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Water balance in afforestation chronosequences of common oak and Norway spruce on former arable land in Denmark and southern Sweden

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ABSTRACT

Precipitation, throughfall and soil moisture were measured, and interception, transpiration and water recharge were estimated in four afforestation chronosequences on former arable land at two Danish locations (Vestskoven and Gejlvang) and at one southern Swedish location (Tönnersjöheden). Afforestation was performed using Norway spruce (*Picea abies* (Karst.) L.) and common oak (*Quercus robur* L.) at Vestskoven and only Norway spruce at Gejlvang and Tönnersjöheden. Four to five stands of different ages (5–92 years) were studied in each of these chronosequences. Hydrological fluxes were calculated using the soil hydrological model SWAP. Throughfall flux and soil water content were used for calibration of the model. The simulated water recharge decreased with increased stand age within 30–40 years of afforestation. This was mainly due to increased interception evaporation with age. The annual water recharge was higher below oak stands (149–192 mm yr^{-1}) than below spruce stands (107–191 mm yr^{-1}) of similar age. The relative water recharge was also considerably higher from the sandy glaciofluvial soils at Gejlvang and Tönnersjöheden than from the sandy loamy till soils at Vestskoven.

1. Introduction

In many European countries, surplus agricultural production has led to afforestation of abandoned cropland. Today, abandonment of marginal cropland is making large areas available for alternative land uses in EU countries. Much of this abandoned cultivated land is suitable for afforestation. Due to European Common Agricultural Policy (CAP) reforms, afforestation of arable land is expected to increase in Europe in the coming decades (Rabbinge and van Diepen, 2000).

In several European countries, including Denmark and southern Sweden, a large proportion of the drinking water is derived from groundwater reservoirs. It is high on the agenda to maintain the quality of groundwater within areas assigned as groundwater protection areas. Afforestation of cropland has been implemented as a measure for protection against contamination of valuable or sensitive freshwater resources in Denmark (Grant et al., 2006).

Large-scale conversion of arable land to forest may significantly reduce water recharge to groundwater and surface water (Bosch and Hewlett, 1982; Calder, 1990; Kirby et al., 1991; Whitehead and Robinson, 1993). In wet temperate climates, the higher water use by trees is mainly due to the interception of rainwater by their more rough canopies compared with shorter cropland vegetation (Calder, 1990; Heal et al., 2004). Analyses of the impact of afforestation or deforestation on water recharge indicate that a shift from low vegetation such as arable crop or grassland to mature forest reduces water recharge in the order of 25–45% (Scott et al., 2000; Bastrup-Birk and Gundersen, 2004; Farley et al., 2005). However, most of the analyses concerning changes in water recharge after afforestation have been carried out on catchment scale, whereas investigations on plot scale are scarce (e.g. van der Salm et al., 2006).

The effect of land-use change on water recharge seems to be larger when the change is made to coniferous tree species as opposed to deciduous tree species (Bosch and Hewlett, 1982; Sahin and Hall, 1996; Bastrup-Birk and Gundersen, 2004; van der Salm et al., 2006). In an analysis of 145 catchments, Sahin and Hall (1996) found that for every 10% increase in forest cover, annual water yield decreased by 20–25 mm in coniferous forest and by 17–19 mm in deciduous forest. Moreover, the simulated decrease in water recharge upon afforestation in a Danish catchment was 90 mm yr^{-1} for deciduous trees and 200 mm yr^{-1} for coniferous trees (Bastrup-Birk and Gundersen, 2004). Plantations in high rainfall areas generally result in relatively higher water recharge

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reduction than comparable plantations in lower rainfall catchments (Bosch and Hewlett, 1982). The relationship between the increase in forest canopy and the water recharge also depends on the age of the forest. The maximum run-off reductions following grassland afforestation are found approximately 10–20 years after planting (Farley et al., 2005). Other important factors that influence water recharge and water use following afforestation of former arable land are forest management (e.g. planting density, thinning intensity and forest structure), soil conditions (e.g. texture, organic matter content and preferential flow), the presence of understorey vegetation and pre-afforestation agricultural management (e.g. old drainage pipes left on the site) (Hansen et al., 2007).

The objective of this study was to assess changes in the water balance with time following afforestation of former arable land. The specific aims were to assess the effect of two common tree species (common oak and Norway spruce) and contrasting soil types (sandy loamy and sandy soils) on the change in water balance with particular focus on water recharge. Precipitation, throughfall, soil solution and soil moisture content were measured in four afforestation chronosequences (21 stands in total) established on former cropland within the past 5–92 years. Hydrological fluxes were calculated using a hydrological simulation model.

