Screening for Salt Tolerance in Native and Exotic Shrub Willow

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Abstract

Dryland salinity is a significant agronomic problem across the Canadian prairies, with an estimated four million hectares of salt-affected land. The potential exists to make better use of saline marginal lands by developing them into willow plantations as a bioenergy feedstock; however, relatively little is known about the salt tolerance of willow. Apart from limited anecdotal information, no empirical work has been done to examine willow growth on saline soil. The objective of this study was to compare the relative salt tolerance of 37 different native and exotic hybrid willow clones grown under controlled environment conditions on soils with varying salinity. The soils were collected along a hillslope catena influenced by saline seep salinity, containing high concentrations of sulfate salts, which commonly occurs within western Canada. Most willow clones tested in this study were able to tolerate slightly saline conditions (≤ 5.0 dS/m). In addition, several clones (Alpha, India, Owasco, Tully Champion, and 01X-268-015) showed no reduction in growth with moderate salinity (≤ 8.0 dS/m). This work should help to fill the current knowledge gap regarding the salt tolerance of willow and thus provide recommendations for which clones are best suited for establishment on salt-affected soils in Saskatchewan and abroad.

Introduction

As the world population continues to increase exponentially, the need for renewable sources of energy becomes more important. Currently, the use of biomass-derived energy accounts for approximately 10% of the global energy requirement (Berndes et al., 2003); however, with growing desire worldwide for a secure and environmentally acceptable energy source, there is increased interest in developing biomass production systems for use as a dedicated or ‘purpose-grown’ feedstock for bioenergy production. Canada is no exception, with its high per capita energy consumption and the majority of its energy demand used for transportation and building utilities (Cuddihy et al., 2005). Natural Resources Canada, along with a number of Canadian provinces, declares bioenergy to be a legitimate and sustainable source of energy that will constitute a significant portion of future energy production. The establishment of purpose-grown shrub willow (Salix spp.) plantations represents a viable bioenergy feedstock, especially if the willow can be successfully grown on unproductive land that is marginal for annual crop production, such as saline land. Furthermore, with escalating public concern over converting agronomic food crops into fuel crops and the displacement of arable land from food production into bioenergy production, a great opportunity exists to realize economic and environmental benefits, while restoring public confidence, through the development of non-consumable woody crops, like willow, as a bioenergy feedstock. The ability to grow woody crops on marginal land that is deemed unsuitable for annual crop production would be an added benefit.
Dryland salinity is a significant agronomic problem across the Canadian prairies (Acton and Gregorich, 1995). According to Eilers et al. (1995), the incidence of salinity can be summarized as follows: i) the majority (62%) of arable land in the prairies contains less than 1% saline soil; ii) 36% of the arable land contains 1-15% saline soil; and iii) 2% of the arable land contains more than 15% saline soil. Generally speaking, soil salinity affects around 10% of the cultivated land within the prairies, or approximately four million hectares, translating into farm income losses of approximately $250 million annually (Dumanski et al., 1986). A number of studies have examined salinity in Saskatchewan soils (Hogg and Henry, 1984; Henry et al., 1985; Keller and Van der Kamp, 1988), but accurate estimates of saline-affected area are difficult to establish due to its large aerial extent and inherent variability, given the ephemeral nature of salts moving through the soil profile. Nevertheless, it is has been estimated that there are approximately 1.6 million ha of saline soils in Saskatchewan alone (Rennie and Ellis, 1978) and these lands are either being used to grow low return forage crops or have been abandoned altogether. The potential exists, therefore, to make better use of these saline lands by developing them into short-rotation intensive culture willow plantations, which is not only economically positive for the farmer, but also may provide environmental benefits, such as precluding the build up of surface salts given willow’s phreatophytic nature, along with promoting increased biodiversity within the agricultural landscape. However, no empirical work has been done to examine the growth of different willow clones on soils with varying salinity. The objective of this study was to determine the salt tolerance of a number of exotic and native hybrid willow clones. Identifying salt-tolerant clones could promote the use of willow plantations to revitalize these unproductive agricultural lands; thereby supporting agricultural diversification in Saskatchewan and abroad.

