EU LIFE Programme project
"Demonstration of climate change mitigation potential of nutrients rich organic soils in Baltic States and Finland"

REPORT

ON IMPLEMENTATION OF THE PROJECT

DEMONSTRATION OF CLIMATE CHANGE MITIGATION MEASURES IN NUTRIENTS RICH DRAINED ORGANIC SOILS IN BALTIC STATES AND FINLAND

WORK PACKAGE

FILLING KNOWLEDGE GAPS ON GHG EMISSIONS FROM ORGANIC SOILS (C.1)

ACTIONS

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SUMMARY

Catalogue of climate change mitigation (CCM) measures is aimed to summarize the data obtained in reference (established within the scope of C1) and demonstration sites (established within the scope of C3) and the state of the art of CCM measures in temperate region including socio-economic impact assessment, GHG emission factors and activity data elaborations within the project. Catalogue is linked to the Simulation tool (under development in C5) and contain instructions for application of CCM measures in the partner countries, as well as guidelines for adaptation of the applied methods in temperate region.

The data sources besides the project results used for the preparation of the catalogue are: SNS-120 project results (anthropogenic GHG emissions from organic forest soils and improved inventories and implications for sustainable management), LIFE REstore, Global Warming and Material Cycling in Landscapes, Effect of clear-cut and thinning on forest carbon cycling and other regional projects.

Catalogue of CCM measures is aimed to be widely distributed among policy planners and incorporated into related policy documents and strategies.

Considering the delay with the beginning of GHG and environmental data measurements by about 10 months, the deliverable “Catalogue of climate change mitigation actions” is going to be prepared in two stages:

1) Interim report to set the structure and collate the project information available by midst of 2021 – information on GHG mitigation potential based on literature studies and previous research as well as available socio-economic impact assessment data;
2) Final report by 31/03/2024 by inclusion of the project results (data obtained in reference (C1) and demonstration sites (C3)), full range of socio-economic assessment data as well as interlinkages with Simulation tool (C5). Final report should contain instructions for application of the CCM measures in the partner countries (localized versions) and guidelines for adaptation of the applied methods in temperate region.

ABBREVIATIONS

CCM - climate change mitigation

CH_4 - methane

CO_2 - carbon dioxide

EU – European Union

GHG – greenhouse gas

GWT - ground water table

NEE – net ecosystem exchange

N_2O – nitrous oxide

HWP – harvested wood products

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1. Climate change mitigation actions in forest land

Climate change mitigation in forests with organic soils is not straightforward. Forestry affects the environment in many different ways, depending on the type of forestry, the initial state of the forest and the climate. In general, forest management practices that increase carbon sequestration include:

- afforestation, reforestation and forest restoration;
- increase of tree cover through agroforestry, urban forestry and tree planting in rural landscapes;
- enhancement of forest carbon stocks (in both, biomass and soils) and sequestration capacity through the modification of forestry management practices.

High ground water tables (GWT) are beneficial for maintaining the carbon stocks in organic soil. Over-drainage should always be avoided. Although deepening the water table increases productivity, in Finland it is not necessary after the tree stand volume has exceeded 100–150 cubic metres per hectare (Sarkkola et al., 2010). After this threshold has been reached, the tree stand itself, through efficient transpiration, maintains sufficient drainage. In Latvia growing stock on peat soils

Drainage of forests on organic soils often leads to carbon dioxide (CO_2) net emission from soil due to loss of peat. This emission can be compensated for by the increased tree growth. However, many drained peatlands have low tree growth due to nutrient limitations. Tree growth at these peatlands can be effectively increased by fertilization, but fertilization has been also found to increase decomposition rates. Ojanen et al. (2019) in the study in Finland concluded that fertilization of low-productive peatland forests has potential for climate change mitigation in the decadal time scale. The study revealed that the great increase in productivity due to fertilization leads to a long-term increase in tree stand CO_2 sink that clearly exceeds the increase in soil CO_2 net emissions. The effect of fertilization on CH_4 emissions was generally negligible. CH_4 emissions from ditches would also be reduced if ditches were cleaned in addition to fertilization. While fertilization may increase N mineralization through enhanced decomposition, also net primary production increases leading to increased N demand. Thus, fertilization does not seem to induce a risk of N_2O emissions (Ojanen et al., 2019).

In Finland, main attention has so far focused on the regulation of GWT levels, due to the identified contribution of deep drainage to increased CO_2 emissions. The working hypothesis has been put forward that taking advantage of the biological drainage of the tree stand through continuous-cover management, and simultaneously shifting from regular DNM to maintaining only a limited proportion of the ditches, based on catchment-based evaluation, might reduce soil emissions. This is based on an idea that in such management, the GWT remains at a moderate or shallow-drained level (30 cm below the soil surface as in IPCC 2014), which reduces CO_2 emissions but still prevents CH_4 emissions, while being the minimum requirement for sustained forest growth (Sarkkola et al., 2010). Research on such management has started in 2016, but so far there are no published results. One challenge is that a harvesting operation, such as realizing the shift into continuous-cover management, always results in a disturbance in the soil and thus, reduction in the emissions may emerge only after the disturbance impact has passed. In Latvia according to National coniferous forest inventory growing stock in forests with drained organic soils can reach 800 $m^3\ ha^{-1}$. Average growing stock of different species in forests with nutrient rich drained and wet soils is compared in Figure 1 and 2. In birch stands with drained nutrient-rich soils growing stock in average is 33% bigger than in forests with wet soils, in spruce stands this difference is 75%. Pine is uncommon in nutrient-rich non-drained soils.

