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Review

Impact of different establishment methods in terms of tillage and weed management systems on biomass production of willow grown as short rotation coppice

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ABSTRACT

To date little information is available on methods including soil preparation and weed control in SRC. For this purpose, in 2010, a field trial with willow cv. 'Tordis' was established in southwest Germany. Three different tillage systems (mouldboard plough, chisel plough + ley crop, no-till) were implemented in the establishment year in combination with eight chemical and mechanical weed management systems. Over a period of three years, plant and weed specific parameters were collected to determine the effect of tillage systems and weed treatments on final biomass production of willow. The highest biomass yields were obtained by mouldboard plough with chemical weed control (14.0 Mg ha^{-1} dry matter) as well as by mouldboard plough with rotivation and band spraying of herbicides (14.2 Mg ha^{-1} dry matter), followed by 13.7 Mg ha^{-1} dry matter in no-till with broadcast application of herbicides. Chisel ploughing with ley crop led to lower willow yields in most weed treatments. It was assumed that chisel ploughing + ley crop would lead to a high competition for light, water and nutrients especially in the first year. Consequently, it is not recommended as an establishment method for willow. Additionally, mulching with wood chips and no weed management generally resulted in low biomass yields. Overall, the results suggest that the tillage system in combination with effective chemical or mechanical weed control is of major importance for the success of willow establishment.

1. Introduction

Over the last decade the overall demand for woody biomass has increased rapidly in Europe in order to meet the ambitious renewable energy targets. Short rotation coppice (SRC) is considered to have great potential in contributing to renewable heat, power and fuel production in Europe. Crops designated for heat production are mainly fast-growing woody plants like willows (*Salix* spp.) and poplars (*Populus* spp.) [1]. In 2012, the heat production from biomass had a share of 10.4% of the end energy consumption in Germany [2]. However, this wood may also be used in biomass cogeneration plants to create electricity. The amount of these electricity plants in Germany grew from less than 100 in 2002 to more than 600 in 2013, resulting in a total electric capacity of about 1550 MW [3]. Planting of SRC can significantly contribute to the amount of wood required by these and other facilities.

SRCs are defined as fast-growing trees grown on agricultural land and harvested in short rotation intervals [4]. In Germany, willows and poplars proved to be best suited on most sites [5] as they are characterized by rapid growth and good regeneration ability. The cultivation of SRC for wood production on former agricultural land in Germany increased within the period of 2008–2011 from 5000 to 6000 ha [6]. The implementation of SRC plantations can contribute to a saving of fossil fuels whilst offer the ability to sequester more carbon over longer periods than annual crops [7]. Furthermore, greenhouse gas emissions can be reduced by using alternative crop management practices compared to annual crops [8]. However, farmers still hesitate to plant fast growing trees on crop-land due to different hurdles ranging from production and management risks, high establishment costs and

Abbreviations: DBH, diameter at breast height, 1.30 m; SRC, Short Rotation Coppice.

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uncertain supply contracts to minimize the given financial risk over plantation periods of 15–20 years. As most farmers do not have a lot of experience in SRC production, the investment additionally comes with a set of uncertainties concerning establishment methods, plantation management and economic performance.

It has been estimated that during the establishment year, weed competition can reduce SRC growth by 50%–95% [9]. Thus, the long-term yield capacity of a SRC is based on a successful establishment phase. Currently, the most practiced method of SRC establishment is mouldboard ploughing with chemical weed control [10,11]. However, not much information on, and experience with, SRC establishment is available on reduced soil tillage systems in combination with suitable weed management strategies designated for a lower input of machinery and herbicides. Hence, this study aims to test, compare and evaluate different establishment methods for willow as SRC. The establishment methods consist of three different soil tillage systems (mouldboard plough, chisel plough + *Lolium perenne* L. as undersown crop, and no-till) combined with eight different combinations of chemical and mechanical weed control techniques. A weed-free area is especially important during the establishment phase due to a low competitive ability of the unrooted cuttings.

