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Afforestation of former agricultural land with *Salicaceae* species – Initial effects on soil organic carbon, mineral nutrients, C:N and pH

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ABSTRACT

Different species of *Salicaceae* are of interest for bioenergy production in Sweden. Surplus agricultural land is available and can be used for bioenergy plantations. Documentation of the effects of afforestation on soil properties is of importance for future recommendations on the choice of tree species and management measures.

Hybrid aspen (*Populus tremula* × *Populus tremuloides*), poplar (*Populus* spp.) and willow (*Salix* spp.) were planted on former arable land at four sites in Sweden. Planting densities were 1500 plants ha^{-1} for hybrid aspen and poplar, and 14,800 plants ha^{-1} for short rotation coppice (SRC) willow. The present study comprised five years following plantation with the aim to quantify the afforestation effects on mineral soil variables, i.e. soil organic carbon (SOC), nitrogen (N), phosphorus (P), base cations (K, Mg, Ca), C:N ratios and pH. The soil variables were estimated by repeated sampling, i.e. prior to planting and at the end of the fifth season. A litter layer was present in the fifth year and included in the C estimates.

The SOC pools were generally unchanged compared to pre-planting conditions. Total N pools had increased in SRC willow plantations and P pools had decreased in hybrid aspen and poplar plantations. Plant available K and Mg concentrations increased in the upper 0–10 cm soil and decreased in the lower 10–30 cm for all species, indicating redistribution by plant uptake and recycling through litter decay. Concentrations and pools of Ca were unchanged. The C:N ratio and pH were reduced with ca 10% and 0.1 units, respectively, for all species. No specific effect of species was observed in the mineral soil, but SRC willow had lower C:N ratio in aboveground litter compared to the other species. Thus, five years growth of *Salicaceae* on former agricultural land resulted mainly in general soil effects associated with the cessation of annual management measures, enhanced litter production from trees and ground vegetation, and probably also with altered soil physical conditions, for example humidity and temperature, in the growing plantations.

1. Introduction

Different species of *Salicaceae* are currently grown in ca 70 countries all over the world in mixed forests and plantations or as individual trees. Their area exceeds 80 Mha globally (Ball et al., 2005). The *Salicaceae* species are native to the temperate and subtropical zones. They are fast-growing and easy to cultivate which makes them suitable for several purposes such as wood production, soil and water protection, phytoremediation or bioenergy. Willows have been cultivated for bioenergy purposes in Sweden during the last 30 years and the current plantation area is estimated at ca 9800 ha (Swedish Board of Agriculture, 2014). The attention to *Populus* species and to hybrid aspen in particular can be traced back to the 1940s when the Swedish Match Company was involved in breeding of species and crossings suitable for match wood production. The land area used for commercial *Populus* production in Sweden has remained small until recently when the area planted with hybrid aspen and poplars reached more than 2000 ha (Rytter et al., 2011).

Worldwide deforestation is regarded as the second greatest source of anthropogenic greenhouse gas emissions (IPCC, 2013). Increasing the forested area may therefore have a positive impact on mitigation of high atmospheric CO_2 levels. Afforestation of former agricultural land has been suggested as an important carbon (C) sink in Europe (Powlson et al., 1998). In Sweden, set-aside agricultural land is available and may be cultivated with energy crops for future substitution of fossil fuels (Anon., 2006; Larsson et al., 2009). The C sequestration potential of poplar and willow plantations was estimated at 1.7 Tg C annually, if planted on

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400,000 ha former arable land, which correspond to nearly one tenth of the annual anthropogenic C emissions in Sweden today (Rytter, 2012a). The influence of former land use, species, productivity, soil conditions, soil disturbance and climate on sequestration of soil organic carbon (SOC) has been demonstrated in a number of synthesis studies and reviews (e.g. Agostini et al., 2015; Guo and Gifford, 2002; Paul et al., 2002; Vesterdal et al., 2013). Studies of SOC changes under *Salicaceae* species show varying results. Hansen (1993) found an initial decrease, followed by a recovery. Other studies have reported SOC decreases (Ens et al., 2013), increases (Dimitriou et al., 2012; Kahle et al., 2007; Lafleur et al., 2015; Sartori et al., 2006), or no changes (Grigal and Berguson, 1998; Lockwell et al., 2012; Rytter et al., 2015). Soil preparation and planting procedures may cause disturbance of the soil with subsequent release of CO_2 to the atmosphere. Studies of afforestation with *Salicaceae* suggested that SOC sequestration was significantly correlated with tree age and that soils acted primarily as a source and later as a sink for C (Grigal and Berguson, 1998; Hansen, 1993; Jug et al., 1999). However, the time schedule for afforested arable soils of various types to recover from an initial disturbance and become C sinks is still relatively unknown. Hansen (1993) found that a net addition of SOC occurred in 6–12 years-old plantations with hybrid poplar, but there is a need for more studies on this subject.

