Comparison between two and five years rotation models in poplar, willow and black locust Short Rotation Coppices (SRC) in North West Italy

Gianni Facciotto 1, Sara Bergante 1, Laura Rosso 1, Gianfranco Minotta 2

ABSTRACT Currently, SRC plantations should produce multiple assortments, both for industrial and energetic uses, for being economically profitable. SRC trials comparing two different cultivation models (very high density model — vHDM, 8,333 trees ha⁻¹ with 2 years rotation; high density model — HDM, 1,667 trees ha⁻¹ with 5 years rotation) were established in 2005 in two sites (Casale Monferrato and Cavallermaggiore), on agricultural land with alluvial soils in the Western Po Valley (Italy). Both models were applied to poplar (clone 83.141.020), willow (clone S76-008) and black locust (provenance Energy). After 6 years from planting, the two treatments did not show significant differences in terms of cumulative biomass yield, with poplar being the most productive species at Casale Monferrato (64.65 and 63.76 Mg ha⁻¹ with HDM and vHDM, respectively). Black locust showed the lower yield at both sites. In HDM poplar exhibited the highest stem DBH, at both sites, reaching mean values of 15.0 and 17.8 cm at Casale Monferrato and Cavallermaggiore, respectively. In HDM, poplar was the only species capable to reach stem dimensions compatible with industrial destinations at the end of the first 5-years rotation.

KEYWORDS: biomass yield, planting density, cultivation model.

Introduction

On a global scale, increasing energy demand and the need to mitigate climate change emphasize the importance of renewable energy sources. Bio-energy from tree plantations is thus expected to become one of the alternative solutions for energy supply in many countries (Mizey and Racz 2010). A lot of research projects on biomass production from fast growing woody species such as poplar (Populus spp.), willow (Salix spp.), black locust (Robinia pseudoacacia L.) and others, have been conducted throughout the world in order to detect the more suitable planting material and cultural practices to provide high yields and favourable economic results (Manzone et al. 2017, Posza and Borbély 2017, Bender et al. 2016, Bergante and Facciotto 2015, Pleguezuelo et al. 2015, Benetka et al. 2014, Mughini et al. 2014, Redèi et al. 2008, Buschi et al. 2007, Facciotto et al. 2007, Bonari et al. 2004). Given the low market price of woody biomass and consequent low returns, there is still a need for research about many aspects of short rotation woody crops, such as plantation design, rotation length and farm organization (Canellas et al. 2012). Indeed, the choice of planting density influences tree growth, timing of cultural inputs, rotation length, wood quality and, finally, yields and income.

In Italy, typical Short Rotation Coppice (SRC) crops are established with densities of 5,500-8,500 trees ha⁻¹ with 2 or 3-year rotation lengths using mainly poplar clones (Facciotto et al. 2014, Sabatti et al. 2014, Di Matteo et al. 2012). In other countries, under suitable environmental conditions, it is possible to reach densities of about 40,000 trees ha⁻¹ and more with willow clones (Danfors et al. 1998, Kopp et al. 1997). Generally in sites with available water (rain or soil) and cool-temperate climate, very high density are more productive than low density SRC plantations (Armstrong et al. 1999); however, yield is not always linearly correlated with planting density (Kopp et al. 2001, Danfors et al. 1998, Kopp et al. 1997), due to the high competition effects and difficult weed and pest control (Mitchell 1995). With these SRC models each tree produces many stems of small diameter, so wood quality is low and the harvested biomass is suitable only for combustion or particle boards.

SRC plantations established with densities of 1,100-1,670 trees ha⁻¹ and grown with a 5-year rotation cycle have the potential to produce larger assortments suitable not only for energy but also for other more profitable uses (i.e. packaging, oriented strand board - OSB and pulp industries), so widening the market for the woody material produced by the crop. At present, experimental data on yield performances of these 5-year rotation crops are still scarce in Italy, although they could be an alternative to the typical energy woody crops for many farms located in the Po Valley (Manzone et al. 2014, Gonzales-Garcia 2012) due to the better quality of the harvested wood and greater similarity to the traditional ten-year rotation poplar stands widely distributed in the Po Valley and destined for the plywood industry. Indeed, lengthening of the harvest interval may increase the net energy yield of SRC plantations (Nassi et al. 2010, Paris et al. 2015) as well as stand
biodiversity (Weger et al. 2013), thus improving the environmental sustainability of these systems.

