Coppicing Evaluation of Short Rotation Coppice in the Southeast of the U.S. to Determine Appropriate Harvesting Methods

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Renewable fuels are being tested as an alternative for fossil fuels. For the Southeast U.S., the use of woody biomass has proven to be an excellent source of renewable energy in terms of cost-benefit and availability. Short rotation woody crops (SRWC) are timber plantations with exclusive characteristics that can meet the intensive demand for wood due to their fast growth and ability to coppice. Generally, SRWC require more maintenance than other popular woody crops, which might increase the cost of establishment for each new cycle of rotations. However, due to their coppicing ability, the same plantation may be harvested up to 5 times with no need of establishing a new one, which decreases costs. There are still uncertainties related to the best silviculture treatments at the harvesting stage and after the re-sprouting period in terms of optimizing the volume and vigor of SRWC stands. The species used in this experiment were Eucalypt (*Eucalyptus urograndis*) (Florida) and Cottonwood (*Populus deltoides*) (Arkansas). Plots were established in both locations and harvested in different seasons (summer and winter), and were revisited six months, and two years after harvesting to investigate re-growth and sprouting development. This study aims to explore the growth behavior of 2-year-old SRWC species by inspecting biomass gain over time, stem formation (stem crowding & dispersion), and mortality rates, in order to improve methods for harvesting multi-stem coppice stands.

Introduction

Renewable energy resources are a major topic today. Rapid population growth combined with the depletion of limited oil deposits reinforce the need to develop alternative and renewable sources of energy. Sustainable projects and government programs in several countries aim to encourage the consumption of renewable sources of energy rather than fossil fuels (i.e., oil, gas, and coal).

Biomass energy or ‘’bioenergy’’, which refers to the energy from plants and plant-derived material (National Energy Renewable Laboratory, 2016), have been commonly used throughout the world due to their sustainable characteristics. Under the big umbrella of bioenergy resources, woody crops (e.g., *Eucalyptus* spp., *Salix* spp., and *Populus* spp.) designed to produce biomass feedstock (wood) for energy production have been noted as a reasonable alternative to fossil fuels (Hauk, Knoke, and Wittkopf 2014). As opposed to solar and wind power, where the energy response is exclusively dependent on weather conditions and time of

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day, the production of woody biomass can be adjusted to meet consumer demand (Hauk, Knoke, and Wittkopf 2014).

Short rotation woody crops (SRWC) have shown to be an excellent choice for woody plantations for those seeking to produce attractive yields through the use of fast growing tree species. The U.S. Department of Energy defines SRWC as intensively-managed tree species that can be harvested after 8 to 10 years (or possibly as few as 3 years), yielding large amounts of harvested biomass. The downside of the adoption of SRWC supply system is that it requires intensive maintenance, which increases cost. In general, SRWC require closely monitored weed control, pest management, fertilization, close spacing of trees, use of genetically superior plants, and efficient harvest and post-harvest processing (Tuskan 1998). However, depending on the harvesting method and the specie used, rotations can be reduced to 3 year-cycles due to the ability to coppice. Coppicing enables certain tree species to naturally regenerate stems from the stump after the first harvest is complete (Souza et al. 2016). Choosing this option will decrease expenditures by reducing the amount of time needed for maintenance during each cycle as well as establishment costs (i.e., planting), and increase productivity once the regrowth commences immediately after harvesting by taking advantage of a live and fully developed root system (Souza et al. 2016).

Poplars (*Populus* spp.), sycamore (*Platanus occidentalis* L.), silver maple (*Acer saccharum* March), and hybrid willow (*Salix* spp.) were previously considered to be model species for woody biomass production throughout most of the U.S. (Tuskan 1998). Eucalyptus (*Eucalyptus* spp.), on the other hand, is an exotic species that was introduced to the U.S. in the mid 1800’s for use in wood fiber production (Cowles et al. 1995), and eventually became part of the SRWC. Currently, the most promising crops adopted for energy plantations are poplar, southern pine, willow, and eucalypt (Souza et al. 2016).

In the southeastern U.S., where pulp and paper mills are the final destination for timber, the harvest system commonly used is known as the ‘’whole-tree system’’ (WTS), which involves the use of a feller-buncher, a skidder, and a loader designed to handle relatively large (e.g., 30-40 cm dbh) softwood trees without having to cut them into smaller logs. The alternative is a cut-to-length (CTL) system. In a CTL system, a harvester is used to harvest the tree and process it into logs. Feller-bunchers used in WTS and harvesters used in CTL are the most commonly used machinery for harvesting large-scale tree plantations worldwide; however, both systems are poorly adapted for plantations of SRWC where trees are much smaller (Schweier et al. 2015).

