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Evaluation of greenhouse gas emissions and area of organic soils in cropland and grassland in Latvia – integrated National forest inventory data and soil maps approach

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Abstract. The aim of the research was to assess distribution of organic soils in farmlands for the time period between 1990 and 2015, as well as to carry out a recalculation of GHG emissions from organic soils in grassland and cropland. We evaluated the area of typical organic soils using digitized soil maps created between 1960s and 1980s there were 183,000 ha of cropland and grassland on organic soils. A selected number of areas on organic soils intersecting with the National forest inventory (NFI) plots were surveyed. We found that 66 ± 10% of surveyed plots still conforms to criteria for organic soils according to Intergovernmental Panel on Climate Change (IPCC) guidelines; in the rest of plots soil organic matter has been mineralized and these areas do not conform to IPCC criteria of organic soils. The following distributionof organic soils was estimated in cropland – 6.3 ± 3.3% in 1990 and 4.1 ± 3.4% in 2015, but in grassland – 11.6 ± 3.6% in 1990 and 7.7 ± 3.9% in 2015. The annual reduction of GHG emissions due to reduction of area of organic soils in cropland in 2015 corresponds to 1,400,000 tonnes CO_2 eq. in comparison to 1990 and in grassland – to 1,100,000 tonnes CO2 eq. The estimated reduction of the GHG emissions due to conversion of organic soils into mineral soils, comparing the average value in 2005–2009 with the projection for 2021–2030 on average will correspond to 313,000 tonnes CO2 eq. annually, however LULUCF sector still won't become a net CO_2 sink according to the GHG inventory data on other land use categories and carbon pools.

Key words: cropland, grassland, GHG emissions, organic soil.

INTRODUCTION

Soil is the largest terrestrial carbon pool and, as such, it can be turned into the largest source of greenhouse gas (GHG) emission from terrestrial ecosystems, depending on land use type and management activities. Globally about 1,220–1,550 Pg of carbon (C) is stored in soils as organic matter to a depth of 1 m and 2,376–2,450 Pg C – to a depth of 2 m. These amounts are significantly higher than C storage in atmosphere and terrestrial plants (Eswaran et al., 1995; Lal, 2004b). Soil organic matter, which consists of carbon-based compounds, influences soil chemical, physical and biological properties. It provides fertility, biological activity and attachment of nutrients to soil adsorption complex and also influences soil structure, air and moisture content. Organic matter also has a significant role in carbon cycle, whereas the carbon cycle along with changes in GHG concentrations is an important component of the biochemical cycle

(FAO, 2004; Nikodemus, 2009; Heikkinen, et al., 2013). Soils with more than 12–18% of organic carbon (approximately 20–30% of organic matter) are considered organic soils (Eggleston et al., 2006). Maintenance of optimal content of soil organic carbon (SOC) secures preconditions for development of healthy forest stands and better plant growth. It also increases net primary production, yieldswater retention capacity and efficiency of fertilizers and irrigation. SOC can reduce plant water stress, erosion, pesticide and nutrient leaching to aquatic ecosystems and mitigates climate change by off-setting anthropogenic emissions through C sequestration in trees and soils (Stoate et al., 2001; Jankauskas et al., 2007; Brock et al., 2011). Most of cropland contains 2–10% of organic matter in topsoil (Bot & Benites, 2005). C content in topsoil is a significant soil quality indicator because content of organic matter is directly proportional to C content in soil (Heikkinen et al., 2013). SOC is also important for ensuring a consistent global food supply. Adoption of SOC conserving agricultural practices can increase food production by 17.6 Mt $year^{-1}$ (Sá et al., 2017).

It is well known that drainage and cultivation of organic soils promotes CO_2 emission from soil, because decomposition rate of organic matter in fertile drained organic soils is relatively high (Maljanen et al., 2010). Soil monitoring results across Europe show a decrease in soil organic carbon stock (Capriel, 2013; Heikkinen et al., 2013), although these results are somewhat controversial (Chapman et al., 2013; Reynolds et al., 2013). In Europe approximately 45% of agricultural lands have low or very low content of organic matter (< 2%). The above-mentioned problem is particularly relevant in countries of Southern Europe, but it is reported in Latvia too (Nikodemus, 2009; Lugato et al., 2014). Climate change is expected to further reduce SOM – it is projected that warmer and wetter climate is likely to increase C losses and thus GHG emissions from organic soils (Jansons et al., 2013; Zeps et al., 2017).