SRC trials comparing two different cultivation models: very high density model - vHDM (8,333 trees ha\(^{-1}\) with 2-year rotation), and high density model – HDM (1,667 trees ha\(^{-1}\) with 5-year rotation) both applied to poplar (clone Populus × canadensis Mönch), willow (hybrid of Salix babitonica L. ex Salix matsudana Koidz. S76-008 breeder: CREA Forestry and Wood, Italy), and black locust (provenance of Robinia pseudoacacia L. Energy from Hungary) were therefore conducted at two sites in the Western Po Valley, Piedmont Region (North-West Italy).

**Material and methods**

**Site description**

Two experimental plantations were established in the spring of 2005 at two sites in the Western Po Valley (Tab. 1): at the “Mezzi” farm near Casale Monferrato (Site 1) and belonging to the CREA Forestry and Wood., the Research Agency of the Italian Ministry of Agricultural, Food and Forestry Policies; at the “Alasias Plant” farm close to Cavallermaggiore (Site 2). The climate is transitional between the Continental and Mediterranean type, with hot dry summers, rainy autumns and springs and cool winters; the growing season is from April to October (Tab. 1). The sites have deep and sandy or sandy-loam soils with neutral or moderately alkaline pH, low salinity and active limestone (Tab. 1). The water table is below 4 m in both sites.

**Experimental plots**

Experimental plots were established with 8,333 trees ha\(^{-1}\) in vHDM and 1,667 trees ha\(^{-1}\) in HDM spaced 3 m between rows × 0.40 m along the row and 3 × 2 m, respectively. Rotation length was two and five years for vHDM and HDM, respectively. Each model was established with poplar, willow and black locust using clones/provenances recently selected for biomass by CREA Forestry and Wood, under the Po Valley environments. Each plantation covered an area of 0.30 ha. Poplar and willow vHDM plots were established with stem cuttings 20 cm in length prepared in late winter - early spring and hydrated for a few days before planting. One-year-old seedlings were planted in vHDM black locust plots; at the time of planting these seedlings were subjected to stem pruning to stimulate shoot emission.

HDM plots were created using poplar and willow one-year-old stems deprived of roots and branches; these stems were hydrated for ten days and then planted (vertically) in holes 80 cm deep. Black locust HDM plots were established with one-year-old seedlings left unpruned to favour the development of single-stem individuals.

Before planting the soil was ploughed 40 cm deep, harrowed and treated with NPK (15:15:15) fertilizer, at a dose of 600 kg ha\(^{-1}\). A mixture of herbicides (Methochlor 2.5 l ha\(^{-1}\) + Pendimetalin 2.5 l ha\(^{-1}\)) was applied immediately after planting; subsequently, weed control was performed with mechanical interventions (harrowing) during the first year from planting and after each harvesting in vHDM and during the first two years after planting in HDM. Two insecticide treatments with Chlorpyrifos-methyl + Deltamethrin 2 kg ha\(^{-1}\) were applied against the leaf beetle (Chrysomela populi L.) in poplar plots.

The experimental plantations were irrigated three times during the first, second and third growing season. Watering was suspended starting from the 4th year. Sprinkler (30 mm for each event) and flooding irrigation were applied at Site 1 and Site 2, respectively.

After each harvest, vHDM plots were treated with slow-release N fertilizer (70 kg ha\(^{-1}\)) and with Glufosinate ammonium (8 kg ha\(^{-1}\)) for weed control. The harvesting was performed every two years in vHDM with different strategies. First and second harvest in combined activity with a circular saw, collection with a telescopic handler and separated chipping machine. Third harvest in one operation with a Class harvester and chipping machine. In HDM model an operator felled the trees with a chainsaw, which were then collected with a telescopic handler; chipping was done separately three months later (Spinelli et al. 2012). Fig. 1 shows the timing of the harvest operations in vHDM and HDM plots.

**Table 1 - Climate (mean of 30 years) and soil (top 30 cm) properties at the two sites. Mean annual precipitation (R), Mean precipitation from April to October (vR), Mean annual temperature (T), Average maximum monthly temperatures (Tmax), Average minimum monthly temperatures (Tmin).**