Managing SRWC is generally time consuming due to the unfavorable harvesting conditions caused by the agglomeration of stems. In these plantations, multiple stems grow from a single stump, which raises concerns regarding the efficiency of mechanized harvesting (Suchomel et al. 2011). Most of SRWC are initially planted with narrow spacing between trees (e.g., 1 m), and the coppiced material, or regenerated stems, are generally small, branchy, and diverse in shape (Schweier et al. 2015). Furthermore, the growth behavior of coppiced stems varies between species, with differences in number of stems per stump, morphology of stems, and direction of growth being of primary interest. Because most harvesting tractors are designed to operate in single-stem plantations, there are still uncertainties related to their viability for operating in multiple-stem SRWC stands. For these reasons, large equipment, such as that used in WTS or CTL systems, may not be feasible for handling SRC. Special mechanization and/or cutting techniques may be desired in order to promote efficient harvesting.

Feller-bunchers may prove more appropriate than harvesters for handling SRC because of their compact design and the variety of attachable cutting heads that can be used (Schweier et al. 2015). Furthermore, small-scale feller-bunchers (e.g., skid-steers) have been considered an effective option for felling and bunching energy crops such as SRWC. Skid-steers have an even more compact design, smaller cutting heads, and lower fuel consumption compared to regular feller-bunchers, which improves the operational feasibility and reduces costs.

The majority of manufacturers of forestry tractors and cutting heads do not design their equipment for harvesting multiple stems with a single cut, but rather to operate in single-stem plantations, or, by cutting one stem at a time from a clump if handling aged coppice forests (McEwan et al 2016). However, the latter method has been shown to be inefficient for harvesting stems from dense clumps because feller-bunchers have difficulty penetrating clumps without damaging adjacent stems, causing significant losses in productivity.

Small-scale feller-buncher cutting heads are designed to handle small trees, normally not larger than 38 centimeters in diameter (based on an average of product specifications of the U.S. and Canada manufactures: DFM, FECON, and DAVCO). The utilization of small cutting heads better serves the needs of energy plantations, which rely on lower capital investment and maintenance costs. The two known systems of small cutting heads used in North America are disc saw and shear, which differ in their cutting mechanism. Other essential features of cutting heads include the grabbing and accumulator arms. When operating in a clump, the grabbing arm makes the first contact, grasping the bundle of stems together as the stems are cut at their base with a single cut. However, there are still uncertainties related to the capability of the grabbing arms for grasping multiple-stems with a single swing in SRWC. Due to the possible scattered formation of stems within a stump, a considerable amount of biomass could be either left behind, or grabbed by the machine operator in a second attempt, therefore requiring two cutting cycles at the same stump. In either case, there will be a significant negative impact on productivity.

There is a necessity for developing new cutting methodologies and equipment for SRWC. Few studies have investigated the growth behavior of re-sprout stems and the impacts that stem-crowding might cause on harvesting productivity.

Project description

In this study, we focused on examining the physical characteristics of 2 year-old SRWC stands. More specifically, we aimed to evaluate and categorize stem crowding patterns, and determine whether the grabbing arms of current small-scale cutting heads are capable of involving entire clumps. We hypothesized that the two-year old coppiced trees could be efficiently harvested based on their physical characteristics, through the use of skid-steer cutting heads currently available in the North American market.

Two sites (Table 1) were selected for evaluating the effects of harvesting during different seasons on coppicing development in SRC. The selected sites are located in South Florida (planted with clonal *E. urograndis*) and central Arkansas (planted with clonal Cottonwood: *Populus deltoides*). Harvests took place at each study site in two different seasons of the year: summer and winter. The study plots in all sites were approximately 1 acre in size.

