Sustainability of willow SRF during later cutting cycles

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1. INTRODUCTION

In Sweden, willow (*Salix* spp. L.) short rotation forestry (SRF) became a commercial crop in the early 1990´s and currently 15 000 ha is established on agricultural land (Gustav Melin, Agrobränsle AB, Örebro, Sweden, pers. com). Willow SRF is planted with 1.8 10^4 cuttings ha^{-1} and needs careful management – such as weed control during establishment and fertilisation – to reach high production levels. Harvest is done every 3-5 years (= cutting cycle) and after harvest the stumps produce new sprouts. The life span of a willow SRF plantation is expected to be 20-30 years (Ledin, 1996) but the knowledge about long term stand development and production levels is limited. Earlier studies have shown increased biomass production in the 2nd cutting cycle compared to the 1st cutting cycle (Hytönen, 1995; Hofmann-Schielle *et al.,* 1999; Labrecque and Teodorescu, 2003) while other studies show that stool mortality, as a result of interactions between cutting cycle length, site fertility and plant density, may reduce long term biomass production in willow SRF stands (Willebrand and Verwijst, 1993; Verwijst, 1996).

Sustainability of SRF comprises economical, social and biological aspects. This paper focuses on the sustainability of woody biomass production in willow SRF stands. The development of biomass production over three cutting cycles is described and related to individual plant performance. The consequences of the found results for commercial practise are discussed and management measures are suggested.

2. MATERIAL AND METHODS

The study was carried out in a willow clonal trial established in 1990 on agricultural land outside Västerås in central Sweden (59°37' N, 16°40 E, 10 m above sea level). The soil is a clay soil of post glacial sediments (Alriksson *et al*., 1997). Stem cuttings, 20 cm in length, were planted manually in a double-row design with alternating inter-row distances of 70 cm and 130 cm and a spacing of 50 cm between cuttings within the rows, giving an overall planting density of 2.0 10^4 cuttings·ha^{-1}. The trial was divided into four replicates, each containing 12 randomly distributed monoclonal 10 x 10 m plots with 200 plants in each plot. All measurements and assessments were done on samples from 72 plants in central 6 x 6 m net plots. Two species and twelve clones were represented in the trial, *S. viminalis* L. (11 clones) and *S. dasyclados* Wimm. (1 clone). In the 1st, 2nd, and 3rd cutting cycle the trial was fertilised with 285 kg N ha^{-1}, 310 kg N ha^{-1} and 157 kg N ha^{-1} respectively. The trial was harvested by a commercial willow harvester in March 1994, 1998 and 2002.

Measurements were carried out during three consecutive 4-year cutting cycles; 1990-1993, 1994-1997 and 1998-2001. Plant survival was assessed annually 1990-2001 on 288 plants per clone. Measurements of living woody biomass started in 1991, when the shoots were two-years-old, and were thereafter done annually. A sample of 40 plants per clone was measured and the plants were given individual position numbers so that the same plants could be identified and measured every year. If a plant died it was replaced, keeping the number of measured plants constant. Two methods to measure living woody biomass for individual plants were used (Nordh and Verwijst in press.). In the years 1991-1992 and 1994-2000 a non-destructive method, based on the allometric relation between stem diameter at 55 cm above shoot base (D_{55}) and shoot dry weight (W), was used (Equation 1).

$$W = b \cdot D_{55}^{c} \qquad (1)$$

where b and c are parameters estimated by a destructive sample of 20-30 shoots (Telenius and Verwijst, 1995). In 1993 and 2001 a method based on destructive sampling was used.

Standing dead woody biomass on living plants was measured at two occasions. In 1997 and 2001, all dead shoots from 5 and 40 living plants per clone respectively, were measured destructively. Individual plant weights and plant survival were used to calculate biomass production as ton dry matter per hectare (t DM ha^{-1}).

3. RESULTS AND DISCUSSION

The mean standing living woody biomass for all 12 clones after the 1^{st}, 2^{nd} and 3^{rd} cutting cycle was 31.6 t DM ha^{-1}, 34.1 t DM ha^{-1} and 24.6 t DM ha^{-1} respectively (Figure 1). The annual production increased for each year in the 1st cutting cycle but in the 2nd and 3rd cutting cycle the annual production peaked in the second year and decreased thereafter. Dead standing shoots were also present on most living plants and these shoots contribute to the harvestable biomass in willow SRF (Hytönen, 1995) although most dead shoots are small (Verwijst, 1991). During the 1st cutting cycle, there were few shoots on each plant and low shoot mortality and the dead woody biomass was assumed to be negligible. However, the year after harvest in the 2nd and 3rd cutting cycle there were 2.9 10^5 shoots ha^{-1} and 2.4 10^5 shoots ha^{-1}. At the end of the 2nd cutting cycle 84 % of the shoots had died due to self thinning and the mean standing dead woody biomass for all 12 clones was 7.8 t DM ha^{-1}. The corresponding figures for the 3rd cutting cycle were 73 % and 2.7 t DM ha^{-1}.

The mean plant survival for all 12 clones after the establishment in 1990 (year 1) was 90 % and in the end of 1st, 2nd and 3rd cutting cycle the survival was 87 %, 72% and 60 % respectively (Fig. 2). Plant density after three cutting cycles was 1.2 10^4 plants ha^{-1}.