<table>
<thead>
<tr>
<th></th>
<th>Site1</th>
<th>Site 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Latitude</td>
<td>45°08’’N</td>
<td>44°43’’N</td>
</tr>
<tr>
<td>Longitude</td>
<td>08°27’’E</td>
<td>07°41’’E</td>
</tr>
<tr>
<td>Altitude m asl</td>
<td>116</td>
<td>285</td>
</tr>
<tr>
<td>R mm</td>
<td>746.0</td>
<td>626.5</td>
</tr>
<tr>
<td>vR mm</td>
<td>402.0</td>
<td>503.5</td>
</tr>
<tr>
<td>T °C</td>
<td>12.9</td>
<td>11.5</td>
</tr>
<tr>
<td>Tmax °C</td>
<td>24.1</td>
<td>25.2</td>
</tr>
<tr>
<td>Tmin °C</td>
<td>0.2</td>
<td>0.5</td>
</tr>
<tr>
<td>Sand %</td>
<td>87.0</td>
<td>85.7</td>
</tr>
<tr>
<td>Silt %</td>
<td>9.7</td>
<td>11.0</td>
</tr>
<tr>
<td>Clay %</td>
<td>3.3</td>
<td>3.3</td>
</tr>
<tr>
<td>pH</td>
<td>8.0</td>
<td>7.2</td>
</tr>
<tr>
<td>P2O5 tot %</td>
<td>1.6</td>
<td>1.5</td>
</tr>
<tr>
<td>K2O ass. mg/100g</td>
<td>2.4</td>
<td>0.2</td>
</tr>
<tr>
<td>N2 Kjeldahl g/kg</td>
<td>0.50</td>
<td>0.13</td>
</tr>
<tr>
<td>C org. %</td>
<td>4.64</td>
<td>1.71</td>
</tr>
</tbody>
</table>
Comparison between two and five years rotation models in poplar, willow and black locust Short Rotation Coppices (SRC) in North West Italy

**Data collection**

The following parameters were recorded at the end of each growing season on the studied trials:

1. Plant rooting (%) at the end of the first growing season;
2. Plant survival (%) from the second to sixth year after planting;
3. Stem diameter at breast height (DBH) (mm) of all living shoots over 150 cm in height;
4. Number of living sprouts per tree/stump.

Stem DBH was measured on all the tree/stump samples collected in the middle part of the plots (9 trees/stumps per plot in HDM and 69 trees/stumps in vHDM).

Cumulative biomass yield was expressed in dry matter per hectare (Mg dm$^{-1}$ ha$^{-1}$) and was estimated using the following power equations applied to all measured shoots (dominant and dominated). The power equations were derived from the literature for vHDM (poplar: Facciotto et al. 2005; black locust: Facciotto and Bergante 2005; willow: Cerrillo et al. 2008) or specially improved for HDM model measuring single trees during the harvest (DBH, total length and fresh weight; on a subsample dry weight also).

1. Poplar vHDM: $dw = 0.5560 \times D_{100}^{2.166} \quad n=1900 \quad \text{RMSE}=0.93$
2. Willow vHDM: $dw = 1.0 \times D_{100}^{2.123} \quad n=300 \quad \text{RMSE}=0.99$
3. Black locust vHDM: $dw = 1.0 \times D_{100}^{2.123} \quad n=210 \quad \text{RMSE}=0.99$
4. Poplar HDM: $dw = 0.1019 \times D_{50}^{2.046} \quad n=81 \quad \text{RMSE}=0.92$
5. Willow HDM: $dw = 0.0821 \times D_{50}^{2.038} \quad n=47 \quad \text{RMSE}=0.92$
6. Black locust HDM: $dw = 0.0991 \times D_{50}^{2.038} \quad n=39 \quad \text{RMSE}=0.94$

where ‘n’ is number of sampled trees, ‘dw’ is dry weight in g for vHDM or kg for HDM, and ‘D$_{50}$’ is stem DBH in mm for vHDM or cm for HDM. To assess the differences between the actual weight of shoot samples collected during harvest and the predicted values of power equations derived from the literature, the root mean square error (RMSE) was calculated. It resulted as 77 g, 147 g and 212 g for poplar, willow and black locust, respectively.

**Statistical design and analysis**

Experimental plots were arranged in a split-plot design with three replications. Density treatment was allocated in the whole plot and species in the sub plot.

A multifactor ANOVA was conducted separately for each site considering density (1,660 vs 8,333 trees ha$^{-1}$) and species (poplar vs willow vs black locust) factors. The analyses were done using the SPSS statistical package. Figure 2 was performed using R software (ver. 3.5.1, 2018) and package ‘ggplot2’ (Wickham 2016).