Land-use changes may influence mineral nutrient pools, pH and carbon:nitrogen (C:N) ratios in the soil. A slow but continuous change of the soil properties of former arable soils was suggested to be initiated immediately after afforestation with *Salicaceae* (Jug et al., 1999) and with Norway spruce and oak (Ritter et al., 2003). Slow changes in soil chemistry may occur when the soil organisms are adapted to a different litter type, which is the case at afforestation of arable soils (e.g. Binkley, 1995; McClaugherty et al., 1985). Documented early effects of afforestation of former arable soils with various tree species were decreased pH, base saturation and base cation pools with time (Alriksson and Olsson, 1995; Jug et al., 1999; Ritter et al., 2003). An increase of the C:N ratio in mineral soils following afforestation has been noted which could be explained by the supply of organic matter with higher C:N ratio from the new forest, cessation of N fertilization and redistribution of N from mineral soil to biomass and litter (e.g. Jug et al., 1999; Rosenqvist et al., 2010). However, lower soil C:N ratios were found in spruce plantations on former agricultural soils than in plantations on old mixed-forest soils indicating a long-term effect of the former land use (Koerner et al., 1997). Studies of young plantations with *Salicaceae* on former arable soils showed that soils were generally depleted in inorganic N, total N, phosphorus (P), potassium (K) and calcium (Ca) after 3–10 years cultivation (Ens et al., 2013; Jug et al., 1999). Thus, following the changes in soil chemical variables repeatedly after afforestation is important and it will provide data for proper management aiming at an environmentally sustainable production.

The effect of tree species on soil properties has long been a subject of interest and the influence of various species on sizes of nutrient stocks, their distribution in the soil profile, C:N ratio and pH has been studied (Alban, 1982; Binkley, 1995; Hagen-Thorn et al., 2004; Nordén, 1994; Oostra et al., 2006). Specific species effects have been found at afforestation and, for example, lime stands had higher pH and base cation pools than spruce on former arable soils (Hagen-Thorn et al., 2004). Studies of *Salicaceae* species in this context are rare. Jug et al. (1999) found no specific effects of species on soil properties in plantations with *Salicaceae* species on former arable land, but additional studies of the subject is desirable to complete the picture.

Production of bioenergy from fast-growing tree plantations gives the opportunity to meet an increased demand for renewable energy in the near future. Surplus arable land is available and can be used for bioenergy plantations. Accordingly, there is a need for increased knowledge concerning the impact of afforestation with different fast-growing tree species on soil properties. The objective of the present study was to quantify soil effects of plantations with *Salicaceae* at former arable sites in Sweden. The species were hybrid aspen (*Populus tremula* × *Populus tremuloides*), poplar (*Populus* spp.) and willow (*Salix* spp.). The hypotheses were (I) changes in soil variables will be observed already after five years afforestation and (II) differences in soil variables between the *Salicaceae* species will occur.

2. Material and methods

2.1. Site description and experimental design

The study was performed at four former arable sites at latitudes 56–64° and longitudes 13–21° in Sweden (Table 1). The sites were situated near the communities Lövånger (LOV), Bjästa (BJA), Länghem (LAN) and Svalöv (SVA). The climate in Sweden is temperate. The mean length of the vegetation period of the sites varies between 155 and 210 days (Table 1). Average monthly temperature and precipitation in January and July for the study sites are shown in Table 1. Current soil morphology in Sweden is strongly influenced by the last glacial period, Weichsel, which ended about 10,000 years ago (Lundquist, 1994). The dominant soil is till that was formed under glacial ice and covers 75% of the land area. Postglacial sediments originate from the postglacial land uplift and are found in central Sweden and along the northern coast (SGU, 2015). The spread of the study sites over the country implies a variation in soil characteristics from moraine clay and loam in the south to postglacial silt in the north (Table 1). A comprehensive study of Swedish agricultural soils classified 64% of the investigated soils as loams (Eriksson et al., 1999). The soils in the present study are all mineral soils which have been cultivated with annual crops during the last decades. LAN was transferred to tree plantation from active agriculture land when the study started. The sites LOV and SVA were fallows during eight and four years, respectively, and the site BJA was fallow with shrub vegetation during four years prior to plantation of the *Salicaceae* species (Table 1).

The sites were planted in May–July 2009 with hybrid aspen (*P. tremula* L. × *P. tremuloides* Michx.), poplar (*Populus* ssp.) and willow (LOV, BJA: *Salix dasyclados* Wimm., LAN, SVA: *Salix schwerini* E.L. Wolf × *Salix viminalis* L.) in a randomized block design with four replications of each species at each site. The species were randomly distributed on plots of 0.16 ha (40 m × 40 m) in each of the four blocks per site. Each species was represented on 16 plots in total. The sites were prepared by ploughing and harrowing in autumn 2008. Chemical weed controls were applied in 2008 and 2009. Herbicides with the active substance glyphosate were used. Thereafter, mechanical weed control was performed on a few occasions when needed. The plantations were unfertilized during the study period and without irrigation. Further details concerning site preparation are found in Rytter and Lundmark (2010). Hybrid aspen and poplar were planted with one year old plants and willow was planted with 18 cm long cuttings. Hybrid aspen and poplar were planted with the stand density 1500 plants per ha and with an expected rotation of 20–25 years (Rytter et al., 2011; Rytter and Lundmark, 2010). Short rotation coppice willow (SRC) were planted with the stand density 14,800 stems per ha, in double rows with 1.5 m/0.75 m spacing between rows and 0.60 between plants in a row according to the commercial standard in Sweden, and with rotations of 4–5 years (e.g. Mola-Yudego and Aronsson, 2008). Above ground measurements, i.e. survival, diameter in breast height (130 cm, DBH) and tree height were performed during the winter seasons 2013/14 (Rytter and Lundmark, 2014). The