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S E Biotechnol. Agron. Soc. Environ. 2000 **4** (4), 272–274

Carbon sequestration in Danish forests

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The Danish national reports on land-use change and forestry has so far only considered C sequestration in existing forests and in afforestation areas on former arable land. The standing stock of wood in existing forests was 55.2 Mm^3 in 1990, and the annual net increment for 1990–1999 (wood increment minus harvested wood) was around 600,000 m^3 equivalent to 916 Gg CO_2 per year. It is the strategy of the Danish Government to double the forested area over the next 80–100 years by encouraging afforestation of arable land. Afforestation activities started in 1990, and C sequestration in new forests increased from 4 Gg CO_2 in 1991 to 57 Gg CO_2 in 1998. Wood volumes were converted to Gg C by using conversion factors slightly modified from the 1996 revised IPCC Guidelines. The presentation will focus on the methods behind these estimates and give examples of current studies and research needs from a Danish point of view.
Keywords. CO_2 sequestration, net annual increment, afforestation, flux, Denmark.

1. INTRODUCTION

Denmark has contributed with two National Communications (NC) on emissions of greenhouse gases (GHG), and NC2 was submitted in 1997. The latest report on GHG emissions was submitted to UNFCCC in May 2000 (Illerup *et al.*, 2000). In 1998, the emission of CO_2 amounted to 60.125 Mt without taking forest sinks into account. In the same year, the emission of N_2O amounted to 9.454 Mt CO_2-equivalents, and the emission of CH_4 amounted to 6.024 Mt CO_2-equivalents.

The Danish national reports on Land-Use Change and Forestry has so far only considered sequestration of CO_2-C in forests. The standing stock of wood in 1990 was derived from the Danish National Forest Inventory of 1990 (NFI1) (Statistics Denmark, 1994). The inventory is carried out every 10 years and is based on questionnaires to forest owners. The forested area was 417,000 ha or approximately 10% of the land area. Broadleaved tree species made up 34% and coniferous species made up 66% of the forest area. The standing stock of wood was 55.2 Mm^3 distributed on 43% broadleaved species and 57% coniferous species. This stock of wood was equivalent to 23,600 Gg C or 86,526 Gg CO_2. Forest soil organic matter was not directly included in reporting. Wood volumes are converted to carbon stores by a general expansion factor (2) and conversion factors of 0.19 $t\,C{\cdot}m^{-3}$ for conifers and 0.29 $t\,C{\cdot}m^{-3}$ for broadleaves. The Danish expansion factor and the conversion factors result in slightly lower C stores than when using Intergovernmental Pannel on Climate Change (IPCC) factors (5% lower for broadleaves and 13% lower for conifers). The Danish factors differ from IPCC factors because of lower volume to dry weight ratios that are more appropriate for Danish tree species (Moltesen, 1988).

2. WORKING GROUP 1 RELATED ACTIVITIES (Inventory of C sinks and sources)

2.1. Carbon sequestration in existing forests

Net C sequestration in the period 1990–1998 was the result of a net increase in standing stock of the existing forests and afforestation of former arable land. Net C sequestration in existing forests is partly a result of an uneven age class distribution with relatively more young stands.

The estimated wood increment for the period 1990–1999 was also available from the questionnaire-based NFI1 of 1990. Export of wood from the forest due to thinning operations and clearcutting was estimated from the annual agricultural statistics. The annual net increment for 1990–1999 (wood increment minus harvested wood) was around 600,000 $m^3{\cdot}y^{-1}$. Wood volumes are converted to carbon stores by the same method as mentioned for carbon stocks in 1990. The resulting net sink for CO_2 in forests existing in 1990 was 916 Gg $CO_2{\cdot}y^{-1}$ for the period 1990–1999.

The basis for these calculations is not satisfactory. The second forest inventory based on questionnaires will be ready in 2000 and will temporarily improve estimates of net carbon storage. However, a sample-based forest inventory is currently planned for NFI 3 to replace the questionnaire approach used for all NFI's until now. This type of forest inventory will be more similar to inventories used in other countries, e.g. Sweden, and it will be updated continuously by sampling one fifth of the forest area per year. With regard to estimation of carbon stores and changes in these, the new inventory provide an opportunity to also include sampling of soils on a selected number of plots.

2.2. Carbon sequestration due to afforestation of former arable land

In 1989 the Danish Government decided to encourage a doubling of the forested area within a tree generation of approximately 80–100 years (National Forest and Nature Agency, 2000). In order to reach this target, an afforestation rate of roughly 4–5,000 $ha \cdot y^{-1}$ is needed. Afforestation is carried out on soils formerly used for agriculture (cropland). Except for 1999, the afforestation rate has been lower than needed (about 2,000 $ha \cdot y^{-1}$). The sum of governmental and private afforestation (National Forest and Nature Agency, 2000) was used in calculations.

Accounting approach. Full carbon accounting is used in a manner by which C-stock changes are based on area multiplied by uptake. Uptake is calculated using a simple carbon storage model based on the Danish yield tables for Norway spruce (representing conifers) and oak (representing broadleaves) (Møller, 1933). The annual CO_2 fluxes during a period of 140 years of the model trees oak and spruce are shown in **figure 1**. The amounts of carbon sequestered in successive generations of afforestation areas are summed up in the model to give the total carbon storage in a specific year.

Wood volumes are converted to carbon stores by the same method as mentioned for carbon stocks in 1990. Decomposition rates for the various slash components are included in the model. Carbon storage in wood products may be included in the accounting by use of a module with turnover rates for the various wood products. For more information see Danish Energy Agency (2000).