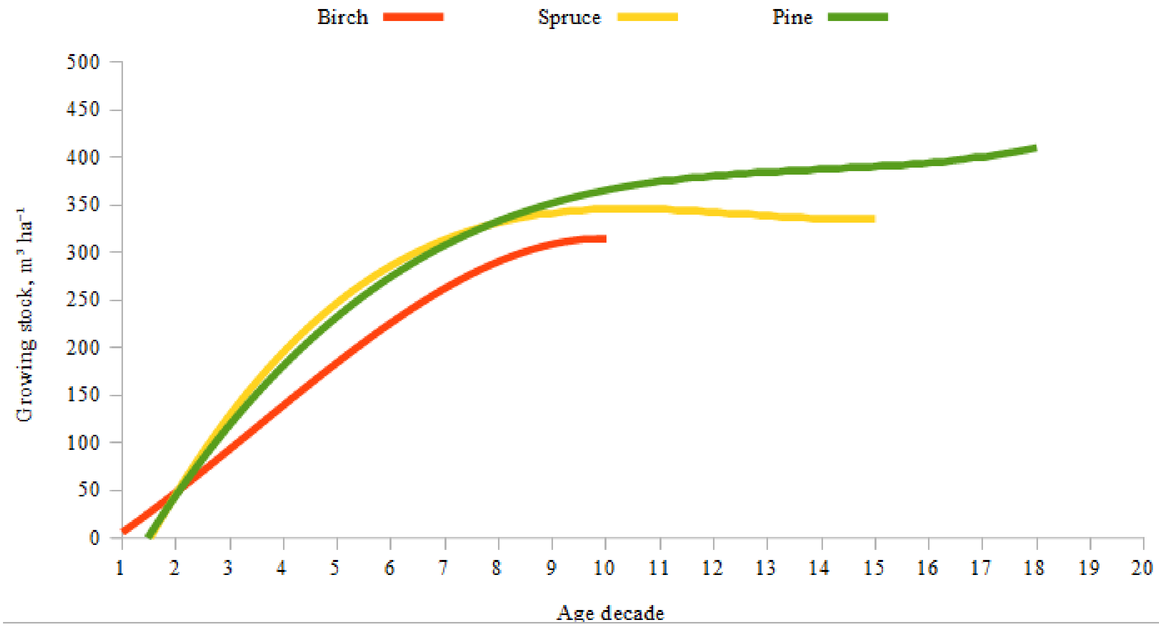

Figure 1: Growing stock in forests with drained organic soils in Latvia according to

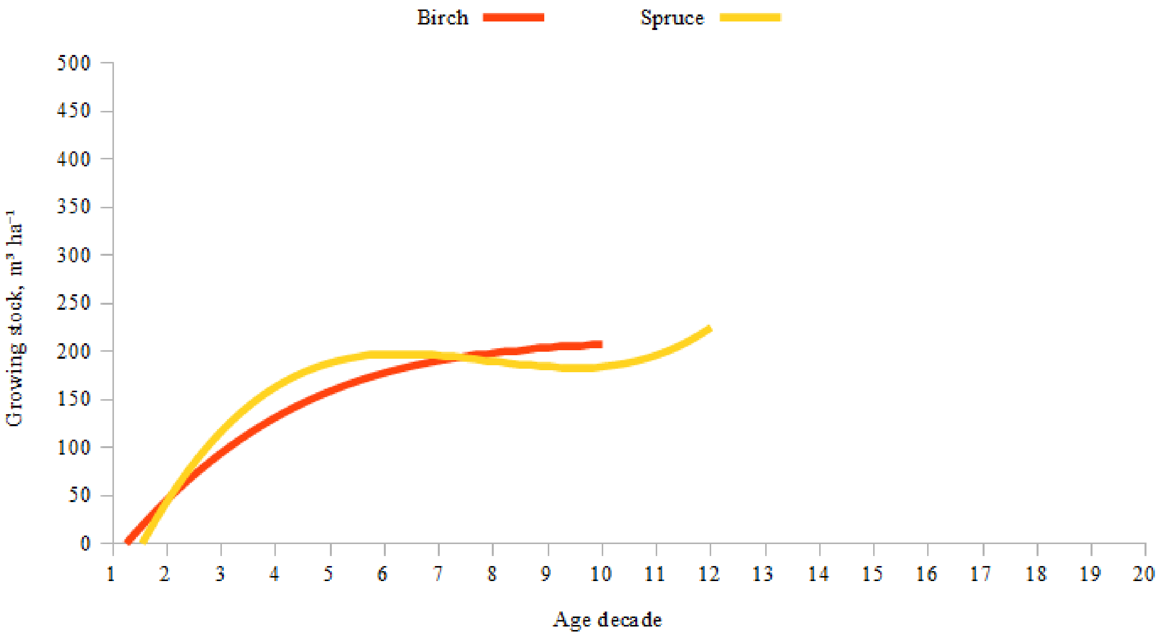

Figure 2: Growing stock in forests with wet organic soils in Latvia according to National forest inventory.

Another option currently considered and studied is replacing the maintenance of drainage systems with fertilization by wood ash. The idea behind this is that the reduced tree growth rate under moderate or shallow-drained GWT may rather be due to low nutrient availability in the limited oxic soil layer than the wetness as such. Wood ash increases tree stand carbon sequestration and tree litter inputs to the soil, both being beneficial for the site carbon balance. If simultaneously the decomposition processes in the soil are not accelerated to the relatively high GWT, CCM is achieved.

1.1 Conventional afforestation considering shorter rotation (LVC302)

<table>
<tr><td>Short description of the action</td><td colspan="3">Afforestation is restoration on ecosystem on deforested lands and nutrient-rich bogs and in spite of potentially negative impact of species closely associated with artificial landscapes (cropland and grassland) afforestation contributes to formation of semi-natural forest land dominant ecosystems typical for Latvia. Efficient use of abandoned farmlands which do not produce any added value contributes to social and economic sustainability.</td></tr>
<tr><td>CCM impact</td><td colspan="3">Values typical for the highest fertility classes can be used in calculation; however, the afforestation period depends from quality of soil preparation, planting material and early tending. The highest uncertainty of the impact of afforestation on GHG emissions is characteristic for the first 2 decades after afforestation. Tier 2 methods can be used to estimate impact on soil carbon stock change and GHG emissions. The net GHG reduction potential in case of 70 years long rotation is 1855 tons CO_2 eq ha^{-1} (26 tonnes CO_2 ha^{-1} yr^{-1}). The net GHG reduction potential in case of 40 years long rotation is 1218 tonnes CO_2 eq ha^{-1} (30 tonnes CO_2 ha^{-1} yr^{-1}). Actual GHG emission reduction potential may be about twice smaller because the GHG emissions from soil in cropland in grassland can be overestimated in Temperate climate zone.</td></tr>
<tr><td>Area characteristics</td><td colspan="3">Nutrient- rich organic soil, peat layer sickness at least 30cm, groundwater at least 30 cm during the growing season.</td></tr>
<tr><td>Any associated risks or potential implementation obstacles</td><td colspan="3">Afforestation may compete with requirement to retain certain area of grasslands and rewetting initiatives. Production of planting material appropriate to organic soils requires investments in forest nurseries, similarly, soil scarification requires investments in machinery and workforce hampering quick implementation of the measures.</td></tr>
<tr><td rowspan="5">Costs and benefits associated with implementation of the action</td><td rowspan="2">Cost/benefit position</td><td colspan="2">Costs ("+")/benefits ("-"), EUR ha^{-1}</td></tr>
<tr><td>1st year</td><td>Next years</td></tr>
<tr><td>Investment</td><td>1500</td><td>300</td></tr>
<tr><td>Management costs</td><td>-</td><td>900</td></tr>
<tr><td>Income</td><td>-</td><td>8000</td></tr>
<tr><td>CCM potential</td><td colspan="3">Measure has long term impact; for conventional management systems for living and dead wood, litter and HWP it is 71-91 years according to the age based rotation lengths, for intensified plantation forest scenario it is 40-50 years. Impact on soil depends from carbon stock in organic soil, respectively it depends from carbon stock in soil at steady state and difference in decomposition rate. Two alternatives are evaluated in the project – intensified and extensified coniferous forests. The area of organic soils considered in the calculation is 152 kha. Use of conventional management systems for spruce or pine would lead to increase of CO_2 removals and reduction of GHG emissions by 79 mill. tons CO_2 in all carbon pools during 20 years period. Intensified management and shortening of rotation would lead to 90 mill. tons CO_2 removals during 20 years period. It should be noted that GHG emissions from soil in cropland and grassland may be overestimated now, therefore the emission reduction will be smaller. GHG emissions from soil in nutrient-rich organic soils in forest land can also be smaller than the estimated emission rates, which will also affect GHG emission reduction rate.</td></tr>
</table>