Globally soils contain 1,500 Pg (1 Pg = 1Gt = 10^{15} g) of organic carbon, however the carbon stock is decreasing. Carbon sequestration in soils can be achieved by increasing the flux from the atmosphere to the terrestrial or by slowing down decomposition. One of the best options for soil carbon sinks, is to increase carbon stock in degraded soils (Smith, 2004). Soil degradation is a change in the soil health status resulting in a diminished capacity of the ecosystem to provide goods and services (FAO, 2018). Loss of soil organic matter is an important criterion of soil degradation, as it is vitally important to soil productivity. Decomposition of soil organic matter is encouraged by intensive agricultural practices like deep drainage and ploughing. Ploughing raises the average temperature of soil by mixing oxygen into it and thus contributing to organic matter decay. Also crop cultivation returns less organic matter to the soil than does native vegetation (Fact sheet no. 3: Organic matter decline, 2009). Soil organic matter is also reduced by soil erosion. 18.3 million hectares of agricultural lands in Europe are considered as degraded soils (FAO, 2004).

Agricultural lands can be not only a carbon sink, but also can act a source of GHG emissions. The amount of N_2O and CH_4 emissions from agricultural sector in European Union (EU) is about 465 Mt CO_2 eq. annually (EEA, 2013). The carbon losses from managed organic soils in cropland and grassland in EU countries at the same time equals to 70 Mt of CO_2, according to the latest EU GHG inventory report for 1990–2015, which means if C losses from organic soils were added to the agriculture sector emissions, it would result in a 15% addition to net emissions. Land use type and management practices significantly affect the ratio of input and losses of organic carbon in soil

(Poeplau et al., 2015). Good farming practice is a cost-effective method for decreasing GHG emissions, while ensuring soil quality and food security (Lal, 2004b; 2004a).

The main activities that influence carbon stock in cropland are management of agricultural residues, ploughing, fertilization, selection of crops and intensity of agriculture (continuous or periodical crop cultivation), irrigation, periodical alternation ofcrop cultivation periodically alternates with cultivation of pasture grass and hay. Drainage can significantly (by 28–38% since 1900 in temperate zone alone) reduce carbon stock in organic soils (Armentano & Menges, 1986). It is estimated also that C accumulation in cropland, where ploughing, crop rotation, crop coverage, nutrient input and water management are well-balanced, can reach 200–600 kg ha^{-1} C annually (Lal, 2004a).

Grassland is one of the most widespread types of vegetation globally, that comprises one fifth of world's terrain. It is assumed that 200–300 Pg or about 30% of soil C is stored in grassland (Genxu et al., 2002). In contrary to tendencies of C stock in croplands, long-term results of soil monitoring in Europe show an increase of C content in soil in grassland (Lettens et al., 2005), illustrating the potential for management practices to effectively increase soil C stocks. However, studies in Latvia have demonstrated no difference in C stock in grassland and cropland (Bardule et al., 2017). Other studies show a tendency of increase or retention of soil C stock in natural grasslands in areas, where management activities have taken place without facilitating land degradation, and in improved grasslands, but in degraded grassland areas decrease of C stock was observed (Maia et al., 2009). Good grassland management practices can be used to decrease GHG emissions from soil (Ogle et al., 2004).

