Effects of planting density on growth and yield of hybrid willow (Salix spp.) crops.

J. Caputo, T.A. Volk, L. Abrahamson, G. Johnson
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Introduction

• Wood can be used as a renewable alternative to fossil fuels in the production of energy and products.
• SRWC are widely seen as becoming key sources of consistent, reliable woody feedstocks.
• Hybrid willow (Salix spp.) is a promising and well-studied SRWC.
Willow Biomass Production Cycle

Site Preparation

Planting

First year growth

Coppice

Early spring after coppicing

Harvesting

One-year old after coppice

Three-year old after coppice
Distribution of Expenses Over 22 Years

Cost shares in %, undiscounted

- Stock removal: $740 ha\(^{-1}\)
- Transport: $1,179 ha\(^{-1}\)
- Harvest: $3,778 ha\(^{-1}\)
- Fertilizer: $1225 ha\(^{-1}\)
- Establishment: $2,709 ha\(^{-1}\)
- Administration: $276 ha\(^{-1}\)
- Land cost and insurance: $1,955 ha\(^{-1}\)

(Buchholz and Volk 2010)
Impact of Establishment Costs

- Planting stock accounts for 60 – 80% of establishment costs.
- Current planting costs are about $0.12 per cutting.
- Reducing planting density would reduce establishment costs and increase the IRR.
- Need to better understand the effect of planting density on yield.

Changes in establishment costs and IRR with changes in planting stock costs.
Willow Cash Flow Model

Welcome to EcoWillow v.1.0 (Beta)

An Economic Analysis Tool for Willow Short-Rotation Coppice Plantations for Wood Chip Production

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(Available to download from http://www.esf.edu/willow/download.asp/)

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Idealized Stand Development

(From Oliver and Larson 1996)
Density-Mass Relationship

Fig. 6. Mean stool weight with the different plant arrangements and different number of plants ha\(^{-1}\) at the end of the first cutting cycle (1989–1993).

(Bergkvist and Ledin 1998)
Density and Sprouting…

Fig. 3. Shoot numbers per stool with the different plant arrangements and different number of plants ha$^{-1}$ 2 years after first harvest.

(Bergkvist and Ledin 1998)
Density-Yield Relationships

(Bergkvist and Ledin 1998)

Figure 2. Stem biomass production (tonnes DM ha⁻¹) with the different plant arrangements and different number of plants ha⁻¹ at the end of the first cutting cycle (1989–1993).

(Willebrand and Verwijst 1993)

Figure 3. Standing dry weight-density relations for 2 (--, o), 3 (---, △) and 4-year rotation periods (--, ▽). Open symbols indicate a first harvest, grey symbols a second harvest and black symbols a third harvest. Data were fitted with the Mitscherlich function.
Current Recommendations

• 15,400 plants/ha ($1848/ha if $0.12 per cutting)
• Research on S. *viminalis* in Europe.
• Research from North America on ‘SV1’ (*S. dasyclados*), densities ranging from 15,151-111,111 plants/ha.
• No research on lower densities, or differences between different varieties or growth forms in North America.
Planned Density Trial

- Tully, NY.
- Fully replicated complete block design (5 densities, 4 varieties, 4 reps, n=80).
- Established in 2007.
- Sister study in Waseca, MN.
Planned Density Trial
Four willow varieties

<table>
<thead>
<tr>
<th>Variety</th>
<th>Commercial Name</th>
<th>Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>9871-31</td>
<td>Sherburne</td>
<td><em>Salix sachalinenis x Salix miyabeana</em></td>
</tr>
<tr>
<td>9882-34</td>
<td>Fish Creek</td>
<td><em>Salix purpurea</em></td>
</tr>
<tr>
<td>99207-18</td>
<td>Owasco</td>
<td><em>Salix viminalis x Salix miyabeana</em></td>
</tr>
<tr>
<td>SX64</td>
<td>SX64</td>
<td><em>Salix miyabeana</em></td>
</tr>
</tbody>
</table>
## Five density treatments

<table>
<thead>
<tr>
<th>Spacing (m)</th>
<th>Density (plants/ha)</th>
<th>Planting Cost ($/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>17,498</td>
<td>$2099.76</td>
</tr>
<tr>
<td>0.6</td>
<td>14,352</td>
<td>$1722.24</td>
</tr>
<tr>
<td>0.75</td>
<td>11,665</td>
<td>$1399.80</td>
</tr>
<tr>
<td>1.0</td>
<td>8,749</td>
<td>$1049.88</td>
</tr>
<tr>
<td>1.5</td>
<td>5,833</td>
<td>$699.96</td>
</tr>
</tbody>
</table>
Methods

• For each willow variety, subsampled 5 stems within each of 5 broad diameter classes (n=25). Measured oven-dry mass.
• Used linear regression to plot Ln-mass against Ln-diameter.
• Allometrics used to estimated standing biomass for each of three three years.
# Allometric equations

<table>
<thead>
<tr>
<th>Variety</th>
<th>Equation</th>
<th>R² Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>9871-31</td>
<td>$Y = 2.5792X - 2.1923$</td>
<td>0.992</td>
</tr>
<tr>
<td>9882-34</td>
<td>$Y = 2.7055X - 2.3190$</td>
<td>0.996</td>
</tr>
<tr>
<td>99207-18</td>
<td>$Y = 2.6632X - 2.3271$</td>
<td>0.994</td>
</tr>
<tr>
<td>SX64</td>
<td>$Y = 2.5386X - 1.9778$</td>
<td>0.995</td>
</tr>
</tbody>
</table>

X = Ln-diameter (mm)
Y = Ln-mass (g)
Establishment year survival (%) vs Initial planting density (plants/ha)

- Clone: $P=0.0037$
- Density: $P=0.7664$
- Clone X Density: $P=0.9702$
clone $P=0.0118$
density $P<0.0001$
clone X density $P=0.3713$
clone $P<0.0001$

density $P<0.0001$

clone X density $P=0.3037$
clone $P=0.0004$
density $P<0.0001$
cloned X density $P=0.5333$
clone \( P=0.2455 \)
density \( P=0.0309 \)
clone \( \times \) density \( P=0.7449 \)
clone $P=0.2432$
density $P=0.1745$
clone X density $P=0.7638$
clone $P=0.0273$
density $P=0.1768$
clone X density $P=0.7838$
Mean Annual Increment (SX64)

M.A.I. (ODT/ha/year)

Year after coppice

density (/ha)

- 5833
- 8749
- 11665
- 14352
- 17498
Conclusions...

• Highest total volume production after 3 years with 9882-34 (~25-35 ODT/ha).
• Trend of higher yields at mid- and high density ($P>0.05$)
• M.A.I peaked in year 1 or year 2 across all varieties, sooner at higher densities and with faster growth.
• There seems to be a flexible ‘window’ of planting densities and rotation lengths.
Conclusions...

• Similar trends from the UK...
• Bullard et al. (2002) found significantly higher yields with increasing density (34% between most and least dense plot), peak of 11.4 10 t ha\(^{-1}\) yr\(^{-1}\).
• Wilkinson et al. (2007) found significantly higher yields with higher density, > 10 t ha\(^{-1}\) yr\(^{-1}\).
Next Steps…

• Collect harvest data across multiple rotations, necessary to determine long-term trends.
• Analyze data from Waseca, MN.
• Update EcoWillow Model:
  • Optimal economic rotation will likely be different from optimal physical rotation.
References…


Buchholz, T. and T.A. Volk. 2010 Improving the profitability of willow crops – identifying opportunities with a crop budget model. Bioenergy Research. Published online.


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