Harvesting Systems and Costs for Short Rotation Poplar

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Abstract
The objective of this review is to compare the cost of coppice and longer rotation poplar harvesting technology. Harvesting technology for short rotation poplar has evolved over the years to address both coppice harvest and single-stem harvest systems. Two potential approaches for coppice harvesting are modified forage harvesters and modified mulcher-balers. Both of these systems effectively handle multi-stemmed feedstock. Total harvesting cost to roadside likely ranges from $11 to $15 Mg green. The most significant harvesting constraint with coppice systems is the requirement for dormant season operations. More conventional poplar harvesting at production scales uses forest machines for felling and extraction. The Billion Ton Update report used previous productivity studies to estimate a roadside cost for felling and skidding of about $6 Mg green (unchipped). With chipping cost, single-stem systems are about the same roadside price as coppice harvesting. Other factors such as stand establishment, feedstock storage, and rotation length are more likely to determine an economically optimum management system.

Keywords: coppice, costs, felling, swath harvester

Introduction
Any assessment of the US biomass supply considers purpose-grown woody crops an important component of the future feedstock mix. The Billion Ton Update (US Department of Energy 2011) describes four woody crops—willow, poplar, eucalyptus and pine—as potential bioenergy feedstocks. Under a high yield scenario woody crops may provide as much as 115 Mg (126M dry tons) per year by 2030. Woody crops can be grown in many regions of the country, offer flexibility of supply and storage by having inventory "on the stump", provide a range of ecosystem values in addition to simple biomass volume, and are responsive to intensive management practices that increase productivity.

Poplar species are the most widely adaptable woody crop considered in the High Yield Scenario. Berguson *et al*. (2010) describe the history of plantings in the Pacific Northwest and Lake States. Many of these plantations were originally established as a source for pulpwood supply with rotation ages of eight or more years. Currently there are more than 15,000 ha (37,000 ac) concentrated near the Columbia River. In Minnesota hybrid poplar has been established on 1000's of ha of private and industry land. A conservative estimate of plantation yield from these plantings is about 9 Mg ha^{-1} yr^{-1} (4 dry tons ac^{-1} yr^{-1}). Coleman *et al.* (2008) evaluated clonal varieties of poplar, sycamore and eucalyptus in South Carolina and found similar yields.

While it is clear that poplar can be grown for woody feedstock the most significant unknown is the technology and cost for harvesting. Depending on management practice the harvesting system may need to accommodate coppiced, small-stem material or larger single-stem trees. Harvesting methods for coppiced material tend to be derived from agricultural equipment while harvesting methods for single-stem stands are generally purpose-built forest machines. Each approach has advantages and disadvantages, none of these techniques are fully evolved and there is a sense that improved harvesting technology could reduce costs through gains in efficiency.

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This paper reviews current harvest system technologies for harvesting short-rotation poplar, recognizing the need for technologies to address both single-stem and multi-stemmed management systems. Three harvest systems are identified and production rates and costs are explored for each.

Poplar Harvesting Systems

A review of existing literature shows that many different machines have been tested since the 1980's. Several authors have compiled extensive reviews of equipment (Stokes and Hartsough 1986; Hartsough and Yomogida 1996, Verani *et al*. 2008). Many early trials embraced the idea of agricultural-type continuous forward harvesting, but differed in their approach. Equipment developers tested different cutting mechanisms, different collection and chipping methods, different types of prime movers. System development also led to tests of alternative ways to move material to roadside—chip forwarding, skidding with grapple skidders, or moving large bunches with alternative machines such as front-end loaders.

Functionally two types of systems have evolved: a) chip-at-the-stump or b) chip at roadside. The selection of an appropriate system depends primarily on stem size and is thus determined by the type of SRWC management. Smaller stems are more difficult to handle economically and are therefore more suited to chip-at-the-stump approaches that quickly convert material to mass handling. Larger stems are more amenable to single-stem felling and handling systems including traditional forestry harvesting technology.

Chip-at-the-stump Harvesting

Most of the poplar in the US is managed on longer rotations with the goal of larger diameter single stems that can be utilized for multiple products. An alternative plantation strategy however is coppicing. Coppice systems reduce site prep and establishment costs and maximize utilization of site productivity. However coppice management imposes particular constraints on equipment operation. First, the economics of coppice management depend on minimal mortality of the stools. This means that the cutting mechanism must sever the tree cleanly with little bark damage. Equipment traffic must also minimize stump and root system damage. The coppice produces multiple small diameter stems that must be collected and densified at the point of cutting to allow cost-effective material handling. Coppice felling has to quickly and cleanly cut multiple stems across the row width. This generally leads to some type of swath cutting head, usually with circular saws for a clean cut.

An additional constraint is that coppice systems may require all harvesting during the dormant season. This helps maximize site productivity and stand vigor. Practically this means that operations must be able to proceed during the wettest time of the year in the US South or during winter conditions in the Lake States. Dormant season operation also means that harvesting equipment must be able to move to different applications in other seasons or it must achieve full utilization during a limited operating season. A harvester operating 20-hr shifts for 4 months could log 1600 operating hours for example. Finally, dormant season harvesting means that the feedstock will have to be stockpiled with concomitant storage and handling issues.

The most advanced coppice harvester is the Case New Holland 9080 forage harvester[2] with an FB130 coppice cutter. Abrahamson *et al.* (2010) describe the basic machine and its evolution from agricultural machine to willow harvester. The equipment is continuing to be upgraded to effectively harvest larger diameter poplar. Production rates of 2 ha (5 ac) per hour in 12 cm (5 in) diameter poplar have been reported in field trials.

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[2] Reference to any specific commercial products does not constitute or imply its endorsement or recommendation by the United States Government. Such reference is solely for the information of the reader.