According to Kyoto protocol and Decision 2/CMP.6 of the Conference of the Parties reporting of CO_2 removals and GHG emissions caused by management of cropland and grassland in the second commitment period (2013–2020) is voluntary. It is expected that after 2020 reporting of these activities will become mandatory for countries listed in the Annex I of Kyoto protocol, including Latvia (United Nations, 1998). From January 1, 2021, Latvia has to prepare and maintain annual inventory, in which all GHG emissions and CO_2 removals due to cropland and grassland management must be accurately reflected.According to Eggleston et al. (2006) and Hiraishi et al. (2013), calculations of the main sources of GHG emissions and CO_2 removals (key sources) should be done in accordance with scientifically verified national methodologies, but for minor non-CO_2 sources of the emissions the default calculation methods and emission coefficients provided in the guidelines can be used. The land use, including area of organic soils, should be represented in spatially explicated way, which includes 'wall to wall' inventories, as well as statistical inventories like National forest inventories (NFIs). The aim of this study is to assess distribution of organic soils in cropland and grassland for the period between 1990 and 2015, according to NFI data and the digital soil maps elaborated within the scope of the European Economic Area financial instrument funded project 'Promotion of sustainable land resource management by creating a digital soil database', as well to recalculate GHG emissions from drained organic soils in grassland and cropland.

MATERIALS AND METHODS

Analysis of digital soil map data

The plot specific data of the 2nd cycle of NFI (2009–2013) was used to select sample plots with agricultural land use. Only those NFI sample plots were used which have only one land use type within the boundaries of sample plot (500 m^2 circle). The geographical information systems (GIS) layer of NFI was intersected with the digital soil map layer (mapping took place in 1960's – 1980's), to select only those NFI sample plots, which conforms to Intergovernmental Panel on Climate Change (IPCC) organic soil definition (Table 1).

Table 1. Soil types used in selection of organic soils (Kārkliņš, 2016)

No.	Soil type in national classification	Symbol in national soil classification	Approximation to WRB 2014
1.	Alluvial marshy (Aluviālā purva)	AT	Histosols, Fluvisols, Gleysols, Phaenozems
2.	Humic-peaty podzolic gley sod (Trūdaini-kūdrainās velēnu podzolētās gleja)	PGT	Gleysols, Planosols, Stagnosols, Gleyic Podzol, Umbrisols
3.	Bog peat (Augstā purva kūdra)	Ta	Fibric Histosols, Dystric Histic Gleysol
4.	Bog peat gley (Augstā purva kūdras gleja)	Tag	Fibric Histosols, Dystric Histic Gleysol
5.	Transition mire peat (Pārejas purva kūdra)	Tp	Hemic Histosols, Dystric Histic Gleysol
6.	Transition mire peat gley (Pārejas purva kūdras gleja)	Tpg	Hemic Histosols, Dystric Histic Gleysol
7.	Fen peat (Zemā purva kūdra)	Tz	Sapric Histosol, Histic Gleysol
8.	Fen peat gley (Zemā purva kūdras gleja)	Tzg	Sapric Histosol, Histic Gleysol
9.	Humic-peaty gley sod (Trūdaini-kūdrainās velēnu gleja)	VGT	Gleysols, Planosols, Stagnosols

Data conversion to area units was carried out by determination of the total area of NFI sample plots (8.04 10^6 m^2) and by dividing it with the total area of Latvia according to data on the total area obtained from GIS Latvia 10.2 map (64.6 10^9 m^2). According to this estimate 1 m^2 of a NFI plots corresponds to 0.80 ha of the country area. This figure is later used to extrapolate area of organic soil as well as to determine uncertainty using standard error of proportion.

Field surveys

A set of NFI plots where land use in the 2nd NFI cycle was cropland or grassland and met the criteria of organic soils according to Table 1 was surveyed in autumn of 2016. The number of the NFI plots to be visited was determined according to the preliminary assessment of area of organic soils outside forests using digitized soil maps. According to the assessment there are about 500 NFI plots on organic soils in cropland

and grassland. To represent at least 20% of NFI plots on organic soils in cropland and grassland, 50 NFI plots reported to the Rural Support Service (RSS) as cropland or grassland and 40 NFI plots that were not reported by RSS, but are managed as cropland or grassland and intersects with the polygons of organic soils, were randomly selected. The definitions applied in the National GHG inventory and implemented in the NFI are used in selection. The main difference between grassland and cropland is evidence of ploughing – there should not be signs of ploughing in grassland for at least 20 years. Only complete polygons and plots not bordering with other land use types, were selected for the field survey. Management practices were not considered in the selection, except dominant land use (e.g. cropland or grassland).