1.2 Paludiculture – afforestation of grassland with black alder and birch (LVC303)

<table>
<tr><td>Short description of the action</td><td colspan="3">Planting trees or enhancing of natural afforestation by scarification of soil. Tree species tolerant to periodic flooding, e.g. birch or alder should be used. Mounding is recommended as soil scarification method. Duration of the impact of the measure is at least one full rotation of trees; further reduction or increase of GHG emissions depends from management practices applied to the next generation of trees. Impact on soil GHG emissions is continuous, however the "sign" of the impact and the scale is not yet evaluated. There is significant probability that rewetting (if it is not already done) can increase soil GHG emissions.</td></tr>
<tr><td>CCM impact</td><td colspan="3">Quantitative impact of this measure is not yet estimated in Latvia due to lack of reliable activity data and soil emission factors. In case of planting birch net GHG reduction equals to 2.5 tons CO_2 eq. ha^{-1} yr^{-1} during 120 years period.</td></tr>
<tr><td>Area characteristics</td><td colspan="3">Nutrient- rich organic soil, peat layer sickness at least 30cm, groundwater at least 30 cm during the growing season</td></tr>
<tr><td>Any associated risks or potential implementation obstacles</td><td colspan="3">Management risks due to floods significantly affects the net reduction of GHG emissions in forested paludicultures. Significant increase of emissions may be also associated with soils due to seasonal fluctuations of groundwater level.</td></tr>
<tr><td rowspan="5">Costs and benefits associated with implementation of the action</td><td rowspan="2">Cost/benefit position</td><td colspan="2">Costs (“+”)/benefits (“-”), EUR ha^{-1}</td></tr>
<tr><td>1st year</td><td>Next years</td></tr>
<tr><td>Investment</td><td>2000</td><td>-</td></tr>
<tr><td>Management costs</td><td>-</td><td>900</td></tr>
<tr><td>Income</td><td>-</td><td>6000</td></tr>
<tr><td>CCM potential</td><td colspan="3">Not estimated yet. Due to high risk of natural disturbances this measure is hardly predictable and can be recommended in areas, where conventional afforestation methods becomes expensive due to investments in drainage systems or to ensure implementation of the nature conservation targets,</td></tr>
</table>

1.3 Continuous forest cover as a forest regeneration method in spruce stands (LVC308)

<table>
<tr><td>Short description of the action</td><td colspan="3">The scope of the measure is to replace clear-felling with repeated selective felling and formation of uneven age stands. The effect is based on assumption that continuous forest coverage avoids increase of groundwater level and CH_4 emissions from soil. The measure is applicable in management of shade-tolerant species, in Latvia it is only spruce.</td></tr>
<tr><td>CCM impact</td><td colspan="3">CCM impact is not estimated and proved yet. However, the method has been included in national guidelines for good forest management in Finland. The method should be treated equally with conventional management in the revised support scheme that is under evaluation currently (Korkiakoski et al., 2019; Nieminen et al., 2018; Ojanen & Minkkinen, n.d.). Duration of impact is not verified yet, can be considered as long term in case of strip cleaning and short term in case of selective harvest, because artificial forest regeneration is possible only in strips. Not estimated yet. Not estimated, negative effect can be associated with distribution of root rot and other forest pests negatively affecting resilience of ecosystems; however no scientific verification is done.</td></tr>
<tr><td>Area characteristics</td><td colspan="3">Nutrient- rich organic soil, peat layer sickness at least 30cm, groundwater at least 30 cm during the growing season</td></tr>
<tr><td>Any associated risks or potential implementation obstacles</td><td colspan="3">Current experience in commercial thinning demonstrates significant increase of mortality in spruce stands after thinning sooner or later leading to salvage logging and regeneration of the stand. However there should be potential of strip harvesting in pine stands with following artificial regeneration with pine or birch. Area of clearfellings in Latvia is much smaller than in Finland, therefore, the effect might be much smaller than expected in Latvia, since in small felling site surrounding stands can compensate reduction of evapotranspiration in the felling site. Selective felling considerably increase harvest costs reducing competitiveness of wood deliveries from organic soils and limits possibility to invest in forest regeneration.</td></tr>
<tr><td rowspan="5">Costs and benefits associated with implementation of the action</td><td rowspan="2">Cost/benefit position</td><td colspan="2">Costs ("+")/benefits ("-"), EUR ha^{-1}</td></tr>
<tr><td>1st year</td><td>Next years</td></tr>
<tr><td>Investment</td><td>-</td><td>-</td></tr>
<tr><td>Management costs</td><td>-</td><td>-</td></tr>
<tr><td>Income[1]</td><td>3000</td><td>6000</td></tr>
<tr><td>CCM potential</td><td colspan="3">The applicability of the measure is not validated in Baltic states. Up to 1.5 million hectares can be subjected to this measure in Finland. The measure cannot be recommended in Latvia.</td></tr>
</table>

[1]Potential incomes due to extraction of currently growing trees as stumpage price.