**Results and Discussion**

**Site 1 - Casale Monferrato**

At the end of the first year, HDM and willow exhibited the highest rooting percentage between models and among species, respectively (Tab. 2), with mean values varying from 77% (HDM) to 90% (willow). These percentages were similar to those observed in other SRC trials conducted in the Po Valley (Bergante et al. 2010). The differences decreased over time and after six years from planting survival percentage was statistically similar between models and among species. At the end of the trials the mean survival rate was 77 and 50% for HDM and vHDM, respectively. The slight increase in survival percentage observed in black locust plots over the years was due to new stumps originating from the root suckers after the harvesting operations. The high mortality observed in vHDM willow plots was due to the action of rodents which prefer young willow shoots (Danell et al. 1991, Gill 1992). Biomass yield did not show any statistical difference between models, while poplar exhibited a higher production than willow and black locust at the 5th and 6th year after planting (Tab. 3) and this difference was statistically significant.

At the end of the trials mean biomass values varied from 51.63 (HDM) to 55.58 Mg ha$^{-1}$ (vHDM), being 64.21, 51.60 and 45.01 Mg ha$^{-1}$ for poplar, willow and black locust, respectively. Black locust vHDM plots showed a constant increase in biomass yield throughout the three harvesting cycles, while poplar and...
willow exhibited an increase in biomass yield from the first to the second cycle and a decrease from the second to the third. Black locust reached the lowest productivity among HDM plots; this was probably due to the use of unpruned seedlings as planting material and therefore to a slow plant recovery after transplanting, as suggested by the relatively low biomass yield in the second year (Tab. 3). On the whole, the yield trends observed in these trials at Site 1 are consistent with data reported by other authors working with the same species (Verlinden et al. 2015, Paris et al. 2011, Facciotto and Bergante 2005). Geyer et al. (2006) reported no differences in biomass yield for black locust SRC plantations established on the central plains of the USA and submitted to cutting cycles of one, two or five years. Lamerre et al. (2015) observed similar yields in poplar SRC established in an alley-cropping agroforestry system and harvested with 3 and 6-year rotation cycles in Germany. In SRC plantations established in Scotland with poplar, alder and willow, the harvest of biomass reduced yield by 26% with respect to the non-coppiced, single stem trees (Proe et al. 2002), while Weger et al. (2013) reported an increase in biomass yield along with the length of the rotation in poplar SRC established in the Czech Republic, but these effects were not so evident in the present trials.

### Table 2 - Site 1: Rooting (1st year) and survival (from 2nd to 6th year) values (%) and ANOVA results (F values).

<table>
<thead>
<tr>
<th>Model</th>
<th>Species</th>
<th>1st y</th>
<th>2nd y</th>
<th>3rd y</th>
<th>4th y</th>
<th>5th y</th>
<th>6th y</th>
</tr>
</thead>
<tbody>
<tr>
<td>HDM</td>
<td>Poplar</td>
<td>93</td>
<td>93</td>
<td>89</td>
<td>89</td>
<td>75</td>
<td>65</td>
</tr>
<tr>
<td></td>
<td>Willow</td>
<td>99</td>
<td>96</td>
<td>96</td>
<td>94</td>
<td>92</td>
<td>84</td>
</tr>
<tr>
<td></td>
<td>Black Locust</td>
<td>79</td>
<td>76</td>
<td>72</td>
<td>72</td>
<td>71</td>
<td>83</td>
</tr>
<tr>
<td>vHDM</td>
<td>Poplar</td>
<td>76</td>
<td>75</td>
<td>74</td>
<td>74</td>
<td>67</td>
<td>66</td>
</tr>
<tr>
<td></td>
<td>Willow</td>
<td>82</td>
<td>73</td>
<td>53</td>
<td>45</td>
<td>37</td>
<td>37</td>
</tr>
<tr>
<td></td>
<td>Black Locust</td>
<td>73</td>
<td>70</td>
<td>64</td>
<td>58</td>
<td>59</td>
<td>66</td>
</tr>
<tr>
<td>Average:</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>HDM</td>
<td>90</td>
<td>88</td>
<td>86</td>
<td>85</td>
<td>79</td>
<td>77</td>
</tr>
<tr>
<td></td>
<td>vHDM</td>
<td>77</td>
<td>73</td>
<td>64</td>
<td>59</td>
<td>54</td>
<td>56</td>
</tr>
<tr>
<td>F values:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Model (M)</td>
<td>19.97**</td>
<td>16.11</td>
<td>13.56</td>
<td>18.01</td>
<td>14.9</td>
<td>4.21</td>
</tr>
<tr>
<td></td>
<td>Species (S)</td>
<td>4.66**</td>
<td>3.1</td>
<td>2.78</td>
<td>3.75</td>
<td>0.76</td>
<td>4.22</td>
</tr>
<tr>
<td></td>
<td>M × S</td>
<td>0.95</td>
<td>1.59</td>
<td>5.99*</td>
<td>5.56*</td>
<td>10.82**</td>
<td>10.79**</td>
</tr>
</tbody>
</table>
* significant p≤0.05; ** highly significant p≤0.01