A complete coppice system would include the 9080 with tractors and chip wagons to transfer material to roadside. Because the 9080 has no onboard chip storage it requires a coordinated system of shuttle wagons to keep operating. Simple system modeling with 5.5 t (6 ton) capacity trailers, 55 Mg (60 ton) per hour 9080 production rate, and an average 366 m (1200 ft) distance to roadside would suggest that the system requires three tractors, three chip wagons, and the harvester.

The CNH 9080 costs about $575,000 and would have an estimated hourly cost with operator of about $250 per productive hour. Each tractor and wagon with operator could cost about $125 per productive hour for a total system cost of $625 per hour. If the system moves 55 Mg (60 tons) green per productive hour the cost to roadside would be $11.36 per Mg ($10.42 per green ton) chipped. These costs are obviously sensitive to the assumption of production rate. Larger trees, lower volume per acre, too small of trees could all reduce production rate. If the production rate was only 41 Mg (45 green tons) per hour the cost to roadside would increase to $15.24 per Mg ($13.89 per green ton). Spinelli *et al*. (2009) performed similar types of production studies on several sites using a variety of commercially available forage harvesters. More recently, Fiala and Bacenetti (2012) examined a newer version of the heavy duty coppice header. Their trials confirmed a 60 Mg per hour production rate.

An alternative swath cutting system that has been tested in poplar is the Anderson WB55 Biobaler (Savoie *et al*. 2010). This swath cutting machine uses a mulching-type rotary cutter to both sever and chop the feedstock. Unlike the forage harvester the material is collected and compressed into round bales. Cutting and baling can be separated from transport to roadside. This offers the possibility of longer operating season, roadside inventory and storage, and lower capital investment. In one poplar trial the WB55 achieved 19 Mg (21 green tons) per productive hour with a bale weight of about 512 kg (1100 lbs).

The WB55 costs about $125,000 and an appropriately configured towing tractor adds another $150,000. This results in an operating rate of about $117 per hour. This includes operating costs for twine, fuel, and an operator. An additional operation is necessary to collect the bales and transfer them to roadside. This can be done with standard agricultural round bale handling loaders and trailers or with forestry equipment such as a forwarder. Klepac and Rummer (2010) evaluated the Biobaler system and estimated forwarder productivity with bales at 18 Mg (20 green tons) per productive hour, approximately matching the production rate of the Biobaler. Total system cost to roadside would be about $10.39 per Mg ($9.35 per green ton) baled. It is important to note that bales are not quite the same feedstock form as green chips. If the bales need to be reground there will be additional costs to produce feedstock equivalent to the CNH product.

Chip-at-roadside Systems

Longer rotation plantation management yields larger diameter stems. This generally leads to the use of conventional forestry machines that are designed to handle heavier material. McDonald and Stokes (1994) studied a shear feller-buncher working in a 6-year-old sycamore plantation and found average felling production 18 Mg (20 green tons) per hour. Spinelli *et al*. (2002) looked at three different kinds of forestry feller-bunchers working in eucalyptus plantations in California. Production ranged from 18 to 25 Mg (20 to 28 green tons) per hour. These felling studies have highlighted the need to optimize productivity through the interaction of bunch size, tree size, and accumulator capacity.

Typical mechanized forestry operations are most cost-effective using grapple skidders to move bunched wood to roadside. McDonald and Stokes (1994) found a production rate of 25 Mg (27 green tons) per hour at a skid distance of 400 m (1300 ft) when the feller-buncher put two accumulations in each bunch. If the felling operation maximized bunch size with four accumulations skidding productivity increased to 33 Mg (36 green tons) per hour. Spinelli *et al*. (2002) measured skidding productivity at 40 Mg (44 green tons) per hour in their study of eucalyptus stands. Skid distance averaged 250 m (823 ft).

The Billion Ton Update (US Dept of Energy 2011) estimated SRWC harvesting cost based on the assumptions of conventional forestry machines working in poplar. Drawing on exemplar production rates from previous case studies in sycamore, eucalyptus and poplar an average felling production rate of 18 Mg (20 green tons) per hour was selected. Skidding productivity was assumed to be twice felling productivity (suggesting a balanced system of two feller-bunchers working with one skidder). With total hourly costs for two small feller-bunchers and one grapple skidder of $210 per hour, the roadside felling and skidding cost would be $5.83 per Mg ($5.25 per ton) green. The total harvesting cost in the Billion Ton Report including chipping at roadside was about $11 Mg ($10 per ton) green.

Discussion

The three systems described above represent currently feasible approaches to harvesting short rotation poplar. Permutations of each have been tried and may offer advantages in specific situations (i.e. soft soils, longer extraction distance). However the key is that there are technically viable options for harvesting poplar of all sizes. Economically the harvesting costs are similar. Coppice harvesting is in the range of $11 to $15 per Mg green and whole-tree harvesting to chips is only slightly less expensive. Note that the costs presented in this paper only include machine rates and do not include allowances for profit or overhead. Thus they are valid for relative comparison but should not be considered a "market price" for feedstock.

It should also be noted that these cost estimates from previous harvesting trials are only productive hour estimates. There could well be significant issues of equipment utilization, shift schedules and weather delays that would occur at operational scales. Coppice harvesting systems will be more sensitive to these constraints given the tightly linked production functions and operating season constraints.

Harvesting technology is defined to a large degree by tree size and stand conditions. The initial selection of management regime will likely hinge on the economics of stand management, not harvesting cost. If the system will utilize a coppice rotation then swath harvesters will be required. If the system will use longer rotations then small forestry equipment will likely be the technology of choice. Further equipment development opportunities exist to improve efficiency and better match operating functions to specific feedstock requirements. As conversion technology matures and feedstock specifications are better understood these opportunities can be explored.

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