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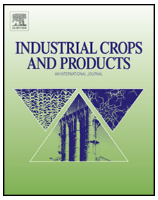

Determining effects of sodicity and salinity on switchgrass and prairie cordgrass germination and plant growth

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ABSTRACT

Marginal and degraded lands are expected to be important resources in the production of biofuel feedstocks in order to avoid real or perceived competition with food, feed and fiber production. Globally, there are millions of hectares of salt-affected land available for lignocellulosic feedstock production. Greenhouse experiments determined the effects of irrigating with water having different levels of salinity and sodicity on seedling emergence, plant growth, and cation balance in plant tissues in several populations of switchgrass (*Panicum virgatum* L.) and prairie cordgrass (*Spartina pectinata* Link). The effect of salt stress on seedling emergence was more pronounced in switchgrass than prairie cordgrass with 31 and 15% reduction, respectively, compared with pure water. In a two-season greenhouse pot experiment, aboveground dry biomass production in control treatments was 8 and 21% higher in prairie cordgrass pc17-102 and pc17-109, respectively, than in EG 1102 switchgrass. Switchgrass EG 1102 produced greater biomass than prairie cordgrass populations when irrigated with moderately saline (5 dS m^{-1}) water, although differences were not detected with highly saline water (10 dS m^{-1}). Switchgrass EG 2101 emergence, plant growth and cation balance were severely affected by increasing levels of salinity. Overall, several prairie cordgrass populations and lowland switchgrass cultivars were found to have good emergence and high biomass production under moderate to high salt stress and may be good candidates for lignocellulosic feedstocks on salt-affected land.

As the volumes of cellulosic biofuels required to be incorporated into ground transportation liquid fuel increase to meet the 2022 requirements of the Renewable Fuel Standard (EISA, 2007; Schnepf and Yacobucci, 2013), production of current and novel lignocellulosic feedstocks will need to increase as well. Production of perennial grasses for forage is widespread, and according to the U.S. Billion Ton Update (United States Department of Energy, 2011), it is expected that these crops will play a significant role in meeting biofuel feedstock requirements. However, the potential competition between energy, food/feed, and environmental needs is often used to stress the importance of growing bioenergy crops on marginal, less-productive land rather than on prime agricultural land (Tilman et al., 2009).

Globally, more than 800 million ha are salt-affected, including an estimated 397 million ha of saline and 434 million ha of sodic land (Munns, 2005; Rengasamy, 2010). It has been estimated that 10% of cultivated land on Canadian prairies is salt affected with an annual farm income loss of $250 million, increasing by at least $1 million annually (Dumanski et al., 1986; Hangs et al., 2011). Salt-affected lands are also widespread in much of the Western U.S.

Salt-affected soils are impacted by high salt concentrations to the extent that soil and water quality and plant health are impacted. Salinization occurs via discharge soils, saline seeps, evaporating ponds, shallow water tables, saline water irrigation, salt spray, penetration of ocean water, and naturally occurring saline/sodic soils caused by parent rock material (McCauley and Jones, 2005; Millar, 2003; Tober et al., 2007). Increased precipitation levels can also result in higher water tables and increased soil salinity as has occurred over the past 15 years in the Red River Valley in the Northern Great Plains of the U.S. (Lobell et al., 2010). Perennial plants provide maximum ground cover and minimize water evaporation from soils that concentrates salts at the soil surface. Perennial, cool-season grasses have the highest tolerance for soil salinity, but warm-season grasses typically have the potential to produce higher biomass yields (Tober et al., 2007).