2. Material and methods

2.1. Site

In 2010, a field trial was established at the experimental station 'Ihinger Hof' of the University Hohenheim located in the state of Baden-Württemberg, Germany (Latitude: 48.44° N; Longitude: 8.56° E, average annual temperature 8.3 °C, average annual rainfall 693 mm). Field preparation started in autumn 2009. The trial was carried out on a loess derived soil of the Trias group classified as luvisol and luvisol-pelosol with winter wheat as the previous crop on the field site (Table 1). The trial site was fenced off by a construction site fence to protect the willows from deer browsing.

2.2. Climate

Temperature and rainfall at the trial site varied over the years (Fig. 1). Precipitation was highest in 2010 with 701.9 mm and lowest in 2011 with 591.3 mm. Average temperature ranged from 8.1 °C in 2010 to 9.9 °C in 2011. Planting of willows was done in a rather dry April in 2010. However, heavy rainfall events in May and summer 2010 negated the potential water stress effect that may have accrued earlier in the year.

2.3. Plantation design and establishment strategies

The trial was established as a two factorial completely randomized split-plot design with three replications. Main plots were characterized by three different types of soil preparation consisting of MP = mouldboard ploughing (20–22 cm depth) in October 2009 and harrowing (12–15 cm depth) in spring, CP = chisel plough (12–15 cm depth) in August 2009 and sowing of ryegrass (*L. perenne* L.) cv. 'Kabota' with a sowing rate of 30 kg ha^{-1} and NT = no-till. Subplots consisted of eight different types of chemical and mechanical weed management systems (Table 2). Implemented weed treatments can be characterized as chemical weed management with broadcast application of different pre- and post-emergent herbicides (1–3), a combination of chemical and mechanical weed management where the chemicals were only applied within the willow rows and mechanical treatment between the rows (mulching, rotivation and rolling, 4–6), wood chip application from landscaping residues at a layer thickness of 7.5 cm within the rows (7) and no weed control (8). The herbicides used can be classified as residual pre-emergence herbicides and non-selective post-emergence herbicides. Table 3 illustrates the trade names, active ingredients, target and the application rates of the herbicides. Details towards each treatment are given in Table 2. In the following years, no further weed management was conducted.

In April 2010, willow hybrid 'Tordis' ((*Salix viminalis x Salix scherinii*) *x S. viminalis*) was planted at the trial site. To begin with, 20 cm long willow cuttings were placed vertically by hand in single rows with a distance of 2.0 m × 0.5 m. The subplot size was 12 m × 8 m. This resulted in a total area of 96 m^2 per plot. Every subplot contained four rows with 24 woody plants each. Both outer rows as well as four plants at both ends of the rows were not included in the data collection. Consequently, the data collection took place in a core plot with two rows consisting of 16 willows each. In April 2012, fertilizer was applied on all plots with an N amount of 80 kg ha^{-1} using ENTEC (7.5% Nitrogen-N, 18.5% Ammonia-N and 13% Sulphur).

2.4. Sampling

Over the years 2010–2012, data on phenology, survival rates, plant height, number of shoots per cutting, diameter at breast height (DBH), and weed coverage were collected. Data were collected in the rows of the core plot. The height was measured by a telescopic measuring stick, DBH with a caliper, numbers of shoots per cutting were counted and the weed coverage was valued. The undersown ryegrass was not counted as a weed. The stem diameter was measured on every plant of the sample which was six plants per plot. The diameter at breast height was determined at each shoot, which had reached the measurement height of 1.30 m. Such a variable feature like stem diameter based on different numbers of shoots per cutting can cause large inaccuracies when it should be concluded up to one hectare. In 2013, total biomass yield was determined by hand harvesting the whole plantation with a chainsaw. The cut was made about 3 to 5 cm above the soil surface. Water content was calculated using the difference between fresh weight and oven-dried samples.

Table 1
Local site parameters.

Parameter	
Elevation above sea level (m)	450–508
Geology	Germanic Trias Group (Keuper and Muschelkalk)
Soil classification	Luvisol and Luvisol-Pelosol
Soil type	clay loam/sandy loam
Humus content (%)	1.6
Soil N_t (%)	0.14
pH	7.4