Depth of groundwater and thickness of organic rich layer were determined, as well as soil samples from topsoil were collected for analyses in all of the selected plots. Content of total carbon and carbonates (according to ISO 10694:1995 and ISO 10693:1995 standards), as well as soil texture and pH (ISO 11277:2009 and ISO 10390:2005, accordingly) was determined in the soil samples, and compliance with threshold values of organic carbon content for organic soils was determined according to Eggleston et al., 2006. Soil sampling was done to a 20 cm depth according to Penman, 2003. Sampling was carried out during August and October, 2016. Soil samples were collected in 4 replicates of mixed (undefined volume) samples in 13–15 m distance from centre of the NFI plots at 0°, 90°, 180° and 270° from North. Thickness of organic layer was determined in grassland as a border between organic and mineral soil layers and in croplands if it is deeper than mixed topsoil layer. Groundwater level was determined by digging wells in ground until water saturated layer is reached.

Calculation of area of organic soils and greenhouse gas emissions

It is necessary to know the area of organic soils in cropland and grassland to calculate GHG emissions. The current area of organic soils was calculated by multiplying the relative area of organic soils from surveyed plots with the total area of organic soils from digital soil map database (Eq. 1) both for cropland and grassland. It shows the current state of organic soil, assuming that some areas of organic soil, which were mapped in 1960's – 1980's, have turned from organic to mineral soils.

$$A_{2016} = p \cdot A_{database}^{total} \tag{1}$$

where $A2016$ – current total area of organic soils for cropland/grassland, ha; $A_{database}^{total}$ – total area of organic soil for cropland/grassland from digital soil map database, ha; p – relative area of organic soils according to the implemented survey.

The total area of organic soils for cropland and grassland in the digital soil map is assumed to correspond to 1970, which is the approximate mean mapping year. The reduction of area of organic soils since 1970 was calculated by linear interpolation of the area of organic soils in 1970 and 2016.

Annual reduction of area of organic soil was calculated as:

$$\Delta \mathrm{A} = \frac{A_{database}^{total} - A_{2016}}{Y} \tag{2}$$

where ΔA – Annual reduction of area of organic soils, ha; Y – period from soil mapping to field surveys in this study, in this case 46 years.

Emissions from organic soils in cropland and grassland were calculated by multiplying the area of organic soils with IPCC default emission factors (Eq. 3.). Emission factor for temperate region for cropland and for temperate deep drained nutrient rich grassland (7.9 and 6.1 t ha^{-1} C annually, in cropland and grassland, respectively) was used.

$$E_{CO_2} = A_J \cdot EF \tag{3}$$

where E_{CO_2} – CO_2 emissions from cropland/grassland, tonnes CO_2 eq. annually; A_j – area of cropland/grassland in year j, ha; *EF* – IPCC default emissions factor, tonnes CO_2-C ha^{-1} annually. The most conservative assumptions (emission factors for nutrient-rich organic soils in temperate moist climate zone) are used in calculation to avoid underestimation of the emissions and to keep conformity with the methodologies used in the National GHG inventory.

Statistical data analysis

Confidence interval ($\alpha = 0.05$) of sample proportion was calculated according to Eq. 4 to show the uncertainty of the total distribution of organic soils and distribution of organic soils in cropland and grassland.

$$CI_i = Z \cdot \sqrt{\frac{p \cdot (1 - p)}{n}} \tag{4}$$

where CI_i – confidence interval for i value; Z – the probability of normal distribution; p – proportion of the organic soil, %; n – total number of croplands or grasslands assessed.

In order to extrapolate study results to country level to determine uncertainity of distribution of organic soils, two uncertainties were combinedtogether following to the approach in the IPCC guidelines Volume 1 Chapter 3, respectively, uncertainity of relative area of organic soil in in cropland and grassland is combinied with and uncertainty of changes in relative area of organic soils (Eq. 5).

The same approach applied to the whole period.

$$CI_i^{combined} = p \cdot CI_i^{total} + CI_i \tag{5}$$

where CI_i^{total} – confidence interval for proportion of the organic soils from total NFI plots which intersect with layer of soil database; p – relative area of the organic soils in the soil database intersecting with NFI plots

RESULTS AND DISCUSSION

Digital soil map data analysis

Digitalized soil maps surveyed between 1960s and 1980s are available for 3,888,000 ha or 60% of the country's area. 58% of areas with soil cartographic data are farmlands, 32.8% – forest.

