Shrub Willow (*Salix* spp.)

**BACKGROUND**

Research and development of shrub willows as biomass crops has been occurring since the mid-seventies in Europe (Börjesson 1999; Volk et al., 2004; Rowe et al., 2008) and early-eighties in North America (Volk et al., 2006, Volk and Luzadis, 2009) because of the multiple environmental and rural development benefits associated with their production and use. Shrub willows have several characteristics that make them ideal feedstock for biofuels, bioproducts and bioenergy: high yields that can be obtained in three to four year rotations, ease of propagation from dormant hardwood cuttings, a broad underutilized genetic base, ease of breeding for several characteristics, and ability to resprout after multiple harvests (Fig 1).

The use of shrub willow for SRWC systems has been extensively evaluated over the past two decades with research centered in Northeastern and western Canada, Sweden, and the US.

**BIOLOGY AND PRODUCTION SYSTEM**

**Site Preparation:** The shrub willow cropping system consists of planting genetically improved varieties in fully prepared open land where weeds have been controlled. Preparing field prior to planting is an essential step in the biological and economic success of willow biomass crops. Typically, field preparation begins in the fall of the year before planting and involves a combination of chemical and mechanical techniques to control weeds. Planting takes place in the spring between the end of April and the beginning of June. In addition, trials incorporating cover crops such as winter rye or white clover during the establishment year has reduced provided cover that would help reduce erosion potential and lower weed pressure without impeding willow establishment and early growth (Adiele and Volk, 2011).

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Planting and Management: Willows are planted as unrooted, dormant hardwood cuttings at about 15,000 plants ha\(^{-1}\) using mechanized planters that are attached to farm tractors and operate at about 0.8 ha hr\(^{-1}\) (Fig 2). To facilitate the management and harvesting of the crop with agricultural machinery, willows are planted in a double-row system. Following the first year of growth, the willows are cut back close to the soil surface during the dormant season to stimulate coppice regrowth, which increases the number of stems per stool from 1-2 to 8-13 depending on the variety. After an additional three to four years of growth, the stems are mechanically harvested during the dormant season after the willows have dropped their leaves.

Harvesting: Different types of harvesting systems have been developed over the years, including whole stem, cut and bail, and single pass cut and chip systems of different sizes. At present, forage harvesters with a specially-designed cutting head cut for woody crops is the most common technique used, producing uniform and consistent-sized chips that can be collected and delivered directly to end users for conversion to bioenergy, biofuels and/or bioproducts - with no additional processing (Fig 3).

Post-Management: The plants will re-sprout the following spring when they are typically fertilized with about 100 kg N ha\(^{-1}\) of commercial fertilizer or organic sources like manure or biosolids. However, fertilization may not be necessary on some sites. The willows are allowed to grow for another three to four year rotation before they are harvested again. The crop can be maintained for seven rotations before the rows of willow stools begin to expand to the point that they are no longer accessible with harvesting equipment. At this point the crop can be replanted by killing the existing stools with herbicides after harvesting and the killed stools are chopped up with a heavy disk and/or grinding machine followed by planting that year or the following year.

BREEDING AND GENETIC IMPROVEMENTS
Worldwide there are 350 to 500 species of willow (Kuzovkina et al., 2008, Smart et al., 2008), with growth forms ranging from prostrate, dwarf species to trees with heights of greater than 40 m. The species used in woody crop systems are primarily from the subgenus Caprisalix (Vetrix), which has over 125 species worldwide (Kuzovkina et al., 2008). While these species have many characteristics in common, their growth habits, life history, and resistance to pests and diseases
vary, which is important in the successful development of woody crops. Willow’s ability for vegetative propagation means that once superior individuals with genetic gains are identified, they can be maintained and those individuals can be multiplied rapidly for deployment.

Selection trials of new varieties from the initial rounds of the breeding programs in the late 1990s have produced yields that are up to 15-20% greater in the first rotation, and 30% greater in the second rotation than the standard varieties used in early yield trials. These results indicate that there is a large potential to make use of the wide genetic diversity of shrub willows to improve yields with traditional breeding and selection (US DOE, 2011).

**BIOMASS PRODUCTION**

A rapid growth rate is one of the attributes that make shrub willows an appealing biomass crop. First-rotation, non-irrigated research-scale trials in the US Northeast have produced yields (oven dry ton - odt) of 8.4 to 11.6 Mg ha\(^{-1}\) yr\(^{-1}\). Second rotation yields of the five best producing varieties in these trials increased by 18–62% compared to first-rotations and in subsequent rotations yields are maintained and largely dependent on weather conditions.

The most recent yield trials using improved varieties of willow are showing yield increases of 20-40%. Growth rates of new willow varieties exceed 15 Mg (oven dry) ha\(^{-1}\) yr\(^{-1}\) (Volk et al., 2011) planted in Quebec, Canada (Fig 4). The mean yield of improved willow varieties grown in Canada and the US is 11.31 Mg (oven dry) ha\(^{-1}\) yr\(^{-1}\) (Fig 4). Yields of fertilized and irrigated unimproved varieties of willow grown for three years have exceeded 27 Mg (oven dry) ha\(^{-1}\) yr\(^{-1}\) in the Northeast and Midwest US.

**QUESTIONS OR COMMENTS?**

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