### Table 3 - Site 1: cumulative dry matter biomass yield (Mg ha−1) at the 2nd, 4th, 5th and 6th year after planting (HDM was harvested at the 5th year, vHDM at the 2nd, 4th and 6th year) and ANOVA results (F values).

<table>
<thead>
<tr>
<th>Model</th>
<th>Species</th>
<th>2nd y</th>
<th>4th y</th>
<th>5th y</th>
<th>6th y</th>
</tr>
</thead>
<tbody>
<tr>
<td>HDM</td>
<td>Poplar</td>
<td>8.15</td>
<td>48.10</td>
<td>64.25</td>
<td>64.65</td>
</tr>
<tr>
<td></td>
<td>Willow</td>
<td>13.40</td>
<td>44.58</td>
<td>53.55</td>
<td>54.92</td>
</tr>
<tr>
<td></td>
<td>Black Locust</td>
<td>4.05</td>
<td>27.08</td>
<td>33.42</td>
<td>35.32</td>
</tr>
<tr>
<td>vHDM</td>
<td>Poplar</td>
<td>14.19</td>
<td>39.05</td>
<td>45.64</td>
<td>63.76</td>
</tr>
<tr>
<td></td>
<td>Willow</td>
<td>12.55</td>
<td>29.69</td>
<td>34.41</td>
<td>48.27</td>
</tr>
<tr>
<td></td>
<td>Black Locust</td>
<td>12.37</td>
<td>28.41</td>
<td>36.26</td>
<td>54.71</td>
</tr>
<tr>
<td>Average:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>HDM</td>
<td>8.54</td>
<td>39.92</td>
<td>50.40</td>
<td>51.63</td>
</tr>
<tr>
<td></td>
<td>vHDM</td>
<td>13.04</td>
<td>32.39</td>
<td>38.77</td>
<td>55.58</td>
</tr>
<tr>
<td>F values:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Model (M)</td>
<td>4.96</td>
<td>1.57</td>
<td>1.63</td>
<td>0.08</td>
</tr>
<tr>
<td></td>
<td>Species (S)</td>
<td>3.69</td>
<td>4.33</td>
<td>6.82**</td>
<td>7.08**</td>
</tr>
<tr>
<td></td>
<td>M × S</td>
<td>3.64</td>
<td>1.15</td>
<td>2.65</td>
<td>2.78</td>
</tr>
</tbody>
</table>
** highly significant p≤0.01
The resprouting capacity after cutting is an important physiological trait influencing biomass yield in SRC crops (Ceulemans and Deraedt 1999); it is a genetic property that varies according to species and genotype, and frequently considered in the selection phase because it affects production, wood quality and ease of harvesting (Dillen et al. 2013). Tables 4 and 5 report the mean sprout number observed on each stump in HDM and vHDM, respectively. In HDM differences among species started to become significant during the 4th year, with black locust showing the highest value for this factor (1.7 sprouts per stump) followed by willow (1.5), while no sprouts were detected on poplar plants during the first 5-year rotation. After the first harvesting all three species exhibited a good sprouting ability with a number of sprouts per stump equal to 9.4, 4.6 and 4.0 for willow, black locust and poplar, respectively. In vHDM the differences between species were already significant at the end of the first 2-year cycle, with the highest value evidenced by willow (1.5 sprouts per stump) followed by black locust (1.1). In these plots the number of sprouts increased considerably after the second cutting and remained almost stable during the other years. At the end of the trials the number of sprouts per stump was 6.1, 2.8 and 2.0 for willow, poplar and black locust, respectively. Therefore, willow exhibited the highest sprouting ability regardless of the model, as already observed in other SRC trials (Cerrillo et al. 2008, Facciotto et al. 2008, Weih 2004).