The total area of organic soils in NFI plots with available soil cartographic material is 505,000 ha or 13%. Half of the organic soils are located in forests and 36% are located in farmlands about 5% are settlements and related infrastructure, mostly drainage systems in agricultural lands or forest lands, and 7% are areas with high groundwater level, respectively rewetted and naturally wet soils. The most common reason of rewetting is deterioration of drainage systems.

Cropland on organic soil is represented in the NFI database with one land use subcategory – cereals; in grassland and extensively cultivated cropland the majority of the area corresponds with the definition of grasslands and pastures, but 17% of the area corresponds to the definition of forest (naturally afforested agricultural land). The total area of farmlands on organic soils is 183,000 ha (8.1% of farmlands).

The most common type of organic soils in cropland and grassland is fen peat soil (*Sapric Histosol* or *Histic Gleysol*), 67%. The proportion of semihydromorphic soils, which canfulfil the criteria of organic soils, is higher in cropland, compared to grassland. According to Latvian soil classification, semihydromorphic soils are soils developed in planes or depressions on fine-textured parent material. Soil profile is water-saturated for a long period within a year including the growing season. This soil class includes Gley, Podzolic-gley and Alluvial soils. All the studied semihydromorphic soils according to WRB-2014 are histosols (Kārkliņš, 2016).

The area of organic soils in cropland and grassland reported in the 2017 GHG inventory report is 142,000 ha (Gancone et al., 2017). The annual CO_2 emissions from organic soils in cropland and grassland according to the latest national GHG inventory report in Latvia equals to 3.7 million tonnes (Gancone et al., 2017). Extrapolation of obtained data on the share of organic soils in the NFI plots (in cropland – 3.3% and in grassland – 10.8%) to the area of cropland and grassland reported in the GHG inventory report would increase the total CO_2 emissions from cropland and grassland on organic soil by 19% (up to 4.3 million tonnes). Such an increase influences the GHG balance in LULUCF sector, as well as in the whole national GHG inventory (14% and 4% increase of GHG emissions, but changes are within the limits of the uncertainty of the default emission factor.

Application of the soil map analysis derived research result on the share of organic soil in cropland and grassland in the GHG inventory would increase GHG emissions in the whole time series from 1990, including 2005–2009, which is set as a potential reference period for the GHG emissions reduction target for grassland and cropland management in 2021–2030.

Assuming that the actual share of organic soils in cropland and grassland is decreasing due to mineralization of organic matter, use of the activity data, which are based on soil maps originated 30–50 years ago would lead to considerable overestimation of the GHG emissions in the reference period, which will be used to set the climate change mitigation targets for grassland and cropland management. A part of organic soils has been mineralized during this time or emits considerably less GHG due to land use changes. In order to improve the accounting of GHG emissions from organic soils the effect of mineralization of organic matter and land use change should be verified and demonstrated with field measurements or modelling data. The main issues to solve are determination of the actual distribution of organic soils in cropland and grassland in NFI plots in Latvia; evaluation of the soil mineralization process to predict GHG emissions from organic soils depending on the depth of organic soil layer and content of organic matter in soil; analysis of land use changes in areas with organic soils, using data about age of forest stands in NFI plots on former arable lands and remote sensing data characterizing conversion of cropland to grassland in 1990–2005; and periodic assessment of soil carbon stock in NFI plots in cropland and grassland on organic soils (once in 5 years by determination of changes in soil carbon content and depth of organics rich layer) to provide field measurement data for verification of the modelled emissions' projections.

Estimated and historical GHG emissions from organic soils can be significantly affected by elaboration of national GHG emission factors for the key sources of emissions, which should be locally verified to ensure compliance of the national GHG inventory with requirements of Kyoto protocol. If emission factors turn out to be significantly smaller than the default values of the IPCC guidelines, like it is approved by studies in forest lands (Lazdiņš et al., 2014; Lupikis & Lazdins, 2015), the net emissions due to management of organic soils will be considerably lower due to a larger area of organic soils in the past.

