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Climate change mitigation potential of trees in shelter belts of drainage ditches in cropland and grassland

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Latvian State Forest Research Institute SILAVA

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Report

Nutrients retention capacity of the shelter belts in farmlands[1]

Salaspils, 2023

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Anotation

Action 2 (01.01.2022-30.06.2023) is aimed put together data from field measurements of soil GHG fluxes, carbon input with litter and fine roots and nutrient retention effect of woody crops in shelter belts. Considering that planting of trees can affect GHG emissions from drainage ditches, the measurement program involves GHG fluxes in drainage ditches in areas with and without trees in the shelter belts. GHG fluxes and soil heterotrophic respiration had been measured using methodology proved in LIFE Restore project (Lupiķis, 2019). GHG fluxes had been be measured in existing study sites in Latvia. Above-ground litter samples coarse litter from ground and fine litter at 1 m height had been be collected during 1 vegetation season in 4 planting scenarios in Latvia representing different tree species maturity groups and species of fast growing species more suitable for the shelter belts according to preliminary assessment (hybrid poplar, aspen, alders and birch; commercial clones of willow and hazel). Area of the study sites had been estimated using LiDAR data, and nutrients, as well as DOC outflow had been estimated on the base of remote measurements with manual quality control plots.

Results of study are published and available in open access papers entitled *"Soil-to-Atmosphere GHG Fluxes in Hemiboreal Deciduous Tree and Willow Coppice Based Agroforestry Systems with Mineral Soil"* (https://doi.org/10.3390/land12030715) and *"Long-Term Effect of Wood Ash and Wastewater Sludge Fertilization on Tree Growth in Short-Rotation Forest Plantations on Abandoned Agricultural Land: A Case Study"* (https://doi.org/10.3390/su152316272), simple remote sense data use *"Remote-Sensed Tree Crown Diameter as a Predictor of Stem Diameter and Above-Ground Biomass in Betula pendula Roth and Populus tremuloides Michx. × Populus tremula L. Plantations"* (https://doi.org/10.3390/land12112006).

Technical report is part of sub task 2.2 aimed conduct literature review, existing agricultural outflow monitoring data and verified by field measurement data (water chemical content in lysimeters and ditches) in study sites. The comparison of data is already included in publication mentioned above. Technical report is general overview of buffer strips, buffer belts, shelter belts ecology and biomass accumulation potential.

Summary

The strategic use of shelterbelts in farmlands can significantly contribute to the retention and cycling of nutrients, enhancing soil fertility and agricultural productivity.

Shelterbelts, also known as windbreaks, play a significant role in enhancing nutrient retention in farmlands. Their ability to retain nutrients is primarily attributed to several key factors:

Shelterbelts reduce the velocity of wind across the surface of the soil, which in turn lessens the amount of soil erosion. This is particularly important in retaining topsoil, which is rich in nutrients. Less erosion means more nutrients are retained in the soil where crops can utilize them.

The presence of trees and shrubs in shelterbelts contributes to the accumulation of organic matter in the soil as leaves and other plant materials fall and decompose. This organic matter is a key component of soil fertility, providing essential nutrients to crops.

Some shelterbelt species, particularly leguminous trees and shrubs, have the ability to fix atmospheric nitrogen, enriching the soil with this essential nutrient. This process contributes to the overall nutrient availability in the surrounding farmland.

Shelterbelts can also help in conserving soil moisture. By reducing wind speed, they reduce the rate of evaporation from the soil surface, thereby maintaining soil moisture levels. This can improve the availability of water-soluble nutrients to crops.

Shelterbelts can modify the microclimate in their immediate vicinity, often leading to improved growing conditions. This can indirectly impact nutrient uptake by crops, as better growth conditions can enhance root development and nutrient absorption efficiency.

By trapping snow and rainwater, shelterbelts can reduce the runoff of fertilizers and pesticides from farmlands. This not only prevents the loss of these nutrients but also protects nearby water bodies from pollution.