### Table 4 - Site 1: number of sprouts per stump and ANOVA results (F values) in HDM plots.

<table>
<thead>
<tr>
<th>Model</th>
<th>Species</th>
<th>1st y</th>
<th>2nd y</th>
<th>3rd y</th>
<th>4th y</th>
<th>5th y</th>
<th>6th y</th>
</tr>
</thead>
<tbody>
<tr>
<td>HDM</td>
<td>Poplar</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>4.0</td>
</tr>
<tr>
<td></td>
<td>Willow</td>
<td>1.0</td>
<td>1.6</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
<td>9.4</td>
</tr>
<tr>
<td></td>
<td>Black Locust</td>
<td>1.0</td>
<td>1.6</td>
<td>2.1</td>
<td>1.7</td>
<td>1.6</td>
<td>4.6</td>
</tr>
<tr>
<td>Average:</td>
<td></td>
<td>1.0</td>
<td>1.4</td>
<td>1.5</td>
<td>1.4</td>
<td>1.4</td>
<td>6.0</td>
</tr>
<tr>
<td>F values:</td>
<td></td>
<td>-</td>
<td>0.99</td>
<td>4.91</td>
<td>9.80*</td>
<td>20.17**</td>
<td>10.80**</td>
</tr>
</tbody>
</table>

* significant p≤0.05; ** highly significant p≤0.01

### Table 5 - Site 1: number of sprouts per stump and ANOVA results (F values) in vHDM plots.

<table>
<thead>
<tr>
<th>Model</th>
<th>Species</th>
<th>1st y</th>
<th>2nd y</th>
<th>3rd y</th>
<th>4th y</th>
<th>5th y</th>
<th>6th y</th>
</tr>
</thead>
<tbody>
<tr>
<td>vHDM</td>
<td>Poplar</td>
<td>1.1</td>
<td>1.2</td>
<td>4.9</td>
<td>3.8</td>
<td>5.0</td>
<td>4.2</td>
</tr>
<tr>
<td></td>
<td>Willow</td>
<td>1.5</td>
<td>2.5</td>
<td>6.4</td>
<td>4.4</td>
<td>7.4</td>
<td>6.1</td>
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<tr>
<td></td>
<td>Black Locust</td>
<td>1.1</td>
<td>1.3</td>
<td>2.6</td>
<td>2.0</td>
<td>3.7</td>
<td>2.7</td>
</tr>
<tr>
<td>Average:</td>
<td></td>
<td>1.2</td>
<td>1.6</td>
<td>4.7</td>
<td>3.4</td>
<td>5.4</td>
<td>4.4</td>
</tr>
<tr>
<td>F values:</td>
<td></td>
<td>30.04**</td>
<td>64.74**</td>
<td>14.94**</td>
<td>17.75**</td>
<td>30.27**</td>
<td>23.60**</td>
</tr>
</tbody>
</table>

** highly significant p≤0.01

### Table 6 - Site 2: rooting (1st year) and survival (from 2nd to 6th year) values (%) and ANOVA results (F values).

<table>
<thead>
<tr>
<th>Model</th>
<th>Species</th>
<th>1st y</th>
<th>2nd y</th>
<th>3rd y</th>
<th>4th y</th>
<th>5th y</th>
<th>6th y</th>
</tr>
</thead>
<tbody>
<tr>
<td>HDM</td>
<td>Poplar</td>
<td>77</td>
<td>80</td>
<td>80</td>
<td>80</td>
<td>80</td>
<td>77</td>
</tr>
<tr>
<td></td>
<td>Willow</td>
<td>99</td>
<td>99</td>
<td>99</td>
<td>97</td>
<td>97</td>
<td>84</td>
</tr>
<tr>
<td></td>
<td>Black Locust</td>
<td>99</td>
<td>100</td>
<td>99</td>
<td>92</td>
<td>99</td>
<td>95</td>
</tr>
<tr>
<td>vHDM</td>
<td>Poplar</td>
<td>84</td>
<td>84</td>
<td>85</td>
<td>85</td>
<td>83</td>
<td>81</td>
</tr>
<tr>
<td></td>
<td>Willow</td>
<td>94</td>
<td>94</td>
<td>92</td>
<td>92</td>
<td>87</td>
<td>83</td>
</tr>
<tr>
<td></td>
<td>Black Locust</td>
<td>75</td>
<td>67</td>
<td>69</td>
<td>66</td>
<td>64</td>
<td>65</td>
</tr>
<tr>
<td>Average:</td>
<td></td>
<td>92</td>
<td>93</td>
<td>92</td>
<td>90</td>
<td>92</td>
<td>85</td>
</tr>
<tr>
<td>F values:</td>
<td></td>
<td>Model (M)</td>
<td>2.95</td>
<td>28.69*</td>
<td>27.63*</td>
<td>20.95*</td>
<td>13.58</td>
</tr>
<tr>
<td>Specie (S)</td>
<td>32.13**</td>
<td>6.63*</td>
<td>8.06*</td>
<td>4.31</td>
<td>3.97</td>
<td>0.4</td>
<td></td>
</tr>
<tr>
<td>M × S</td>
<td>31.46**</td>
<td>10.61**</td>
<td>10.63**</td>
<td>3.95</td>
<td>8.37*</td>
<td>5.75*</td>
<td></td>
</tr>
</tbody>
</table>