Survey of organic soils in National forest inventory (NFI) plots

Most of the surveyed plots (84%) are located on grassland. The most common (65%) soil type is fen peat (*Sapric Histosol* or *Histic Gleysol*), which is concentrated mostly in grassland. The most common soil types in cropland are fen peat (*Sapric Histosol* or *Histic Gleysol*) and Humic-peaty gley sod (*Gleysols*, *Planosols* or *Stagnosols*).

Regardless of soil type, groundwater is mostly located below 30 cm, i.e. the majority of the area on organic soils can be characterized as deeply drained according to IPCC (Eggleston et al., 2006). In 74% of the surveyed plots groundwater level is deeper than 30 cm from surface. The exceptions are found in the alluvial plains and glades.

According to the soil carbon content and texture analyses 66 ± 10% of the surveyed areas are organic soils, and the other 34 ± 10% – mineral soils. The majority of historical fen peat soils (*Sapric Histosol* or *Histic Gleysol*) are still classified as organic soil. Only 26 ± 9% of the fen peat soils are mineralized. Transfer from organic to mineral soil (according to IPCC) in the semihydromorphic soils has been found in up to 60 ± 14% of the surveyed areas. Transfer can be explained with a relatively small depth of organic soil layer (< 30 cm) in these soils in the surveyed plots. Soils in cropland have mineralized the most (57 ± 16% from the initial area of organic soil do not meet the IPCC thresholds for organic soils). In grassland 27 ± 12% of areas no longer meet the criteria for organic soil.

Carbon content in soil is the main factor to distinguish organic and mineral soils. Carbon content in mineral soils in the surveyed plots in topsoil (0–20 cm soil layer) is almost 5 times smaller than in the organic soils. But it is still 2 times higher than in mineral soils in Latvia in average (Lazdiņš et al., 2013; Bardule et al., 2017). It means, that the GHG emissions from these soils are most likely continuing regardless of the loosing status of organic soils, however there are no published data substantiating GHG emissions from carbon rich mineral soils in Latvia or surrounding regions with similar conditions.

Assuming that the actual GHG emissions from managed organic soils can be characterized with default emissions' factors (7.9 and 6.1 t ha^{-1} C annually, in cropland and grassland, respectively), it is estimated that the average carbon stock in topsoil (0–20 cm, 285 t ha^{-1} C) of organic soil will decompose in 40 years. Since the average depth of peat layer in cropland and grassland is 57 cm, it is estimated that around 2060 the proportion of organic soil will be reduced by half, comparing with the current situation.

The deepest organic soil layers are found in glades and alluvial planes. Depth of organic soil layer in organic soils in cropland and grassland exceeds 40 cm. In grassland the average depth of organic layer in organic soils is 75 cm, but in croplands it is significantly smaller – 41 cm.

More mineralized soils have been found in areas, where groundwater level is deeper than 30 cm below the surface (37% of cases). Areas, where groundwater is above 30 cm, transfer from organic to mineral soil occurred in 27% of cases.

All plots surveyed in this study were divided into cropland and grassland in order to determine average changes in land use. According to this classification 35 ± 15% of organic soils in cropland and 33 ± 13% of grassland have mineralized. Obtained numbers are used in order to calculate changes in area of organic soil from the moment, when soil mapping was done.

Definition of cropland in IPCC guidelines is different from the NFI definition. A part of grassland is counted as cropland in the GHG inventory (category grasslands in NFI) because these areas are periodically ploughed, but generally maintained as grassland. In order to calculate proportion of organic soils in cropland, a part of organic soils in grassland are counted as organic soils of cropland, by assuming that proportion of organic soils in cropland, which are counted in the NFI as grassland, is similar to the grassland, which belong to the category of grasslands in GHG inventory.