Prairie cordgrass is a C4 perennial rhizomatous grass that is native to most of the U.S. and as far north as 60°N in Canada. It is often found in dense, pure stands in riparian areas due to its aggressive rhizome spread and its tall stature (Weaver, 1954). It is well adapted to both dry land and wet soils found along marshes,

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roadside ditches, and other low-lying areas (Mobberley, 1956). Recently, prairie cordgrass has gained attention as a bioenergy crop due to its tolerance of abiotic stresses and potential to produce high biomass on marginal land. In a field study in southwestern Quebec, Canada, Madakadze et al. (1998) noted that prairie cordgrass showed the greatest potential for high biomass yields in short-season conditions due to its ability to take advantage of both early spring and fall solar radiation compared with several switchgrass cultivars and other warm-season grasses. They also found that prairie cordgrass had significantly greater tiller number, height, and thickness and generally more and longer leaves. Boe and Lee (2007) found that prairie cordgrass tended to be more productive than three upland switchgrass cultivars during a 4-year field study in South Dakota, U.S.

Switchgrass is also a C4 perennial rhizomatous grass native to most of the U.S. east of the Rocky Mountains (Hitchcock, 1971). The U.S. Department of Energy identified switchgrass as a model energy crop due to its high biomass yields, its adaptability to a wide range of soil types and climatic conditions, and its ability to produce relatively high biomass yields on marginal and less-productive soils (Lee et al., 2007; Lynd et al., 1991; McLaughlin et al., 2002; McLaughlin and Kszos, 2005; Sanderson et al., 1996).

Salinity is typically measured by the soil or water's ability to conduct an electrical current, termed electrical conductivity (EC), which is measured in decisiemens per meter ($\mathrm{dS\,m^{-1}}$). Sodicity, a term denoting a high concentration of sodium in the cation balance, is often measured by calculating the sodium adsorption ratio (SAR) with the following formula:

$$\mathrm{SAR} = \frac{[\mathrm{Na}^{+}]}{\sqrt{([\mathrm{Ca}^{2+}] + [\mathrm{Mg}^{2+}] \div 2)}}$$

Saline water or soil has a pH less than 8.5, an EC greater than $4\,\mathrm{dS\,m^{-1}}$, and a SAR less than 13. Sodic water or soil has a pH greater than 8.5, an EC less than $4\,\mathrm{dS\,m^{-1}}$, and a SAR greater than 13. A sodic-saline classification corresponds to water or soils with pH less than 8.5, an EC greater than $4\,\mathrm{dS\,m^{-1}}$, and a SAR greater than 13 (McCauley and Jones, 2005; Millar, 2003).

Prairie cordgrass is considered moderately salt tolerant compared with the halophytic species in same genus, smooth cordgrass (*Spartina alterniflora*) and saltmeadow cordgrass (*Spartina patens*), all of which commonly occur in Atlantic and Gulf coastal salt marshes (Konisky et al., 2006; Warren et al., 1985). The ornamental grass, sand cordgrass (*Spartina bakeri*) is also known to be highly salt-tolerant (Glen, 2004). Prairie cordgrass has salt glands on the leaf blades and sheaths whereby excess salt is extruded (Kim et al., 2012). Montemayor et al. (2008) found that prairie cordgrass thrives in saline and waterlogged peat fields in New Brunswick, Canada, and showed no growth response in salinity levels ranging from 2 to $20\,\mathrm{dS\,m^{-1}}$ and pH ranging from 4.5 to 2.5.

Switchgrass is considered somewhat salt-tolerant, although the related species *Panicum amarum* is highly salt-tolerant (Glen, 2004). Growth of 'Blackwell' switchgrass, an upland ecotype, was not inhibited by high soluble salt levels present in anaerobically digested waste-activated sewage sludge, with the highest biomass yields being produced in pure sludge at EC $8.8\,\mathrm{dS\,m^{-1}}$ (Rodgers and Anderson, 1995). Harper and Spooner (1983) found that Blackwell established well from seed in acidic, saline bauxite minesoils, but provided poor groundcover and produced little biomass in a study in which soil pH and salinity levels were not reported.