Materials and Methods

Collection and Preparation of Saline Soils

The saline soils used in this study were collected from a continually-cropped field (pea-wheat-barley rotation), located approximately 7 km southeast of Central Butte, SK (UTM Coordinates: 13U 400114 5620205). The soils were predominantly Solonetzic loam soils of the Kettlehut Association, with an Agricultural Capability Classification rating of Class 4 (SCSR, 1985). Soils of varying salinity were collected along a hillslope catena, influenced by saline seep salinity, containing high concentrations of sulfate salts, which commonly occurs within western Canada (Fig. 1; Wiebe et al., 2007). The development of saline seeps along such hillslopes is primarily due to the effects of a semi-arid climate and hydrogeology on the translocation and subsequent concentration of naturally occurring salts within near-surface discharge soil layers downslope. Briefly, the soils at this site are greatly influenced by the relatively thin glacial till parent material, derived from the underlying Cretaceous marine clay-shale bedrock rich in Na, Ca, and Mg sulphate salts. Saline seeps typically develop wherever saline groundwater occurs within 1.5 m of the surface, coupled with a local recharge zone, such as upland areas with slopes of 0-2% (Miller et al., 1981; Daniels, 1987). Excess soil water (i.e., beyond evapotranspirative demand) in the upland recharge area infiltrates beyond the root zone, through thin shale-modified salt-rich parent material and contacts the impermeable shale, before moving laterally downslope as unsaturated flow (Holm and Henry, 1982; Henry et al., 1987). As the groundwater follows the local hydraulic gradient downslope, it dissolves and carries salts until concentrating them at or near the soil surface through capillary action and evaporation, particularly during the drier mid-summer months. Consequently, there is a distinct gradient of increasing soil salinity moving downslope, often with the formation of a white salt crust in the depressional area where the salt concentration is the highest.
Figure 1. Hillslope catena near Central Butte, SK where four saline soils were collected along a transect of increasing salinity, due to a saline seep, for use in a growth chamber experiment.
Soils were intensively sampled along a 300m transect from the top of the knoll to the depression, and their electrical conductivities measured, before choosing four slope positions to collect the soils needed to achieve the desired salinity levels for the pot study. Soil was collected from the Ap horizon at each location, air-dried, and then blended to achieve four salinity levels—determined using electrical conductivity values derived from 1:2 (soil:water) extractions (Fig. 2). The four target salinity levels (dS/m; EC<sub>1:2</sub>), classified according to SSTL (1990) were: non-saline (0.1); very slightly saline (1.0); slightly saline (2.0); and moderately saline (4.0). Logistically, the use of 1:2 extractions supported the quickest and most precise blending of the soil into the desired salinity levels; however, the salinity of the saturated paste extracts (EC<sub>e</sub>) were also determined for each soil and will be referred to henceforth, because it is the standard measure of soil salinity in the literature. Additionally, soil nutrients, sodium adsorption ratio (SAR), and pH were also assessed for each soil (Table 1).

![Figure 2](image_url)

**Figure 2.** Collecting Ap horizon soil along a saline hillslope catena near Central Butte, SK (a), blending air-dried soils to achieve desired salinity levels (0.1, 1.0, 2.0, and 4.0 dS/m; b), determined using electrical conductivity values from 1:2 (soil:water) extractions (c).

**Table 1.** Selected Properties of Saline Soils Used to Screen for Salt Tolerance Among Different Native and Exotic Shrub Willow Species