According to above-mentioned assumptions it is estimated that the proportion of organic soils in cropland in 1990 was 6.3 ± 3.3% from the total area, accordingly, more than it is reported now (5.18% of cropland). A part of areas of organic soils have mineralized and the proportion of organic soils in croplands has now dropped to 4.1 ± 3.4%. Similar tendencies have been observed in grasslands. Historically there were 11.6 ± 3.6% organic soils in grassland, but now it has been dropped to 7.7 ± 3.9%. The proportion of organic soils in grassland historically was bigger than the values used in the GHG inventory (5.18% of the grassland area). It can be explained with different criteria for selection of organic soil in earlier reporting (LU Consulting, 2010). The average proportion of organic soils (5.18%) for the GHG inventory was obtained using a different methodological approach – only soils with depth of organics rich layer exceeding 30 cm were considered. Since more detailed information on organic soils is available from the digitalized maps and evaluation of the classification systems applied in different soil inventory cycles, semihydromorphic soils with high content of organic carbon are counted as the organic soils.

Calculations of greenhouse gas (GHG) emissions in cropland and grassland with various inventories

According to the newest GHG inventory report (1990–2015), in 2015 GHG emissions from organic soils in croplands and grassland was 4,135 thousand tonnes CO_2 eq. annually, mostly from cropland (3,276 thousand tonnes CO_2 eq. annually). GHG emissions from grassland have been significantly decreased since 1990 and reached 860 thousand tonnes CO_2 eq. in 2015 because of afforestation of pastures and set-aside areas. The majority of GHG emissions from organic soils in agricultural lands are CO_2, according to GHG inventory data (3,298 thousand tonnes CO_2 eq. in 2015). Methane (CH_4) emissions in croplands come from drainage ditches, but in grassland – from ditches and soil. CH_4 emissions significantly decrease, when groundwater level is below 20 cm (Soosaar et al., 2011), which corresponds with the actual situation of 74% of surveyed plots. It means that in the future it is appropriate to invest in developing methane factors, in order not to overestimate impact of these GHG emissions on climate change in Latvia. A summary of GHG emissions from organic soils is given in Table 2. It is not expected that GHG emissions from organic soils in grassland would significantly increase in future, whereas in croplands a significant increase has been projected, when the cropland areas that have been afforested and transformed to grassland will be returned to production agriculture.

Table 2. Summary of greenhouse gas (GHG) emissions in croplands and grassland in the current inventory, thousand tonnes CO2 eq. annually (Gancone et al., 2017)

Year	1990	1995	2000	2005	2010	2015
CO_2	3,686	3,579	3,441	3,297	3,221	3,298
N_2O	739	719	693	666	651	667
CH_4	195	188	180	171	166	170
total	4,620	4,486	4,313	4,134	4,038	4,135

Application of the study data on distribution of organic soils in cropland and grassland and linear interpolation between the current status and historical distribution of organic soils, a decrease of GHG emissions in cropland in 2015 reaches 300 thousand tonnes CO_2 eq., in comparison to the recent GHG inventory report, but in 1990s the emissions from organic soils significantly increased (in 1990 by 1,000 thousand tonnes CO_2 eq.) due to increase of area of organic soils in the activity data. Total GHG emissions in cropland in 2015 were 3,000 thousand tonnes CO_2 eq. Due to continuous reduction of area of organic soils there is continuous trend in reduction of GHG emissions since 1990. From 1990 to 2015 GHG emissions in croplands decreased by 1,400 thousand tonnes CO_2 eq. annually.

In grassland application of the new activity data on distribution of organic soils also creates continuous decrease of GHG emissions from organic soils after 1990; however, it has to be considered that the total GHG emissions from drained organic soils in grassland would increase by 400 thousand tonnes CO_2 eq. in 2015 in comparison to the recent GHG inventory report and by 1,300 thousand tonnes CO_2 eq. in 1990 due to increase of the share of organic soils. From 1990 to 2015 GHG emissions from organic soils in grassland decreased by 1,100 thousand tonnes CO_2 eq. Summary of difference between currently reported GHG emissions and the recalculated data is provided in Table 3.

Table 3. Difference between recalculated greenhouse gas (GHG) emissions from organic soils in cropland and grassland in comparison with the values reported in GHG inventory report, thousand tonnes CO2 eq. annually (Gancone et al., 2017)

Year	1990	1995	2000	2005	2010	2015
CO_2	1,827	1,475	1,120	790	503	226
N_2O	343	275	207	144	88	32
CH_4	115	94	73	53	37	22
total	2,285	1,844	1,400	988	627	280

Total GHG emissions from organic soil in croplands and grassland, according to the new activity data, in 2015 was 6,900 thousand tonnes CO_2 eq.