The improved soil conditions under shelterbelts, such as increased organic matter and moisture content, can enhance soil microbial activity. These microbes play a crucial role in breaking down organic matter and making nutrients available to plants.

Retention and cycling of nutrients, enhancing soil fertility and agricultural productivity.

Windbreaks

Windbreaks, an agroforestry practice, consist of strategically arranged linear plantings of trees and shrubs within agricultural landscapes. These structures, also known as hedgerows, shelterbelts, living snow fences, or vegetated environmental buffers, serve dual roles by providing economic, environmental, and social benefits as part of managed agroecosystems (Smith et al., 2021). The choice of species, tailored to local climate and soil conditions, is essential for their long-term effectiveness and ease of maintenance.

Primarily, windbreaks mitigate wind erosion and enhance environments, boosting crop yields in fields and orchards. Tall windbreaks modify the microclimate, favorably influencing pollination and fruit set, leading to increased yields. Furthermore, they reduce wind speed, thereby minimizing mechanical damage to crops from wind-blown particle abrasion and friction caused by fruit against plant parts during strong winds (Norton, 1988). This also lessens premature fruit drop, protecting the harvest.

Beyond these direct benefits, windbreaks help curb the spread of plant diseases (Tamang et al. 2010) , reduce honeybee mortality in winter (Haydak 1958), and enhance honeybee foraging in windy conditions (Hennessy et al. 2020). They boost livestock production in harsh weather, diminish the risk of livestock mortality during winter storms (Norton 1988), and reduce soil erosion (Englund et al. 2021). Their presence improves water-use efficiency, lowers energy and heating costs (Dewalle and Heisler 1988), and offers control over blowing snow, dust, chemical sprays (Bentrup et al. 2019), or odors (Tyndall 2009; Popov et al. 2022). For example, windbreaks can reduce pesticide drift by up to 80 to 90 percent (Bentrup et al. 2019).

Windbreaks are also employed for non-wind-related purposes, such as providing shade for livestock, visual screening, aesthetic enhancement, recreational opportunities such as hunting (Grala et al. 2009), and yielding wood and non-timber forest products (Brandle et al. 2004). Recognized for their ecosystem services, windbreaks contribute to biodiversity enhancement, wildlife habitat, carbon storage, pollinator habitat, and soil and water quality protection, with benefits extending beyond the farm (Smith et al. 2021). For instance, moths, flies, bees, and butterflies often utilize windbreaks for travel (Bentrup et al. 2019).

Furthermore, windbreaks, or shelterbelts, play a vital role in nutrient retention on farmlands (Englund et al. 2021). Their capacity to retain nutrients is attributed to a combination of factors: reducing soil erosion, accumulating organic matter, fixing nitrogen, conserving moisture, modifying the microclimate, curtailing chemical runoff, and boosting soil microbial activity.

Soil Erosion Reduction

Soil erosion poses a significant threat to soil fertility and agricultural productivity in Europe. It leads to the loss of organic matter and crucial nutrients, adversely impacting vegetation growth and biodiversity (Scherr 2000). Notably, 24% of European land experiences erosion rates exceeding 2 t ha-1 yr-1, with severe erosion affecting approximately 12.7% of the territory (Wuepper 2019). This erosion results in an annual loss of approximately 0.43% in crop productivity on the 12 million hectares of agricultural land in the EU, translating to an economic cost of about 1.25 billion euros (Panagos et al. 2018).

Wind erosion, classified as low in the majority of Europe's agricultural landscapes (Englund et al. 2020). Shelterbelts, which are strategically planted rows of trees and shrubs, have been identified as an effective countermeasure against wind erosion. Accordingly, windbreaks are assumed to be capable of reducing soil loss due to wind erosion to a low level, but not beyond that threshold (Englund et al. 2021). It's important to note that windblown soil can carry inoculum for bacterial and fungal diseases, as well as provide potential entry points for pathogens. Therefore, controlling wind erosion through the use of shelterbelts may also play a significant role in reducing the incidence and severity of crop diseases (Hodges and Brandle 1996; Brandle et al. 2004).