Although mature plants can be injured by salt stress, plants are most susceptible during germination and seedling growth (Tober et al., 2007). Seed germination of sea rocket (*Cakile maritime* Scop.), a halophytic Brassica, was inhibited when treated for 9 days with NaCl solution above 100 mM, but when non-germinated seeds were then moved to pure water, essentially all seeds germinated, showing that germination was inhibited by osmotic stress (Debez et al., 2004). Scheinost et al. (2008) recommended a 50% increase in PLS (pure live seed) seeding rates when planting tall wheatgrass (*Thinopyrum ponticum* (Podp.) Z.-W. Liu & R.-C. Wang) on saline soils compared with non-saline soils even though it can survive in saline soils as high as $26\,\mathrm{dS\,m^{-1}}$. Schmer et al. (2012) found that seed germination in 'Red River' prairie cordgrass was poorest overall and was affected most by increased salinity compared with several cultivars of switchgrass, big bluestem (*Andropogon gerardii* Vitman), and indiangrass (*Sorghastrum nutans* (L.) Nash). The salinity tolerance of 'Alamo' and 'Kanlow' switchgrasses, two lowland ecotypes, was found to be intermediate with both having high germination percentages at $0\,\mathrm{dS\,m^{-1}}$, but exhibiting reduction in germination percentages as salinity was increased to $20\,\mathrm{dS\,m^{-1}}$. In a growth chamber study, Carson and Morris (2012) found that germination in 'Cave-in-Rock' switchgrass, an upland ecotype, decreased by 15, 61 and 95% when subjected to NaCl solutions of 5, 10 and $15\,\mathrm{dS\,m^{-1}}$, respectively, when compared with the pure water control. Kim et al. (2012) reported a greater impact of salinity on seed germination, seedling survival, above- and belowground biomass production for Cave-in-Rock switchgrass than on Red River prairie cordgrass. They also noted an increasing accumulation of sodium in shoot tissue in switchgrass with increasing levels of salinity, whereas shoot sodium levels in prairie cordgrass remained low.

The goals of this study were to determine the effects of saline and saline-sodic irrigation water on: (1) seedling emergence and growth of several populations of prairie cordgrass and switchgrass; and (2) the aboveground growth during the first growing season and the above- and belowground growth during the second growing season of selected prairie cordgrass and switchgrass populations.

1. Materials and methods

1.1. Plant materials

Seeds of three switchgrass (EG 2101, EG 1101 and EG 1102, Blade® Energy Crops, Thousand Oaks, CA, USA) cultivars and six prairie cordgrass (Red River, pc17-102, pc17-109, pc19-106, pc20-102 and pc46-109) populations were stored at 4 °C prior to initiation of the experiment. Red River (Millborn Seeds Inc., Brookings, SD, USA) is a commercially available prairie cordgrass germplasm. All other prairie cordgrass populations were wild populations originating in various locations throughout the Midwestern U.S. Switchgrass EG 2101, EG 1101, and EG 1102 are improved cultivars of Cave-In-Rock, Alamo, and Kanlow bred for high biomass yield, respectively. To test seed viability prior to the greenhouse emergence study, a germination test was conducted on fungicide-treated (ApronMaxx® RTA®, Syngenta Crop Protection, Inc., Greensboro, NC, USA) caryopses (prairie cordgrass) or whole seed (switchgrass) to confirm seed viability based on a method described by Kim et al. (2012). In brief, the bottoms of 10-cm Petri dishes were lined with seed germination blotter paper and saturated with deionized water. Twenty seeds of a given species/cultivar/germplasm were placed in each dish and all dishes sealed with parafilm to prevent evaporation. Three replications were randomly placed in a growth chamber at 15 °C dark/30 °C light with a 16-h photoperiod, and germination checks were conducted approximately every other day for 15 days.

1.2. Seedling emergence

A greenhouse experiment was conducted in Urbana, IL, to determine the effects of varying levels of sodicity and salinity on seedling emergence and growth. The experiment was conducted as a split