Comparing with data reported in the GHG inventory report, application of new activity data on organic soils would significantly increase the net GHG emissions, comparing with the current state. In the recent years recalculated GHG emissions from organic soils in cropland and grassland are decreasing and in following inventories they will be smaller than the currently published forecasts (Ratniece et al., 2017). Further improvements are necessary to clarify proportion of organic soils in cropland and grassland in different periods. It is obvious that share of organic soil in cropland could be bigger in the past due to the fact that the area of cropland was considerably larger and the most of the currently abandoned or periodically cultivated areas were used in production of fodder or other crops. However, farming activities on organic soils in the past still should be evaluated.

A summary of estimates of GHG emissions using the recalculated activity data is provided in Table 4. Comparing recalculated GHG data for the potential reference period for cropland and grassland management (2005–2007) with recalculated data in 2015 (assuming that they are characterizing GHG emissions' in 2016–2020 and onwards, if no changes in activity data takes place), GHG emissions from organic soils will decrease by 313 thousand tonnes CO_2 eq. annually, i.e. in 2021–2030 decrease of GHG emissions will reach about 3,133 thousand tonnes CO_2 eq.

Table 4. Summary of recalculated greenhouse gas (GHG) emissions in cropland and grassland, thousand tonnes CO2 eq. annually (Gancone et al., 2017)

Year	1990	1995	2000	2005	2010	2015
CO_2	5,513	5,054	4,561	4,088	3,724	3,524
N_2O	1,082	994	900	810	739	699
CH_4	310	282	253	224	203	193
total	6,905	6,330	5,713	5,121	4,665	4,415

However, the projected decrease of GHG emissions is not sufficient to change the LULUCF sector in Latvia from source of CO_2 into a sink. Final result of recalculations of the GHG emissions from drained organic soils depends also from land use practices, intensification of agriculture and conversion of grasslands into croplands might result in an increase of GHG emissions from organic soil. Less intensive production whereas may result in larger reduction of GHG emissions. Mineralization of organic soils is another factor affecting GHG emissions in long term prospective.

CONCLUSIONS

1. According to results of the analysis of digitalized soil maps there are 182 thousand ha of cropland and grassland on organic soils. The area of organic soils in cropland and grassland is larger than it is reported in the greenhouse gas (GHG) inventory. The most probable reason for significant difference is different interpretation of semihydromorphic soils in data reported earlier. Application of activity data from digitized soil maps could lead to considerable overestimation of the emissions, because the mineralization of organic matter can considerably reduce area of organic soils in comparison to early 1990s.

2. 66% of the surveyed plots still correspond to Intergovernmental Panel on Climate Change (IPCC) criteria of organic soils, but the rest of soils are already mineralized, although average carbon content in soil is still 2 times higher than the average values in mineral soils in cropland and grassland in Latvia. It means that these soils can still generate GHG emissions in spite of losing status of organic soils. Additional studies determining equilibrium point for carbon content in different soils are necessary to increase accuracy of the emissions' estimates and to improve definition of organic soils.

3. Area of organic soil in cropland is 65% from the initial value, but in grassland – 67% from the initial area of organic soils. Mineralization of organic soils will continue for at least 40 years if linear mineralization rate is considered.

4. As a result of this study the following proportion of organic soils in croplands was determined – 6.3 ± 3.3% in 1990 and 4.1 ± 3.4% in 2015, but in grassland – 11.6 ± 3.6% in 1990 and 7.7 ± 3.9% in 2015.

5. The reduction of GHG emissions from organic soil from 1990 to 2015 due to application of new activity data is 1400 thousand tonnes CO_2 eq. in cropland and 1100 thousand tonnes CO_2 eq. in grassland.

6. Reduction of GHG emissions due to mineralization of organic matter will reach 313 thousand tonnes CO_2 eq. annually in 2021–2030, in comparison with the average values in 2005–2007, but land use, land use change and forestry (LULUCF) sector still will be a net source of GHG emissions.

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