Shelterbelts can reduce wind erosion by 22 to 60 percent, thereby improving the physical and chemical properties of farmland soils (Wang et al. 2017; Kong et al. 2022). It is achieved by diminishing wind velocity across soil surfaces, enhancing the retention of nutrient-rich topsoil. However, it's important to note that shelterbelts comprising single, short-cycle tree species may have a reduced functional lifespan in controlling wind erosion, leading to further degradation of farmland soils (Zhou et al. 2012).

Shelterbelts not only mitigate soil erosion but also contribute to the formation of new soil aggregates, improving erosion resistance and enhancing soil stability (Zhou et al. 2012; Kong et al. 2022; Sun et al. 2022). Their strategic implementation can therefore play a crucial role in preserving soil health and agricultural productivity across Europe.

Organic Matter Accumulation

Soils represent the largest terrestrial pool of organic carbon (C) and have the potential to act as significant carbon sinks, removing CO_2 from the atmosphere. Shelterbelts, composed of trees and shrubs, play a crucial role in this process (Canadell et al. 2007; Powlson et al. 2011; Dhillon and Van Rees 2016). As areas of carbon accumulation, they contribute to the formation of soil organic matter (SOM), thereby enhancing the soil's carbon storage capacity (Chendev et al. 2015).

Shelterbelts' effectiveness in carbon sequestration is multifaceted. They increase SOC by intercepting wind, leading to the deposition of wind-blown organic detritus. This process, combined with the reduction of surface soil carbon loss due to wind and water erosion, further bolsters their role as carbon sinks (Mize et al. 2008; Dhillon and Van Rees 2016). Additionally, tree cover in shelterbelts has been observed to decrease soil bulk density and increase water-stable aggregates (WSA), without adversely affecting soil pH (Khaleel et al. 2020).

The impact of shelterbelts extends beyond the quantity of SOM to also influence its quality and composition. Studies by (Dhillon and Van Rees 2016) and (Dhillon et al. 2017) found that SOM in shelterbelts was enriched with processed carbon forms, such as aliphatic C, aromatic C, and ketones, compared to agricultural fields, which had higher content of simple sugars and alcohols. Different species of shelterbelts have varying impacts on the type of carbon stored. For instance, hybrid poplar shelterbelts tend to increase labile carbon forms like carbohydrates, while Manitoba maple leads to a higher abundance of more recalcitrant aliphatic carbon forms. These recalcitrant forms, such as aliphatic and aromatic carbon, are more resistant to degradation and thus contribute to longer-term carbon storage (Krull et al. 2003; Lorenz et al. 2007).

It is also notable that the age of shelterbelts affects their carbon sequestration capacity. Younger shelterbelts (less than 20 years old) may initially lose SOC, but there is a positive correlation between shelterbelt age and SOC accrual. Other stand characteristics, including tree height, diameter, crown width, and surface litter, also positively correlate with increased SOC concentration (Dhillon and Van Rees 2016).

In addition to these benefits, the presence of trees and shrubs in shelterbelts contributes to the accumulation of organic matter in the soil. As leaves and other plant materials fall and decompose, they add essential nutrients to the soil, enhancing its fertility and further supporting the growth of crops.

Nitrogen Fixation

Shelterbelt species, particularly leguminous trees and shrubs are integral in enriching soil with essential nutrients, notably nitrogen, through atmospheric nitrogen fixation. This process enhances the overall nutrient availability in surrounding farmlands. An example is *Caragana arborescens*, commonly found in Canadian prairies shelterbelts. Its ability to form root nodules and fix atmospheric nitrogen enhances N availability, as evidenced in an intercropping study in Saskatchewan where nitrogen transfer was observed from caragana to willow (*Salix miyabeana*) (Issah et al. 2015).