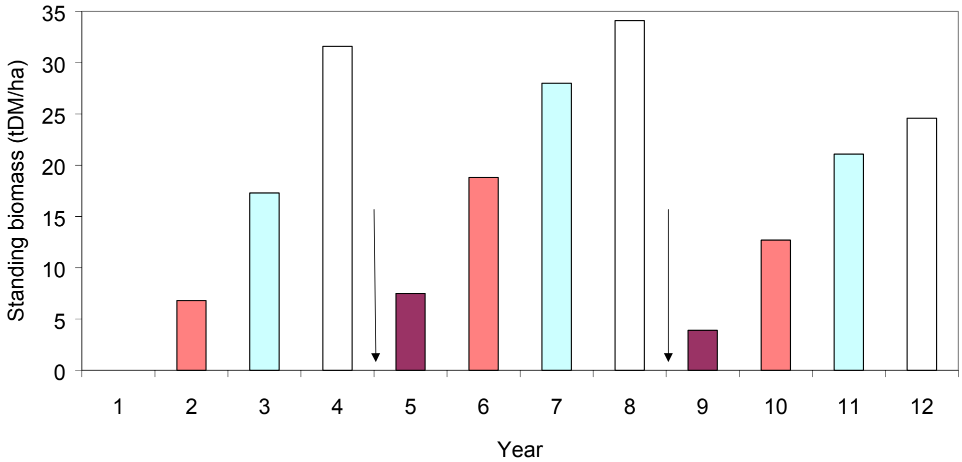

Figure 1. Mean standing living woody biomass for the 12 clones in the end of each growing season during three cutting cycles in the willow clonal trial established 1990 (year 1). Arrows indicate harvest, n = 12

Plant mortality varied between years. The high mortality in year 1 (10 %) depended on poor cutting quality and the low mortality (< 1 %) during the rest of the 1st cutting cycle indicates that competition between plants was low. Competition between plants caused an increased plant death in the end of the 2nd cutting cycle, and in year eight the plant mortality was 13 % (Figure 2). Mortality was also relatively high in the first year of the 3rd cutting cycle (7 %) but was 4 % or less in the following years.

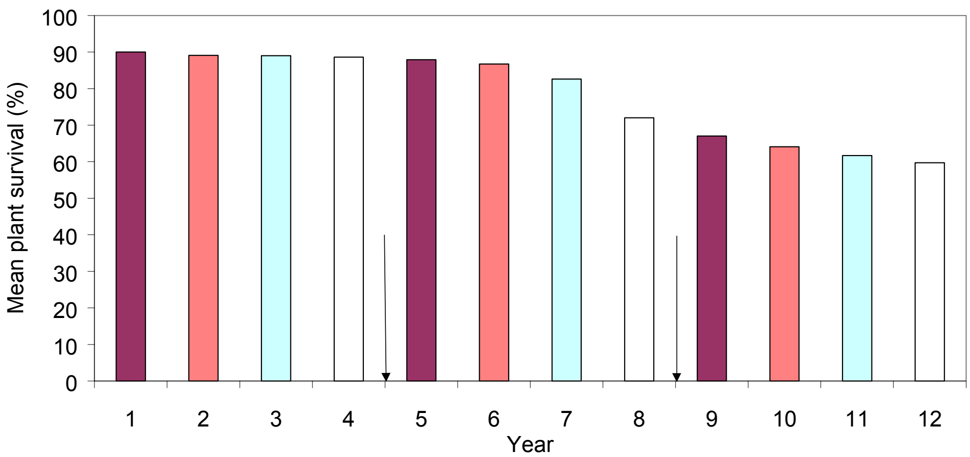

Figure 2. Mean plant survival each year during three cutting cycles for the 12 clones in the willow clonal trial established 1990 (year 1). Arrows indicate harvest, n = 12

The highest survival was found among plants that performed well from the start and were the heaviest after the two first years, and the lowest survival was found among initially small plants. Plants that had a dry weight ≥ 1 10^3 g after the second growing season (year 2) had a 100 % survival in year 12 while plants with a dry weight < 1 10^2 g had 18 % survival in year 12. Consequently, a plant size hierarchy was established already in the 1st cutting cycle and this hierarchy was maintained throughout the 12-year period, i.e., initially large plants remained large and initially small plants remained small.

These trends, described as means for all clones, were also clearly visible in the dynamics of each of the 12 clones.

The results from this study have implications for the management of willow SRF in commercial practise. Cutting quality is important for plant survival and production during the 1st cutting cycle and also has an effect on the establishment of a plant size hierarchy that is maintained in later cutting cycles. Therefore, not only cutting vitality but also size uniformity is an important cutting characteristic. The timing of harvest in relation to standing biomass is also of significance for the maintenance of long term productivity. Part of the decrease in biomass production in the 3rd cutting cycle may be explained by the relatively high plant mortality that occurred, mainly among smaller plants, in the end of the 2nd cutting cycle (Figure 2). This density dependent plant mortality may have been avoided or delayed if harvest in the 2nd cutting cycle had been performed after the third instead of the fourth growing season. As new improved and fast growing clones are introduced on the market (Larsson, 1998; Åhman and Larsson, 1999), the length of the cutting cycles may need to be shortened and/or the plant density reduced for a given site fertility.

4. ACKNOWLEDGEMENT

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