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Research paper

Effects of mechanical weed control or cover crop on the growth and economic viability of two short-rotation willow cultivars

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ABSTRACT

Willow grown as short rotation coppice (SRC) is sensitive to weed competition, so herbicide treatment combined with mechanical weed control is recommended when establishing a plantation. This study compares that practice with two mechanical, row crop cultivator (RC) and row crop cultivator with torsion weeder (RCT), and two cultural treatments, cover crop (CC) and cut cover crop (CCC), to control weeds. Willow responses to these treatments were compared during the first three years after planting using two cultivars, Gudrun and Tordis with broad and narrow leaves, respectively. At harvest, the RCT treatment had produced 27% more biomass than the RC treatment (13.9 vs 11.0 Mg ha^{-1} dry matter) and approximately three times more than the cultural treatments. However, the standard control treatment, herbicides and row crop cultivator (HRC), produced more than all other treatments (17.3 Mg ha^{-1} dry matter). The two cultural treatments had higher plant mortality (CC 26.2% and CCC 32.8%) than the other treatments (HRC 2.7%, RC 7.0% and RCT 7.0%) after the first harvest cycle. No interaction between cultivar and treatment was found for willow shoot biomass, weed biomass or plant mortality. Overall, however, Gudrun had lower plant mortality and less weed biomass after the first harvest cycle than Tordis. All treatment and cultivar combinations gave positive financial annual returns when the whole life-span of the plantation was considered. This study suggests that without using herbicides, it is possible to establish a willow SRC plantation that produce enough to be economically viable.

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1. Introduction

Renewable energy sources must replace non-renewable sources to a greater extent in order to slow CO_2 emissions to the atmosphere and associated global warming. One option is to produce woody biomass from willow shrubs (*Salix* spp.) managed as short-rotation coppice (SRC). This high-yielding perennial crop has a good environmental profile with regards to its high energy balance [1], carbon sequestration properties [2] and low use of pesticides [3], and is grown commercially in several European countries. The expected productive life span of a willow SRC plantation is around 20 years and annual biomass yield in a well-managed commercial plantation can exceed 10 Mg ha^{-1} dry matter [4]. However, to achieve this high production level, successful establishment of the plantation is essential. Poor weed control can ruin young plantations and weed problems explain much of the disappointment farmers report with the crop [5]. The recommended practice when establishing a willow SRC plantation is to spray the field with a broad-spectrum herbicide in the autumn before planting followed by ploughing a couple of weeks later [6]. In the following spring the field is harrowed and dormant unrooted stem cuttings are planted at a density of ~13,000 cuttings ha^{-1}. A pre-emergence herbicide is applied immediately after planting, followed by several mechanical and/or chemical weed control treatments later in the season. If the weed control has been efficient during the first year, there is usually no need for additional weed control during the following years [7]. However, weeding may also be needed in the year after planting and in rare cases also after each harvest, which is performed 5–7 times over the 20 years. The fact that herbicides are usually only applied during establishment and termination of a plantation, i.e.

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during approximately three seasons out of 20, contributes to the good environmental profile of willow SRC. This could be further improved by reducing or omitting the use of herbicides, in line with the EU Directive 2009/128/EC [8]. It states that all professional users should follow the general principles of integrated pest management (IPM), which involves preventative and non-chemical strategies to control pests (including weeds), but chemicals may be used when the other measures are not sufficient. Hence, it is essential to study options for an IPM strategy in willow SRC, without compromising the economic viability of the plantation. Different means of controlling weeds provide the potential to reduce the environmental impact of weed management and at the same time reduce the selection pressure for resistance to a specific herbicide [9]. This is important since the number of herbicides permitted for use in Europe is decreasing and no herbicides with new modes of action have been introduced to the market in recent years [10,11].

One possible non-chemical weed control method that might be suitable for willow SRC is to seed a cover crop when the willow is planted in the spring. An ideal cover crop does not suppress the crop but only the weeds, by competing for resources and/or releasing allelopathic substances. In addition, cover crops can have other positive effects such as reducing soil erosion, increasing soil organic matter, and in the case of legumes, fixing nitrogen [12]. In North America, living cover crops [13] and autumn-sown cover crops killed off in early spring just prior to planting [14] have been tested when establishing willow SRC. The main objective in those studies was reduced soil erosion and not specifically restricted use of herbicides. Cover crops in combination with herbicides proved to be the best option tested in those studies.