1.4 Strip harvesting in pine stands (LVC313)

<table>
<tr><td>Short description of the action</td><td colspan="3">Actually this measure means reduction of area clear-felling sites by creating of small openings sufficient for regeneration of forest or extraction of long strips (20 to 40 m wide) following with strips of trees. This measure is applicable in forests dominant by tree species, which can't regenerate under canopy of other species (the most of tree species in Latvia except spruce). The measure is aimed to avoid increase of groundwater level and CH_4 emissions after harvesting.</td></tr>
<tr><td>CCM impact</td><td colspan="3">Retaining of low groundwater level ensures that CH_4 emissions are not increasing periodically, while CO_2 emissions from soil remains at initial level and surrounding trees ensures substitution of carbon stock in litter and soil during regeneration of openings or strips.</td></tr>
<tr><td>Area characteristics</td><td colspan="3">Nutrient- rich organic soil, peat layer sickness at least 30cm, groundwater at least 30 cm during the growing season.</td></tr>
<tr><td>Any associated risks or potential implementation obstacles</td><td colspan="3">Smaller felling sites increase harvesting and forest regeneration costs and may have negative effect on surrounding stands due to root damages. Smaller openings also increase areas affected by the side effect, where forest regeneration is problematic due to shading of young trees and competition for nutrients.</td></tr>
<tr><td rowspan="5">Costs and benefits associated with implementation of the action</td><td rowspan="2">Cost/benefit position</td><td colspan="2">Costs ("+")/benefits ("-"), EUR ha^{-1}</td></tr>
<tr><td>1st year</td><td>Next years</td></tr>
<tr><td>Investment</td><td>-</td><td>-</td></tr>
<tr><td>Management costs</td><td>-</td><td>-</td></tr>
<tr><td>Income[2]</td><td>3000</td><td>6000</td></tr>
<tr><td>CCM potential</td><td colspan="3">The CCM potential is not estimated yet. The threshold values of area of clear-felling sites affected by the increase of groundwater level is not estimated, therefore the measure cannot be recommended for implementation without further investigation.</td></tr>
</table>

[2]Potential incomes due to extraction of currently growing trees as stumpage price.

1.5 Semi-natural regeneration of regeneration felling site with grey alder without reconstruction of drainage systems (LVC309)

<table>
<tr><td>Short description of the action</td><td colspan="3">Grey and black alder, as well as birch, are tree species with the highest level of tolerance to periodic flooding while retaining high productivity by planting trees on mounds and improvement of surface drainage to avoid losses due to natural disturbances caused by periodic increase of groundwater level. Planting of trees on mounds also reduces duration of forest regeneration period when carbon losses significantly exceeds removals.</td></tr>
<tr><td>CCM impact</td><td colspan="3">The CCM effect is associated with increase of CO_2 removals in living biomass and other carbon pools including harvested wood products (HWP) due to faster growth. Mounding and shallow drainage furrows ensures that upper soil layers are continuously aerated thus avoiding CH_4 emissions. However, effect of the measure is not scientifically proved yet. Assuming that growth rate after implementation of the measure changes from values typical for wet forests to values characteristic in drained soils, the net emission reduction reach 9,9 tons CO_2 eq. ha^{-1} yr^{-1} during 120 years period; however, this effect is diminished by natural disturbances and limitations in local conditions.</td></tr>
<tr><td>Area characteristics</td><td colspan="3">Lower bog peat soil, peat layer thickness at least 30 cm, during the groundwater vegetation season higher than 30 cm, the dominant species black alder or birch, stand age or diameter of stand trees has reached the limit values specified for regeneration felling.</td></tr>
<tr><td>Any associated risks or potential implementation obstacles</td><td colspan="3">Natural disturbances (periodic increase of groundwater level) may limit or completely diminish climate change mitigation effect and result in significant economic losses. Improvement of water regime might be problematic in many cases due to inappropriate terrain.</td></tr>
<tr><td rowspan="5">Costs and benefits associated with implementation of the action</td><td rowspan="2">Cost/benefit position</td><td colspan="2">Costs (“+”)/benefits (“-”), EUR ha^{-1}</td></tr>
<tr><td>1st year</td><td>Next years</td></tr>
<tr><td>Investment[3]</td><td>1500</td><td>300</td></tr>
<tr><td>Management costs</td><td>-</td><td>900</td></tr>
<tr><td>Income</td><td>-</td><td>8000</td></tr>
<tr><td>CCM potential</td><td colspan="3">CCM potential is not estimated yet, additional CO_2 removals may reach 20% or more depending from local conditions and possibilities to improve water regime.</td></tr>
</table>

[3]Additional forest regeneration costs comparing natural and artificial regeneration.

1.6 Application of wood ash after commercial thinning in spruce stands (LVC307)

<table>
<tr><td>Short description of the action</td><td colspan="3">Complex forest management measure – wood ash recycling in drained organic soils. Similarly to forest fertilization with mineral fertilizers this measure integrates application of wood ash, pre-commercial thinning, commercial thinning and regenerative felling and, particularly, maintenance of drainage systems. Wood ash can be applied 10-15 years before commercial thinning or regenerative felling. Respectively it can be done once per rotation (before regenerative felling) or several times (2-4) per rotation applying wood ash right after thinning. Strip roads are mandatory necessary for all types of fertilization, therefore permanent network of strip-roads is necessary. In combination with more intensive and regular thinning fertilization can double CO2 removals in forest lands. Wood ash has easily accessible short term and uncertain long term impact.</td></tr>
<tr><td>CCM impact</td><td colspan="3">Application of wood ash in forests with drained soils, specifically, spruce forests reduces GHG emissions by 1.7 tons CO_2 eq. ha^{-1} yr^{-1} (204 tons CO_2 eq. ha^{-1} yr^{-1}). The impact is ensured by additional increment in living biomass to to increase of reserves of potassium, phosphorus and other nutrients in soil. Additional increment is also associated with higher level of evapotranspiration and reduction of groundwater level resulting with smaller CH_4 emissions. However, this effect is not yet estimated. Fertilization with wood ash instead of ditch network maintenance is accepted form of management in Finland. Is expected to be profitable and cost-effective for the forest owner (Ahtikoski & Hökkä, 2019; Hökkä et al., 2012; Huotari et al., 2015).</td></tr>
<tr><td>Area characteristics</td><td colspan="3">Nutrient- rich organic soil, peat layer sickness at least 30 cm, groundwater at least 30 cm during the growing season.</td></tr>
<tr><td>Any associated risks or potential implementation obstacles</td><td colspan="3">Wood ash may not be efficient in areas, where limited resources of nitrogen are prohibiting of forest growth. It may be a case in nutrient poor soils. Spreading of wood ash may be complicated in soils with low bearing capacity and improperly implemented can result in soil damages and increase of natural disturbances.</td></tr>
<tr><td rowspan="5">Costs and benefits associated with implementation of the action</td><td rowspan="2">Cost/benefit position</td><td colspan="2">Costs (“+”)/benefits (“-”), EUR ha^{-1}</td></tr>
<tr><td>1st year</td><td>Next years</td></tr>
<tr><td>Investment[4]</td><td>120</td><td>-</td></tr>
<tr><td>Management costs</td><td>-</td><td>-</td></tr>
<tr><td>Income[5]</td><td>-</td><td>420</td></tr>
<tr><td>CCM potential</td><td colspan="3">The effect of this measure may reach more than 1 mill. tons CO_2 eq. yr^{-1} only in Latvia, if wood ash is applied in peatlands.</td></tr>
</table>