<table>
<thead>
<tr>
<th>Soil</th>
<th>NO&lt;sub&gt;3&lt;/sub&gt;-N (mg/kg)</th>
<th>P</th>
<th>K</th>
<th>S</th>
<th>EC&lt;sub&gt;1:2&lt;/sub&gt;*</th>
<th>EC&lt;sub&gt;e&lt;/sub&gt;**</th>
<th>SAR</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7</td>
<td>19</td>
<td>423</td>
<td>13</td>
<td>0.1</td>
<td>0.8</td>
<td>1.4</td>
<td>7.1</td>
</tr>
<tr>
<td>2</td>
<td>8</td>
<td>51</td>
<td>649</td>
<td>295</td>
<td>1.0</td>
<td>3.6</td>
<td>3.4</td>
<td>7.4</td>
</tr>
<tr>
<td>3</td>
<td>17</td>
<td>54</td>
<td>657</td>
<td>708</td>
<td>2.0</td>
<td>5.0</td>
<td>4.9</td>
<td>7.6</td>
</tr>
<tr>
<td>4</td>
<td>16</td>
<td>40</td>
<td>674</td>
<td>1610</td>
<td>4.0</td>
<td>8.0</td>
<td>9.9</td>
<td>7.9</td>
</tr>
</tbody>
</table>

*<sup>§</sup> 1 (non-saline), 2 (very slightly-saline), 3 (slightly-saline), 4 (moderately-saline).

*<sup>*EC<sub>1:2</sub></sup> – Electrical conductivity of a 1:2 (soil:water) extract.

*<sup>**EC<sub>e</sub></sup> – Electrical conductivity of a saturated paste extract.
Willow Material Used

Plant material of 37 different willow clones was collected from one-year-old stools in the spring of 2009 from clonal trial plots located in Saskatoon (Table 2), sectioned into 15 cm cuttings, and planted in pots containing varying salinity levels (Fig. 3).

![Figure 3. Collecting willow stems from clonal trial plots (a), sectioning stems into cuttings (b), and growing cuttings in pots containing soils of varying salinity (c).]

<table>
<thead>
<tr>
<th>Clone</th>
<th>Species</th>
<th>Sex</th>
<th>Clone</th>
<th>Species</th>
<th>Sex</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allegany</td>
<td><em>S. purpurea</em></td>
<td>F</td>
<td>(20) Saratoga</td>
<td><em>S. purpurea</em> x <em>S. miyabeana</em></td>
<td>F</td>
</tr>
<tr>
<td>Alpha</td>
<td><em>S. viminalis</em></td>
<td>F</td>
<td>(21) Saskatoon D3</td>
<td><em>S. discolor</em></td>
<td>?</td>
</tr>
<tr>
<td>Canastota</td>
<td><em>S. sachalinensis</em> x <em>S. miyabeana</em></td>
<td>M</td>
<td>(22) Saskatoon E3</td>
<td><em>S. eriocephala</em></td>
<td>?</td>
</tr>
<tr>
<td>Charlie</td>
<td><em>S. alba</em> x <em>S. glattelterri</em></td>
<td>?</td>
<td>(23) Sherburne</td>
<td><em>S. sachalinensis</em> x <em>S. miyabeana</em></td>
<td>F</td>
</tr>
<tr>
<td>Cicero</td>
<td><em>S. sachalinensis</em> x <em>S. miyabeana</em></td>
<td>F</td>
<td>(24) SV1</td>
<td><em>S. dasyclados</em></td>
<td>F</td>
</tr>
<tr>
<td>Fabius</td>
<td><em>S. viminalis</em> x <em>S. miyabeana</em></td>
<td>F</td>
<td>(25) SX-61</td>
<td><em>S. sachalinensis</em></td>
<td>F</td>
</tr>
<tr>
<td>Fish Creek</td>
<td><em>S. purpurea</em></td>
<td>M</td>
<td>(26) SX-64</td>
<td><em>S. miyabeana</em></td>
<td>M</td>
</tr>
<tr>
<td>Hotel</td>
<td><em>S. purpurea</em></td>
<td>?</td>
<td>(27) Taberg</td>
<td><em>S. viminalis</em> x <em>S. miyabeana</em></td>
<td>F</td>
</tr>
<tr>
<td>India</td>
<td><em>S. dasyclados</em></td>
<td>M</td>
<td>(28) Truxton</td>
<td><em>S. viminalis</em> x <em>S. miyabeana</em></td>
<td>F</td>
</tr>
<tr>
<td>Juliet</td>
<td><em>S. eriocephala</em></td>
<td>?</td>
<td>(29) Tully Champion</td>
<td><em>S. viminalis</em> x <em>S. miyabeana</em></td>
<td>F</td>
</tr>
<tr>
<td>Marcy</td>
<td><em>S. sachalinensis</em> x <em>S. miyabeana</em></td>
<td>F</td>
<td>(30) Verona</td>
<td><em>S. viminalis</em> x <em>S. miyabeana</em></td>
<td>F</td>
</tr>
<tr>
<td>Millbrook</td>
<td><em>S. purpurea</em> x <em>S. miyabeana</em></td>
<td>F</td>
<td>(31) 94001</td>
<td><em>S. purpurea</em></td>
<td>M</td>
</tr>
<tr>
<td>Oneida</td>
<td><em>S. purpurea</em> x <em>S. miyabeana</em></td>
<td>M</td>
<td>(32) 00X-026-082</td>
<td><em>S. eriocephala</em></td>
<td>M</td>
</tr>
<tr>
<td>Oneonta</td>
<td><em>S. purpurea</em> x <em>S. miyabeana</em></td>
<td>M</td>
<td>(33) 00X-032-094</td>
<td><em>S. eriocephala</em></td>
<td>?</td>
</tr>
<tr>
<td>Onondaga</td>
<td><em>S. purpurea</em></td>
<td>M</td>
<td>(34) 01X-268-015</td>
<td><em>S. viminalis</em> x (S. sachalinensis x <em>S. miyabeana</em>)</td>
<td>?</td>
</tr>
<tr>
<td>Otisco</td>
<td><em>S. viminalis</em> x <em>S. miyabeana</em></td>
<td>F</td>
<td>(35) 9837-77</td>
<td><em>S. eriocephala</em></td>
<td>F</td>
</tr>
<tr>
<td>Owasco</td>
<td><em>S. viminalis</em> x <em>S. miyabeana</em></td>
<td>F</td>
<td>(36) 9882-041</td>
<td><em>S. purpurea</em></td>
<td>F</td>
</tr>
<tr>
<td>S25</td>
<td><em>S. eriocephala</em></td>
<td>F</td>
<td>(37) 99208-038</td>
<td><em>S. viminalis</em> x <em>S. miyabeana</em></td>
<td>F</td>
</tr>
<tr>
<td>S365</td>
<td><em>S. caprea</em></td>
<td>F</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Experimental Design, Growing Conditions, and Sampling Protocol