Various mechanical weeding devices could also be used to replace herbicides during establishment of willow SRC. Several of these, such as inter-row crop cultivators, row rototillers and disc harrows, were tested during the development of cultivation systems for willow SRC in Sweden in early 1990s [15]. In most cases, all types of weeding equipment satisfactorily controlled the weeds between rows, but weeds within rows were not removed and competed strongly for resources with the willow plants. However, with a torsion weeder it is possible to mechanically control weeds within rows [16,17]. This device consists of two flexible tines tilted towards each other flanking one crop row. The two tines, which can be mounted on a row crop cultivator, uproot weeds near the crop and cover them with soil using a vibrating and dragging movement. Torsion weeders have been used successfully in several row crops, such as onions [17], beans and sugar beet [16].

Weed competitive ability is known to differ with plant genotype in other crops such as wheat [18] and soybean [19]. Growth habit [20], morphology [21,22], canopy architecture [23] and tolerance to drought [24] are traits that may differ between willow cultivars. These traits could influence the weed competitive ability of willow at different stages of crop establishment. The ability of willow to compete with any weeds surviving control measures are probably of greater importance in non-chemical control regimes, since these are usually less efficient than herbicide strategies [25]. Furthermore, certain non-chemical weed control strategies might match certain clonal traits better than others, and vice versa.

In addition to being effective, weed control strategies should not be too expensive. This is especially true in a low-value cash crop such as willow SRC. The recommended establishment practice [6] has been proven to control weeds efficiently and at a cost that allows a positive economic return under Swedish conditions [26]. However, both income (which is dependent on amount of harvested biomass) and the cost of controlling weeds might be affected by a change in weed control strategy. Hence, to investigate whether a certain weed management strategy is economically justifiable, an economic calculation must also consider changes in these two factors.

The objectives of the present study were to 1) investigate whether two willow cultivars with different growth habits differed in their response to certain weed control strategies in terms of biomass production, plant mortality and weed suppression during the first harvest cycle; 2) evaluate the effects of five different weed control strategies on willow SRC biomass production; 3) analyse the expected economic returns from two cultivars under the different weed control strategies, during the first harvest cycle and extrapolated over the entire life span of the plantation.

2. Materials & methods

2.1. Site

The study was conducted close to the campus of the Swedish University of Agricultural Sciences in Alnarp in southern Sweden (55°38′N, 13°4′E, 3 m above sea level). The experimental field was surrounded by a 90 cm high fence with a mesh size of 25 mm to prevent damage by wild animals. Annual precipitation was 740 mm, 565 mm and 590 mm in 2011, 2012 and 2013, respectively, a variation representative of the area [27]. Prior to the experiment, the site had been managed as a conventional agricultural field, with a six-year crop rotation (winter oilseed rape, winter wheat, winter wheat, sugar beet, spring wheat and spring barley).

2.2. Soil characteristics

A total of 30 soil samples were taken between willow double rows to a depth of 25 cm, along a transect running diagonally across the field, in July 2011. All samples were mixed and a sub-sample of this mix was analysed by Agrilab AB (Uppsala, Sweden). Analysis of organic matter was performed according to KLK 1965:1, pH according to ISO 10390 and soil texture according to SS 27123 and SS 27124. The pH of the soil was 7.4 and the content of organic matter, clay, silt and sand was 2.4%, 16.0%, 32.5% and 49.1%, respectively.

2.3. Experimental design

The trial was laid out in a complete randomised block design with five treatments (Table 1) and two commercial willow cultivars in four blocks. Plot size was 9 m × 7 m and each plot had 80 plants in four double rows (east-west direction), with 10 plants per row. The distance between and within double rows was 1.5 m and 0.75 m, respectively, and the distance between plants within rows was approximately 0.7 m. This planting system is commonly used in Swedish commercial willow plantations and gives a density of approximately 13,000 plants per hectare. A border row of the cultivar Tora was planted around each plot and around the whole trial.

2.4. Treatments

The following five treatments (Table 1) were included in the study: Herbicides and row crop cultivator (HRC), row crop cultivator (RC), row crop cultivator with torsion weeder (RCT), cover crop (CC) and cut cover crop (CCC). Dates of weed control measures are shown in Table 1. The 'HRC' control treatment was performed according to a Swedish manual for cultivation of willow SRC [6]. The four non-chemical treatments were chosen based on the fact that they were low-cost, e.g. they used equipment commonly found at farms, somewhat modified in case of the 'RCT' treatment.

In the year before planting, the experimental field had a spring barley crop. There was no need for herbicide treatments during the

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