The following carbon pools were included for afforestation stands: whole tree biomass (including roots) and slash. Based on studies of soils in a

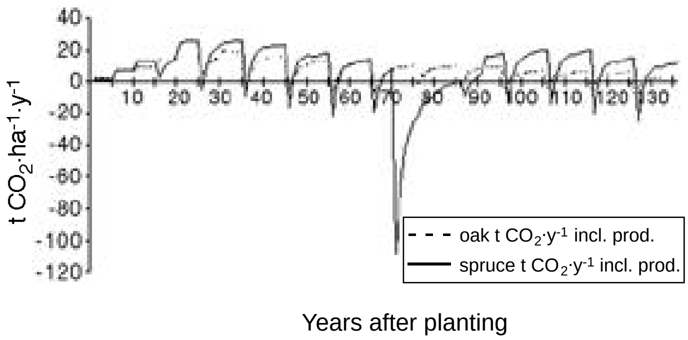

Figure 1. Calculated CO_2 flux during two rotations of spruce and one rotation of oak in Denmark.

chronosequence of afforested stands, no significant changes in soil organic matter was expected to take place during the first 30 years following afforestation.

The yield tables used for calculation of carbon stores are valid for yield class 2 (on a scale decreasing from 1 to 4). An afforestation ratio between conifers and broadleaves of 1:3 was assumed. There is no distinction made between forest growth rates on different soil types.

The annual sequestration of CO_2 in forests established since 1990 has gradually increased to 57 Gg CO_2 in 1998. During the commitment period 2008–2012 (5 years), it has been calculated that the Danish afforestation activities will result in sequestration of 474 Gg C equivalent to 1.738 Gg CO_2. This amount of C results from the afforestation of 52,700 ha of former arable land over the period 1990–2012.

3. WORKING GROUP 2 RELATED ACTIVITIES (Analysis of forest management practices)

Currently there is no CO_2 mitigation strategy related to forest management practices in Denmark. However, it has been suggested to establish research on the questions related to article 3.4 of the Kyoto Protocol (Ministry of Environment and Energy, 2000), i.e. the influence of forest management and in particular the time required for changes in forest management to affect C stores on forests. The Danish policy on climate (Ministry of Environment and Energy, 2000) addressed several issues concerning the sink capacity of forests, e.g., influence of management methods, storage of CO_2 in wood products, the value for society of CO_2 sequestration in forests as estimated by use of environmental economics.

Forest management measures that may increase carbon stores in Denmark could be:

– Changing the silvicultural system from clear cutting systems to systems having a more continuous forest cover (e.g. by use of natural regeneration);
– Increasing the stock of wood in forest stands and soils by reduced thinning intensity;
– A change in tree species;
– A change in soil drainage towards more wet soils (no maintenance of ditches, etc., will increase soil C storage).

4. PERSPECTIVES AND RESEARCH NEEDS

4.1. National research programmes connected to COST E21

Working group 1

– Carbon sequestration in biomass and soils following afforestation of former arable land. Period: 1998–2001.

Contact: Lars Vesterdal, Danish Forest and Landscape Research Institute
Funding: Danish Energy Agency

– SOROFLUX - Atmosphere/Soil Exchange of C and N compounds and Atmosphere/Canopy Exchange of C and N compounds.
Period: 1997-2000.
Contact: Kim Pilegaard, Teis N. Mikkelsen, Risoe National Laboratory.
Funding: Danish Environmental Research Programme.

Working group 2

– Influence of whole-tree harvesting for bioenergy production on soil carbon stores.
Period: 1998–2001.
Contact: Lars Vesterdal, Finn Vanman Jørgensen, Danish Forest and Landscape Research Institute.
Funding: Danish Energy Agency

– Influence of biomass export for energy purposes – consequences for carbon stores in agricultural and forest soils. (including the influence of land-uses on soil carbon stores).
Period: 1999–2002.
Contact: Bent Tolstrup Christensen, Danish Institute of Agricultural Sciences, Lars Vesterdal and Finn Vanman Jørgensen, Danish Forest and Landscape Research Institute.
Funding: Danish Energy Agency

– Influence of whole-tree harvesting for bioenergy production on future growth.
Period: 2000–2002
Contact: Niels Heding, Danish Forest and Landscape Research Institute.
Funding: Danish Energy Agency.

4.2. EU coordinated research programmes connected to COST E21

Working group 1

– Afforestation management in northwestern Europe – influence on nitrogen leaching, groundwater recharge, and carbon sequestration (AFFOREST).
Period: 2000-2004.
Contact: Karin Hansen, Lars Vesterdal, Danish Forest and Landscape Research Institute.
Network: Belgium, Denmark, Sweden, the Netherlands.
Funding: EU 5th Framework Programme

– EUROFLUX – Long term carbon dioxide and water vapour fluxes of European forests and interactions with the climate systems.
Period: 2000–2002.
Contact: Niels Otto Jensen, Risoe National Laboratory.
Network: Belgium, Denmark, Finland, France, Italy, Germany, the Netherlands, Sweden, United Kingdom
Funding: EU 5th Framework Programme

Working group 2 management

– Afforestation management in northwestern Europe – influence on nitrogen leaching, groundwater recharge, and carbon sequestration (AFFOREST).
Period: 2000-2004.
Contact: Karin Hansen, Lars Vesterdal, Danish Forest and Landscape Research Institute.
Network: Belgium, Denmark, Sweden, the Netherlands.
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Manuscript received 3 October 2000