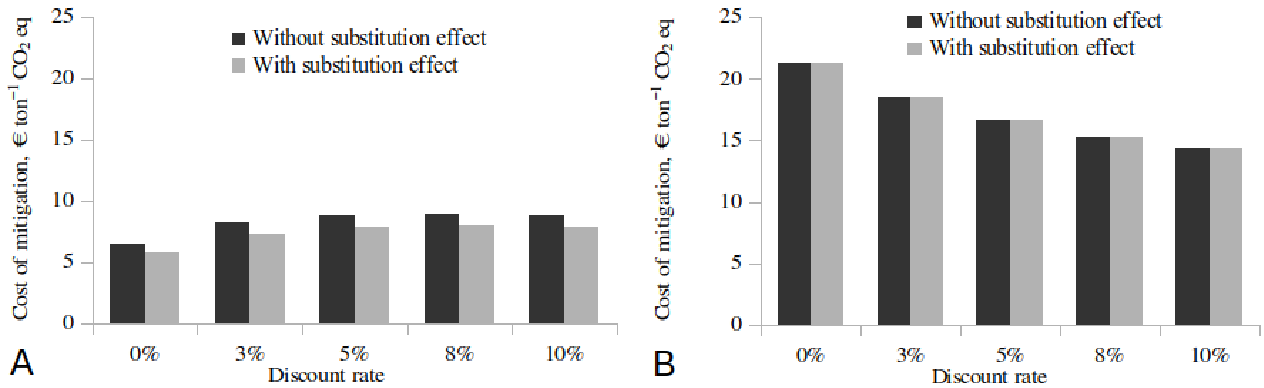

Figure 3. Cost of climate change mitigation effect; **(a)** afforestation of grassland and maintenance of drainage systems; **(b)** afforestation with following rewetting.

The studies on other species (spruce and pine) proves significantly bigger mitigation effect due to smaller emissions from soil and bigger carbon input with litter and forest floor vegetation (Bārdule et al., 2021; Butlers et al., 2022) turning organic soils into carbon sink after afforestation; however, uncertainty of these estimates are high and there is no statistically significant difference; therefore, there is need for further studies to improve accuracy of the emissions' projections. IPCC default CO_2 emission factor (total ecosystem exchange) for grassland in temperate climate region is 6.1 tons CO_2-C yr^{-1} ha^{-1} (Eggleston et al., 2006), which is about six times smaller than the factor applied in the study and based on the research findings in nutrient poor soils (Licite & Lupikis, 2020). Improvement of the national emission factors might lead to increase of the potential positive effect of afforestation.

CONCLUSIONS

Afforestation with birch ensures the reduction of GHG emissions from organic soils; however, the afforested area still remains a source of emissions. Rewetting is not contributing to the further reduction of GHG emissions; moreover, the cost of emission reduction is significantly higher in the case of rewetting in comparison to the afforestation and retaining the drainage system. The substitution effect has a significant potential role in the emission reduction; therefore, the mitigation effect can be maximized only in managed forests. Long term effect of afforestation depends on the additional substitution effect ensured by biofuel.

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