Available online at www.sciencedirect.com

ScienceDirect

http://www.elsevier.com/locate/biombioe

Long-term yield effects of establishment method and weed control in willow for short rotation coppice (SRC)

Søren Ugilt Larsen [a,b], Uffe Jørgensen [a], Jens Bonderup Kjeldsen [a], Poul Erik Lærke [a,*]

[a] Aarhus University, Department of Agroecology, Blichers Allé 20, DK-8830 Tjele, Denmark
[b] AgroTech – Institute for Agri Technology and Food Innovation, Agro Food Park 15, DK-8200 Aarhus N, Denmark

ARTICLE INFO

Article history:
Received 16 June 2014
Received in revised form
25 September 2014
Accepted 1 October 2014
Available online 26 October 2014

Keywords:
Cutting
Billet
Lay-flat planting
Chemical weed control
Mechanical weed control
Salix

ABSTRACT

A prerequisite for successful willow production is a reliable and economically competitive establishment of the crop. Here, we compare different establishment methods including long-term yield effects. A field trial with the new-bred variety Bjørn was established in 1996 and included four establishment methods; 1) vertical planting of standard 0.2 m cuttings; 2) horizontal planting of 0.1 m billets; 3) horizontal planting of 0.2 m billets; 4) horizontal planting of 1.8 m rods. All establishment methods were combined with mechanical and chemical weed control during the establishment year. Dry matter (DM) yield was measured over 6 harvest rotations corresponding to 16 years. In 1st rotation, yield differed significantly between establishment methods with highest yield for 1.8 m rods (10.4 Mg ha^{-1} year^{-1}), intermediate yield for cuttings and 0.2 m billets (8.6 and 8.5 Mg ha^{-1} year^{-1}, respectively) and lowest for 0.1 m billets (5.6 Mg ha^{-1} year^{-1}). No differences were found in 2nd rotation. Over 1st and 2nd rotation, mechanical weed control resulted in significantly lower yield than chemical control when combined with 0.1 m billets. Cuttings and 1.8 m rods were compared over 1st, 2nd, 3rd, 5th and 6th rotation. Rods gave higher yield in 1st rotation, lower yield in 3rd rotation but there were no significant yield differences in 2nd, 5th and 6th rotations, resulting in similar mean yields of 12.4 and 11.9 Mg ha^{-1} year^{-1} for cuttings and rods over the whole period. The general yield development over time indicates a relatively stable long-term yield level.

1. Introduction

Driving down the costs of establishment and increasing crop vigour and competitiveness are important developmental goals for the market introduction of short rotation willow crops as alternatives to conventional agricultural crops. Whereas the production of many traditional crops has been developed and optimized for centuries, willow for biomass production is still a relatively new crop which needs further improvement.

Establishment costs constitute one of the highest cost units of SRC cultivation and, in general, it is only exceeded by

* *Corresponding author*. Tel.: +45 87 15 76 92; fax: +45 87 15 47 98.
E-mail address: poule.laerke@agrsci.dk (P.E. Lærke).
http://dx.doi.org/10.1016/j.biombioe.2014.10.001
0961-9534/

the costs of land rent and harvesting and chipping [1]. Seen over the life-time of a willow crop (often around 20 years), the establishment costs have been found to constitute up to 30% [2], 16–20% [3] or 13% [4] of the total costs of willow production. In a review of a large number of studies, Hauk et al. [1] found a mean value of 16% of the total costs but with a large variation, e.g. due to variation in planting density.

Because the establishment costs falls in year one, while the first harvest typically occurs after three or four years, the establishment costs represents a major cash flow problem in willow production. Among various reasons, this may contribute to the need for support mechanisms, which is found in most studies of the financial viability of willow production [3,5]. Incentive programmes for willow production may be constructed in various ways [6] and in many countries, establishment costs are partly or fully compensated for by public subsidies, e.g. by payment of approx. 45% of the establishment costs in Denmark, 40–50 % in Scotland [5] and 30% in parts of Germany [7]. In the long run this is not likely to continue, and the development of cheaper, and if possible better, establishment methods will be in demand.

