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Research paper

Planting rates and delays during the establishment of willow biomass crops

Charles Bush, Timothy A. Volk, Mark H. Eisenbies*

State University of New York, College of Environmental Science and Forestry, 1 Forestry Dr., Syracuse, NY 13210, USA

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ABSTRACT

Biomass for bioproducts and bioenergy can be sourced from multiple sources. There is little information on commercial planting operations for willow biomass crops in North America. The objectives of this study were to evaluate the field capacities of two commercial machines (Step and Egedal Energy Planter) planting willow crops in northern New York State, determine the amount and distribution of delays. A study was conducted to evaluate planter activities. The two machines had similar mean field capacities (C_f) ranging from 0.89 to 1.14 ha h^{-1}. Above-average rainfall in the later part of the planting season decreased C_f by over 20% for the Step planter from 1.14 to 0.91 ha h^{-1}; largely due to delays in the headlands. Approximately 70% of the total delay time associated with the Step planter consisted of long-duration delays (>5 min) compared to 35% for the Egedal. Quality of planting stock was an issue for operations; undersized stems resulted in feeding issues. Several potential factors were identified for improved planting operations: loading stems and clearing feeding mechanisms at each turn, improved planting stock and quality control, improving machine design for wet conditions, and improved preparation for in-field repairs. In-field delays should be minimized to reduce demand on the crew and ensure a more uniform crop is established in the field.

1. Introduction

The development of sustainably produced biomass as a feedstock for biofuels, bioproducts, and bioenergy is of interest due to concerns about energy security, environment and human health, rural economic development, and the need to diversify products and markets for forestry and agriculture. Biomass can come from a variety of sources including forests, agricultural crops, various residue streams, and dedicated woody or herbaceous crops. The "Billion Ton" study suggests that dry biomass at 67 \$ Mg_{dry}^{-1} could result in the deployment of 140–350 Tg_{dry} for various scenarios by 2030 [1]. This deployment would put millions of hectares of land into production, create thousands of rural jobs, and produce an array of environmental benefits.

Interest in short rotation woody crops (SRWC) has developed over the past few decades because of the environmental and rural development benefits associated with their production and use [2]. SRWC development in the northern temperate regions of the U.S. has concentrated on shrub willow (*Salix* spp.) grown on short rotations using coppice management. In addition, hybrid poplar (*Populus* spp.) may be grown on slightly longer rotations using a single stem system primarily for the solid wood and pulp markets. While tens of thousands of hectares of poplar have been deployed in the United States in the Midwest and Pacific Northwest, large scale deployment of willow has been limited in North America.

Despite the numerous environmental and rural development benefits associated with willow biomass crops, these systems have not yet been widely adopted and as a result feedstock production systems, markets and supply systems are in their infancy in terms of development. The main technical barrier to deployment is the current high cost to produce and deliver perennial energy crops to an end user [3]. A commercial SRWC enterprise will not be viable unless stakeholders are able to realize a reasonable rate of return on their investments. Under current conditions in the northeastern United States an initial investment of 1980–2475 \$ ha^{-1} to

Abbreviations: BCAP, Biomass Crop Assistance Program; C_f, field capacity; FS, C_f at field speed; FSD, C_f in field including delay time; GPS, global positioning system; HLD, C_f of field operations including turn times and all delays; HLT, C_f of field operations including turn time in headland; NOAA, National Oceananic and Atmospheric Administration; SRWC, short rotation woody crops; USDA, United States Department of Agriculture.

* Corresponding author. SUNY-ESF, 1 Forestry Dr., 341 Illick Hall, Syracuse, NY 13210, USA.
E-mail address: mheisenb@esf.edu (M.H. Eisenbies).

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establish willow biomass crops is not recouped until 9–12 years after planting [3]. The internal rate of return from well-established and managed willow biomass crops and a delivered price of 60 $ Mg_{dry} is 5.5% over a 22 year period. The delay in recovering upfront costs, narrow margins, and the uncertainty of the long-term prospects for a woody biomass market create barriers to the deployment of this crop. While establishment costs are 15–25% of the overall cost of the crop, they are important because they are the first large investment in the system and the quality of crop establishment impacts the yield and returns from the crop for the next 20–25 years [4].

A USDA Biomass Crop Assistance Program (BCAP) project area for willow biomass crops in northern NY was announced in June 2012 [5]. The project will support the production of willow on 580 ha of land in a three county region. ReEnergy Holdings LLC has signed agreements with the landowners growing willow biomass crops to purchase all of the biomass produced under this program and use it for the production of power and/or heat and power in one of its facilities in northern NY. The BCAP program provides cost share payments to growers for establishing biomass crops and annual rental payments to landowners in years when there is no harvest. Together the programs components address a number of barriers to the deployment of the crop including the high upfront costs, inconsistent cash flow, and uncertain future markets.