* significant p≤0.05; ** highly significant p≤0.01
**Site 2 - Cavallermaggiore**  

At Site 2 most of the rooting and survival values (Tab. 6) were higher than those observed at Site 1. During the first 3-4 years of the trials survival rate was higher in HDM than in vHDM, and for willow than for poplar and black locust plants. In the subsequent years the statistical differences disappeared, even if HDM maintained higher absolute survival rates than vHDM. Only the interaction model x species remained significant till the end of the trials. Six years after planting survival rates were 77, 84 and 95% for poplar, willow and black locust, respectively in HDM plots and to 81, 83 and 65% for the same species in vHDM plots.

**Biomass yield** also reached higher values at Site 2 (Tab. 7), but the differences between models and among species were not significant, probably because of the high variability of the observed data (Fig. 2). At the end of the trials mean cumulative biomass values were equal to 83.93 and 62.75 Mg ha⁻¹ for HDM and vHDM, respectively and to 81.53, 70.37 and 68.12 Mg ha⁻¹ for poplar, willow and black locust, respectively. Therefore even at this site poplar confirmed its high production potential, particularly in HDM plots. On the whole, the trends of biomass accumulation observed here were similar to those detected at Site 1.

**Table 7** - Site 2: cumulative dry matter biomass yield (Mg ha⁻¹) in the 2nd, 4th, 5th and 6th year from planting (HDM was harvested at the 5th year, vHDM at the 2nd, 4th and 6th year) and ANOVA results (F values).

<table>
<thead>
<tr>
<th>Model</th>
<th>Species</th>
<th>2nd y</th>
<th>4th y</th>
<th>5th y</th>
<th>6th y</th>
</tr>
</thead>
<tbody>
<tr>
<td>HDM</td>
<td>Poplar</td>
<td>7.46</td>
<td>57.74</td>
<td>102.88</td>
<td>105.83</td>
</tr>
<tr>
<td></td>
<td>Willow</td>
<td>12.32</td>
<td>49.35</td>
<td>66.66</td>
<td>73.46</td>
</tr>
<tr>
<td></td>
<td>Black Locust</td>
<td>7.60</td>
<td>45.62</td>
<td>66.88</td>
<td>72.50</td>
</tr>
<tr>
<td>vHDM</td>
<td>Poplar</td>
<td>5.38</td>
<td>28.30</td>
<td>41.86</td>
<td>57.22</td>
</tr>
<tr>
<td></td>
<td>Willow</td>
<td>10.80</td>
<td>35.73</td>
<td>51.91</td>
<td>67.29</td>
</tr>
<tr>
<td></td>
<td>Black Locust</td>
<td>11.04</td>
<td>34.85</td>
<td>48.86</td>
<td>63.74</td>
</tr>
<tr>
<td>Average:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HDM</td>
<td></td>
<td>9.12</td>
<td>50.90</td>
<td>78.81</td>
<td>83.93</td>
</tr>
<tr>
<td>vHDM</td>
<td></td>
<td>9.08</td>
<td>32.96</td>
<td>47.54</td>
<td>62.75</td>
</tr>
<tr>
<td>F values:</td>
<td></td>
<td>0.00</td>
<td>7.91</td>
<td>13.89</td>
<td>6.93</td>
</tr>
<tr>
<td>Model (M)</td>
<td></td>
<td>7.26*</td>
<td>0.18</td>
<td>2.19</td>
<td>1.36</td>
</tr>
<tr>
<td>Specie (S)</td>
<td></td>
<td>2.52</td>
<td>2.06</td>
<td>5.72*</td>
<td>3.74</td>
</tr>
</tbody>
</table>