[4]Spreading of wood ash.
[5]Stumpage price of additional increment.

1.7 Forest regeneration (coniferous trees) in naturally wet sites (LVC312)

<table>
<tr><td>Short description of the action</td><td colspan="3">Mounding, improvement of water regime and use of high quality planting material ensures increase of CO_2 removals in living biomass in forests with naturally wet organic soils, where natural forest regeneration methods results in low quality stands.</td></tr>
<tr><td>CCM impact</td><td colspan="3">The climate change mitigation effect in optimal conditions reach 5.8 tons CO_2 eq. ha^{-1} yr^{-1} (694 tons CO_2 eq. ha^{-1} in 120 years period). This estimate considers reduction of carbon losses and GHG emissions from soil and additional removals in living biomass due to improvement of water regime and shorter forest regeneration period.</td></tr>
<tr><td>Area characteristics</td><td colspan="3">Nutrient-rich organic soil, peat layer sickness at least 30 cm, groundwater above 30 cm during the growing season</td></tr>
<tr><td>Any associated risks or potential implementation obstacles</td><td colspan="3">Natural disturbances may diminish effect of the measure and result in economic losses. Local terrain conditions may not be favourable to improve water regime, therefore, CH_4 emissions remains high. Many areas, where the measure can be implemented, are subject of different management restrictions; therefore, the real potential is significantly smaller than the theoretical estimates.</td></tr>
<tr><td rowspan="5">Costs and benefits associated with implementation of the action</td><td rowspan="2">Cost/benefit position</td><td colspan="2">Costs (“+”)/benefits (“-”), EUR ha^{-1}</td></tr>
<tr><td>1st year</td><td>Next years</td></tr>
<tr><td>Investment</td><td>1500</td><td>300</td></tr>
<tr><td>Management costs</td><td>-</td><td>900</td></tr>
<tr><td>Income</td><td>-</td><td>8000</td></tr>
<tr><td>CCM potential</td><td colspan="3">CCM potential is not estimated since activity data (groundwater level maps) are not developed to the level necessary to model emissions under different management regimes. The total emission reduction potential in Latvia is about 1 mill. tons CO_2 eq. yr^{-1}.</td></tr>
</table>

1.8 Riparian buffer zone in forest land planted with black alder (LVC311)

<table>
<tr><td>Short description of the action</td><td colspan="3">Management of riparian zones is aimed to utilize nutrients approaching to the water bodies from surrounding forest stands and agricultural soils. Better soil scarification methods, planting material and improved water regime by establishment of network of shallow furrows increases capability of plants to utilize nutrients and exceeding soil water. Managed buffer zones are bends of trees around water streams.</td></tr>
<tr><td>CCM impact</td><td colspan="3">Climate change mitigation is associated with CO_2 removals in living biomass and reduction of CH_4 emissions from soil. The net impact is not yet estimated however, significant improvement of stand composition and growth rate would result in net reduction of GHG emissions by 1.2 tons CO_2 eq. ha^{-1} yr^{-1} (148 tons CO_2 eq. ha^{-1} in 120 years period). The removals of CO_2 in living biomass is compensated partly by increased carbon losses from soil.</td></tr>
<tr><td>Area characteristics</td><td colspan="3">Nutrient-rich organic soil, peat layer sickness at least 30 cm, groundwater above 30 cm during the growing season.</td></tr>
<tr><td>Any associated risks or potential implementation obstacles</td><td colspan="3">Management of buffer zones is restricted by legal acts prohibiting clearfellings and other management activities around water streams, therefore trees can be planted at certain distance from the water streams significantly decreasing areas suitable for this measure.</td></tr>
<tr><td rowspan="5">Costs and benefits associated with implementation of the action</td><td rowspan="2">Cost/benefit position</td><td colspan="2">Costs ("+")/benefits ("-"), EUR ha^{-1}</td></tr>
<tr><td>1st year</td><td>Next years</td></tr>
<tr><td>Investment</td><td>1500</td><td>300</td></tr>
<tr><td>Management costs</td><td>-</td><td>900</td></tr>
<tr><td>Income</td><td>-</td><td>8000</td></tr>
<tr><td>CCM potential</td><td colspan="3">CCM potential is not estimated yet due to limited information on CH_4 emissions and area potentially suitable for establishment of buffer zones.</td></tr>
</table>

2. Climate change mitigation actions in agriculture land

Paquel et al. (2017) concluded that the main option to reduce GHG emissions from organic soils in Netherlands is to elevate the groundwater level in order to reduce the oxidation of the organic material. This can be done either by technical measures or through increasing the water level and extensification of the land use. One of the technical options is the use of submerged drainage, which still allows for agricultural activities, but reduces emissions. A first analysis for the Netherlands shows that the use of submerged drains and raising water levels for grassland areas with deep drainage could reduce emissions from organic soils by 1-2 mill. tons CO_2 per year, which would be a reduction of about 35%. Extrapolating this reduction to all grassland under organic soils in the EU would lead to a potential mitigation of about 13 mill. tons CO_2 per year. In addition N_2O emissions from cultivated organic soils, which are reported under the sector Agriculture, will be reduced as well if measures are taken. These emissions are currently reported at 13 mill. tons CO_2-eq per year (EU NIR 2017) and could be reduced by 4.7 mill. tons CO_2-eq (36%, which is the same reduction percentage as for CO_2). Consequently a total mitigation potential of about 30 mill. tons CO_2-eq yr^{-1} would be possible for organic soils under grassland and cropland (Paquel et al., 2017).