The experimental setup was a completely randomized design with four replicates. A total of 592 pots were used (i.e., 37 clones x four saline soils x four replicates). One-litre pots were filled with 1.3 kg of saline soil (bulk density approximately 1.3 g/cm$^3$) and watered to field capacity (28%, v/v), before inserting a single willow cutting. Pots were maintained at this soil moisture level by watering every two days for the first two weeks and then daily for the remainder of the experiment. The surface of each pot was covered with white plastic beads to reduce evaporative losses. The pots were placed randomly in a Conviron® controlled environment chamber (Controlled Environments Inc., Pembina, ND.). The willow were grown under a 18:6 h (light:dark) photoperiod, with air temperatures of 22:18 °C (day:night). Relative humidity was approximately 70%. Lighting was provided using Cool White VHO fluorescent and incandescent lamps (Sylvania, Drummondville, ON.). Photon flux density was approximately 400 μmol/m$^2$/s at canopy level and was measured using a LI-COR quantum light meter (model LI-189; LI-COR Inc., Lincoln, NE.). Cutting diameter was measured at the start of the experiment and after 60 days heights were measured before the plants were harvested and the above- and below-ground biomass determined (Fig. 4).

Figure 4. Maintaining field capacity moisture of saline soil (a), harvesting the willow after 60 days (b), and washing roots from each pot to determine below-ground biomass (c).

Statistical Analyses

Measurement variables were analysed using PROC GLM in SAS (version 9.1; SAS Institute Inc., Cary, NC.). Means comparisons were performed using least significant differences (LSD) at a significance level of 0.05. Homogeneity of variances and normality of distributions of all data sets were checked prior to the analysis. No data transformations were necessary.