*significants p≤0.05

**Table 8** - Site 2: number of sprouts per stump and ANOVA results (F values) in HDM plots.

<table>
<thead>
<tr>
<th>Model</th>
<th>Species</th>
<th>1st y</th>
<th>2nd y</th>
<th>3rd y</th>
<th>4th y</th>
<th>5th y</th>
<th>6th y</th>
</tr>
</thead>
<tbody>
<tr>
<td>HDM</td>
<td>Poplar</td>
<td>1.0</td>
<td>1.3</td>
<td>1.1</td>
<td>1.1</td>
<td>1.0</td>
<td>9.0</td>
</tr>
<tr>
<td></td>
<td>Willow</td>
<td>1.0</td>
<td>1.1</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>8.0</td>
</tr>
<tr>
<td></td>
<td>Black Locust</td>
<td>1.0</td>
<td>1.1</td>
<td>1.5</td>
<td>1.5</td>
<td>1.4</td>
<td>4.3</td>
</tr>
<tr>
<td>Average:</td>
<td></td>
<td>1.0</td>
<td>1.13</td>
<td>1.20</td>
<td>1.22</td>
<td>1.17</td>
<td>7.08</td>
</tr>
<tr>
<td>F values:</td>
<td></td>
<td>1.0</td>
<td>1.13</td>
<td>1.20</td>
<td>1.22</td>
<td>1.17</td>
<td>7.08</td>
</tr>
</tbody>
</table>

**Table 9** - Site 2: number of sprouts per stump and ANOVA results (F values) in vHDM plots.

<table>
<thead>
<tr>
<th>Model</th>
<th>Species</th>
<th>1st y</th>
<th>2nd y</th>
<th>3rd y</th>
<th>4th y</th>
<th>5th y</th>
<th>6th y</th>
</tr>
</thead>
<tbody>
<tr>
<td>vHDM</td>
<td>Poplar</td>
<td>1.1</td>
<td>1.2</td>
<td>3.9</td>
<td>2.8</td>
<td>6.3</td>
<td>5.1</td>
</tr>
<tr>
<td></td>
<td>Willow</td>
<td>1.6</td>
<td>1.6</td>
<td>7.4</td>
<td>5.1</td>
<td>10.3</td>
<td>8.3</td>
</tr>
<tr>
<td></td>
<td>Black Locust</td>
<td>1.3</td>
<td>1.5</td>
<td>2.0</td>
<td>1.7</td>
<td>3.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Average:</td>
<td></td>
<td>1.36</td>
<td>1.44</td>
<td>4.43</td>
<td>3.20</td>
<td>6.54</td>
<td>5.13</td>
</tr>
<tr>
<td>F values:</td>
<td></td>
<td>19.6**</td>
<td>-</td>
<td>66.8**</td>
<td>21.4**</td>
<td>22.4**</td>
<td>56.9**</td>
</tr>
</tbody>
</table>

** highly significant p≤0.01
*Stem diameter in HDM plots*

Stem DBH measured in HDM plots at the end of the 5th growing season is reported in Tab. 10 for both sites. Poplar exhibited the highest stem DBH regardless of site, reaching mean values of 15.0 and 17.8 cm at Site 1 and Site 2, respectively. Willow and black locust had DBH values much lower than 15 cm, which can be considered as the minimum compatible with the industrial uses of the harvested biomass such as packaging, OSB and pulp industries. The slight diameter growth observed with black locust particularly at Site 1 might be due to the root sprouts emitted by many single-stem individuals during the first rotation. These sprouts could have affected negatively the growth of the main stem when the vigour of young seedlings was still relatively low.

**Conclusions**

In these trials HDM and vHDM did not show significant differences in terms of biomass yield six years after planting; both models can allow a fast accumulation of biomass as required in SRC crops. Among the tested planting materials, poplar clone 83.141.020 exhibited the highest yield and, in HDM plots, it was the only one to reach a mean DBH compatible with industrial uses. Thus, this clone/species appears to be the most capable of achieving the objectives of this crop and, at least at the moment, it should be preferred for the establishment of HDM plantations in the Western Po Valley. However, HDM plants revealed a good resprouting ability when cut at the end of the first 5-year rotation cycle regardless of the tested species. Therefore, from the second rotation onwards, HDM will probably produce only wood for energy or particle boards unless sprouts are properly thinned to recover a single-stem structure. However, to achieve more robust results, trials should be extended to other clones/species and to several HDM rotations in order to evaluate the trend of biomass yield throughout subsequent cycles.

**References**


Comparison between two and five years rotation models in poplar, willow and black locust Short Rotation Coppices (SRC) in North West Italy


Comparison between two and five years rotation models in poplar, willow and black locust Short Rotation Coppices (SRC) in North West Italy