Kekkonen et al. (2019) within the study in Finland reported that for the fields on organic soils potentially removable from cultivation, afforestation is a viable option from a life-cycle analysis viewpoint, but the emissions of N_2O at least will continue at a rate similar to those of cultivated soils, excluding fertilization related emissions. Afforestation involves drainage as well, and as long as there is peat above the groundwater level it will be prone to decomposition. The most efficient mitigation measure in these cases can be rewetting. It runs the risk of high CH_4 emissions and high nutrient losses to watercourses, but in some cases has been found to turn agricultural sites carbon neutral or to carbon sink. With the right crop selection, it may even be possible to continue cultivation in rewetted conditions (i.e. paludiculture).

The conversion of agricultural land into nature or paludiculture (i.e. productive use of wet and rewetted peatlands) is a more effective option, but also has a larger impact and might be more appropriate in areas where land is cheaper and less intensively used. In the EU, for cropland on organic soils a land use conversion to extensive grassland or nature would be the most relevant option, as the cropland area on organic soils is relatively small, only about 1.3% of the total cropland area, whereas emissions from that land are very high. It is assumed that half of this land could be taken out of production or converted to more extensive grassland use. This could result in an emission reduction of about 12 mill. tons CO_2-eq yr^{-1} (assuming emissions are reduced by 75% after conversion). Several EU Member States consider or have already policies for the conversion of arable land on organic soils to nature or grassland, e.g. Denmark, Luxembourg, Latvia, and Germany. However, a quantification of the mitigation potential is mostly not provided. Latvia reported for instance that "conversion of 1 ha of cropland to grassland considering 5.2% share of organic soils [in Latvia] would reduce CO_2 emissions by 0.3 tonnes CO_2 ha^{-1} annually" (Paquel et al., 2017). As noted before there is no scientific approval for this assumption.

Combination of rewetting and paludiculture is pursued as a wider CO_2 mitigation option in drained organic soils. Paludiculture combines biomass production at higher water levels by using both light-weight harvesting machines and flood tolerant crop species (e.g. *Typha*, *Azolla*, *Sphagnum*, *Phragmites*, *Salix* and *Alnus*). However, information on the overall GHG balance for paludiculture is lacking. Karki et al. (2014) investigated the GHG balance of peatlands grown with reed canary grass (RCG) and rewetted to various extents. Raising the GWL to the surface decreased both the net ecosystem exchange (NEE) of CO_2 and N_2O emissions whereas CH_4 emissions increased. Total cumulative GHG emissions (for 10 months) corresponded to 0.08, 0.13, 0.61, 0.68 and 0.98 kg CO_2 eq. m^{-2} from the GWL treatments at 0, -10, -20, -30 and -40 cm below the soil surface, respectively. The results showed that a reduction in total GHG emissions can be achieved without losing the productivity of newly established RCG when GWL is maintained close to the surface (Karki et al., 2014).

In Sweden, Norberg (2017) evaluated GHG emissions from cultivated organic soils including effect of cropping system, soil type and drainage. The overall conclusion was that no specific crop can be considered as a way to mitigate climate change by reducing greenhouse gas emissions from drained cultivated peat and carbon-rich soils during the growing season. Site-specific effects were a key factor for the greenhouse gas emissions rather than the cropping system. Furthermore, there was no difference in carbon dioxide emissions between a groundwater level at 50, 75 and 100 cm below the soil surface. Only carbon dioxide emissions at near water-saturated conditions deviated significantly. In most peat soils, maximum carbon dioxide emissions occurred already at low soil water suction (0.5 m water column).

For instance, in Finland, instead of intensive food or feed production, some cultivated peatlands are in extensive use due to poor productivity or challenging cultivation conditions. Such low-yielding, thick layered peat soils in extensive use would be more useful to either be rewetted, restored or under paludiculture in order to meet the emission targets. Such plots can be found in Finland about 23,000 ha, which is approximately 1% of the total cultivated area (Kekkonen et al., 2019). By rewetting, restoring or transferring these fields to paludiculture, Finland could reduce about 10% of the emissions from cropland in the land use and land use change sector. In general, paludicultures are considered as natural ecosystems. In the long term, mire vegetation captures carbon and "stores" it in peat.

In agricultural land including organic soils, agroforestry provides for greater C sequestration than through conventional options alone while leaving the bulk of the land in agricultural production. In large parts of temperate and boreal Europe, implementation of afro-forestry remains rather limited. Besides uncertainties on the legislative and economic level, this might result from a lack of actual quantification of the ES provided and the lack of knowledge on implications of agroforestry on field management. Under temperate and boreal climatic conditions actual quantitative estimates of climate mitigation impact especially in lands on organic soils remain extremely scarce. Thus, further research and quantification is needed regarding the effect of tree presence on soil organic carbon and net GHG emissions in organic soils (Pardon et al., 2017; Schoeneberger et al., 2012).

A key component for sustaining production in grassland ecosystems is the maintenance of soil organic matter (SOM), which can be strongly influenced by management. Many management techniques intended to increase forage production may potentially increase SOM, thus sequestering atmospheric carbon. (Conant et al., 2001) reviewed studies examining the influence of improved grassland management practices and conversion into grasslands on soil C worldwide to assess the potential for C sequestration. Results from 115 studies containing over 300 data points were analysed. Management improvements included fertilization (39%), improved grazing management (24%), conversion from cultivation (15%) and native vegetation (15%), sowing of legumes (4%) and grasses (2%), earthworm introduction (1%)

and irrigation (1%). Soil C content and concentration increased with improved management in 74% of the studies, and mean soil C increased with all types of improvement. Carbon sequestration rates were highest during the first 40 years after treatments began and tended to be greatest in the top 10 cm of soil. Impacts were greater in woodland and grassland biomes than in forest, desert, rain forest, or shrubland biomes. Conversion from cultivation, the introduction of earthworms, and irrigation resulted in the largest increases. Rates of C sequestration by type of improvement ranged from 0.11 to 3.04 Mg C ha^{-1} yr^{-1}, with a mean of 0.54 Mg C ha^{-1} yr^{-1} and were highly influenced by biome type and climate. Conant et al. (2001) concluded that grasslands can act as a significant carbon sink with the implementation of improved management. Also Conant et al. (2017) concluded that improved grazing management, fertilization, sowing legumes and improved grass species, irrigation, and conversion from cultivation all tend to lead to increased soil C, at rates ranging from 0.105 to more than 1 Mg C ha−1 yr−1. These are general assumptions that apply mainly to SOM in mineral soils. Further studies are necessary to specify impacts of different management approaches in grasslands on organic soils on net GHG emissions at ecosystem level in boreal and temperate cool moist climate zone at ecosystem level.