Results and Discussion

Most willow clones tested in this study were able to tolerate slightly saline conditions (≤ 5.0 dS/m), with no effect of salt level on number of stems, height, or total above- and below-ground biomass (Figs. 5-8). In addition, several clones (Alpha, India, Owasco, Tully Champion, and 01X-268-015) showed no reduction in growth with moderately salinity (≤ 8.0 dS/m; Fig. 8). Moreover, it is interesting to note the relatively lush (i.e., greener and larger) growth of the salt-tolerant clone “India” with increasing salinity (Fig. 9d). This may be due to the presence of residual fertilizer nutrients in these highly saline soils. All regions of the catena received the same fertilizer rates in the past, but given the historically poorer crop growth in the salt affected zones, reduced plant uptake and removal would contribute to higher extractable nutrient levels (i.e., Soil 3 and 4; Table 1).
Figure 5. Mean (n = 148) stem count of native and exotic willow clones grown on soils of varying salinity (dS/m). Bars having the same letter are not significantly different (P >0.05) using LSD.

Figure 6. Mean (n = 148) height of native and exotic willow clones grown on soils of varying salinity (dS/m). Bars having the same letter are not significantly different (P >0.05) using LSD.
Figure 7. Mean (n = 148) total biomass (shoot + root) of native and exotic willow clones grown on soils of varying salinity (dS/m). Bars having the same letter are not significantly different (P >0.05) using LSD.

Figure 8. Total biomass (i.e., shoot + root; n = 4) of different native and exotic willow clones grown for 60 days in moderately-saline (8.0 dS/m) soil. See Table 1 for clone identification. Bars having the same letter are not significantly different (P >0.05) using LSD.
Willow has a very broad genetic base, with an estimated 450 species within the genus *Salix* (Argus, 1997) — of which, 125 species are currently being used in short-rotation intensive culture plantations (Keoleian and Volk, 2005). Given that the clones examined in this study were primarily hybrids among only 10 different willow species (Table 2), the apparent differences in salt tolerance observed among the willow clones is promising, considering that this assessment represents less than 10% of the available willow. Additionally, tremendous intraspecific variation in salt tolerance has been reported for other woody plants, such as *Populus* spp. (Rowland et al., 2004), which is the only other genera within the family *Salicaceae* with willow and, therefore, it is reasonable to assume that willow might share similar variation in salt tolerance among its species.

The degree of saline seep expression is controlled by climatic, hydrogeological, and agricultural factors. The potential to mitigate the aggravating effects of adverse climate and hydrogeological processes is limited. Consequently, implementing agricultural practices aimed at managing hillslope water dynamics is the only practical option available to help prevent, control, or

**Figure 9.** The effect of increasing soil salinity (dS/m) on growth of relatively salt intolerant (Onondaga; above) and tolerant (India; below) willow clones after 10 (a, c) and 60 (b, d) days. Note the relatively lush India with increasing salinity after 60 days.
reverse saline seep development. Specifically, cropping systems that adopt the use of deep-rooted, high water-using, and perennial species, such as willow, would greatly reduce the accumulation and deep percolation of available soil water lost below the rooting zone in the recharge area, (Miller et al., 1981; Henry et al., 1987; Wiebe et al., 2007). Furthermore, establishing salt-tolerant willow within seepage areas also would support the amelioration of this saline soil, by lowering of the water table in these shallow groundwater flow systems discharge areas, thereby supporting leaching of the salts from the profile over time (Daniels, 1987; Henry, 2003). The opposite is apparent when willow rings around sloughs are removed, which often hastens slough-ring salinity problems by trapping less snow (i.e., reduced leaching potential) and increasing evapotranspiration-driven capillary rise and accumulation of surface salts (PFRA, 2000).

Conclusion

The identification of salt-tolerant hybrid willow clones is important when considering options for reclaiming salt-affected marginal lands within western Canada that are deemed unsuitable for annual crop production. We were able to identify clones of willow that could tolerate moderate levels of soil salinity that would preclude the growth of many annual crops. Further research in the field is required to validate the differences in salt tolerance of willow clones observed in this controlled environment study.

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