How much carbon is sequestered in soil after afforestation of agricultural land in Northern Europe?

SNS Nordic Forest Research

Afforestation of former crop- and grasslands is encouraged in several north European countries. According to the reports to the Kyoto Protocol of the UNFCCC, almost 30 000 ha is afforested annually in the Nordic-Baltic region. Afforestation is regarded as key measure to support greenhouse gas emission reductions, but key questions remain regarding the contribution of soils to the carbon sink of the new forests. Studies within CAR-ES have shown that afforestation generally leads to increases in soil organic carbon (SOC) stocks, but the context such as former land-use, soil type and tree species will affect the C sink strength and the stability of the sequestered SOC.

Soil profiles in adjacent forest and agricultural land have different distributions of organic matter (Fig. 1). After afforestation, the homogenization and frequent manipulations associated with agriculture will cease and this suggests a potential for SOC sequestration after conversion to forest. Within CAR-ES this question was addressed by a meta-analysis of the influence of former land-use, tree species, forest age and soil type on SOC sequestration after afforestation in Northern Europe (Iceland, Ireland, Denmark, Sweden, Finland, Lithuania).

Former land use was a key factor controlling the sink strength of soils. Positive effects of afforestation on SOC stocks were identified on former cropland (+20%), heathland (+15%) and barren land (+64%, in Iceland). In contrary, afforestation of grasslands had a small negative effect on SOC stocks (-8%). This is because grasslands hold higher SOC stocks before afforestation than frequently tilled and intensively managed croplands.

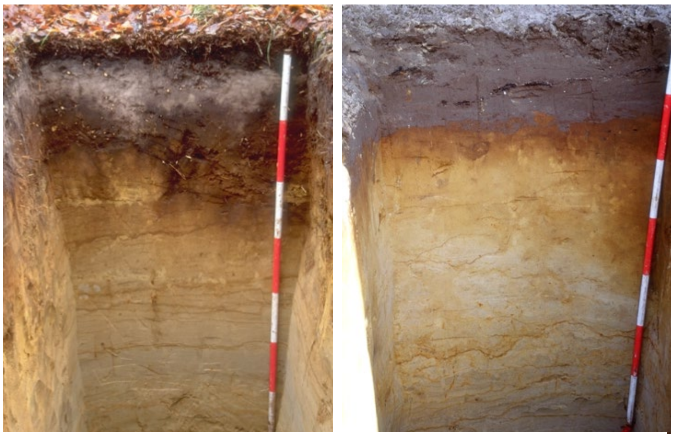

Fig. 1. The land use has a strong influence on soil organic matter and its distribution in the soil. Two adjacent soil profiles from beech forest (left) and cropland (right) on podzolized sandy soil in Denmark. The homogenized plough layer (0-30 cm) is visible.

Soil carbon changes slowly, and a certain forest age is often required for SOC changes to occur. A 30-year lag period was observed for Northern Europe, often with an initial loss before C sequestration could be detected (Fig. 2). More than 30 years after afforestation, the increase in SOC stock became stronger for former croplands (+38%) and former heathlands (+27%), but was still largely unchanged for former grassland (-7%).

The **tree species** influences the SOC sequestration rate as C in forest floor accumulates faster after afforestation with conifers (+0.35 t C/ha/yr) than deciduous tree species (+0.10 t C/ha/yr) over ca. 90

years. However, afforestation with broadleaves can result in higher SOC sequestration in the former plough layer of the mineral soil.

The **soil type** chosen for afforestation also matters. The change in SOC stocks were most positive for sandy soils (+35%) with no change for loamy soils. There is little knowledge for drained cropland soils, but with discontinued maintenance of ditches and drains, wetter conditions after afforestation would be expected to boost soil C sequestration.

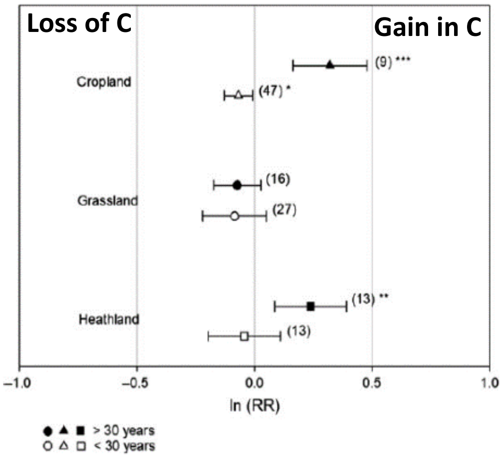

Fig. 2. Soil organic carbon gains/losses expressed as response ratios (RR = $SOC_{forest}/SOC_{non\text{-}forest}$) for 20-30 cm depth for three former land uses and after less and more than 30 years since afforestation (Bárcena et al. 2014).

How to best sequester SOC by afforestation?

Based on CAR-ES reviews and studies we recommend afforestation of former croplands, heathlands and barren lands, and on sandy soil types. If soils are actively drained, this should be ceased. More information about afforestation of wet organic soils is needed to support recommendations. Planting of conifers will lead to fast C sequestration in forest floors, but deciduous species are expected to sequester more stable C in mineral soil. Afforestation by natural woody colonisation of abandoned agricultural land will sequester C in soils at a slower rate than after active planting.

The variability in SOC stock change after afforestation may be related to legacies of previous management (soil N and pH) within the land uses croplands and grassland, i.e. how much manure, fertilizer or lime was applied, and whether crop residues were retained on site. Such legacy effects are now studied in CAR-ES to better model the SOC sequestration after afforestation.

For Northern Europe we need more information on afforestation of wet soils and peatlands, as soil C losses have been observed after afforestation of some organic soils. Knowledge is also scarce regarding afforestation of former heathlands, eroded lands and mined peatlands.

Most knowledge of afforestation effects on SOC has come from active afforestation based on tree planting. Natural colonization of abandoned farmland provides a varied habitat for biodiversity, but we know little about the magnitude and rate of SOC sequestration when trees establish naturally and slower than after planting. How can we speed up developments in soil biodiversity and other ecosystem services including SOC sequestration after afforestation? Inoculation of afforested soil with microbiome from old forest soils may prove to be an efficient method, and this is now studied in Denmark.

Literature:

Bárcena, T.G., Kiær, L.P., Vesterdal, L., Stefánsdóttir, H.M., Gundersen, P., Sigurdsson, B.D. (2014). Soil carbon stock change following afforestation in Northern Europe: a meta-analysis. Glob Change Biol 20, 2393-2405. https://doi.org/10.1111/gcb.12576

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Fact Sheet 03 from Centre of Advanced Research in Ecosystem Services
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