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Research paper

Biomass, spacing and planting design influence cut-and-chip harvesting in hybrid poplar

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ABSTRACT

Hybrid poplar is a woody crop grown for the production of bioenergy, biofuels and bioproducts. Harvesting is often the largest single cost in the production system and the development and optimization of equipment is evolving. The objective of this study was to evaluate the performance of a single-pass, cut-and-chip harvesting operation in commercial plantings that included four cultivars, two spacing treatments, and two coppice planting designs (dedicated, and interplanted with sawtimber). Approximately 15 h of harvesting using a New Holland 9080 forage harvester equipped with a purpose-built coppice header was monitored over four days. Stand biomass ranged between 34 and 78 Mg ha^{-1}of fresh biomass and effective material capacity (C_m) of the harvester ranged from 10 to 78 Mg h^{-1}of fresh biomass excluding headland activities. Tree spacing had a significant effect on C_m but cultivar and planting design did not. The treatments did not have discernible effects on machine fuel consumption (mean 83 L h^{-1}; σ 16.4) or crop-specific fuel consumption for fresh biomass (mean 1.34 L Mg^{-1}; σ 0.31). Crop-specific fuel consumption was positively correlated with engine load, and negatively correlated with standing biomass; this result was statistically significant but negligible (<1%) in terms of liters of fuel used for each additional Mg ha^{-1} of stand biomass for engine loads ranging between 30% and 110%.

1. Introduction

Sources of biomass for bioproducts and bioenergy include forests, agricultural crops, various residue and waste streams, and dedicated woody or herbaceous crops [1,2]. However, an important challenge is to create supply systems that are cost effective and efficiently deliver large quantities of biomass while maintaining quality [1]. Additionally, there are concerns about the environmental impact of these sources, their sustained performance, the technical constraints for conversion, as well as a stable and predictable policy environment [3–6]. It is unlikely that any one source of feedstock will dominate since supplies of dedicated crops as well as agricultural and forest residuals are subject to a variety of market forces and prices [1]. Short-rotation woody crops (SRWC) have had some commercial success in the United States [7,8], and they have the potential to provide ecosystem and environmental benefits in addition to energy production [9–11].

SRWC are managed using a combination of techniques and knowledge from both agriculture and forestry. These systems typically have higher planting densities and more intensive management than most forest systems. In many cases, stands are regenerated by coppice rather than planting [12]. The reported range for above-ground yield for short-rotation poplar ranges between 2 and 19 Mg ha^{-1} yr^{-1}of oven dried biomass depending on site characteristics, soil properties, climate, and cultivar, but most yields range between 9 and 13 Mg ha^{-1} yr^{-1} [7,13,14]. Although SRWC systems might include agronomic practices such as irrigation, management strategies are still grounded on silvicultural practices used in forestry. The timing of weed control and fertilization rates are similar to forest plantation systems, and growth, yield, and stem form can be highly influenced by spacing [12,15,16].

The Northwestern United States is an important region with

Abbreviations: C_m, Effective Material Capacity; C_f, Effective Field Capacity; GPS, global positioning system; LLC, limited liability company; SPCC, single pass cut and chip; SRWC, short-rotation woody crop.

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substantial lands and infrastructure devoted to the production of wood and wood fiber [1]. One potentially important crop includes dedicated *Populus* grown as SRWC [17]. One of the principal advantages of poplar is the ability to vegetatively propagate from hardwood cuttings and coppice under field conditions [18]. This method of crop establishment takes full advantage of clonal selection and substantially reduces nursery and establishment costs. Clonal plantings create uniform stands that are favorable for machine operations during harvesting.

Harvesting of SRWC can be accomplished with a variety of machines and systems [19,20]. Dedicated systems have been in development since the early 1980's [21–24], and continue to be refined and improved [25–28]. There are two general approaches to harvesting in these systems. The first is cutting and chipping the material with a piece of equipment in a single pass across the field (Single Pass Cut and Chip – SPCC). The second is harvesting the material as whole stems and chipping or processing it as a separate operation. Both systems have advantages and disadvantages, but due to their efficiency completing multiple steps in one process, SPCC systems have generally been shown to minimize harvesting costs [29]. Newer cut-and-chip systems address many of the hurdles faced by previous equipment; namely slower machine and material harvesting rates in the field, lower durability, inconsistent feeding and cutting, and quality issues associated with shredded or oversized chips [30]. The vision of advanced uniform feedstock supply systems is to incorporate needed preprocessing steps in advance of the biorefinery gate; the goal to deliver feedstock with consistent quality characteristics and cost advantages that allow easier integration with other woody biomass supply chains [31]. Additionally, improvements in providing feedstock that meet end-user specifications could lead to cost improvements elsewhere in system [32,33]. These SPCC systems have been deployed on a range of short-rotation woody crops in many countries [32,34–36].

