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Poplar and willow plantations on agricultural land in Sweden: Area, yield, groundwater quality and soil organic carbon ☆

Ioannis Dimitriou [a], Blas Mola-Yudego [b,c,*]

[a] Department of Crop Production Ecology, Swedish University of Agricultural Sciences (SLU), P.O. Box 7043, S-750 07 Uppsala, Sweden
[b] School of Forest Sciences, University of Eastern Finland, P.O. Box 111, 80101 Joensuu, Finland
[c] Norwegian Institute of Bioeconomy Research (NIBIO), P.O. Box 115, 1431 Ås, Norway

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ABSTRACT

Poplars (*Populus* spp.) and Willows (*Salix* spp.) are predominantly grown in plantations on arable land in southern and central parts of Sweden to produce biomass for energy and other purposes. The present study aims at characterizing their present situation with special emphasis on the current extension of the cultivation, expected yield levels as well as on their effects on soil and water. The data sources combine own measurements with existing data, trials and records from previous studies. The results show that poplar and willow currently entail 1322 and 9830 ha in Sweden, respectively, being distributed in similar areas in central and south parts of the country, with an average plantation size of 2.59 and 3.87 ha. Productivity varies depending on the measurement methods, being 6.90 and 7.7 Mg ha^{-1} year^{-1} for poplar and willow, respectively, when estimating standing biomass based on small plots but being about half this value when based on harvesting records from commercial experience. Concerning the impact on groundwater quality, poplar plantations presented higher values of NO_3-N and lower values of PO_4-P than willow. These differences were consistent along seasons in case of NO_3-N, and were only observed in autumn in the case of PO_4-P. The results showed no differences between the plantations systems concerning the organic carbon on soil, although in the subsoil (>40 cm) there were slight higher values in case of willow plantations.

1. Introduction

Fast-growing tree plantations are a promising source of biomass with a large potential to feed the demand of raw materials for the energy sector and other conventional industrial purposes. In general, fast-growing plantations are expected to produce a high annual yield and are subject to more intensive practices and shorter rotation periods than conventional forestry. The genera *Populus* and *Salix* include species commonly considered for fast-growing plantations, and are to a certain extent in commercial use in Europe in management regimes called short rotation forestry (FAO, 2008).

Besides high yields, however, it has been highlighted in recent years the additional ecosystem services they can deliver. Several authors have underlined the important role that the development of fast-growing plantations can play in the reduction of CO_2 emissions to the atmosphere through the production of biomass for fossil substitution and CO_2 storage in vegetation and soil (e.g. Börjesson et al., 1997; Dubuisson and Sintzoff, 1998; Cannell, 2003; Rytter, 2012), the positive effects on biodiversity when planted in open spaces, the benefits on rural economies as the result of the diversification of farm crops, and the additional possibilities for environmental control and wastewater treatments, when implemented (Börjesson, 1999; Aronsson and Perttu, 2001; Keoleian and Volk, 2005; Börjesson and Berndes, 2006).

These additional properties stress the importance of not only assessing fast growing plantations in the light of yield production, but in their overall environmental performance, including, among others, aspects such as biodiversity, water and soil quality. This is the case of Sweden, where plantations of both *Populus* (including both poplar and hybrid aspen) and *Salix* have been established in the last decades, predominantly grown on arable land in small plantations where research has been conducted to assess both their productivity as well as their environmental performance.

Most of this research has been primarily targeting willow plantations, due to the larger area planted. For instance, there are

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* Corresponding author at: School of Forest Sciences, University of Eastern Finland, P.O. Box 111, 80101 Joensuu, Finland.
E-mail address: blas.mola@uef.fi (B. Mola-Yudego).

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several studies for willow yield under controlled conditions (e.g. Christersson, 1986, 1987), at commercial level (e.g. Mola-Yudego and Aronsson, 2008; Mola-Yudego, 2011), including the environmental effects under controlled conditions (e.g. Dimitriou and Aronsson, 2011; Weih and Nordh, 2005), in commercial fields (González-García et al., 2012, 2013) and specifically on groundwater (Dimitriou et al., 2012a) and soil quality (Dimitriou et al., 2012b). Concerning poplar, it has been the subject of studies particularly focused on their productivity (e.g. Christersson, 1996, 2010), but there is limited available information of similar level in order to compare both cultivation systems. Dimitriou and Aronsson (2011) suggested that poplars can perform equally well as willows in nitrogen leaching terms if well-established, but there is limited empirical evidence to assess this claim, as despite the many similarities between poplar and willow plantations, there are important differences between both plantations systems concerning their management regimes (rotations, spacing, fertilization practices, etc.). Indeed, Schmidt-Walter and Lamersdorf (2012) reported that poplars grown for several years showed significantly reduced nitrate concentrations in their groundwater compared to willow fields of similar management.

In this context, the present paper aims at characterizing the present situation of short rotation forestry in Sweden, focusing on poplar and willow plantations, with special emphasis on the current extension of the cultivation, on expected yield levels as well as on their effects on groundwater and carbon on soil.