Soil processes like nitrogen fixation, nitrification, denitrification, and ammonification are predominantly mediated by soil bacteria (Toth et al. 2020). Interestingly, *Elaeagnus angustifolia* (Russian olive), a non-legume, has been shown to fix nitrogen and is used in shelterbelts in southern Alberta and prairie regions of the USA (Ezra and Mac 1913). Among the 650 woody species capable of fixing atmospheric N2, 515 belong to the Leguminosae family. However, non-leguminous N2-fixing trees (NFTs) like Alnus and Casuarina are also significant in tropical agroforestry systems (Vanitha et al. 2022). Soil improvement in these systems occurs through direct nitrogen contribution by trees, increased nutrient turnover, and erosion control via strategic tree planting and mulching with tree prunings.

In European agroforestry systems, leguminous trees serve as one of the options for introducing new nitrogen sources through symbiosis with root-nodulating bacteria. This process can contribute notable amounts of nitrogen to the soil each year, potentially ranging from tens to hundreds of kilograms per hectare (Kim and Isaac 2022). An example of such a tree is the black locust (*Robinia pseudoacacia*), which forms a symbiotic relationship with *Rhizobium* bacteria.

This species has been recognized for its ability to improve the nitrogen and carbon content in forest soils, a feature that is beneficial in various European landscapes (Mazurek and Bejger 2014).

Moisture Conservation

Shelterbelts, by reducing wind speed, play a significant role in conserving soil moisture, which is crucial for plant growth. This reduction in wind speed not only diminishes evaporation from the soil surface but also aids in managing water vapor transfer, as noted by (Brandle et al. 2004). However, it's important to recognize that under conditions of limited moisture, competition between the windbreak and crops can negatively impact yield due to factors like allelopathy, nutrient deficiency, shading, and soil moisture deficiency (Kort 1988). Tree-root pruning might mitigate some forms of this competition, depending on the windbreak species rooting patterns, root pruning depth, and soil moisture levels (Hou et al. 2003).

Furthermore, field windbreaks are effective in capturing moisture from snow, thereby distributing it across the field and enhancing crop yields by 15-20% through increased moisture and protection against wind desiccation (Brandle et al. 2004). In Romania, studies (Vasilescu 2014) have shown that shelterbelts positively influence soil humidity, correlating with the growth of agricultural crops. Similarly, agroforestry configurations, including shelterbelts, trap snow and reduce sublimation, contributing to improved crop germination, growth, and yield during drought years. This extra snow also enhances the recharge of aquifers in protected areas (Kort et al. 2012). Additionally, the protective effects of shelterbelts include decreased wind speed and lower saturation vapor pressure deficits, further conserving soil moisture and improving the availability of water-soluble nutrients to crops (Ryszkowski and Kedziora 2007).

Microclimate Modification

In agroforestry, Cadaghi single-row windbreaks are instrumental in modifying microclimates to enhance crop production for Florida growers (Tamang et al. 2010). Windbreaks primarily reduce temperature and wind speed, thus diminishing air movement and altering temperatures in cropped areas. Changes in wind speed and turbulence due to shelterbelts alter the microclimate, reducing exchange rates between the atmosphere and soil and plant surfaces. This leads to a slight increase in average daily temperature and humidity in the sheltered area, enhancing overall growing conditions and indirectly impacting nutrient uptake by crops, as better growth conditions can enhance root development and nutrient absorption efficiency (Mize et al. 2008).

This environmental modification benefits pollinator activity and efficiency, especially important for pollinators like honeybees, whose energy can be redirected from cooling to honey production when shaded by shelterbelts. Additionally, shelterbelts protect against winter winds, reducing honey bee hive winter mortality (Bentrup et al. 2019).

Tall windbreaks can isolate the microclimate within an orchard, leading to soil temperature increases up to 3°C and resulting in earlier fruit maturity (Norton 1988). The extent of microclimate changes depends on various factors, including the windbreak's structure, orientation, and atmospheric conditions (Brandle et al. 2004). Shelterbelts typically create warmer conditions during the day and cooler temperatures at night, fostering rapid plant growth in spring and fall (Hodges and Brandle 1996). This results in 5% to 50% higher crop yields.