Within the study in the Republic of Ireland Renou-Wilson et al. (2012, 2016) concluded that extensive grassland over organic soil is on average, an annual source of CO_2 when drained (138-232 g C m^{-2} yr^{-1}) and a sink when rewetted (-40 g C m^{-2} yr^{-1} in the ungrazed rewetted grassland). A wet organic soils under grassland display high CH_4 emissions especially if the water is close to the surface. However, maintaining the water table at – 20 cm may be sufficient to reduce CO_2 losses from respiration while keeping CH_4 emissions low and therefore raising the water table could be used as a GHG mitigation tool in organic soils under grassland.

In Finland, as forage production as rotational grasses is classified as cropland in the GHG inventory, Finnish grasslands are mainly abandoned fields and thus there are limited possibilities to guide their management. Some abandoned fields have been successfully rewetted and restored to close to natural state.

2.1 Agroforestry – fast growing trees and grass (LVC306)

<table>
<tr><td>Short description of the action</td><td colspan="3">One of the most efficient measure in agricultural soils considering planting of trees and bushes and intensive management for HWP and solid biofuel production. During the first years after establishment the areas are used for fodder or seed production ensuring early economic benefic. Rotation period – around 20 years.</td></tr>
<tr><td>CCM impact</td><td colspan="3">Planting of poplars in grassland and continuation of fodder production for several years ensures GHG emission reduction by about 15,5 tons CO_2 eq. ha^{-1} yr^{-1} (1855 tons CO_2 eq. ha^{-1} in 120 years period). This include carbon stock change in living and dead biomass and reduction of carbon losses and GHG emissions from soil (Bardule et al., 2016; Lazdiņa et al., 2019).</td></tr>
<tr><td>Area characteristics</td><td colspan="3">Nutrient- rich organic soil, peat layer sickness at least 30cm, groundwater at least 30 cm during the growing season</td></tr>
<tr><td>Any associated risks or potential implementation obstacles</td><td colspan="3">Establishment of agroforestry systems requires considerable investments, which are not available for farmers, and even if the funding is available, planting material and relevant management services may not be accessible due to high demand. Natural disturbances may significantly limit the GHG emission reduction potential.</td></tr>
<tr><td rowspan="5">Costs and benefits associated with implementation of the action</td><td rowspan="2">Cost/benefit position</td><td colspan="2">Costs (“+”)/benefits (“-”), EUR ha^{-1}</td></tr>
<tr><td>1^{st} year</td><td>Next years</td></tr>
<tr><td>Investment</td><td>3000</td><td>300</td></tr>
<tr><td>Management costs</td><td>-</td><td>900</td></tr>
<tr><td>Income</td><td>-</td><td>9000</td></tr>
<tr><td>CCM potential</td><td colspan="3">Assuming that at least 50% of organic soils are transferred into agroforestry systems, only in Latvia the GHG mitigation potential 1.2 mill. tons CO_2 eq. yr^{-1}.</td></tr>
</table>

2.2 Conversion of cropland used for cereal production into grassland considering periodic ploughing (LVC301)

<table>
<tr><td>Short description of the action</td><td colspan="3">Conversion of cropland to grassland to reduce GHG emissions from soil. The measure has continuous impact equal to time necessary to decompose exceeding organic matter in soil. In long term difference between both systems is reducing, because in both cases exceeding organic matter will be decomposed at some point and the difference is determined by N_2O and CH_4 emissions. The measure is not associated with additional cost, however income of farmers should be compensated. The measure reduces agriculture production potential; however, due to reduction of N_2O emissions provides opportunity to retain management activities in other sectors.</td></tr>
<tr><td>CCM impact</td><td colspan="3">The implementation potential in Latvia is about 8.5 tonnes CO_2 eq. ha^{-1} both in agriculture and LULUCF sector. However this impact can be overestimated due to decomposition of organic matter not represented by soil maps or overestimated GHG emissions from cropland. The measure interfere with afforestation of organic soils providing significantly higher mitigation effect.</td></tr>
<tr><td>Area characteristics</td><td colspan="3">Nutrient- rich organic soil, peat layer sickness at least 30cm, groundwater at least 30 cm during the growing season</td></tr>
<tr><td>Any associated risks or potential implementation obstacles</td><td colspan="3">Implementation of the measure is associated with transfer of emissions, since production stopped in one place is moved to another. There is no warranty that the production is not moved to another organic soil or production is continued in deforested area, resulting thus in the increase of GHG emissions.</td></tr>
<tr><td rowspan="5">Costs and benefits associated with implementation of the action</td><td rowspan="2">Cost/benefit position</td><td colspan="2">Costs (“+”)/benefits (“-”), EUR ha^{-1}</td></tr>
<tr><td>1st year</td><td>Next years</td></tr>
<tr><td>Investment</td><td>-</td><td>-</td></tr>
<tr><td>Management costs</td><td>-</td><td>-</td></tr>
<tr><td>Income</td><td>-</td><td>-</td></tr>
<tr><td>CCM potential</td><td colspan="3">About 677 ktons CO_2 eq yr^{-1} if all organic soils in cropland are transferred to grassland in Latvia.</td></tr>
</table>