Breeding has led to higher yielding willow clones [8–10] which may improve the competitive ability of willow compared to alternative crops. Often, however, poor management such as incomplete weed control and lack of fertilization under the first commercial introductions of willow has resulted in yields significantly below the potential and thus a poor production economy [11,12].

A very important part of the establishment process is proper weed management during the first year or two, where the willow plants have low competitive ability towards weeds [13,14]. During the establishment year, for instance, plant mortality has been found to be up to 37% and shoot weight reduction up to 96% for willow without weed control compared with willow with weed control [15]. Annual weeds mainly affect the first year's growth until the willow crop has grown competitive [16], while perennial weeds may seriously hamper the crop over the whole lifetime. Weeds can be controlled by various herbicides although some herbicides may also cause damage on the willow crop [13,17,18]. Alternatively, weed control may be done by mechanical methods or in a combination of mechanical and chemical weed control [13]. However, there appears to be limited knowledge on the relative effect of various mechanical and chemical methods.

Traditionally, willow has been established by cuttings that could be planted by the use of a traditional planting machine also used for trees and vegetables. The development around 1990 of the Step Planter by the Swedish company Salix Maskiner introduced a much faster planting process, where whole rods are cut into standard length cuttings directly during the planting process. However, this planting machine needs well assorted rods and it is a complex machine that can be costly in maintenance. In response to these problems, the Swedish company Henriksson Salix AB in the early 1990s investigated the use of an Austoft sugar cane planter to plant 'billets' (i.e. large wood chips) harvested by an Austoft sugar cane harvester. All handling was done by machine, and the billets were distributed in furrows and covered by approximately 2 cm soil [19]. This resulted in very low planting costs and most often proper establishment, and the method was used for establishing some hundred hectares of willow in Skåne in Sweden. The main disadvantages of the method was the need for large amounts of mother material, which was a problem with newly introduced varieties, and the difficulty of storing and transporting the harvested billets for a longer time without loss of quality.

Inspired by old knowledge on willow production for barrel hoops, baskets etc. [20], the owner of Nordic Biomass in Denmark, Johannes Falk, introduced an idea in 1993 for a totally different planting principle and established a pioneer trial where he buried whole willow rods horizontally in approximately 10 cm deep furrows. This first test of the method of the so-called 'lay-flat' planting method showed surprisingly even and good sprouting of shoots along the rods. This fostered the wish for controlled experiments to compare the method with the existing method using traditional cuttings. Therefore, a trial was established in 1996 in Denmark to compare the establishment principles of cuttings, billets and lay-flat planting of rods [19]. Since these trials also gave promising results, Nordic Biomass developed a prototype lay-flat planter in 1998. Over the next couple of years, this prototype was tested in the UK by Border Biofuels to establish several experiments over the UK, and results for the first two harvest rotations have been published for a trial in Wales [21] and a trial in Northern Ireland [22]. Here, we report results from one of the trials established in Denmark in 1996 with comparison of different establishment methods using cuttings, billets or rods as well as their combined effect with two different weed control methods in the establishment year. The effects of two of the establishment methods on yield were followed over five of six harvest rotations over 16 years. Thus, the trial focused on three research questions: i) Can willow be established satisfactorily by use of 1.8 m rods or 0.1 and 0.2 m billets rather than the traditional 0.2 m vertically placed cutting? ii) Can weeds be controlled satisfactorily during the establishment of willow by use of mechanical weed control rather than chemical control? iii) Can the yield level of willow be maintained over a long time-span including several harvest rotations and is the long-term yield influenced by the establishment method?

2. Materials and methods

2.1. *Experimental design and management*

The experimental work was carried out on a loamy sand soil [23] at Research Centre Foulum in the middle of Jutland, Denmark (56° 30′N, 9° 35′E). Prior to the experiment, the field was in regular rotation with grain and seed crops and was almost free of perennial weeds. It was ploughed and harrowed to prepare a proper planting bed.

An experiment was established on May 1st and 2nd 1996 with plant material from one year old shoots of the willow clone Bjørn (*Salix viminalis* × *Salix schwerinii*) bred by Lantmännen SW Seed AB in Sweden (granted variety protection in 1996). Willow was planted in a double row system with 0.75 m internal distance between plant rows within double rows and with 1.25 m between double rows. The trial was established according to a split-plot design with