While research on willow biomass crops has been occurring in the northeast U.S. since the mid-1980's most of the work has focused on smaller plot trials that are less than a hectare to a few hectares in size [6]. As a result commercial willow producers face uncertainties with regards to crop establishment and management at larger scales. The lack of data on large-scale production of the crop creates challenges in planning for crop expansion, especially with the relatively narrow planting window in the spring of the year. Additionally, in order to reduce costs, reliable estimates of system performance are required, especially for establishment and harvesting, which are two of the largest cost factors in the production system [7,8].

A single study from Europe that reported field capacities between 0.28 and 1.2 ha h^{-1} for woody crops (willow, poplar, and black locust) planted at densities of 6700 ha^{-1}, about 44% of the recommended density for willow (15,400 plants ha^{-1}) in the U.S [9,10]. Data on large scale planting operations for willow biomass crops is lacking for North America. This kind of uncertainty creates challenges for producers evaluating the economics of these systems and making well-informed management decisions. Field capacity (C_f) is an important value for growers to use when deciding how many planters and associated equipment is needed to establish a given area of land during the growing season [11,12].

The establishment of willow biomass crops in northern NY as part of the USDA BCAP project area in the spring of 2013 provided an opportunity to collect data on planting rates for willow biomass crops with the following objectives: (1) to document and compare the field capacities for two planters (Step and Egedal Energy planters) that are currently available in northeastern North America; (2) to determine the impact planting delays have on C_f.

2. Methods

2.1. Site description

Planting for this trial occurred on 15 fields in Jefferson County in northern NY in May and June 2013 clustered in three groups near 44°06′46.33″N 76°16′09.40″W, 44°03′47.44″N 76°17′03.23″W, and 44°00′15.03″N 76°06′27.36″W. Individual field sizes ranged from 10 to 40 ha in size. Soils formed in parent materials consisting of marine and glacial lake sediments; they are typically silty-clay or silty-clay-loam in texture, and have mixed mineralogy, variable drainage classes, and variable depths [13]. Fifteen soil series are represented, but the Kingsbury and Chaumont series are the most prevalent; using the US Taxonomic system most soils are classified as Alfisols or Inceptisols with udic or aquic moisture regimes. Slopes were less than 8%. The climate at this location is generally milder than interior parts of the region because of the close proximity to Lake Ontario. These water bodies also extend the growing season [14]. The mean annual temperature is 7.2 °C, the 20-y mean growing degree days are over 2200 days between April and September, and mean annual precipitation is approximately 100 cm y^{-1} [13].

2.2. Planting

Planting stock was sourced from a local supplier (Double A Willow, Fredonia, NY). Twelve different shrub willow cultivars, representing four diversity groups were planted in the spring of 2013. Plantings consisted of mixtures of four to six cultivars that were combined at the edge of the field and loaded onto the planter.

Two planters designed for willow crops were used during the planting season. Crews had agriculture crop production experience but limited experience with willow because commercial willow plantings are not widespread. The first planter was a 1998, four-row Step planter (Salix Maskiner, Hedemora, Sweden) drawn by a Case Maxxum 140 four wheel drive tractor (105 kW). The specific planter unit has been used to establish hundreds of hectares in the northeast and Midwest over the past 15 years. Operators insert 1.5–2.5-m long willow stems into channel that is lined with belts, which take the stem and move it down a set distance. At the base of the channel a section of the stem is cut off and the severed cutting is forced into the ground by a plunger. The Step Planter plants two sets of 0.76-m double rows, 4.88 m between centers resulting in a projected stem density of approximately 13,450 stems ha^{-1} when the spacing between cuttings along a row is set at 51 cm.

The second planter was a 2008, four-row Egedal Energy planter (Egedal Maskinfabrik A/S, Tørring, Denmark) drawn by a John Deere model 7530 four wheel drive tractor (134 kW). The Egedal has been used to plant willow crops in various locations in the northeast U.S. Like the Step planter the Egedal takes a willow stem, cuts them to a preset length and plants them in a single operation. However, instead of actively pushing the cutting into the soil, a furrow slicer creates a slit in the soil, and the cutting is dropped into the opening which is subsequently closed with packing wheels. The Egedal also plants double-rows in a single pass, but its spacing was set for 5.03 m on centers since new planting recommendations suggest leaving more room for the wheels and wheelbase of current harvesting equipment as not to affect harvester performance [10,15]. Projected stem density in this case is approximately 13,050 stems ha^{-1} assuming the distance between cuttings along the row is 51 cm.

2.3. Evaluation of planting operations

Monitoring of planting operations occurred on a 44.3 ha of the 15 fields from May 13 to June 25, 2013. The Step planter was utilized for the entire period. The Egedal planter began operations June 1, 2013. Planting activities were tracked using a combination of GPS data loggers (GeoXM GPS or Juno SB GPS, Trimble Navigation Ltd., Sunnyvale, CA) recording positions every second and field observations by a individual stationed at one end of the field. Equipped with an external antenna these units are capable of 1–3 m accuracy after differential corrections. Observers noted activities such as field entries, exits, maintenance, reloading with planting stock and other planting machinery activities when possible. When the