2. Materials and methods

2.1. Study sites

This study was conducted in two areas in Denmark and one area in southern Sweden differing in soil properties, precipitation and stand characteristics (Tables 1 and 2).

Vestskoven (55°41′N, 12°21′E) is an afforestation area located 15 km west of Copenhagen in Denmark. From 1967 onwards, tree seedlings were successively planted on arable land. The soils are nutrient-rich and moist Stagnic Luvisols (IUSS Working Group WRB, 2006) with a texture of sandy loam developed from calcareous till deposits. The topography in the area is flat (elevation 20–28 m), causing surface runoff to be insignificant. The soil profile bears no signs of restricted drainage due to a high groundwater table, but signs of pseudogley indicate periodically restricted infiltration of precipitation in the relatively fine-textured soil. The climate is temperate, with a mean annual temperature of 7.7 °C and a mean annual precipitation of around 625 mm for the period 1960–1990. Five stands of Norway spruce (*Picea abies* (Karst.) L.) (planted 1997, 1990, 1988, 1973 and 1969) and five stands of common oak (*Quercus robur* L.) (planted 1993, 1988, 1979, 1977 and 1970) were selected to represent chronosequences of 33 years. These stands are denoted VS97, VS90, VS88, VS73, VS69, VO93, VO88, VO79, VO77 and VO70 (V for Vestskoven, S for spruce, O for oak, and the year of planting). A 200-year-old mixed deciduous forest, a 5-ha large forest, Ledøje Plantage (55°42′N, 12°19′E) was located just outside the Vestskoven area. This forest was also established on cropland by planting oak. Today, the overstory is dominated by common oak and sycamore maple (*Acer pseudoplatanus* L.) with a few ash (*Fraxinus excelsior* L.) and beech trees (*Fagus sylvatica* L.), mainly in a sub-layer. This stand is denoted LM1800 (L for Ledøje Plantage, M for mixed deciduous, and the approximate year of planting). For Vestskoven and Ledøje Plantage, more information on the soil and the changes in soil properties after afforestation can be found in Ritter et al. (2003) and Vesterdal et al. (2002). All stands in the Vestskovcen area were located within 1 × 3 km^2.

Table 1
Soil properties of selected stands at Vestskoven, Ledøje Plantage, Gejlvang and Tönnersjöheden.

Horizon	Depth (cm)	Clay	Silt	Sand[a]		C (mg g^{-1})	Bulk density (g kg^{-1})
		<2 μm (%)	2–20 μm (%)	20–200 μm (%)	200–2000 μm (%)		
Vestskoven, Norway spruce (VS69)							
O	−3 to 0						
Ap	0 to 20	14.9	16.9	43.3	24.8	25.4	1.01
Bt	20 to 32	27.9	16.4	33.3	22.4	4.1	1.52
Bt(g)	32 to 48	27.0	15.3	32.4	23.3	3.2	1.29
Btg	48 to 85	22.9	16.2	39.6	21.3	1.8	1.48
Ckg	85 to 95	21.8	17.0	38.9	22.3	–	1.48
Ck(g)	95 to 120	19.7	16.3	43.3	20.7	–	1.22
Ledøje Plantage, mixed deciduous (LM1800)							
A	0 to 45	20.5	17.5	62.0		16.3	1.26
Bwg	45 to 73	22.1	15.9	62.0		3.2	1.65
Ckg	73 to 120	20.2	17.2	62.6		2.7	1.63
Gejlvang, Norway spruce (GS60)							
O	−3 to 0						
EA	0 to 30	2.0	–	16.0	82.0	7.0	–
Bhsm	30 to 70	4.2	4.4	19.4	72.2	13.6	–
C	70 to 90	–	–	6.2	93.7	0.8	–
2C	90 to 140	0.2	1.8	2.6	95.4	0.8	–
Tönnersjöheden, Norway spruce (TS83)							
O	−3 to 0					331.0	
Ap	0 to 5	–	–	–		67.5	–
Ap	0 to 21	9	26	65		46.6	–
B	21 to 55	–	–	–		25.8	–
C	55	–	–	–		7.02	–
Tönnersjöheden, Norway spruce (TS28)							
O	−8 to 0					448.0	–
Ap	0 to 5	–	–	–		78.9	–
Ap	5 to 15	11	26	63		66.9	–
B	15 to 26	–	–	–		45.4	–
BC	26 to 48	–	–	–		–	–
C	48	–	–	–		5.1	–

Data from Vestskoven and Ledøje Plantage are partly from Ritter et al. (2003).
[a] At Ledøje Plantage and Tönnersjöheden, data for sand refer to the entire sand fraction (20–2000 μm).