Improved growing conditions in sheltered areas are attributed to higher soil moisture, daytime temperatures, humidity, and night-time carbon dioxide levels, along with reduced evaporation and cooler night-time air temperatures (Kort 1988). Lower stomatal resistance in sheltered zones enhances photosynthesis due to increased carbon dioxide diffusion. These microclimate modifications are significant factors in yield increases and should be considered in shelterbelt design, along with snow management and erosion control.

Reduction of Chemical Runoff

Windbreaks play a multifaceted role in environmental management within agricultural landscapes. They act as sinks for various agricultural by-products, including eroded topsoil, fertilizers, pesticides, and seeds, effectively trapping airborne chemicals and odors (Mize et al. 2008). Shelterbelts contribute significantly to controlling groundwater pollution, especially from nitrogen compounds, thus forming an essential part of environmental protection strategies (Ryszkowski and Kedziora 2007).

Trees in shelterbelts can capture up to 60% of ammonia emissions from livestock, reducing air pollution and the transfer of NH_3 from the source (Kim and Isaac 2022). Studies have shown that windbreaks can reduce spray drift by up to 80% to 90%, offering a more reliable alternative to conventional methods for minimizing chemical drift (Ucar and Hall 2001). When combined with other methods like drift nozzles and air-assisted delivery, the efficacy of windbreaks in drift mitigation can be significantly enhanced.

Furthermore, biogeochemical barriers such as shelterbelts and peatlands are effective in removing organic carbon and nitrogen compounds from groundwater, particularly when nitrogen is in the form of nitrate (Szczepański et al. 2021). The efficiency of windbreaks is influenced by various factors, including height, length, vegetation density, and species composition. The species of trees used in windbreaks, particularly their foliage type, significantly affects their ability to reduce drift. For example, needle-like foliage can capture more spray than broad leaves (Felsot et al. 2011).

Enhanced Soil Microbial Activity

A recent study highlights the significant role of shelterbelts in enhancing soil biodiversity (Toth et al. 2020). The study found a higher average number of microbial sequences in shelterbelt soil samples compared to arable land, indicating greater bacterial community diversity in farmland shelterbelts. This diversity is likely attributed to enhanced microbial activity in the upper soil layer, enriched by the accumulation of dead branches and leaves. Tree species in shelterbelts can influence soil processes like nutrient cycling and carbon dynamics through plant-microbial interactions and the quality of leaf and root litter (Carnovale et al. 2019).

Soil conditions under shelterbelts, improved by increased organic matter and moisture, are conducive to heightened microbial activity. These microbes are vital in decomposing organic matter and facilitating nutrient availability (Amadi et al. 2017). The relationship between CO2 emissions within shelterbelts and soil temperature and moisture suggests rapid microbial decomposition, particularly during warmer, moister summer periods.

(Nguyen et al. 2023) emphasize the impact of shelterbelt characteristics on soil microbial communities. The height of shelterbelts and their proximity significantly shape bacterial and fungal composition in both spring and summer. Soil microbial diversity, crucial for biogeochemical cycles and soil stability, is typically higher in herbaceous field margins than in adjacent cropped fields (Rivest et al. 2020). The role of dissolved organic matter in soil nutrient cycling is serving both as a substrate for microbial growth and a product of microbial activity (Szajdak and Gaca 2010).

Conclusions – lessons learned

In conclusion, shelterbelts play a fundamental role in enhancing agricultural sustainability, ecosystem health, and environmental management. They provide a multitude of benefits including protection against soil erosion, enhancement of crop yields, improvement of soil moisture and biodiversity, and contribution to carbon sequestration. Their ability to modify microclimates, improve soil nutrient levels, and act as barriers against pollutants underscores their significance in sustainable farming and ecological conservation. The strategic implementation of shelterbelts and windbreaks, considering their design and species composition, is crucial for maximizing these benefits in agricultural landscapes.

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