2. Material and methods

2.1. Description of the plantations

Poplars (*Populus* spp.) have been grown in Sweden predominantly in small stands mainly on agricultural land in southern and central parts of the country. Most of the poplar plantations were established in the 1980 and 1990's on set-aside land for demonstration purposes in order to assess productivity. During that period, the most frequent clones planted were OP-42 (*P. maximowiczii* Henry × *P. trichocarpa* Torr. and Gray), followed by balsam poplar (*P. balsamifera* L.) and black cottonwood (*P. trichocarpa*). However, in recent years, the growing demand for biomass for energy in Sweden has increased the interest in poplars (SOU 2007:36). Poplars in Sweden are in general grown on relatively good agriculture land, careful soil preparation, dense planting (i.e. 1110–1610 trees ha^{-1}; spacing $3 \times 3\ m^2$ or $3 \times 2\ m^2$), weeding during the first 2 years, thinning rarely, fencing, and harvesting after ca. 15–20 years by clear felling (Christersson, 2008). Nitrogen fertilization is usually not performed in poplar stands in Sweden (Christersson, 2010). After harvest, the large majority of the plantations is replanted with only very few plantations left to coppice and regrow from the same stumps.

Willows (Salix spp.) have been cultivated also in the southern and central parts of Sweden. The first plots were established for demonstrations, and the first commercial plantations were established in the middle 1980s, followed by a fast expansion (Mola-Yudego and González-Olabarria, 2010). Due to the use of very short rotations, willow plantations are grown under intensive management practices compared to conventional forestry. The expected life span of a willow plantation is considered to be about 25 years, and the same plantation can be harvested several times, with (cutting cycles) from 3 to 6 years followed by whole-shoot harvesting (Mola-Yudego and Aronsson, 2008; Dimitriou and Rosenqvist, 2011) although the harvest interval is often longer if the growth is poor as the fixed costs related to harvesting operations are high (Helby et al., 2004). After the establishment, the willows coppice and left to regrow from the same stumps. Fertilization is a common practice and the recommended amounts are ca. 70 kg N ha^{-1} yr^{-1} on average during the first cutting cycle, applied especially during the third and fourth year, although several other fertilization management regimes have been suggested (Aronsson et al., 2014). The plantations are established from late April to early June and using one-year old shoots (Nordh, 2005). The most widely used current design in Sweden is the double-row system, with distances between rows of 0.75 m and 1.5 m, and spacing between cuttings, within the rows, of 0.6 m.

2.2. Sources of data

A database was constructed retrieving data from trials, experimental plots, measurements from commercial plantations and the farm register. The data sources were based on secondary sources as well as own measurements, designed to match previous experiments (Table 1). The location and area of the plantations was extracted from the farm register provided by the Swedish Board of Agriculture, for the years 2002 and 2014, as the earliest and latest years available, respectively.

The Swedish farm register included records concerning the location as well as size of the plantations. These data aimed to be exhaustive covering all documented areas planted with poplar or willow in Sweden. About poplar yield measurements, data included the results of 4 previous publications as well as 26 own measurements, based on similar methods than the publications (see Table 1). This resulted in 67 plot measurements that included, at least, location, age, mean diameter and mean and dominant height and their standard deviations and errors, number of trees per hectare, and in some cases direct or indirect estimates of above ground dry biomass or annual yield (oven dry tons, Mg ha^{-1} $year^{-1}$). About willow yield measurements, they were based on published records. The database included 16 publications (see details and complete list in Mola-Yudego et al., 2015), with 466 plot measurements that included location, stools per hectare, area, age and annual yield (oven dry tons, Mg ha^{-1} $year^{-1}$). The commercial plantations were assessed from a pool of 1640 plantations (see details in Mola-Yudego and Aronsson, 2008) and included yield and rotation length along the first cutting cycle.

The groundwater quality records were based on own measurements from commercial plantations. In the case of poplar, 8 commercial plantations were studied during 2012–2015. For willow, 16 plantations were studied during 2009–2011. Organic carbon samples were extracted from 21 and 16 of these plantations for poplar and willow, respectively. The criteria for the selection of the willow plantations are described in detail in Dimitriou et al. (2012a,b), and the criteria for the selection of poplar plantations were defined accordingly.

Table 1
Main sources of data included in the analysis.

Variables	Sources
Areas planted and locations	Swedish Land Register (referred to years 2002 and 2014)
Poplar yields and ages (plots)	Johansson and Karačić (2011), Christersson (2010), Karacic, 2005 and Johansson and Hjelm (2014); own data N = 26
Willow yields and ages (plots)	Mola-Yudego et al. (2015): review of 16 publications
Willow yields (commercial)	Mola-Yudego and Aronsson (2008)
Willow rotation lengths (commercial)	Mola-Yudego and Aronsson (2008)
Poplar water data	Own data N = 8
Poplar soil data	Own data N = 21
Willow water data	Dimitriou et al. (2012a)
Willow soil data	Dimitriou et al. (2012b)