Harvesting operations are one of the largest single costs in most of these production systems due to the cost of equipment and amount of fuel used during operations. Properly matching harvesting equipment to a production system can significantly impact costs and efficiency of a production system [37,38]. Given competitiveness of the energy market, and the frequent occurrence of harvesting operations, especially in systems using coppice management, finding ways of optimizing them is critical [39,40]. Furthermore, there is a need to understand the sources of uncertainty in the harvesting process and removing variation associated with bioenergy production systems and crops so that efficiency can be improved and costs can be reduced [41,42].

Although there are some examples in the literature evaluating aspects of SPCC cut-and-chip, harvester performance, variability is common. Generally, maximum observed effective material capacity (C_m) for fresh biomass has increased steadily with advances in machine technology from about 20 Mg h^{-1} two decades ago to over 60 Mg h^{-1} in recent years; however, even among contemporary studies minimum C_m has not increased appreciably [36]. The variation in harvester performance (i.e. C_m and effective field capacity (C_f)) is related to a variety of factors (machine configuration, operator experience, crop and site conditions, etc.) [32,34]. In SRWC the variability due to these factors becomes particularly important from a planning perspective given how potential interactions could impact harvesting. For example, in crops with a high standing biomass there is a need for most of the machines power to be used for cutting and chipping but power might be diverted to compensate for poor soil conditions or an inexperienced operator [43]. The influence of cultivar selection, spacing and planting design in SRWC, and in particular poplar, on harvester performance is not well understood. The objective of this study is to evaluate the performance of a single-pass, cut-and-chip harvesting operation in hybrid poplar plantings managed on two year coppice cycles, and to relate performance to cultivar and silvicultural prescriptions while controlling, to the degree possible, machine setup, operators, weather, and site conditions.

2. Materials and methods

2.1. Site description

The study site was located at the former Boardman Tree Farm (45°45′12. 43″N, 119°37′4.32″W), a 10,000 ha facility established in the 1990's in Morrow County, OR, USA and operated by GreenWood Resources LLC (GWR) to grow poplar for products including bioenergy and sawtimber. The sandy sites reside on rolling, excessively drained grassland soils of the Columbia Plateau about 230 km east of Portland, OR on the east side of the Pacific Coast Ranges. The soils are mapped as Quincy loamy fine sands, which are categorized as mixed mesic Xeric Torripsamments [44]. In order to successfully grow trees on the site, GWR maintained a drip irrigation system that supplied water to individual trees.

The SRWC trees were planted in the spring of 2010 and harvested the first time after the 2011 growing seasons so the plants in this 2014 trial were two-years-old on a four-year-old root system. The 15 ha research area included three factors: poplar cultivar (four levels), planting design (two levels), and spacing (two levels). The crop consisted of three proprietary hybrid poplar cultivars from *P.* x*generosa* (TD) (PC4 and BC78) and *P.* x*canadensis* (DN) (BC79), and one nonproprietary cultivar from *P. xcanadensis* (DN) (OP367) on 390 m long rows. For each cultivar, planting designs included (1) a dedicated short-rotation poplar and (2) interplanted short-rotation poplar alternating with rows of sawtimber. Spacing for the dedicated rows were 3.05 m between the rows and either 1.22 m or 0.61 m along the row. Along the row, poplars were planted alternating 0.3 m to the left and right of the center line (zig-zag) along the row to accommodate the drip irrigation line. For dedicated crops each row contained poplar being coppiced on two year rotations. In the interplanted treatment rows alternated between SRWC and sawtimber rows and spaced 3.05 m apart. As a result the dedicated poplar was planted at two spacings, 6.1 m between SRWC rows and either 1.22 m or 0.61 m along the row. The sawtimber crop was planted between these SRWC rows at a spacing of 6.1 m and 3.05 m along the row. Sawtimber crops were established at the same time as the short-rotation rows, but intended to be harvested after 10–12 years of growth. For the purposes of this paper, the 0.61 m and 1.22 m down-the-row spacings will be referred to as S6 and S12 respectively for simplicity. Tree diameter and heights were measured on three randomly located plots (3 m × 9 m) per treatment combination.

2.2. Harvest activities

Harvest activities were monitored between November 18–21 and December 10–11, 2014. Mean temperatures ranged between −8 and 1 °C in November and was between 11 and 13 °C in December. Ground conditions were good and sufficiently firm to operate. The harvester platform tested was a New Holland FR9080 harvester, equipped with a New Holland 130 FB coppice header fitted with saw blades that were specifically selected for harvesting poplar as opposed to willow. Poplar blades are comparatively smaller diameter and have larger tips that are better suited for larger-diameter poplar stems. The harvests were managed by an experienced operator with hundreds of hours harvesting short term woody crops using this equipment, and supported by a locally sourced crew and collection vehicles. Various three-axle, 10–15 Mg capacity dump trucks were used to collect chips from the harvester.