2.3 Fast growing species in riparian buffer zones (LVC310)

<table>
<tr><td>Short description of the action</td><td colspan="3">Another kind of agroforestry system considering growing of 15-20 m wide bands of trees and bushes nearby the drainage systems in agricultural lands. The measure is aimed to utilize residual nutrients and water to produce biomass in cropland and intensively managed grassland.</td></tr>
<tr><td>CCM impact</td><td colspan="3">Duration of the impact depends from life-time of buffer zone. Further removals can be ensured by application of more productive crops. Organic soils are not separated in the assessment. Following to proportion of the organic soils impact of areas on organic soils can be 10-15%. Cost – benefit ratio of the measure is not estimated yet.</td></tr>
<tr><td>Area characteristics</td><td colspan="3">Nutrient- rich organic soil, peat layer sickness at least 30cm, groundwater at least 30 cm during the growing season</td></tr>
<tr><td>Any associated risks or potential implementation obstacles</td><td colspan="3">Establishment of agroforestry systems including bends of trees and bushes around water streams requires considerable investments, which are not available for farmers, and even if the funding is available, planting material and relevant management services can be limited or their cost quickly increases due to high demand. Natural disturbances may significantly limit the GHG emission reduction potential.</td></tr>
<tr><td rowspan="5">Costs and benefits associated with implementation of the action</td><td rowspan="2">Cost/benefit position</td><td colspan="2">Costs (“+”)/benefits (“-”), EUR ha^{-1}</td></tr>
<tr><td>1st year</td><td>Next years</td></tr>
<tr><td>Investment</td><td>3000</td><td>300</td></tr>
<tr><td>Management costs</td><td>-</td><td>900</td></tr>
<tr><td>Income</td><td>-</td><td>9000</td></tr>
<tr><td>CCM potential</td><td colspan="3">According to preliminary assessment the net GHG emission reduction potential in Latvia is 0.75 mill. tons CO_2 yr^{-1}.</td></tr>
</table>

2.4 Controlled drainage of grassland considering even groundwater level during the whole vegetation period (LVC305)

<table>
<tr><td>Short description of the action</td><td colspan="3">Groundwater regulation systems ensures retaining of certain groundwater level, e.g. 30 cm ensuring relative low CH_4 ans CO_2 emissions from organic soils. The measure can be used both, in cropland and grassland.</td></tr>
<tr><td>CCM impact</td><td colspan="3">Duration of the impact equals to period of implementation of the measure and life-time of drainage systems. Total impact of the measure is not estimated.</td></tr>
<tr><td>Area characteristics</td><td colspan="3">Nutrient-rich organic soil, peat layer sickness at least 30 cm, groundwater at least 30 cm during the growing season.</td></tr>
<tr><td>Any associated risks or potential implementation obstacles</td><td colspan="3">Data on the emission reduction are not verified by scientific evidences therefore climate change mitigation potential may be overestimated. The terrain conditions in the most cases are not suitable for establishment of controlled drainage systems.</td></tr>
<tr><td rowspan="5">Costs and benefits associated with implementation of the action</td><td rowspan="2">Cost/benefit position</td><td colspan="2">Costs (“+”)/benefits (“-”), EUR ha^{-1}</td></tr>
<tr><td>1st year</td><td>Next years</td></tr>
<tr><td>Investment[6]</td><td>1200</td><td>-</td></tr>
<tr><td>Management costs</td><td>-</td><td>-</td></tr>
<tr><td>Income</td><td>-</td><td>-</td></tr>
<tr><td>CCM potential</td><td colspan="3">Implementation potential, as well as cost-benefit ratio at a national scale is not estimated yet. No controversial impacts are known with the sustainability criteria. The measure may have adverse impact on accessibility of fields during spring and summer season; however, limited data are available on impact of different strategies in regulation of drainage systems.</td></tr>
</table>

[6] Depends on area. Current estimate is based on 3 ha field.

2.5 Introduction of legumes in conventional farm crop rotation (LVC304a, LVC304b)

<table>
<tr><td>Short description of the action</td><td colspan="3">Introduction of legumes into crop rotation in farmland managed in accordance with good practice guidelines for integrated farms. Legumes are sawn in rotation with cereal crop.</td></tr>
<tr><td>CCM impact</td><td colspan="3">GHG emission reduction related to the decrease of N20 and CO2 emissions from soil. Additional biomass – carbon sequestration, reduced nitrogen - effect results from the substitution of synthetic nitrogen fertilizers by biological nitrogen fixation (Wang et al., 2019).</td></tr>
<tr><td>Area characteristics</td><td colspan="3">Nutrient- rich organic soil, peat layer sickness at least 30 cm, groundwater at least 30 cm during the growing season. Area – managed as cropland.</td></tr>
<tr><td>Any associated risks or potential implementation obstacles</td><td colspan="3">Risks: 1) farmers continue usual fertilizing practice without considering legume effect – because of the lack of knowledge; 2) GHG reduction is not reflected in National GHG inventory report because of the lack of necessary data.</td></tr>
<tr><td rowspan="5">Costs and benefits associated with implementation of the action</td><td rowspan="2">Cost/benefit position</td><td colspan="2">Costs (“+”)/benefits (“-”), EUR ha⁻¹</td></tr>
<tr><td>1st year</td><td>Next years</td></tr>
<tr><td>Investment</td><td>-</td><td>-</td></tr>
<tr><td>Management costs</td><td>-</td><td>-</td></tr>
<tr><td>Income</td><td>-</td><td>-</td></tr>
<tr><td>CCM potential</td><td colspan="3">From scientific literature: Increased legume share in crop rotations is recognized as climate change mitigation measure. NO3 (plus ammonium and nitrite) leaching losses would be reduced by up to 20%. There would be associated reduction in direct (up to 50%) and indirect (up to 20%) N2O emissions, and NH3 emissions (c.50%) (Newell Price, J.P., et al., 2011). Annual mitigation potentials are quantified between 0.5 and 1 t CO_2 equivalents per hectare for Great Britain through increased use of nitrogen fixation of clover and introduction of additional species (including legumes) in crop rotations (Rees, R.M., et al., 2013).
National report: According to the IPCC guidelines, after introduction of legumes in crop rotation the management system in the affected fields would be changed to “High, without manure” due to increased input of organic materials and the carbon stock change factor for input will increase to 1.11. 20 years’ transition period is considered in calculation of soil carbon stock changes. Implementation of the measure according to the tier 1 method will contribute to the net CO2 removals in soil –1.32 tonnes CO^2 ha^{-1} annually (26.4 tonnes CO_2 ha^{-1} in total) during 20 years’ period. Carbon sequestration in soil (0-30 cm depth) after 20 years transition period would increase from 65.6t C ha^{-1} to 72.8 t C ha^{-1}.</td></tr>
</table>

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