Table 1. Description of the harvested sites

Site	Location	Species	Age at 1st harvest	Avg. DBH (cm)	Plantation spacing (trees/hectare)
1	Florida	*E. urograndis*	2	12.2	1,994
2	Arkansas	*P. deltoides*	3	4.3	2,088

Each site plot was divided in two equal size plots, and assigned to summer or winter harvest. The winter harvest was performed during December 2013 at site 1 (eucalypt), and during March 2014 at site 2 (cottonwood). The summer harvest at site 1 occurred in May 2014, and in June 2014 at site 2. Two evaluations in each plot took place at approximately 6 months and 2 years after harvest. The dates of evaluation after harvesting were chosen based on the best approximation of the number of growing degree days between winter and summer plots of the same sites (Table 2). The evaluations consisted of measurements of height and diameter of all stems, the number of stems per stump for mortality rate analysis, and the distance apart among stumps of multiple-stems. The latter data was collected with a two dimensional ruler (i.e., *x* and *y* axis), for measuring the dispersion among stems within the same stump.

Table 2. Site evaluation schedule based on growing degree days of each plot after first harvest.

Site	Location	Species	Growing degree days (summer- plots)	Growing degree days (winter plots)
1	Florida	*E. urograndis*	17,630	17,190
2	Arkansas	*P. deltoides*	11,073	11,201

Results

Approximately two years after harvest, the differences in both growth and coppicing development between summer and winter plots were notable, especially for site 2 (cottonwood).

Arkansas – Cottonwood:

At site 2, the winter plot averaged 2.4 cm in DBH, while the summer plot averaged 1.9 cm in DBH. Similar differences were also noted with the number of stems per stump, and stump mortality (e.g. zero re-sprouting) between summer and winter plots in site 2 (figure 1).

Stem mortality for both winter and summer plots was quite divergent over time (i.e., between the first and the second evaluation; 6 months and ~ 2 years after harvest, respectively). During the period between the two evaluations, two stumps died in the winter plot, and seven died in the summer plot. Originally, each plot was planted with approximately 400 trees.

Summer plot:

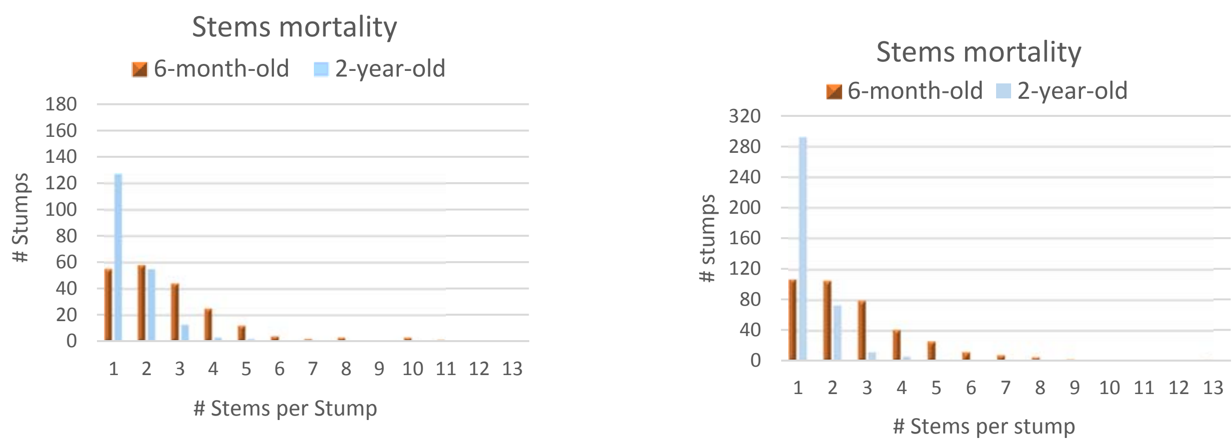
(a)

Age	Live stumps	Live stems
6-month-old	207	566
2-year-old	200	298

Winter plot:

Age	Live stumps	Live stems
6-month-old	386	1047
2-year-old	384	746

(b)



(c)

Figure 1. Charts of the effects on mortality and stem crowding caused by season of harvesting at study site 2 (Cottonwood): (a) Stems and stumps counting. (b) Mortality of stems per stump overtime. (c) Total number of single, dual, and multiple stems.

The average distance between dual-stems was 23 and 27 cm for summer and winter plots, respectively. The methodology for stem crowding analysis for multiple-stems (greater than 2) is still under discussion. At age 2, the results for the summer plot showed that 30% of the stumps are single-stems, 17% formed clumps, and 54% either died or did not coppice. In the winter plot, 73% are single-stems, 8.7% formed clumps, and only 4% died or did not coppice.

Parameters that indicate growth volume were also shown to be different between summer and winter plots at site 2. Winter plot had an average of height of 4.5 meters, whereas summer plot averaged 3.9, when both plots were near 2-year-old (Figure 2).

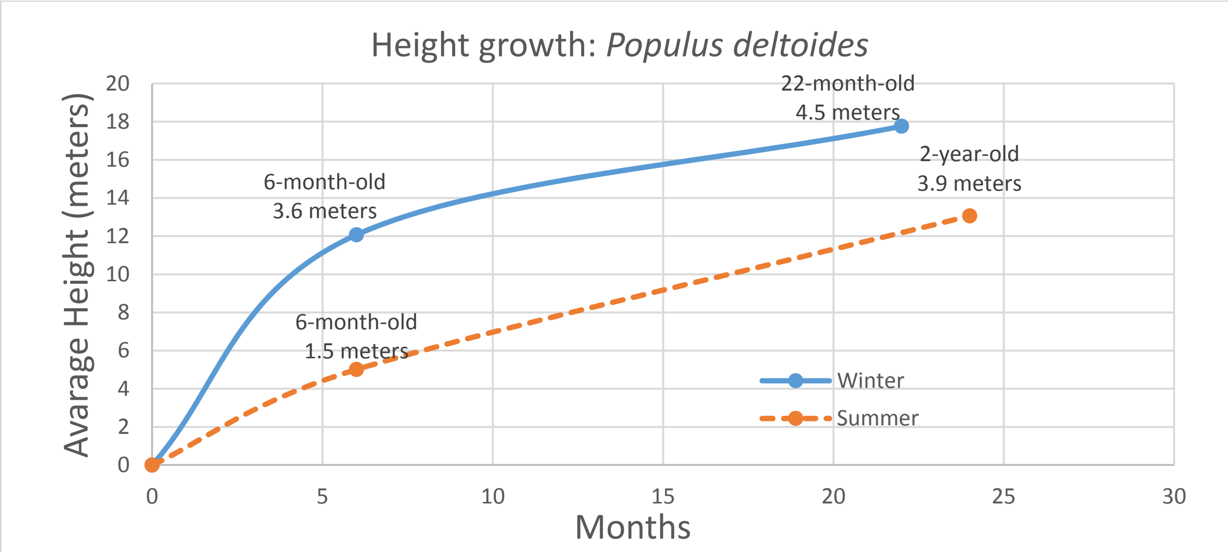


Figure 2. Comparison of height growth overtime between winter and summer plots; (dominant stems).

Final data from site 1 (eucalyptus) were recently collected, and analysis still needs to be completed. Nevertheless, similar differences in height, DBH, and number of stems per stump were noted between the summer and winter plots; however, the magnitude of the differences was much smaller than those observed with cottonwood.

Discussion

~~Unlike poplars, eucalyptus are evergreen without a distinct dormancy phase. The season when sprouting occurs also differs between deciduous and evergreen genera (Ceulemans, McDonald, and Pereira 1996). Therefore the ~~R~~r~~esults in site 2~~from both sites~~ were consistent with most published studies (Souza et al. 2016; Ceulemans, McDonald, and Pereira 1996; Kauter, Lewandowski, and Claupein 2003), with season of harvest playing a major role in SRWC coppicing. For instance, the well-defined dormant-season of *Populus spp.* at winter time ensures a better coppicing response rate, and maximum sprout vigor (Ceulemans, McDonald, and Pereira 1996). Thus, the greater coppicing development observed at winter plot~~s~~ might be attributed to the high availability of carbohydrate reserves stored in the root system at harvesting time.

Through the stem crowding analysis (i.e., dispersion of stems within the same stump), we expect to determine whether season of harvest and/or SRWC species will cause any difficulties for harvesting large clumps. However, the methodology for analyzing these type of data is still being determined. As mentioned before, few studies have investigated this issue, and many uncertainties still exist.

Conclusion

At this point, analysis is ongoing but it clearly shows that season of harvesting had a considerable impact on both stump survival and growth vigor. Therefore, harvesting SRWC during the winter is recommend, and suggested by similar findings from (Souza et al. 2016).

With the dispersion of stems on multi-stem stumps not exceeding 27 cm from each other in both winter and summer plot at site 2s, it appears that stem crowding is not affected by seasonality, and will not impact subsequent harvests.

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